JPL D-48259

Interplanetary Overlay Network (ION)
<u>Design and Operation</u>

V1.8

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DOCUMENT CHANGE LOG

Change Number	Change Date	Pages Affected	Changes/ Notes	General Comments
V1.8	2/6/2009		Update discussion of Contact Graph Routing; document status msg formats.	
V1.7	12/1/2008		Add documentation for one-way-light-time simulators, BP extension interface.	
V1.6	10/03/2008		Add documentation of sm_SemUnend.	
V1.5	09/20/2008		Revisions requested by JPL SQA.	
V1.4	07/31/2008		Add a section on optimizing an ION-based network; tuning.	
V1.3	07/08/2008		Revised some details of Contact Graph Routing.	
V1.2	05/24/2008		Revised man pages for bptrace (user-specified text in trace message), ltprc (more flexible watch command), bprc (just one watch command instead of two, greater flexibility).	
V1.1	05/18/2008		Some additional diagrams.	
V1.0	04/28/2008		Initial version of the ION design and operations manual.	

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1 Design

The Interplanetary Overlay Network (ION) software distribution is an implementation of Delay-Tolerant Networking (DTN) architecture as described in Internet RFC 4838. It is designed to enable inexpensive insertion of DTN functionality into embedded systems such as robotic spacecraft. The intent of ION deployment in space flight mission systems is to reduce cost and risk in mission communications by simplifying the construction and operation of automated digital data communication networks spanning space links, planetary surface links, and terrestrial links.

A comprehensive overview of DTN is beyond the scope of this document. Very briefly, though, DTN is a digital communication networking technology that enables data to be conveyed between two communicating entities automatically and reliably even if one or more of the network links in the end-to-end path between those entities is subject to very long signal propagation latency and/or prolonged intervals of unavailability.

The DTN architecture is much like the architecture of the Internet, except that it is one layer higher in the familiar ISO protocol "stack". The DTN analog to the Internet Protocol (IP), called "Bundle Protocol" (BP), is designed to function as an "overlay" network protocol that interconnects "internets" – including both Internet-structured networks and also data paths that utilize only space communication links as defined by the Consultative Committee for Space Data Systems (CCSDS) – in much the same way that IP interconnects "subnets" such as those built on Ethernet, SONET, etc. By implementing the DTN architecture, ION provides communication software configured as a protocol stack that looks like this:

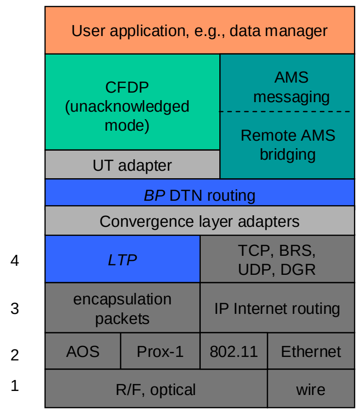


Figure 1 DTN protocol stack

Data traversing a DTN are conveyed in DTN *bundles* – which are functionally analogous to IP packets – between BP *endpoints* which are functionally analogous to sockets. Multiple BP endpoints may reside on the same computer – termed a *node* – just as multiple sockets may reside on the same computer (host or router) in the Internet.

BP endpoints are identified by Universal Record Identifiers (URIs), which are ASCII text strings of the general form:

scheme_name:*scheme_specific_part*

For example:

dtn://topquark.caltech.dtn/mail

But for space flight communications this general textual representation might impose more transmission overhead than missions can afford. For this reason, ION is optimized for networks of endpoints whose IDs conform more narrowly to the following model:

ipn:*element_number*.*service_number*

which enables them to be abbreviated to pairs of unsigned binary integers via a technique called Compressed Bundle Header Encoding (CBHE). CBHE-conformant BP *endpoint IDs* (EIDs) are not only functionally similar to Internet socket addresses but also structurally similar: element numbers are analogous to Internet node numbers (IP addresses), in that they typically identify the flight or ground data system computers on which network software executes, and service numbers are roughly analogous to TCP and UDP port numbers.

More generally, the element numbers in CBHE-conformant BP endpoint IDs are one manifestation of the fundamental ION notion of *node number*: in the ION architecture there is a natural one-to-one mapping not only between node numbers and BP endpoint element numbers but also between node numbers and:

- LTP engine IDs
- AMS continuum numbers
- CFDP entity numbers

1.1 Structure and function

The ION distribution comprises the following software packages:

- ici (Interplanetary Communication Infrastructure), a set of general-purpose libraries providing common functionality to the other packages.
- ltp (Licklider Transmission Protocol), a core DTN protocol that provides transmission reliability based on delay-tolerant acknowledgments, timeouts, and retransmissions.
- bp (Bundle Protocol), a core DTN protocol that provides delay-tolerant forwarding of data through a network in which continuous end-to-end connectivity is never assured, including support for delay-tolerant dynamic routing. The Bundle Protocol (BP) specification is defined in Internet RFC 5050.
- dgr (Datagram Retransmission), a library that enables data to be transmitted via UDP with reliability comparable to that provided by TCP. The dgr system is provided primarily for the conveyance of Meta-AMS (see below) protocol traffic in an Internet-like environment.

- ams (Asynchronous Message Service), an application-layer service that is not part of the DTN architecture but utilizes underlying DTN protocols. AMS comprises three protocols supporting the distribution of brief messages within a network:
    - The core AAMS (Application AMS) protocol, which does message distribution on both the publish/subscribe model and the client/server model, as required by the application.
    - The MAMS (Meta-AMS) protocol, which distributes control information enabling the operation of the Application AMS protocol.
    - The RAMS (Remote AMS) protocol, which performs aggregated message distribution to end nodes that may be numerous and/or accessible only over very expensive links, using an aggregation tree structure similar to the distribution trees used by Internet multicast technologies.

Taken together, the packages included in the ION software distribution constitute a communication capability characterized by the following operational features:

- Reliable conveyance of data over a DTN, i.e., a network in which it might never be possible for any node to have reliable information about the detailed current state of any other node.
- Built on this capability, reliable distribution of short messages to multiple recipients (subscribers) residing in such a network.
- Management of traffic through such a network, taking into consideration:
    - scheduled times and durations of communication opportunities
    - fluctuating limits on data storage and transmission resources
    - data rate asymmetry
    - the sizes of application data units
    - and user-specified final destination, priority, and useful lifetime for those data units.
- Facilities for monitoring the performance of the network.
- Robustness against node failure.
- Portability across heterogeneous computing platforms.
- High speed with low overhead.
- Easy integration with heterogeneous underlying communication infrastructure, ranging from Internet to dedicated spacecraft communication links.

1.2 Constraints on the Design

A DTN implementation intended to function in an interplanetary network environment – specifically, aboard interplanetary research spacecraft separated from Earth and one another by vast distances – must operate successfully within two general classes of design constraints: link constraints and processor constraints.

1.2.1 Link constraints

All communications among interplanetary spacecraft are, obviously, wireless. Less obviously, those wireless links are generally slow and are usually asymmetric.

The electrical power provided to on-board radios is limited and antennae are relatively small, so signals are weak. This limits the speed at which data can be transmitted intelligibly from an interplanetary spacecraft to Earth, usually to some rate on the order of 256 Kbps to 6 Mbps.

The electrical power provided to transmitters on Earth is certainly much greater, but the sensitivity of receivers on spacecraft is again constrained by limited power and antenna mass allowances. Because historically the volume of command traffic that had to be sent to spacecraft was far less than the volume of telemetry the spacecraft were expected to return, spacecraft receivers have historically been engineered for even lower data rates from Earth to the spacecraft, on the order of 1 to 2 Kbps.

As a result, the cost per octet of data transmission or reception is high and the links are heavily subscribed. Economical use of transmission and reception opportunities is therefore important, and transmission is designed to enable useful information to be obtained from brief communication opportunities: units of transmission are typically small, and the immediate delivery of even a small part (carefully delimited) of a large data object may be preferable to deferring delivery of the entire object until all parts have been acquired.

1.2.2 Processor constraints

The computing capability aboard a robotic interplanetary spacecraft is typically quite different from that provided by an engineering workstation on Earth. In part this is due, again, to the limited available electrical power and limited mass allowance within which a flight computer must operate. But these factors are exacerbated by the often intense radiation environment of deep space. In order to minimize errors in computation and storage, flight processors must be radiation-hardened and both dynamic memory and non-volatile storage (typically flash memory) must be radiation-tolerant. The additional engineering required for these adaptations takes time and is not inexpensive, and the market for radiation-hardened spacecraft computers is relatively small; for these reasons, the latest advances in processing technology are typically not available for use on interplanetary spacecraft, so flight computers are invariably slower than their Earth-bound counterparts. As a result, the cost per processing cycle is high and processors are heavily subscribed; economical use of processing resources is very important.

The nature of interplanetary spacecraft operations imposes a further constraint. These spacecraft are wholly robotic and are far beyond the reach of mission technicians; hands-on repairs are out of the question. Therefore the processing performed by the flight computer must be highly reliable, which in turn generally means that it must be highly predictable. Flight software is typically required to meet “hard” real-time processing deadlines, for which purpose it must be run within a hard real-time operating system (RTOS).

One other implication of the requirement for high reliability in flight software is that the dynamic allocation of system memory may be prohibited except in certain well-understood states, such as at system start-up. Unrestrained dynamic allocation of system memory introduces a degree of unpredictability into the overall flight system that can threaten the reliability of the computing environment and jeopardize the health of the vehicle.

1.3 Design Principles

The design of the ION software distribution reflects several core principles that are intended to address these constraints.

1.3.1 Shared memory

Since ION must run on flight processors, it had to be designed to function successfully within an RTOS. Many real-time operating systems improve processing determinism by omitting the support for protected-memory models that is provided by Unix-like operating systems: all tasks have direct access to all regions of system memory. (In effect, all tasks operate in kernel mode rather than in user mode.) ION therefore had to be designed with no expectation of memory protection.

But universally shared access to all memory can be viewed not only as a hazard but also as an opportunity. Placing a data object in shared memory is an extremely efficient means of passing data from one software task to another.

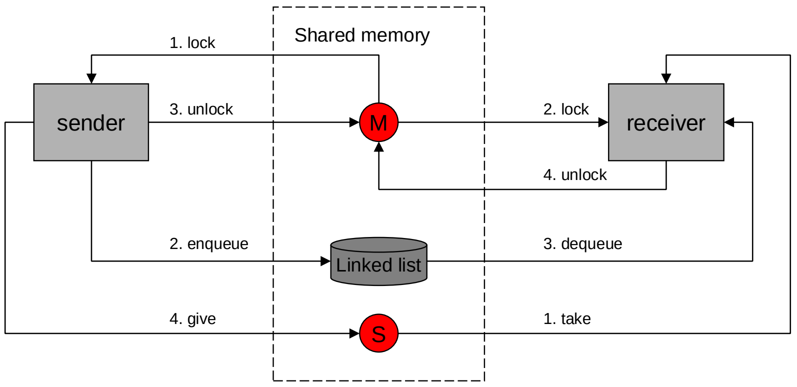


Figure 2 ION inter-task communication

ION is designed to exploit this opportunity as fully as possible. In particular, virtually all inter-task communication in ION follows this model:

- The sending task takes a mutual exclusion semaphore (mutex) protecting a linked list in shared memory (either DRAM or non-volatile memory), appends a data item to the list, releases the mutex, and gives a “signal” semaphore associated with the list to announce that the list is now non-empty.
- The receiving task, which is already pended on the linked list’s associated signal semaphore, resumes execution when the semaphore is given. It takes the

associated mutex, extracts the next data item from the list, releases the mutex, and proceeds to operate on the data item from the sending task.

Semaphore operations are typically extremely fast, as is the storage and retrieval of data in memory, so this inter-task communication model is suitably efficient for flight software.

1.3.2 Zero-copy procedures

Given ION's orientation toward the shared memory model, a further strategy for processing efficiency offers itself: if the data item appended to a linked list is merely a pointer to a large data object, rather than a copy, then we can further reduce processing overhead by eliminating the cost of byte-for-byte copying of large objects.

Moreover, in the event that multiple software elements need to access the same large object at the same time, we can provide each such software element with a pointer to the object rather than its own copy (maintaining a count of references to assure that the object is not destroyed until all elements have relinquished their pointers). This serves to reduce somewhat the amount of memory needed for ION operations.

1.3.3 Highly distributed processing

The efficiency of inter-task communications based on shared memory makes it practical to distribute ION processing among multiple relatively simple pipelined tasks rather than localize it in a single, somewhat more complex daemon. This strategy has a number of advantages:

- The simplicity of each task reduces the sizes of the software modules, making them easier to understand and maintain, and thus it can somewhat reduce the incidence of errors.
- The scope of the ION operating stack can be adjusted incrementally at run time, by spawning or terminating instances of configurable software elements, without increasing the size or complexity of any single task and without requiring that the stack as a whole be halted and restarted in a new configuration. In theory, a module could even be upgraded with new functionality and integrated into the stack without interrupting operations.
- The clear interfaces between tasks simplify the implementation of flow control measures to prevent uncontrolled resource consumption.

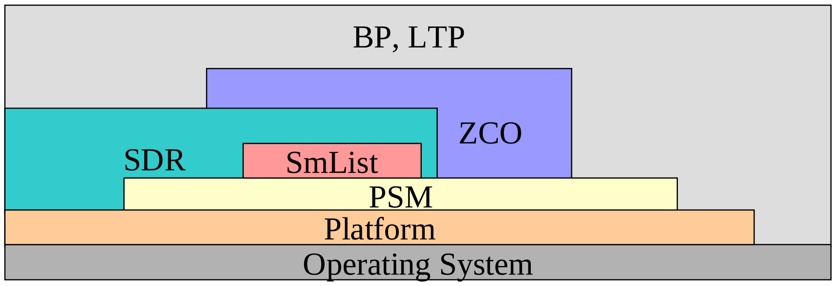
1.3.4 Portability

Designs based on these kinds of principles are foreign to many software developers, who may be far more comfortable in development environments supported by protected memory. It is typically much easier, for example, to develop software in a Linux environment than in VxWorks 5.4. However, the Linux environment is not the only one in which ION software must ultimately run.

Consequently, ION has been designed for easy portability. POSIX™ API functions are widely used, and differences in operating system support that are not concealed within the POSIX abstractions are encapsulated in two small modules of platform-sensitive ION code. The bulk of the ION software runs, without any source code modification whatsoever, equally well in Linux™ (Red Hat®, Fedora™, and Ubuntu™, so far), Solaris® 9, OS/X®, VxWorks® 5.4, and RTEMS™, on both 32-bit and 64-bit processors. Developers may compile and test ION modules in whatever environment they find most convenient.

1.4 Organizational Overview

Two broad overviews of the organization of ION may be helpful at this point. First, here is a summary view of the main functional dependencies among ION software elements:



BP, LTP	Bundle Protocol and Licklider Transmission Protocol libraries and daemons
ZCO	Zero-copy objects capability: minimize data copying up and down the stack
SDR	Spacecraft Data Recorder: persistent object database in shared memory, using PSM and SmList
SmList	linked lists in shared memory using PSM
PSM	Personal Space Management: memory management within a pre-allocated memory partition
Platform	common access to O.S.: shared memory, system time, IPC mechanisms
Operating System	POSIX thread spawn/destroy, file system, time

Figure 3 ION software functional dependencies

That is, BP and LTP invoke functions provided by the sdr, zco, psm, and platform elements of the ici package, in addition to functions provided by the operating system itself; the zco functions themselves also invoke sdr, psm, and platform functions; and so on.

Second, here is a summary view of the main line of data flow in ION's DTN protocol implementations:

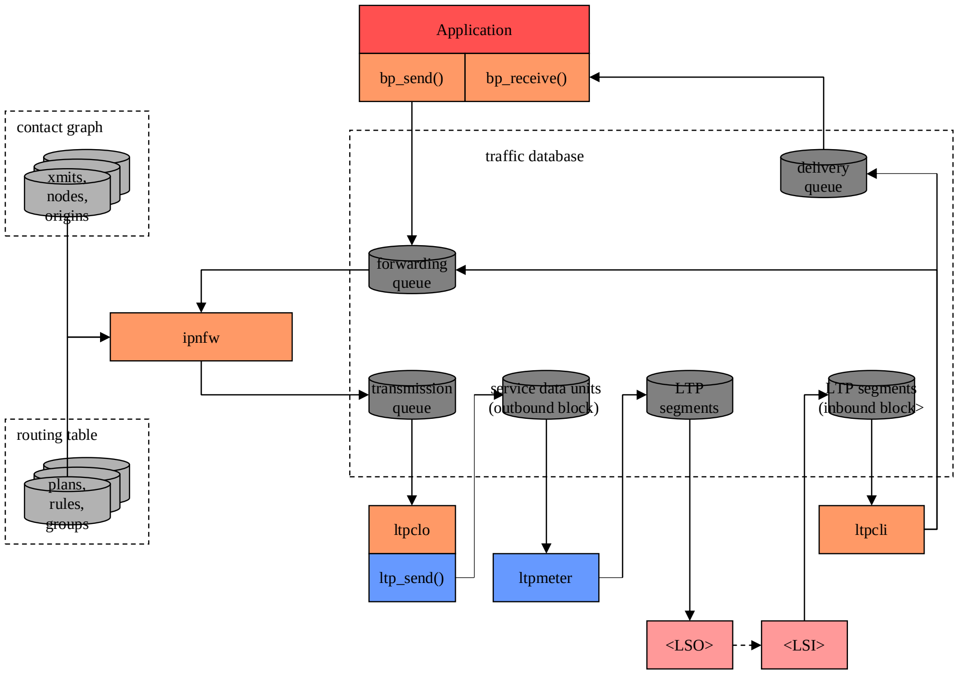


Figure 4 Main line of ION data flow

Note that data objects residing in shared memory, many of them in a nominally non-volatile SDR data store, constitute the central organizing principle of the design. Here as in other diagrams showing data flow in this document:

- Linked lists of data objects are shown as cylinders.
- Darker data entities indicate data that are managed in the SDR data store, while lighter data entities indicate data that are managed in volatile DRAM to improve performance.
- Rectangles indicate processing elements (tasks, processes, threads), sometimes with library references specifically identified.

A few notes on this main line data flow:

- For simplicity, the data flow depicted here is a “loopback” flow in which a single BP “node” is shown sending data to itself (a useful configuration for test purposes). To depict typical operations over a network we would need two instances of this node diagram, such that the <LSO> task of one node is shown sending data to the <LSI> task of the other and vice versa.
- A BP application or application service (such as Remote AMS) that has access to the local BP node – for our purposes, the “sender” – invokes the `bp_send` function to send a unit of application data to a remote counterpart. The destination of the application data unit is expressed as a BP endpoint ID (EID). The application data unit is encapsulated in a bundle and is queued for forwarding.

- The forwarder task identified by the "scheme" portion of the bundle's destination EID removes the bundle from the forwarding queue and computes a route to the destination EID. The first node on the route, to which the local node is able to transmit data directly via some underlying "convergence layer" (CL) protocol, is termed the "proximate node" for the computed route. The forwarder appends the bundle to one of the transmission queues for the CL-protocol-specific interface to the proximate node, termed an *outduct*. Each outduct is serviced by some CL-specific output task that communicates with the proximate node – in this case, the LTP output task **ltpclo**. (Other CL protocols supported by ION include TCP and UDP.)
- The output task for LTP transmission to the selected proximate node removes the bundle from the transmission queue and invokes the `ltp_send` function to append it to a *block* that is being assembled for transmission to the proximate node. (Because LTP acknowledgment traffic is issued on a per-block basis, we can limit the amount of acknowledgment traffic on the network by aggregating multiple bundles into a single block rather than transmitting each bundle in its own block.)
- The **ltpmeter** task for the selected proximate node divides the aggregated block into multiple segments and enqueues them for transmission by underlying link-layer transmission software, such as an implementation of the CCSDS AOS protocol.
- Underlying link-layer software at the sending node transmits the segments to its counterpart at the proximate node (the receiver), where they are used to reassemble the transmission block.
- The receiving node's input task for LTP reception extracts the bundles from the reassembled block and dispatches them: each bundle whose final destination is some other node is queued for forwarding, just like bundles created by local applications, while each bundle whose final destination is the local node is queued for delivery to whatever application "opens" the BP endpoint identified by the bundle's final destination endpoint ID.
- The destination application or application service at the receiving node opens the appropriate BP endpoint and invokes the `bp_receive` function to remove the bundle from the associated delivery queue and extract the original application data unit, which it can then process.

Finally, note that the data flow shown here represents the sustained operational configuration of a node that has been successfully instantiated on a suitable computer. The sequence of operations performed to reach this configuration is not shown. That startup sequence will necessarily vary depending on the nature of the computing platform and the supporting link services. Broadly, the first step normally is to run the **ionadmin** utility program to initialize the data management infrastructure required by all elements of ION. Following this initialization, the next steps normally are (a) any necessary initialization of link service protocols, (b) any necessary initialization of convergence-layer protocols (e.g., LTP – the **ltpadmin** utility program), and finally (c) initialization of the Bundle Protocol by means of the **bpadmin** utility program. BP applications should not try to commence operation until BP has been initialized.

1.5 Package Overviews

1.5.1 Interplanetary Communication Infrastructure (ICI)

The ICI package in ION provides a number of core services that, from ION's point of view, implement what amounts to an extended POSIX-based operating system. ICI services include the following:

1. Platform

The platform system contains operating-system-sensitive code that enables ICI to present a single, consistent programming interface to those common operating system services that multiple ION modules utilize. For example, the platform system implements a standard semaphore abstraction that may invisibly be mapped to underlying POSIX semaphores, SVR4 IPC semaphores, or VxWorks semaphores, depending on which operating system the package is compiled for. The platform system also implements a standard shared-memory abstraction, enabling software running on operating systems both with and without memory protection to participate readily in ION's shared-memory-based computing environment.

2. Personal Space Management (PSM)

Although sound flight software design may prohibit the uncontrolled dynamic management of system memory, private management of assigned, fixed blocks of system memory is standard practice. Often that private management amounts to merely controlling the reuse of fixed-size rows in static tables, but such techniques can be awkward and may not make the most efficient use of available memory. The ICI package provides an alternative, called PSM, which performs high-speed dynamic allocation and recovery of variable-size memory objects within an assigned memory block of fixed size. A given PSM-managed memory block may be either private or shared memory.

3. Memmgr

The static allocation of privately-managed blocks of system memory for different purposes implies the need for multiple memory management regimes, and in some cases a program that interacts with multiple software elements may need to participate in the private shared-memory management regimes of each. ICI's memmgr system enables multiple memory managers – for multiple privately-managed blocks of system memory – to coexist within ION and be concurrently available to ION software elements.

4. Lyst

The lyst system is a comprehensive, powerful, and efficient system for managing doubly-linked lists in private memory. It is the model for a number of other list management systems supported by ICI; as noted earlier, linked lists are heavily used in ION inter-task communication.

5. Llcv

The llcv (Linked-List Condition Variables) system is an inter-thread communication abstraction that integrates POSIX thread condition variables (vice semaphores) with doubly-linked lists in private memory.

6. Smlist

Smlist is another doubly-linked list management service. It differs from lyst in that the lists it manages reside in shared (rather than private) DRAM, so operations on them must be semaphore-protected to prevent race conditions.

7. Simple Data Recorder (SDR)

SDR is a system for managing non-volatile storage, built on exactly the same model as PSM. Put another way, SDR is a small and simple “persistent object” system or “object database” management system. It enables straightforward management of linked lists (and other data structures of arbitrary complexity) in non-volatile storage, nominally within a single file whose size is pre-defined and fixed.

SDR includes a transaction mechanism that protects database integrity by ensuring that the failure of any database operation will cause all other operations undertaken within the same transaction to be backed out. The intent of the system is to assure retention of coherent protocol engine state even in the event of an unplanned flight computer reboot in the midst of communication activity.

8. Sptrace

The sptrace system is an embedded diagnostic facility that monitors the performance of the PSM and SDR space management systems. It can be used, for example, to detect memory “leaks” and other memory management errors.

9. Zco

ION’s zco (zero-copy objects) system leverages the SDR system’s storage flexibility to enable user application data be encapsulated in any number of layers of protocol without copying the successively augmented protocol data unit from one layer to the next. It also implements a reference counting system that enables protocol data to be processed safely by multiple software elements concurrently – e.g., a bundle may be both delivered to a local endpoint and, at the same time, queued for forwarding to another node – without requiring that distinct copies of the data be provided to each element.

10. Rfx

The ION rfx (R/F Contacts) system manages lists of scheduled communication opportunities in support of a number of LTP and BP functions.

1.5.2 Licklider Transmission Protocol (LTP)

The ION implementation of LTP conforms fully to RFC 5326, but it also provides two additional features that enhance functionality without affecting interoperability with other implementations:

- The service data units – nominally bundles – passed to LTP for transmission may be aggregated into larger blocks before segmentation. By controlling block size we can control the volume of acknowledgment traffic generated as blocks are received, for improved accommodation of highly asynchronous data rates.

- The maximum number of transmission sessions that may be concurrently managed by LTP (a protocol control parameter), multiplied by the maximum block size, constitutes a transmission “window” – the basis for a delay-tolerant, non-conversational flow control service over interplanetary links.

In the ION stack, LTP serves effectively the same role that is performed by TCP in the Internet architecture, providing flow control and retransmission-based reliability.

All LTP session state is safely retained in an SDR data store for rapid recovery from a spacecraft or software fault.

1.5.3 Bundle Protocol (BP)

The ION implementation of BP conforms fully to RFC 5050, including support for the following standard capabilities:

- Prioritization of data flows
- Bundle reassembly from fragments
- Flexible status reporting
- Custody transfer, including re-forwarding of custodial bundles upon failure of nominally reliable convergence-layer transmission

The system also provides two additional features that enhance functionality without affecting interoperability with other implementations:

- Rate control provides support for congestion forecasting and avoidance.
- Bundle headers are encoded into compressed form (CBHE, as noted earlier) before issuance, to reduce protocol overhead and improve link utilization.

In addition, ION BP includes a system for computing dynamic routes through time-varying network topology assembled from scheduled, bounded communication opportunities. This system, called “Contact Graph Routing,” is described later in this Guide.

In short, BP serves effectively the same role that is performed by IP in the Internet architecture, providing route computation, forwarding, congestion avoidance, and control over quality of service.

Together, the BP/LTP combination offers capabilities comparable to TCP/IP in the Internet.

All bundle transmission state is safely retained in an SDR data store for rapid recovery from a spacecraft or software fault.

1.5.4 Datagram Retransmission (DGR)

The DGR package in ION is provided as a candidate “primary transfer service” in support of AMS operations in an Internet-like (non-delay-tolerant) environment. The

DGR design combines LTP’s concept of concurrent transmission transactions with congestion control and timeout interval computation algorithms adapted from TCP.

1.5.5 Asynchronous Message Service (AMS)

For an overview of the AMS system, please see section 1.3 of the AMS Programmer’s Guide.

1.6 Acronyms

BP	Bundle Protocol
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
CGR	Contact Graph Routing
CL	convergence layer
CLI	convergence layer input
CLO	convergence layer output
DTN	Delay-Tolerant Networking
ICI	Interplanetary Communication Infrastructure
ION	Interplanetary Overlay Network
LSI	link service input
LSO	link service output
LTP	Licklider Transmission Protocol
OWLT	one-way light time
RFC	request for comments
RFX	Radio (R/F) Contacts
RTT	round-trip time
TTL	time to live

1.7 Network Operation Concepts

A small number of network operation design elements – fragmentation and reassembly, bandwidth management, and delivery assurance (retransmission) – can potentially be addressed at multiple layers of the protocol stack, possibly in different ways for different reasons. In stack design it's important to allocate this functionality carefully so that the effects at lower layers complement, rather than subvert, the effects imposed at higher layers of the stack. This allocation of functionality is discussed below, together with a discussion of several related key concepts in the ION design.

1.7.1 Fragmentation and Reassembly

To minimize transmission overhead and accommodate asymmetric links (i.e., limited "uplink" data rate from a ground data system to a spacecraft) in an interplanetary network, we ideally want to send "downlink" data in the largest possible aggregations – coarse-grained transmission.

But to minimize head-of-line blocking (i.e., delay in transmission of a newly presented high-priority item) and minimize data delivery latency by using parallel paths (i.e., to provide fine-grained partial data delivery, and to minimize the impact of unexpected link termination), we want to send "downlink" data in the smallest possible aggregations – fine-grained transmission.

We reconcile these impulses by doing both, but at different layers of the ION protocol stack.

First, at the application service layer (AMS and, eventually, CFDP) we present relatively small application data units (ADUs) – on the order of 64 KB – to BP for encapsulation in bundles. This establishes an upper bound on head-of-line blocking when bundles are de-queued for transmission, and it provides perforations in the data stream at which forwarding can readily be switched from one link (route) to another, enabling partial data delivery at relatively fine, application-appropriate granularity. In so doing, it makes "proactive fragmentation" within the Bundle Protocol itself unnecessary.

But then, at the BP/LTP convergence layer adapter lower in the stack, we aggregate these small bundles into *blocks* for presentation to LTP:

> Any continuous sequence of bundles that are to be shipped to the same LTP engine and require the same level of delivery assurance (i.e., the same LTP "color") may be aggregated into a single block, to reduce overhead and minimize report traffic.
>
> However, this aggregation is constrained by a block size limit rule: each block must contain an integral number N – where N is greater than zero – complete bundles, but N can only exceed 1 when the sum of the sizes of all N bundles does not exceed the *nominal block size* declared for the applicable *span* (the relationship between the local node and the receiving LTP engine) during LTP protocol configuration via **ltpadmin**.

Given a preferred block acknowledgment period – e.g., an acknowledgment traffic limit of one report per second – nominal block size is notionally computed as the amount of data that can be sent over the link to the receiving LTP engine in a single block acknowledgment period at the planned outbound data rate to that engine.

Taken together, application-level fragmentation and LTP aggregation place an upper limit on the amount of data that would need to be re-transmitted over a given link at next contact in the event of an unexpected link termination that caused delivery of an entire block to fail. For example, if the data rate is 1 Mbps and the nominal block size is 128 KB (equivalent to 1 second of transmission time), we would prefer to avoid the risk of having wasted five minutes of downlink in sending a 37.5 MB file that fails on transmission of the last kilobyte, forcing retransmission of the entire 37.5 MB. We therefore divide the file into, say, 1200 bundles of 32 KB each which are aggregated into blocks of 128 KB each: only a single block failed, so only that block (containing just 4 bundles) needs to be retransmitted. The cost of this retransmission is only 1 second of link time rather than 5 minutes. By controlling the cost of convergence-layer protocol failure in this way, we avoid the overhead and complexity of “reactive fragmentation” in the BP implementation.

Finally, within LTP itself we fragment the block as necessary to accommodate the Maximum Transfer Unit (MTU) size of the underlying link service, typically the transfer frame size of the applicable CCSDS link protocol.

1.7.2 Bandwidth Management

The allocation of bandwidth (transmission opportunity) to application data is requested by the application task that’s passing data to DTN, but it is necessarily accomplished only at the lowest layer of the stack at which bandwidth allocation decisions can be made – and then always in the context of node policy decisions that have global effect.

The “outduct” interface to a given neighbor in the network is actually three queues of outbound bundles rather than one: one queue for each of the defined levels of priority (“class of service”) supported by BP. When an application presents an ADU to BP for encapsulation in a bundle, it indicates its own assessment of the ADU’s priority. Upon selection of a proximate forwarding destination node for that bundle, the bundle is appended to whichever of the neighbor interface queues corresponds to the ADU’s priority.

Normally the convergence-layer output (CLO) task servicing a given outduct – e.g., the LTP output task **ltpclo** – extracts bundles in strict priority order from the heads of the outduct’s three queues. That is, the bundle at the head of the highest-priority non-empty queue is always extracted.

However, if the ION_BANDWIDTH_RESERVED compiler option is selected at the time ION is built, the convergence-layer output (CLO) task servicing a given outduct extracts bundles in interleaved fashion from the heads of the outduct’s three queues:

- Whenever the priority-2 (“express”) queue is non-empty, the bundle at the head of that queue is the next one extracted.
- At all other times, bundles from both the priority-1 queue and the priority-0 queue are extracted, but over a given period of time twice as many bytes of priority-1 bundles will be extracted as bytes of priority-0 bundles.

CLO tasks other than **ltpclo** simply segment the extracted bundles as necessary and transmit them using the underlying convergence-layer protocol. In the case of **ltpclo**, the output task aggregates the extracted bundles into blocks as described earlier and a second daemon task named **ltpmeter** waits for aggregated blocks to be completed; **ltpmeter**, rather than the CLO task itself, segments each completed block as necessary and passes the segments to the link service protocol that underlies LTP. Either way, the transmission ordering requested by application tasks is preserved.

1.7.3 Contact Plans

In the Internet, protocol operations can be largely driven by currently effective information that is discovered opportunistically and immediately, at the time it is needed, because the latency in communicating this information over the network is negligible: distances between communicating entities are small and connectivity is continuous. In a

DTN-based network, however, ad-hoc information discovery would in many cases take so much time that it could not be completed before the information lost currency and effectiveness. Instead, protocol operations must be largely driven by information that is pre-placed at the network nodes and tagged with the dates and times at which it becomes effective. This information takes the form of *contact plans* that are managed by the R/F Contacts (rfx) services of ION's ici package.

The structure of ION's RFX (contact plan) database, the rfx system elements that populate and use that data, and affected portions of the BP and LTP protocol state databases are shown in the following diagram. The node, xmit, and origin data objects contain the information that functions as ION's "contact graph".

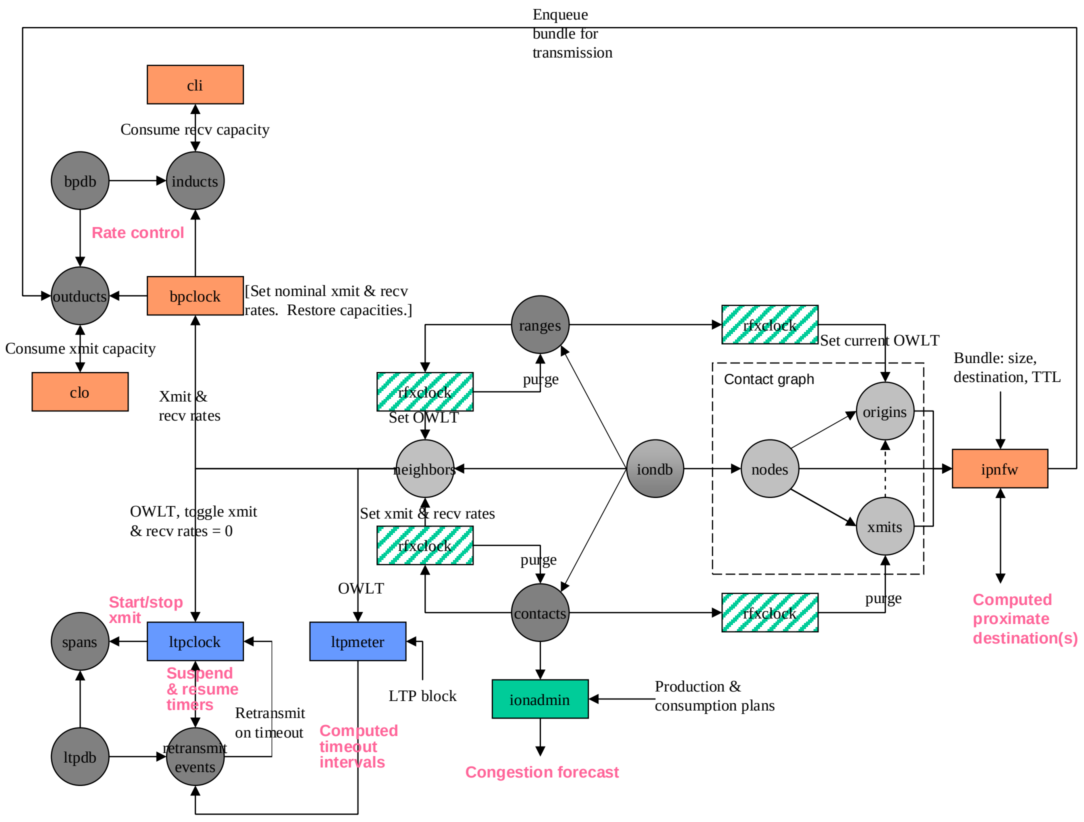


Figure 5 RFX services in ION

(For additional details of BP and LTP database management, see the BP/LTP discussion later in this document.)

To clarify the notation of this diagram, which is also used in other database structure diagrams in this document:

- Data objects of defined structure are shown as circles.
- Solid arrows connecting circles indicate one-to-many cardinality.
- A dashed arrow between circles indicates a potentially many-to-one reference mapping.

- Arrows from processing elements (rectangles) to data entities indicate data production, while arrows from data entities to processing element indicate data retrieval.

A *contact* is here defined as an interval during which it is expected that data will be transmitted by DTN node A (the contact's transmitting node) and most or all of the transmitted data will be received by node B (the contact's receiving node). Implicitly, the transmitting mode will utilize some "convergence-layer" protocol underneath the Bundle Protocol to effect this direct transmission of data to the receiving node. Each contact is characterized by its start time, its end time, the identities of the transmitting and receiving nodes, and the rate at which data are expected to be transmitted by the transmitting node throughout the indicated time period.

A *range interval* is a period of time during which the displacement between two nodes A and B is expected to vary by less than 1 light second from a stated anticipated distance. (We expect this information to be readily computable from the known orbital elements of all nodes.) Each range interval is characterized by its start time, its end time, the identities of the two nodes to which it pertains, and the anticipated approximate distance between those nodes throughout the indicated time period.

The *topology timeline* at each node in the network is a time-ordered list of scheduled or anticipated changes in the topology of the network. Entries in this list are of two types:

- Contact entries characterize scheduled contacts.
- Range entries characterize anticipated range intervals.

Each node to which, according to the RFX database, the local node transmits data directly via some convergence-layer protocol at some time is termed a *neighbor* of the local node. Each neighbor is associated with an outduct – a set of outbound transmission queues – for the applicable BP convergence-layer (CL) protocol adapter, so bundles that are to be transmitted directly to this neighbor can simply be queued for transmission via that CL protocol (as discussed in the Bandwidth Management notes above).

At startup, and at any time while the system is running, **ionadmin** inserts and removes Contact and Range entries in topology timeline of the RFX database. Inserting a Contact that affects at least one node other than the local node causes corresponding Xmit objects to be inserted for the affected Node object(s), for use in route computation. Inserting an Xmit for a Node may entail creation of the Node and/or creation of an Origin for the affected Node. Removing a Contact that affects at least one node other than the local node causes the corresponding Xmits to be removed from the affected Node(s).

Once per second, the **rfxclock** task (which appears in multiple locations on the diagram to simplify the geometry) purges all Contacts and Ranges with end time in the past, resets to zero the data rates and one-way light time (OWLT – that is, range) between the local node and each of its neighbors (represented by Neighbor objects in the volatile database), resets to zero the OWLT between each Node and each of its Origins, and then applies all Contacts and Ranges with start time in the past. Purging a Contact for transmission to some node other than the local node additionally removes the corresponding Xmit object. Applying a Contact sets the transmission or reception data rate between the local node and one of its Neighbors. Applying a Range sets the OWLT for the Origin of one of the affected nodes and either (a) if the other node is the local node, sets the OWLT for the corresponding Neighbor or (b) otherwise sets the OWLT for that other node's Origin. Setting data rate or OWLT for a node with which the local node will at some time be in direct communication may entail creation of a Neighbor object.

1.7.4 Route Computation

ION's computation of a route for a given bundle with a given destination endpoint is accomplished by one of two methods, depending on the destination. In every case, the result of successful routing is the insertion of the bundle into an outbound transmission queue (selected according to the bundle's priority) for one or more neighboring nodes.

But before discussing these methods it will be helpful to establish some terminology:

> Egress plans
>
> ION can only forward bundles to a neighboring node by queuing them on some explicitly specified outduct. Specifications that associate neighboring nodes with outducts – possibly varying depending on the node numbers and/or service numbers of bundles' source entity IDs – are termed *egress plans*.
>
> Static routes
>
> ION can be configured to forward to some specified node all bundles that are destined for a given node to which no *dynamic route* can be discovered from an examination of the contact graph, as described later. Such a specification, termed a *static route*, is a special case of the "group" mechanism described below.
>
> Groups
>
> When the size of the network makes it impractical to distribute all Contact and Range information for all nodes to every node, the job of computing dynamic routes to all nodes may be partitioned among multiple *gateway* nodes. Each gateway is responsible for managing a comprehensive contact graph for some subset of the total network population – a *group*, comprising all nodes whose node numbers fall within the range of node numbers assigned to the gateway. A bundle destined for a node for which no dynamic route can be computed from the local node's contact graph may be routed to the gateway node for the group within whose range the destination's node number falls. (Note that the group mechanism implements *static routes* and *default routes* in CGR in addition to improving scalability; a static route is simply a group comprising only a single destination node.)

We begin route computation by attempting to compute a dynamic route to the bundle's final destination node. The details of this algorithm are described in the section on ***Contact Graph Routing***, below.

If no dynamic route can be computed, we look for a default route. If the bundle's destination node number is in the range of node numbers assigned to the gateways for one or more groups, then we forward the bundle to that gateway node for the smallest such group. (If the gateway node is a neighbor, we simply queue the bundle on the outduct for that neighbor; otherwise we similarly look up the default route for the gateway until eventually we resolve to some egress plan.)

If we can determine neither a dynamic route nor a default route for this bundle, then the bundle cannot be forwarded. If custody transfer is requested for the bundle, we send a custody refusal to the bundle's current custodian; in any case, we discard the bundle.

1.7.5 Delivery Assurance

End-to-end delivery of data can fail in many ways, at different layers of the stack. When delivery fails, we can either accept the communication failure or retransmit the data structure that was transmitted at the stack layer at which the failure was detected. ION is designed to enable retransmission at multiple layers of the stack, depending on the preference of the end user application.

At the lowest stack layer that is visible to ION, the convergence-layer protocol, failure to deliver one or more segments due to segment loss or corruption will trigger segment retransmission if a "reliable" convergence-layer protocol is in use: LTP "red-part" transmission or TCP (including Bundle Relay Service, which is based on TCP)[1].

Segment loss may be detected and signaled via NAK by the receiving entity, or it may only be detected at the sending entity by expiration of a timer prior to reception of an ACK. Timer interval computation is well understood in a TCP environment, but it can be a difficult problem in an environment of scheduled contacts as served by LTP. The round-trip time for an acknowledgment dialogue may be simply twice the one-way light time (OWLT) between sender and receiver at one moment, but it may be hours or days longer at the next moment due to cessation of scheduled contact until a future contact opportunity. To account for this timer interval variability in retransmission, the **ltpclock** task infers the initiation and cessation of LTP transmission, to and from the local node, from changes in the current xmit and recv data rates in the corresponding Neighbor objects. This controls the dequeuing of LTP segments for transmission by underlying link service adapter(s) and it also controls suspension and resumption of timers, removing the effects of contact interruption from the retransmission regime. For a further discussion of this mechanism, see the section below on ***LTP Timeout Intervals***.

Note that the current OWLT in Neighbor objects is also used in the computation of the nominal expiration times of timers and that **ltpclock** is additionally the agent for LTP segment retransmission based on timer expiration.

It is, of course, possible for the nominally reliable convergence-layer protocol to fail altogether: a TCP connection might be abruptly terminated, or an LTP transmission might be canceled due to excessive retransmission activity (again possibly due to an unexpected loss of connectivity). In this event, BP itself detects the CL protocol failure and re-forwards all bundles for which *custody transfer* was requested whose acquisition by the receiving entity is presumed to have been aborted by the failure. This re-

[1] In ION, reliable convergence-layer protocols (where available) are by default used for every bundle. The application can instead mandate selection of "best-effort" service at the convergence layer by setting the BP_BEST_EFFORT flag in the "class of service" parameter, but this feature is an ION extension that is not supported by other BP implementations at the time of this writing.

forwarding is initiated in different ways for different CL protocols, as implemented in the CL input and output adapter tasks.

In addition to the implicit forwarding failure detected when a CL protocol fails, the forwarding of a bundle may be explicitly refused by the receiving entity, again provided the bundle is flagged for custody transfer service. A receiving node's refusal to take custody of a bundle may have any of a variety of causes: typically the receiving node either (a) has insufficient resources to store and forward the bundle, (b) has no route to the destination, or (c) will have no contact with the next hop on the route before the bundle's TTL has expired. In any case, a "custody refusal signal" (packaged in a bundle) is sent back to the sending node, which must re-forward the bundle in hopes of finding a more suitable route.

In the worst case, the combined efforts of all the retransmission mechanisms in ION are not enough to assure delivery of a given bundle, even when custody transfer is requested. In that event, the bundle's "time to live" will eventually expire while the bundle is still in custody at some node: the **bpclock** task will send a bundle status report to the bundle's report-to endpoint, noting the TTL expiration, and destroy the bundle. The report-to endpoint, upon receiving this report, may be able to initiate application-layer retransmission of the original application data unit in some way. This final retransmission mechanism is wholly application-specific, however.

1.7.6 Rate Control

In the Internet, the rate of transmission at a node can be dynamically negotiated in response to changes in level of activity on the link, to minimize congestion. On deep space links, signal propagation delays (distances) may be too great to enable effective dynamic negotiation of transmission rates. Fortunately, deep space links are operationally reserved for use by designated pairs of communicating entities over pre-planned periods of time at pre-planned rates. Provided there is no congestion inherent in the contact plan, congestion in the network can be avoided merely by adhering to the planned contact periods and data rates. *Rate control* in ION serves this purpose.

While the system is running, transmission and reception of bundles is constrained by the *current capacity* in the *throttle* of each outduct and induct. Completed bundle transmission or reception activity reduces the current capacity of the applicable duct by the capacity consumption computed for that bundle. This reduction may cause the duct's current capacity to become negative. Once the current capacity of the applicable duct's throttle goes negative, activity is blocked until non-negative capacity has been restored by **bpclock**.

Once per second, the **bpclock** task increases the current capacity of each induct and outduct throttle by one second's worth of traffic at the nominal data rate for that duct, thus enabling some possibly blocked bundle transmission and reception to proceed.

The nominal data rate for any duct of any CL protocol other than LTP (e.g., TCP) is a constant, established at the time the protocol was declared during ION initialization. For LTP, however, **bpclock** revises all ducts' nominal data rates once per second in accord with the current data rates in the corresponding Neighbor objects, as adjusted by **rfxclock** per the contact plan. This contact-plan-based adjustment is currently not possible for CL protocols other than LTP because at present there is no straightforward mechanism for mapping from Neighbor node number to protocol duct ID for any CL protocol other than LTP. So data flow over LTP links may be episodic, but data flow over non-LTP links is always continuous.

Note that this means that:

- ION's rate control system will enable data flow over non-LTP links even if there are no contacts in the contact plan that announce it. In this context the contact plan serves only to support route computation, and no contact plan is needed at all if static and default routes are provided for all destinations.
- ION's rate control system will enable data flow over LTP links ***only*** if there are contacts in the contact plan that announce it. In this context, announced contacts are mandatory for at least all neighboring nodes that are reachable by LTP.

1.7.7 Flow Control

A further constraint on rates of data transmission in an ION-based network is LTP flow control. LTP is designed to enable multiple block transmission sessions to be in various stages of completion concurrently, to maximize link utilization: there is no requirement to wait for one session to complete before starting the next one. However, if unchecked this design principle could in theory result in the allocation of all memory in the system to incomplete LTP transmission sessions. To prevent complete storage resource exhaustion, we set firm upper limits on both the size of each block and the total number of outbound blocks that can be concurrently in transit at any given time. These limits are established by **ltpadmin** at node initialization time[2].

The product of the nominal block size and the maximum number of transmission sessions that may be concurrently managed by LTP therefore constitutes a transmission "window" – the basis for a delay-tolerant, non-conversational flow control service over interplanetary links. Once the maximum number of sessions are in flight, no new block transmission session can be initiated – regardless of how much outduct transmission capacity is provided by rate control – until some existing session completes or is canceled.

Note that this consideration emphasizes the importance of configuring the nominal block sizes and session count limits of spans during LTP initialization to be consistent with the maximum data rates scheduled for contacts over those spans.

1.7.8 Storage Management

Congestion in a DTN is the imbalance between data enqueuing and dequeuing rates that results in exhaustion of queuing (storage) resources at a node, preventing continued operation of the protocols at that node.

[2] Note that the firm upper limit on block size is distinct from the nominal block size, used to control the acknowledgment traffic rate, that is specific to each span. A span's nominal block size may be less than the block size limit but cannot exceed it.

In ION, the affected queuing resources are allocated from notionally non-volatile storage space in the SDR data store. The design of ION is required to prevent resource exhaustion by simply refusing to enqueue additional data that would cause it.

However, a BP router's refusal to enqueue received data for forwarding could result in costly retransmission, data loss, and/or the "upstream" propagation of resource exhaustion to other nodes. Therefore the ION design additionally attempts to prevent potential resource exhaustion by forecasting levels of queuing resource occupancy and reporting on any congestion that is predicted. Network operators, upon reviewing these forecasts, may revise contact plans to avert the anticipated resource exhaustion.

The SDR data store used by ION serves several purposes: it contains queues of bundles awaiting forwarding, transmission, and delivery; it contains LTP transmission and reception sessions, including the blocks of data that are being transmitted and received; it contains queues of LTP segments awaiting radiation; and it contains protocol operational state information, such as configuration parameters, static routes, the contact graph, etc.

Effective utilization of SDR space is a complex problem. Static pre-allocation of storage resources is in general less efficient (and also more labor-intensive to configure) than storage resource pooling and automatic, adaptive allocation: trying to predict a reasonable maximum size for every data storage structure and then rigidly enforcing that limit typically results in underutilization of storage resources and underperformance of the system as a whole. However, static pre-allocation is mandatory for safety-critical resources, where certainty of resource availability is more important than efficient resource utilization.

The tension between the two approaches is closely analogous to the tension between circuit switching and packet switching in a network: circuit switching results in underutilization of link resources and underperformance of the network as a whole (some peaks of activity can never be accommodated, even while some resources lie idle much of the time), but dedicated circuits are still required for some kinds of safety-critical communication.

So the ION data management design combines these two approaches:

- A fixed percentage of the total SDR data store heap size (by default, 20%) is statically allocated to the storage of protocol operational state information, which is critical to the operation of ION.
- Another fixed percentage of the total SDR data store heap size (by default, 20%) is statically allocated to "margin", a reserve that helps to insulate node management from imprecision in resource allocation estimates.
- The remainder of the heap is allocated to DTN protocol traffic[3]. Of this total:
    - A small fraction (one-sixteenth of the total, but at least 100 KB) is reserved for spikes in the reception of inbound bundles.

[3] Note that, in all occupancy figures, ION data management accounts not only for the sizes of the payloads of all queued bundles but also for the sizes of their headers.

- The *occupied fraction* of the total traffic allocation is either the *current occupancy* of the heap (the sum of the lengths of all bundles currently stored) or the *maximum projected occupancy* (as defined below), whichever is greater.
- The *unoccupied fraction* of the total traffic allocation is the total traffic allocation less the occupied fraction.

The maximum projected occupancy of the node is the result of computing a *congestion forecast* for the node, by adding to the current occupancy all anticipated net increases and decreases from now until some future time, termed the *horizon* for the forecast.

The forecast horizon is indefinite – that is, "forever" – unless explicitly declared by network management via the `ionadmin` utility program. The difference between the horizon and the current time is termed the *interval* of the forecast.

Net occupancy increases and decreases are of four types[4]:

1. Bundles that are originated locally by some application on the node, which are enqueued for forwarding to some other node.
2. Bundles that are received from some other node, which are enqueued either for forwarding to some other node or for local delivery to an application.
3. Bundles that are transmitted to some other node, which are dequeued from some forwarding queue.
4. Bundles that are delivered locally to an application, which are dequeued from some delivery queue.

The **ionadmin** utility program computes a congestion forecast each time it runs, immediately before it exits. The type-1 anticipated net increase (total data origination) is computed by multiplying the node's production rate, as declared via an **ionadmin** command, by the interval of the forecast. Similarly, the type-4 anticipated net decrease (total data delivery) is computed by multiplying the node's consumption rate, as declared via an **ionadmin** command, by the interval of the forecast. Net changes of types 2 and 3 are computed by multiplying inbound and outbound data rates, respectively, by the durations of all periods of planned communication contact that begin and/or end within the interval of the forecast.

If the final result of the forecast computation – the maximum projected occupancy of the node over the forecast interval – is less than the total protocol traffic allocation, then no congestion is forecast. Otherwise, a congestion forecast status message is logged noting the time at which maximum projected occupancy is expected to equal the total protocol traffic allocation.

Congestion control in ION, then, has two components:

[4] Since all bytes of application data conveyed in LTP traffic at an ION node are bytes of bundle traffic, ION data management does not distinguish between the two. Inbound LTP segments are accounted for as bundle traffic that has not yet been reassembled (in effect, merely reorganized) into bundles. Outbound LTP segments are treated as transient copies of bundles that will be purged upon transmission, with no net long-term impact on data store occupancy.

First, ION's congestion detection is anticipatory (via congestion forecasting) rather than reactive as in the Internet.

Anticipatory congestion detection is important because the second component – congestion mitigation – must also be anticipatory: it is the adjustment of communication contact plans by network management, via the propagation of revised schedules for future contacts.

(Congestion mitigation in an ION-based network is likely to remain mostly manual for many years to come, because communication contact planning involves much more than mathematics: science operations plans, thermal and power constraints, etc. It will, however, rely on the automated rate control features of ION, discussed above, which assure that actual network operations conform to established contact plans.)

The computed maximum projected occupancy of the node is additionally retained in the RFX database for the purpose of *admission control*. ION will not permit new bundles to be locally originated when queuing them for forwarding would reduce the unoccupied fraction of the total traffic allocation (as defined above) to less than the level reserved for spikes in inbound bundle reception.

That is, ION's admission control mechanism implicitly recognizes that the node's first responsibility is to conform to contact plans (thus minimizing congestion elsewhere in the network) by receiving expected inbound data whenever possible; this is the reason for maintaining an explicit reserve for inbound bundle reception spikes. Note that there is no such explicit reserve for the node's total net bundle reception rate. This is because an implicit reserve for reception traffic is already built into the congestion forecast computation. Every received bundle is either:

- Immediately delivered to a local application, with no net effect on traffic allocation occupancy.
- Immediately forwarded and transmitted to another node, with no net effect on traffic allocation occupancy.
- Or queued for future forwarding or delivery, in which case its size is already reflected in the computed maximum projected occupancy (limiting the unoccupied fraction of the total traffic allocation) – so it has no additional net effect on traffic allocation occupancy.

1.7.9 Optimizing an ION-based network

ION is designed to deliver critical data to its final destination with as much certainty as possible (and optionally as soon as possible), but otherwise to try to maximize link utilization. The delivery of critical data is expedited by contact graph routing and bundle prioritization as described elsewhere. Optimizing link utilization, however, is a more complex problem.

If the volume of data traffic offered to the network for transmission is less than the capacity of the network, then all offered data should be successfully delivered[5]. But in

[5] Barring data loss or corruption for which the various retransmission mechanisms in ION cannot compensate.

that case the users of the network are paying the opportunity cost of whatever portion of the network capacity was not used.

Offering a data traffic volume that is exactly equal to the capacity of the network is in practice infeasible. TCP in the Internet can usually achieve this balance because it exercises end-to-end flow control: essentially, the original source of data is *blocked* from offering a message until notified by the final destination that transmission of this message can be accommodated given the current negotiated data rate over the end-to-end path (as determined by TCP's congestion control mechanisms). In a delay-tolerant network no such end-to-end negotiated data rate may exist, much less be knowable, so such precise control of data flow is impossible.[6]

The only alternative: the volume of traffic offered by the data source must be greater than the capacity of the network and the network must automatically discard excess traffic, shedding lower-priority data in preference to high-priority messages on the same path.

ION discards excess traffic proactively when possible and reactively when necessary.

<u>Proactive data triage</u> occurs when ION determines that it cannot compute a route that will deliver a given bundle to its final destination prior to expiration of the bundle's Time To Live (TTL). That is, a bundle may be discarded simply because its TTL is too short, but more commonly it will be discarded because the planned contacts to whichever neighboring node is first on the path to the destination are already fully subscribed: the queue of bundles awaiting transmission to that neighbor is already so long as to consume the entire capacity of all announced opportunities to transmit to it. Proactive data triage causes the bundle to be immediately destroyed as one for which there is "No known route to destination from here."

The determination of the degree to which a contact is subscribed is based not only on the aggregate size of the queued bundles but also on the estimated aggregate size of the overhead imposed by all the convergence-layer (CL) protocol data units – at all layers of the underlying stack – that encapsulate those bundles: packet headers, frame headers, etc. This means that the accuracy of this overhead estimate will affect the aggressiveness of ION's proactive data triage:

- If CL overhead is overestimated, the size of the bundle transmission backlog for planned contacts will be overstated, unnecessarily preventing the enqueuing of additional bundles – a potential under-utilization of available transmission capacity in the network.
- If CL overhead is underestimated, the size of the bundle transmission backlog for planned contacts will be understated, enabling the enqueuing of bundles whose transmission cannot in fact be accomplished by the network within the constraints of the current contact plan. This will eventually result in reactive data triage.

Essentially, all <u>reactive data triage </u>– the destruction of bundles due to TTL expiration prior to successful delivery to the final destination – occurs when the network conveys

[6] Note that ION may indeed block the offering of a message to the network, but this is local admission control – assuring that the node's local buffer space for queuing outbound bundles is not oversubscribed – rather than end-to-end flow control. It isalways possible for there to be ample local buffer space yet insufficient network capacity to convey the offered data to their final destination, and vice versa.

bundles at lower net rates than were projected during route computation. These performance shortfalls can have a variety of causes:

- As noted above, underestimating CL overhead causes CL overhead to consume a larger fraction of contact capacity than was anticipated, leaving less capacity for bundle transmission.
- Conversely, the total volume of traffic offered may have been accurately estimated but the amount of contact capacity may be less than was promised: a contact might be started late, stopped early, or omitted altogether, or the actual data rate on the link might be less than was advertised.
- Contacts may be more subtly shortened by the configuration of ION itself. If the clocks on nodes are known not to be closely synchronized then a "maximum clock error" of N seconds may be declared, causing reception episodes to be started locally N seconds earlier and stopped N seconds later than scheduled, to avoid missing some transmitted data because it arrived earlier than anticipated. But this mechanism also causes transmission episodes to be started N seconds later and stopped N seconds earlier than scheduled, to avoid transmitting to a neighbor before it is ready to receive data, and this contact truncation assures transmission of fewer bundles than planned.
- Flow control within the convergence layer underlying the bundle protocol may constrain the effective rate of data flow over a link to a rate that's lower than the link's configured maximum data rate. In particular, mis-configuration of the LTP flow control window can leave transmission capacity unused while LTP engines are awaiting acknowledgments.
- Even if all nodes are correctly configured, a high rate of data loss or corruption due to unexpectedly high R/F interference or underestimated acknowledgment round-trip times may cause an unexpectedly high volume of retransmission traffic. This will displace original bundle transmission, reducing the effective "goodput" data rate on the link.
- Finally, custody transfer may propagate operational problems from one part of the network to other nodes. One result of reduced effective transmission rates is the accumulation of bundles for which nodes have taken custody: the custodial nodes can't destroy those bundles and reclaim the storage space they occupy until custody has been accepted by "downstream" nodes, so abbreviated contacts that prevent the flow of custody acceptances can increase local congestion. This reduces nodes' own ability to take custody of bundles transmitted by "upstream" custodians, increasing queue sizes on those nodes, and so on. In short, custody transfer may itself ultimately impose reactive data triage simply by propagating congestion.

Some level of data triage is essential to cost-effective network utilization, and proactive triage is preferable because its effects can be communicated immediately to users, improving user control over the use of the network. Optimizing an ION-based network therefore amounts to managing for a modicum of proactive data triage and as little reactive data triage as possible. It entails the following:

1. Estimating convergence-layer protocol overhead as accurately as possible, erring (if necessary) on the side of optimism – that is, underestimating a little.

   As an example, suppose the local node uses LTP over CCSDS Telemetry to send bundles. The immediate convergence-layer protocol is LTP, but the total overhead per CL "frame" (in this case, per LTP segment) will include not only the size of the LTP header (nominally 5 bytes) but also the size of the encapsulating space packet header (nominally 6 bytes) and the overhead imposed by the outer encapsulating TM frame.

   Suppose each LTP segment is to be wrapped in a single space packet, which is in turn wrapped in a single TM frame, and Reed-Solomon encoding is applied. An efficient TM frame size is 1115 bytes, with an additional 160 bytes of trailing Reed-Solomon encoding and another 4 bytes of leading pseudo-noise code. The frame would contain a 6-byte TM frame header, a 6-byte space packet header, a 5-byte LTP segment header, and 1098 bytes of some LTP transmission block.

   So the number of "payload bytes per frame" in this case would be 1098 and the number of "overhead bytes per frame" would be 4 + 6 + 6 + 5 + 160 = 181. Nominal total transmission overhead on the link would be 181 / 1279 = about 14%.

2. Synchronizing nodes' clocks as accurately as possible, so that timing margins configured to accommodate clock error can be kept as close to zero as possible.
3. Setting the LTP session limit and block size limit as generously as possible (whenever LTP is at the convergence layer), to assure that LTP flow control does not constrain data flow to rates below those supported by BP rate control.
4. Setting ranges (one-way light times) and queuing delays as accurately as possible, to prevent unnecessary retransmission. Err on the side of pessimism – that is, overestimate a little.
5. Communicating changes in configuration – especially contact plans – to all nodes as far in advance of the time they take effect as possible.
6. Providing all nodes with as much storage capacity as possible for queues of bundles awaiting transmission.

1.8 *BP/LTP detail – how it works*

Although the operation of BP/LTP in ION is complex in some ways, virtually the entire system can be represented in a single diagram. The interactions among all of the concurrent tasks that make up the node – plus a Remote AMS task, acting as the application at the top of the stack – are shown below. (The notation is as used earlier but with semaphores added. Semaphores are shown as small circles, with arrows pointing into them signifying that the semaphores are being given and arrows pointing out of them signifying that the semaphores are being taken.)

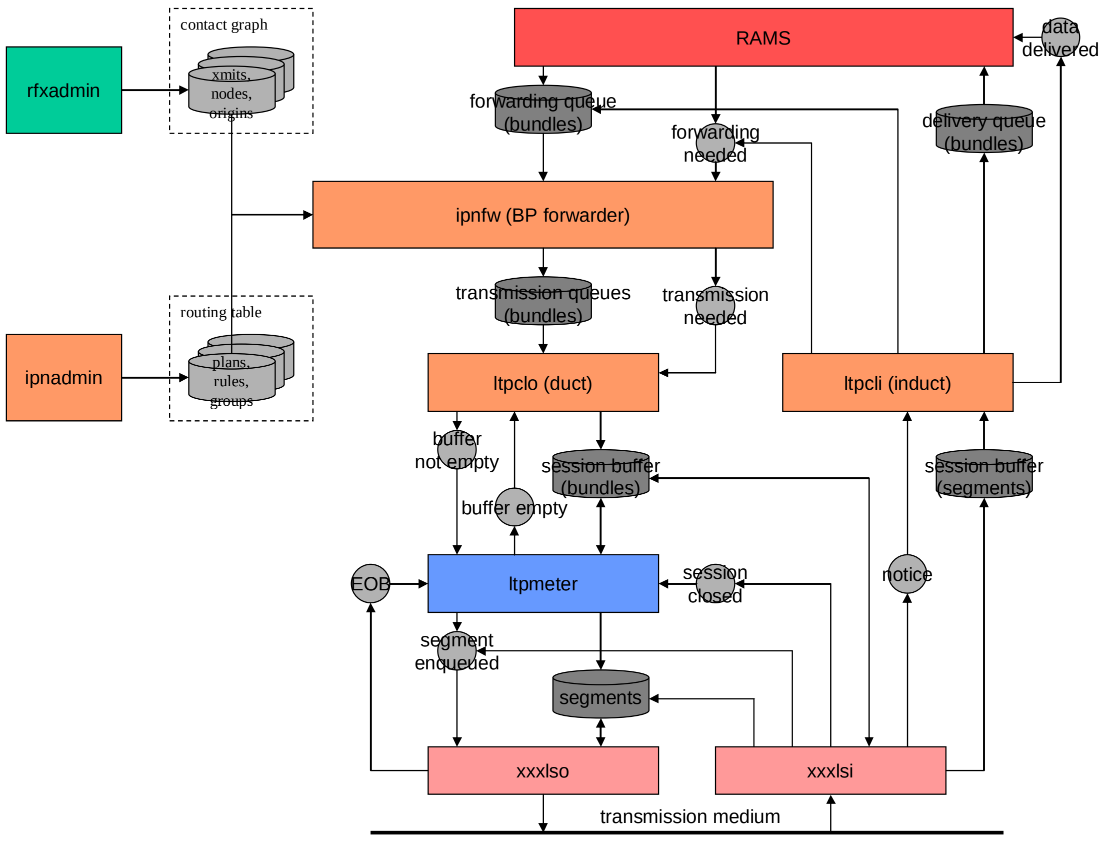


Figure 6 ION node functional overview

Further details of the BP/LTP data structures and flow of control and data appear on the following pages. (For specific details of the operation of the BP and LTP protocols as implement by the ION tasks, such as the nature of report-initiated retransmission in LTP, please see the protocol specifications. The BP specification is documented in Internet RFC 5050, while the LTP specification is documented in Internet RFC 5326.)

1.8.1 Databases

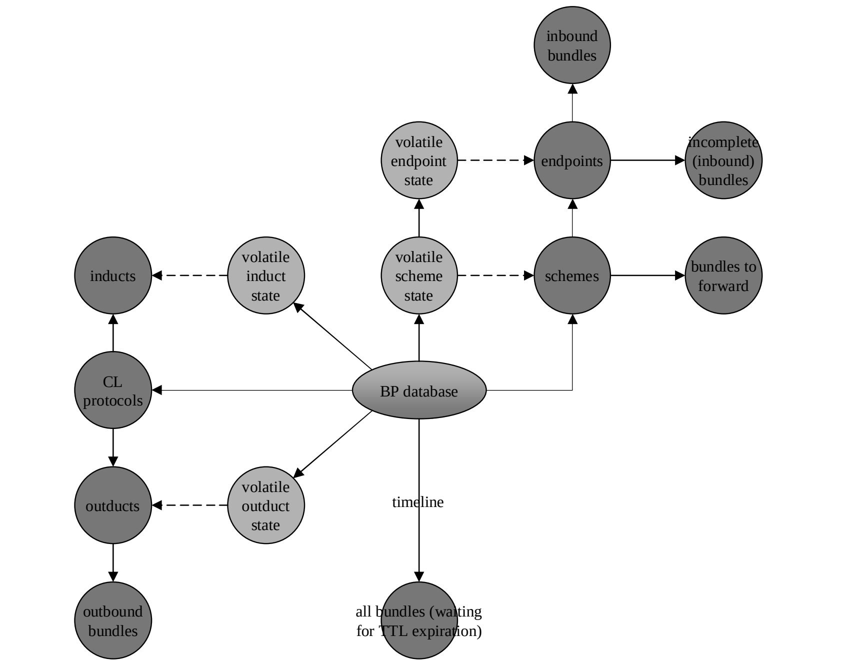


Figure 7 Bundle protocol database

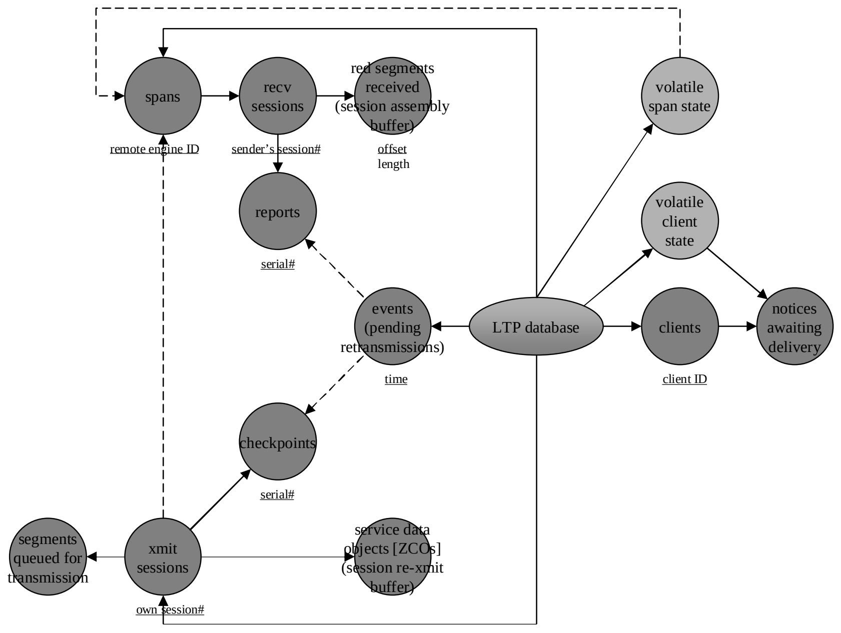
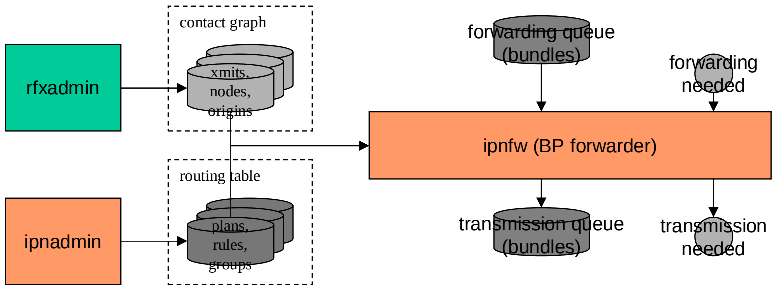


Figure 8 Licklider transmission protocol database

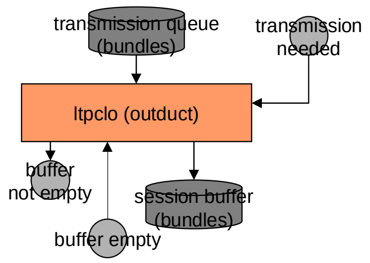
1.8.2 Control and data flow

Bundle Protocol



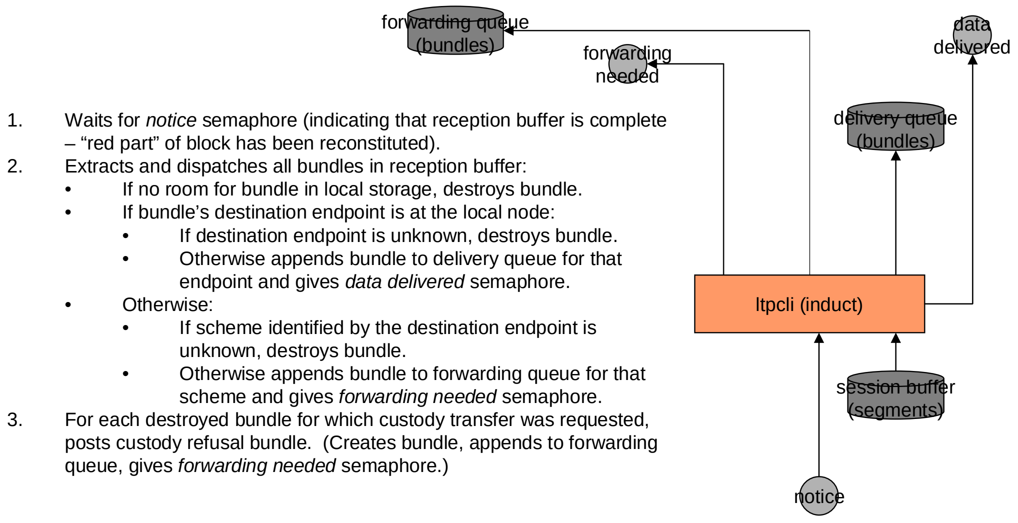
1. Waits for *forwarding needed* semaphore.
2. Gets bundle from queue.
3. Consults routing table and contact graph to determine all plausible proximate destinations – routing.
   - A plausible proximate destination is the destination node of the first entry in a contact sequence (a list of concatenated, connected contact periods) ending in a contact period whose destination node is the bundle's destination node and whose start time is less than the bundle's expiration time.
4. Appends bundle to transmission queue (based on priority) for best plausible proximate destination.
5. Gives *transmission needed* semaphore for that transmission queue.

Figure 9 ION forwarder



1. Waits for *buffer empty* semaphore (indicating that the link's session buffer has room for the bundle).
2. Waits for *transmission needed* semaphore.
3. Gets bundle from queue, subject to priority.
4. Appends bundle to link's session buffer – aggregation. Buffer size is notionally limited by aggregation rate (in nominal usec per block), a persistent attribute of the Link object: the rate at which we want reports to be transmitted by the destination engine.
5. Gives *buffer not empty* semaphore.

Figure 10 ION convergence layer output



1. Waits for *notice* semaphore (indicating that reception buffer is complete – “red part” of block has been reconstituted).
2. Extracts and dispatches all bundles in reception buffer:
   - If no room for bundle in local storage, destroys bundle.
   - If bundle’s destination endpoint is at the local node:
     - If destination endpoint is unknown, destroys bundle.
     - Otherwise appends bundle to delivery queue for that endpoint and gives *data delivered* semaphore.
   - Otherwise:
     - If scheme identified by the destination endpoint is unknown, destroys bundle.
     - Otherwise appends bundle to forwarding queue for that scheme and gives *forwarding needed* semaphore.
3. For each destroyed bundle for which custody transfer was requested, posts custody refusal bundle. (Creates bundle, appends to forwarding queue, gives *forwarding needed* semaphore.)

Figure 11 ION convergence layer input

<u>LTP</u>

1. Waits for *session closed* semaphore (indicating that a new session can be started) – <u>flow control</u>.
2. Initializes session buffer, gives *buffer empty* semaphore.
3. Waits for *buffer not empty* semaphore (indicating that the session buffer is ready for transmission) and *EOB semaphore* (indicating that link service transmission has caught up with the segment queue.
4. Segments the entire buffer into segments of managed MTU size – <u>fragmentation</u>.
5. Appends all segments to segments queue for immediate transmission.
6. Gives *segment enqueued* semaphore.

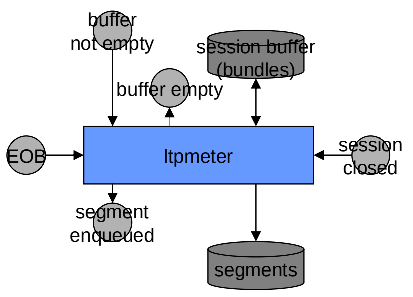


Figure 12 LTP transmission metering

1. Waits for *segment enqueued* semaphore (indicating that there is now something to transmit).
2. Gets segment from queue.
3. If initial transmission of an End Of Block, gives *EOB seg transmitted* semaphore.
4. Sets retransmission timer if necessary.
5. Transmits the segment using link service protocol.

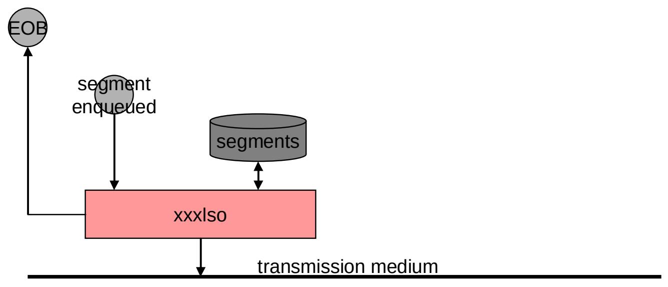


Figure 13 LTP link service output

1. Receives a segment using link service protocol.
2. If data, generates report segment and appends it to queue – reliability. Also inserts data into reception session buffer “red part” and, if that buffer is complete, gives *notice* semaphore to trigger bundle extraction and dispatching by ltpcli.
3. If a report, appends acknowledgement to segments queue.
4. If a report of missing data, recreates lost segments and appends them to queue.
5. If a report of complete reception, clears transmission session buffer and gives *session closed* semaphore.
6. Gives *segment enqueued* semaphore.

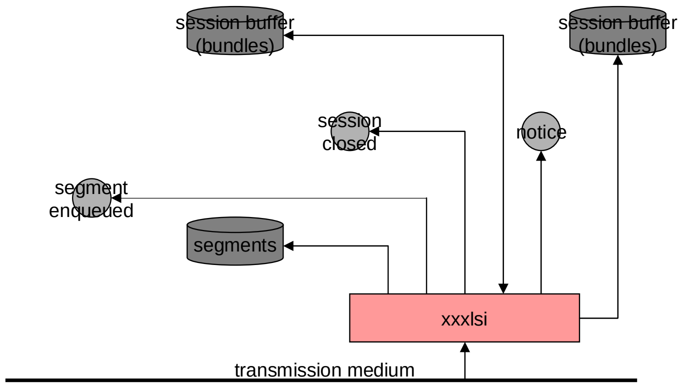


Figure 14 LTP link service input

1.9 Contact Graph Routing

CGR is a dynamic routing system that computes routes through a time-varying topology of scheduled communication contacts in a DTN network. It is designed to support operations in a space network based on DTN, but it also could be used in terrestrial applications where operation according to a predefined schedule is preferable to opportunistic communication, as in a low-power sensor network.

The basic strategy of CGR is to take advantage of the fact that, since communication operations are planned in detail, the communication routes between any pair of "bundle agents" in a population of nodes that have all been informed of one another's plans can be inferred from those plans rather than discovered via dialogue (which is impractical over long-one-way-light-time space links).

1.9.1 Contact Plan Messages

CGR relies on accurate contact plan information provided in the form of contact plan messages that currently are only read from **ionrc** files and processed by **ionadmin**, which retains them in the topology timeline of the RFX database, in ION's SDR data store.

Contact plan messages are of two types: *contact messages* and *range messages*.

Each contact message has the following content:

- The starting UTC time of the interval to which the message pertains.
- The stop time of this interval, again in UTC.
- The Transmitting node number.
- The Receiving node number.
- The planned rate of transmission from node A to node B over this interval, in bytes per second.

Each range message has the following content:

- The starting UTC time of the interval to which the message pertains.
- The stop time of this interval, again in UTC.
- Node number A.
- Node number B.
- The anticipated distance between A and B over this interval, in light seconds.

1.9.2 Contact Graphs

Each node uses Range and Contact timeline entries to build a "contact graph" data structure. The contact graph constructed locally by each node in the network contains, <u>for every other node D in the network</u>:

- A list of *xmit* objects encapsulating Contact start time, stop time, transmitting node number, and data transmission rate, derived from all Contact messages whose receiving node is node D; ordered by start time.
- A list of *origin* objects encapsulating transmitting node number S and that node's presumed current distance from node D, based on the information in Range messages.

This information is periodically updated by the **rfxclock** task, which applies stored Contact and Range messages to the contact graph as their start times are reached, purging Contact and Range messages and corresponding xmit objects whose stop times have passed.

1.9.3 Key Concepts

Well-formed routes

A well-formed route for given bundle is defined as a sequence of contacts such that the first contact is from the bundle's source to some other node, every subsequent contact in the sequence is from the receiving node of the prior contact to some other node, the last contact in the sequence is from some node to the bundle's final destination, and the route contains no loops – i.e., no two contacts in the sequence involve transmission from the same node and no two contacts in the sequence involve transmission to the same node.

Expiration time

Every bundle transmitted via DTN has a time-to-live (TTL), the length of time after which the bundle is subject to destruction if it has not yet been delivered to its destination. The *expiration time* of a bundle is computed as its creation time plus its TTL. When computing the next-hop destination for a bundle that the local bundle agent is required to forward, there is no point in selecting a route that can't get the bundle to its final destination prior to the bundle's expiration time.

OWLT margin

One-way light time (OWLT) – that is, distance – is obviously a factor in delivering a bundle to a node prior to a given time. OWLT can actually change during the time a bundle is en route, but route computation becomes intractably complex if we can't assume an OWLT "safety margin" – a maximum delta by which OWLT between any pair of nodes can change during the time a bundle is in transit between them.

We assume that the maximum rate of change in distance between any two nodes in the network is about 150,000 miles per hour, which is about 40 miles per second. (This was the speed of the Helios spacecraft, the fastest man-made object launched to date.)

At this speed, the distance between any two nodes that are initially separated by a distance of N light seconds will increase by a maximum of 40 miles per second of transit. This will result in data arrival no later than roughly (N + Q) seconds after transmission – where the "OWLT margin" value Q is (40 * N) divided by 186,000 – rather than just N seconds after transmission as would be the case if the two nodes were stationary relative to each other. When computing the expected time of arrival of a transmitted bundle we simply use N + Q, the most pessimistic case, as the anticipated total in-transit time.

Last moment

The *last moment* for sending a bundle during a given contact such that it will arrive at the receiving node prior to some deadline is computed as the deadline minus the sum of (a) the current one-way light time N between the contact's transmitting and receiving nodes (which can be obtained from the origin object for the transmitting node, in the receiving node's list of origins) and (b) the applicable OWLT margin for N, as above. If the contact's start time is after the last moment for the deadline, then clearly no transmission whatsoever that is initiated during that contact can be assured of getting the bundle to the contact's receiving node prior to the deadline.

Capacity

The *capacity* of a contact is the product of its data transmission rate (in bytes per second) and its duration (stop time minus start time, in seconds).

Estimated capacity consumption

The size of a bundle is the sum of its payload size and its header size[7], but bundle size is not the only lien on the capacity of a contact. The total estimated capacity consumption (or "ECC") for a bundle that is queued for transmission via some outduct is a more lengthy computation.

For each recognized convergence-layer protocol, we can estimate the number of bytes of "overhead" (that is, data that serves the purposes of the protocol itself rather than the user application that is using it) for each frame of convergence-layer protocol transmission. If the convergence layer protocol were UDP/IP over the Internet, for example, we might estimate the convergence layer overhead per frame to be 100 bytes – allowing for the nominal sizes of the UDP, IP, and Ethernet or SONET overhead for each IP packet.

We can estimate the number of bundle bytes per CL protocol frame as the total size of each frame less the per-frame convergence layer overhead. Continuing the example begun above, we might estimate the number of bundle bytes per frame to be 1400, which is the standard MTU size on the Internet (1500 bytes) less the estimated convergence layer overhead per frame

We can then estimate the total number of frames required for transmission of a bundle of a given size: this number is the bundle size divided by the estimated number of bundle bytes per CL protocol frame, rounded up.

The estimated total convergence layer overhead for a given bundle is, then, the per-frame convergence layer overhead multiplied by the total number of frames required for transmission of a bundle of that size

Finally the ECC for that bundle can be computed as the sum of the bundle's size and its estimated total convergence layer overhead.

[7] The typical size of an ION bundle header is 26 bytes. This will increase, however, when Bundle Security Protocol is added to ION's BP implementation.

Residual capacity

The *residual capacity* of a given contact between the local node and one of its neighbors, as computed for a given bundle, is the sum of the capacities of that contact and all prior scheduled contacts between the local node and that neighbor, less the sum of the ECCs of all bundles with priority equal to or higher than the priority of the subject bundle that are currently queued on the outduct for transmission to that neighbor.

Plausible opportunity

A *plausible opportunity* for transmitting a given bundle to some neighboring node is defined as a contact whose residual capacity is at least equal to the bundle's ECC. That is, if the capacity of a given contact is already fully subscribed, when computing routes for the next bundle there is no purpose served by assuming transmission during that contact.

Plausible routes

A *plausible route* for a given bundle is a well-formed route whose constituent contacts are all plausible transmission opportunities such that transmission of the bundle during each contact can occur before the last moment for that contact's applicable deadline. The applicable deadline for the last contact in the route is the bundle's expiration time; the applicable deadline for each preceding contact is the end of that contact.

Forfeit time

The *forfeit time* for a plausible route is the time by which the subject bundle must be transmitted from the local node to a neighboring node in order to have any chance of taking that route. Typically it is the stop time of the first contact in the route (the contact between the local node and its neighbor). However, it is possible for the first contact in a route to be a continuous contact, in which case the actual forfeit time may be the stop time of a downstream contact that starts after the start of the first contact but ends before the first contact stops. So, more generally, the forfeit time for a route is the earliest stop time among all contacts in the route.

Excluded neighbors

A neighboring node C that refuses custody of a bundle destined for some remote node D is termed an *excluded neighbor* for (that is, with respect to computing routes to) D. So long as C remains an excluded neighbor for D, no bundles destined for D will be forwarded to C – except that occasionally (once per lapse of the RTT between the local node and C) a custodial bundle destined for D will be forwarded to C as a "probe bundle". C ceases to be an excluded neighbor for D as soon as it accepts custody of a bundle destined for D.

Critical bundles

A Critical bundle is one that absolutely has got to reach its destination and, moreover, has got to reach that destination as soon as is physically possible[8].

[8] In ION, all bundles are by default non-critical. The application can indicate that data should be sent in a Critical bundle by setting the BP_MINIMUM_LATENCY flag in the "class of service" parameter, but this feature is an ION extension that is not supported by other BP implementations at the time of this writing.

For ordinary non-Critical bundles, the CGR dynamic route computation algorithm uses the contact graph to calculate which of the plausible routes to the bundle's final destination is determined to be "best" (as defined below). It then inserts the bundle into the outbound transmission queue for transmission to the neighboring node that is the first step along that route. It is possible, though, that due to some unforeseen delay the selected route will turn out to be less successful than another route that was not selected: the bundle might arrive later than it would have if another route had been selected, or it might not even arrive at all.

For Critical bundles, the CGR dynamic route computation algorithm causes the bundle to be inserted into the outbound transmission queues for transmission to all neighboring nodes that are on plausible routes to the bundle's final destination. The bundle is therefore guaranteed to travel over the most successful route, as well as over all other plausible routes. Note that this may result in multiple copies of a Critical bundle arriving at the final destination.

1.9.4 Dynamic Route Computation Algorithm

We start this algorithm by setting destination variable *D* to the bundle's final destination node number, setting "deadline" variable **X** to the bundle's expiration time, creating an empty list of Proximate Nodes to send to, initializing the forfeit time to infinity, and creating a list of Excluded Nodes, i.e., nodes through which we will not compute a route for this bundle. The list of Excluded Nodes is initially populated with:

- the node from which the bundle was directly received (so that we avoid cycling the bundle between that node and the local node) – unless the Dynamic Route Computation Algorithm is being re-applied due to custody refusal as discussed later;
- all excluded neighbors for the bundle's final destination node.

Then we invoke the **Contact Review Procedure** as described below.

Contact Review Procedure:

> First append node *D* to the list of Excluded Nodes, to prevent routing loops. (We don't want to re-compute routes through *D* in the course of computing routes for the intermediate nodes on any path to *D*.)
>
> Then, for each xmit *m* in node *D*'s list of xmits (in ascending order of transmission start time):
>
>> If *m*'s start time is after the last moment **T** for deadline **X**, then skip this xmit.
>>
>> Otherwise:
>>
>>> If *m*'s transmitting node *S* is the local node (that is, *D* is a neighbor of the local node):
>>>
>>>> Compute the ECC of the bundle, assuming transmission via the local node's outduct to *D*.

> > > > If *m*’s residual capacity is less than the computed ECC, then skip this xmit.
> > > >
> > > > Otherwise, if *D* is already in the list of Proximate Nodes to send this bundle to, then skip this xmit.
> > > >
> > > > Otherwise:
> > > >
> > > > > If *m*’s stop time is less than the forfeit time computed so far for this path:
> > > > >
> > > > > > Set the forfeit time to *m*’s stop time.
> > > > >
> > > > > Add *D* to the list of Proximate Nodes.
> > > > >
> > > > > Note the computed forfeit time in the event that the bundle is queued for transmission to *D*.
> > >
> > > Otherwise:
> > >
> > > > If *S* is already in the list of Excluded Nodes, then skip this xmit.
> > > >
> > > > Otherwise:
> > > >
> > > > > If *m*’s stop time is less than the forfeit time computed so far for this path:
> > > > >
> > > > > > Set the forfeit time to *m*’s stop time.
> > > > >
> > > > > Compute *estimated forwarding latency* **L** as twice the size of the bundle, divided by the data transmission rate for xmit *m*. (This value is used to allow for the time needed by node *S* simply to receive the bundle from <u>its</u> origin, queue it for transmission, and re-radiate it.)
> > > > >
> > > > > Invoke the **Contact Review Procedure** again, recursively, but with destination variable *D* now set to *S* and with deadline variable **X** set to either **T** or the time that is **L** seconds before the stop time of xmit *m*, whichever is earlier.
>
> Finally, remove *D* from the list of Excluded Nodes and let the forfeit time revert to its previous value (unraveling the recursion stack).

At this point, each member of the Proximate Nodes list is a neighboring node to which we can forward the bundle in the expectation that one of that node’s planned contacts will enable conveyance of the bundle on a plausible route toward its final destination.

If the list of Proximate Nodes is non-empty:

> If the bundle is Critical, then we now insert the bundle into the appropriate outbound transmission queue (depending on priority) for every Proximate Node in the list.

Otherwise (the bundle is non-critical, so we must select only a single Proximate Node for transmission):

We insert the bundle into the appropriate outbound transmission queue (depending on priority) of the Proximate Node that has the earliest associated forfeit time[9].

1.9.5 Exception Handling

Conveyance of a bundle from source to destination through a DTN can fail in a number of ways, many of which are best addressed by means of the Delivery Assurance mechanisms described earlier. Failures in Contact Graph Routing, specifically, occur when the expectations on which routing decisions are based prove to be false. These failures of information fall into two general categories: contact failure and custody refusal.

1) Contact failure

A scheduled contact between some node and its neighbor on the end-to-end route may be initiated later than the originally scheduled start time, or be terminated earlier than the originally scheduled stop time, or be canceled altogether. Alternatively, the available capacity for a contact might be overestimated due to, for example, diminished link quality resulting in unexpectedly heavy retransmission at the convergence layer. In each of these cases, the anticipated transmission of a given bundle during the affected contact may not occur as planned: the bundle might expire before the contact's start time, or the contact's stop time might be reached before the bundle has been transmitted.

For a non-Critical bundle, we handle this sort of failure by means of a timeout: if the bundle is not transmitted prior to the forfeit time for the selected Proximate Node, then the bundle is removed from its outbound transmission queue and the Dynamic Route Computation Algorithm is re-applied to the bundle so that an alternate route can be computed.

2) Custody refusal

A node that receives a bundle may find it impossible to forward it, for any of several reasons: it may not have enough storage capacity to hold the bundle, it may be unable to compute a forward route (static, dynamic, or default) for the bundle, etc. Such bundles are simply discarded, but discarding any such bundle that is marked for custody transfer will cause a custody refusal signal to be returned to the bundle's current custodian.

When the affected bundle is non-Critical, the node that receives the custody refusal re-applies the Dynamic Route Computation Algorithm to the bundle so that an alternate route can be computed – except that in this event the node from

[9] Note that this selection criterion biases the algorithm toward minimizing underutilization of fleeting transmission opportunities, rather than toward minimizing delivery latency. The rationale here is that latency can be minimized by declaring the bundle to be Critical, and absent that declaration the waste of expensive communication opportunities is a greater evil than a few minutes or hours of delay in delivery to the final destination.

which the bundle was originally directly received is omitted from the initial list of Excluded Nodes. This enables a bundle that has reached a dead end in the routing tree to be sent back to a point at which an altogether different branch may be selected.

For a Critical bundle no mitigation of either sort of failure is required or indeed possible: the bundle has already been queued for transmission on all plausible routes, so no mechanism that entails re-application of CGR's Dynamic Route Computation Algorithm could improve its prospects for successful delivery to the final destination. However, in some environments it may be advisable to re-apply the Dynamic Route Computation Algorithm to all Critical bundles that are still in local custody whenever a new Contact is added to the contact graph: the new contact may open an additional forwarding opportunity for one or more of those bundles.

1.9.6 Remarks

The CGR routing procedures respond dynamically to the changes in network topology that the nodes are able know about, i.e., those changes that are subject to mission operations control and are known in advance rather than discovered in real time. This dynamic responsiveness in route computation should be significantly more effective and less expensive than static routing, increasing total data return while at the same time reducing mission operations cost and risk.

Note that the non-Critical forwarding load across multiple parallel paths should be balanced automatically:

- Initially all traffic will be forwarded to the node(s) on what is computed to be the best path from source to destination.
- At some point, however, a node on that preferred path may have so much outbound traffic queued up that no contacts scheduled within bundles' lifetimes have any residual capacity. This can cause forwarding to fail, resulting in custody refusal.
- Custody refusal causes the refusing node to be temporarily added to the current custodian's excluded neighbors list for the affected final destination node. If the refusing node is the only one on the path to the destination, then the custodian may end up sending the bundle back to its upstream neighbor. Moreover, that custodian node too may begin refusing custody of bundles subsequently sent to it, since it can no longer compute a forwarding path.
- The upstream propagation of custody refusals directs bundles over alternate paths that would otherwise be considered suboptimal, balancing the queuing load across the parallel paths.
- Eventually, transmission and/or bundle expiration at the oversubscribed node relieves queue pressure at that node and enables acceptance of custody of a "probe" bundle from the upstream node. This eventually returns the routing fabric to its original configuration.

Although the route computation procedures are relatively complex they are not computationally difficult. The impact on computation resources at the vehicles should be modest.

1.10 LTP Timeout Intervals

Suppose we've got Earth ground station ES that is currently in view of Mars but will be rotating out of view ("Mars-set") at some time T1 and rotating back into view ("Mars-rise") at time T3. Suppose we've also got Mars orbiter MS that is currently out of the shadow of Mars but will move behind Mars at time T2, emerging at time T4. Let's also suppose that ES and MS are 4 light-minutes apart (Mars is at its closest approach to Earth). Finally, for simplicity, let's suppose that both ES and MS want to be communicating at every possible moment (maximum link utilization) but never want to waste any electricity.

Neither ES nor MS wants to be wasting power on either transmitting or receiving at a time when either Earth or Mars will block the signal.

ES will therefore stop transmitting at either T1 or (T2 - 4 minutes), whichever is earlier; call this time T_{et0}. It will stop receiving – that is, power off the receiver – at either T1 or (T2 + 4 minutes), whichever is earlier; call this time T_{er0}. It will resume transmitting at either T3 or (T4 - 4 minutes), whichever is later, and it will resume reception at either T3 or (T4 + 4 minutes), whichever is later; call these times T_{et1} and T_{er1}.

Similarly, MS will stop transmitting at either T2 or (T1 - 4 minutes), whichever is earlier; call this time T_{mt0}. It will stop receiving – that is, power off the receiver – at either T2 or (T1 + 4 minutes), whichever is earlier; call this time T_{mr0}. It will resume transmitting at either T4 or (T3 - 4 minutes), whichever is later, and it will resume reception at either T4 or (T3 + 4 minutes), whichever is later; call these times T_{mt1} and T_{mr1}.

By making sure that we don't transmit when the signal would be blocked, we guarantee that anything that is transmitted will arrive at a time when it can be received. Any reception failure is due to data corruption en route.

So the moment of transmission of an acknowledgment to any message is always equal to the moment the original message was sent plus some imputed outbound queuing delay QO1 at the sending node, plus 4 minutes, plus some imputed inbound and outbound queuing delay QI1 + QO2 at the receiving node. The nominally expected moment of reception of this acknowledgment is that moment of transmission plus 4 minutes, plus some imputed inbound queuing delay QI2 at the original sending node. That is, the timeout interval is 8 minutes + QO1 + QI1 + QO2 + QO2 – *unless* this moment of acknowledgment transmission is during an interval when the receiving node is not transmitting, for whatever reason. In this latter case, we want to suspend the acknowledgment timer during any interval in which we know the remote node will not be transmitting. More precisely, we want to add to the timeout interval the time difference between the moment of message arrival and the earliest moment at which the acknowledgment could be sent, i.e., the moment at which transmission is resumed[10].

[10] If we wanted to be extremely accurate we could also subtract from the timeout interval the imputed inbound queuing delay QI, since inbound queuing would presumably be completed during the interval in which transmission was suspended. But since we're guessing at the queuing delays anyway, this adjustment doesn't make a lot of sense.

So the timeout interval Z computed at ES for a message sent to MS at time T_X is given by:

$$Z = QO1 + 8 + QI1 + ((T_A = T_X + 4) > T_{mt0} \mathbin{\&\&} T_A < T_{mt1}) \; ? \; T_{mt1} - T_A : 0) + QI2 + QO2;$$

This can actually be computed in advance (at time T_X) if T1, T2, T3, and T4 are known and are exposed to the protocol engine.

If they are not exposed, then Z must initially be estimated to be (2 * the one-way light time) + QI + QO. The timer for Z must be dynamically suspended at time T_{mt0} in response to a state change as noted by **ltpclock**. Finally, the timer must be resumed at time T_{mt1} (in response to another state change as noted by **ltpclock**), at which moment the correct value for Z can be computed.

2 Operation

One compile-time option is applicable to all ION packages: the platform selection parameters –DVXWORKS and –DRTEMS affect the manner in which most task instantiation functions are compiled. For VXWORKS and RTEMS, these functions are compiled as library functions that must be identified by name in the platform's symbol table, while for Unix-like platforms they are compiled as `main()`functions.

2.1 Interplanetary Communication Infrastructure (ICI)

2.1.1 Compile-time options

Declaring values for the following variables, by setting parameters that are provided to the C compiler (for example, `–DFSWSOURCE` or `–DSM_SEMBASEKEY=0xff13`), will alter the functionality of ION as noted below.

PRIVATE_SYMTAB

This option causes ION to be built for VxWorks 5.4 or RTEMS with reliance on a small private local symbol table that is accessed by means of a function named `sm_FindFunction`. Both the table and the function definition are, by default, provided by the `symtab.c` source file, which is automatically included within the `platform_sm.c` source when this option is set. The table provides the address of the top-level function to be executed when a task for the indicated symbol (name) is to be spawned, together with the priority at which that task is to execute and the amount of stack space to be allocated to that task.

PRIVATE_SYMTAB is defined by default for RTEMS but not for VxWorks 5.4.

Absent this option, ION on VxWorks 5.4 must successfully execute the VxWorks `symFindByName` function in order to spawn a new task. For this purpose the entire VxWorks symbol table for the compiled image must be included in the image, and task priority and stack space allocation must be explicitly specified when tasks are spawned.

FSWSOURCE

This option causes the standard ION logging function, which simply writes all ION status messages to a file named `ion.log` in the current working directory, to be replaced (by `#include`) with code in the source file `fswlogger.c`. A file of this name must be in the inclusion path for the compiler, as defined by `–Ixxxx` compiler option parameters.

It also causes the invocation of the standard `time` function within `getUTCTime` (in `ion.c`) to be replaced (by `#include`) with code in the source file `fswutc.c`, which might for example invoke a mission-specific function to read a value from the spacecraft clock. A file of this name must be in the inclusion path for the compiler.

Finally, if the PRIVATE_SYMTAB option is also set, then the FSWSOURCE option additionally causes the code in source file `mysymtab.c` to be included in `platform_sm.c` in place of the default symbol table access implementation in `symtab.c`. A file named `mysymtab.c` must be in the inclusion path for the compiler.

GDSSOURCE

This option causes the standard ION logging function, which simply writes all ION status messages to a file named `ion.log` in the current working directory, to be replaced (by `#include`) with code in the source file `gdslogger.c`. A file of this name must be in the inclusion path for the compiler, as defined by `–Ixxxx` compiler option parameters.

ION_OPS_ALLOC=*xx*

This option specifies the percentage of the total non-volatile storage space allocated to ION that is reserved for protocol operational state information, i.e., is not available for the storage of bundles or LTP segments. The default value is 20.

ION_SDR_MARGIN=*xx*

This option specifies the percentage of the total non-volatile storage space allocated to ION that is reserved simply as margin, for contingency use. The default value is 20.

The sum of ION_OPS_ALLOC and ION_SDR_MARGIN is sequestered at the time ION operations are initiated: for purposes of congestion forecasting and prevention of resource oversubscription, this sum is subtracted from the total size of the SDR "heap" to determine the maximum volume of space available for bundles and LTP segments. Data reception and origination activities fail whenever they would cause the total amount of data store space occupied by bundles and segments to exceed this limit.

USING_SDR_POINTERS

This is an optimization option for the SDR non-volatile data management system: when set, it enables the value of any variable in the SDR data store to be accessed directly by means of a pointer into the dynamic memory that is used as the data store storage medium, rather than by reading the variable into a location in local stack memory. Note that this option must **not** be enabled if the data store is configured for file storage only, i.e., if the SDR_IN_DRAM flag was set to zero at the time the data store was created by calling `sdr_load_profile`.

NO_SDR_TRACE

This option causes non-volatile storage utilization tracing functions to be omitted from ION when the SDR system is built. It disables a useful debugging option but reduces the size of the executable software.

NO_PSM_TRACE

This option causes memory utilization tracing functions to be omitted from ION when the PSM system is built. It disables a useful debugging option but reduces the size of the executable software.

IN_FLIGHT

This option controls the behavior of ION when an unrecoverable error is encountered.

If it is set, then the status message "Unrecoverable SDR error" is logged and the SDR non-volatile storage management system is globally disabled: the current database access transaction is ended and (provided transaction reversibility is enabled) rolled back, and all ION tasks terminate.

Otherwise, the ION task that encountered the error is simply aborted, causing a core dump to be produced to support debugging.

SM_SEMKEY=0x*XXXX*

This option overrides the default value (0xee01) of the identifying “key” used in creating and locating the global ION shared-memory system mutex.

SVR4_SHM

This option causes ION to be built using svr4 shared memory as the pervasive shared-memory management mechanism. svr4 shared memory is selected by default when ION is built for any platform other than VxWorks 5.4 or RTEMS. (For these latter operating systems all memory is shared anyway, due to the absence of a protected-memory mode.)

POSIX1B_SEMAPHORES

This option causes ION to be built using POSIX semaphores as the pervasive semaphore mechanism. POSIX semaphores are selected by default when ION is built for RTEMS but are otherwise not used or supported; this option enables the default to be overridden.

SVR4_SEMAPHORES

This option causes ION to be built using svr4 semaphores as the pervasive semaphore mechanism. svr4 semaphores are selected by default when ION is built for any platform other than VxWorks 5.4 (for which VxWorks native semaphores are the default choice) or RTEMS (for which POSIX semaphores are the default choice).

MSAP

This option causes ION to be built for VxWorks 5.4 (only) using VxWorks message queues as the pervasive semaphore mechanism, overriding the default selection of VxWorks native semaphores. The message queues used for this purpose have a depth of 1 and a message length of 1. The messages on the queue are content-free; all that matters is the access behavior. “Taking” the semaphore is implemented by posting a blocking read to the message queue, waiting for the message to be delivered, and discarding it. “Giving” the semaphore is implemented by posting a non-blocking write of a single byte, whose value is irrelevant. Selecting this option minimizes the number of explicit semaphore operations performed by ION software.

SM_SEMBASEKEY=0x*XXXX*

This option overrides the default value (0xee02) of the identifying “key” used in creating and locating the global ION shared-memory semaphore database, in the event that svr4 semaphores are used.

SEMMNI=*xxx*

This option declares to ION the total number of svr4 semaphore sets provided by the operating system, in the event that svr4 semaphores are used. It overrides the default value, which is 10 for Cygwin and 128 otherwise. (Changing this value typically entails rebuilding the O/S kernel.)

SEMMSL=*xxx*

This option declares to ION the maximum number of semaphores in each svr4 semaphore set, in the event that svr4 semaphores are used. It overrides the default value, which is 6 for Cygwin and 250 otherwise. .(Changing this value typically entails rebuilding the O/S kernel.)

SEMMNS=*xxx*

This option declares to ION the total number of svr4 semaphores that the operating system can support; the maximum possible value is SEMMNI x SEMMSL. It overrides the default value, which is 60 for Cygwin and 32000 otherwise. (Changing this value typically entails rebuilding the O/S kernel.)

ION_NO_DNS

This option causes the implementation of a number of Internet socket I/O operations to be omitted for ION. This prevents ION software from being able to operate over Internet connections, but it prevents link errors when ION is loaded on a spacecraft where the operating system does not include support for these functions.

ERRMSGS_BUFSIZE=*xxxx*

This option set the size of the buffer in which ION status messages are constructed prior to logging. The default value is 4 KB.

SPACE_ORDER=*x*

This option declares the word size of the computer on which the compiled ION software will be running: it is the base-2 log of the number of bytes in an address. The default value is 2, i.e., the size of an address is 2^2 = 4 bytes. For a 64-bit machine, SPACE_ORDER must be declared to be 3, i.e., the size of an address is 2^3 = 8 bytes.

NO_SDRMGT

This option enables the SDR system to be used as a data access transaction system only, without doing any dynamic management of non-volatile data. With the NO_SDRMGT option set, the SDR system library can (and in fact must) be built from the `sdrxn.c` source file alone.

DOS_PATH_DELIMITER

This option causes ION_PATH_DELIMITER to be set to '\' (backslash), for use in construction path names. The default value of ION_PATH_DELIMITER is '/' (forward slash, as is used in Unix-like operating systems).

noipc

This option indicates that ION is being constructed for Cygwin in the absence of cygserver, which provides implementations of the svr4 ipc functions that ION normally depends on in a Cygwin environment. Setting this option enables ION executables to be compiled and linked with much functionality stubbed out; DGR and AMS will still work, but the LTP and BP packages will not.

2.1.2 Build

To build ICI for a given deployment platform:

1. Decide where you want ION's executables, libraries, header files, etc. to be installed. The ION makefiles all install their build products to subdirectories (named **bin**, **lib**, **include**, **man**, **man/man1**, **man/man3**, **man/man5**) of an ION root directory, which by default is the directory named **/opt**. If you wish to use the default build configuration, be sure that the default directories (**/opt/bin**, etc.) exist; if not, select another ION root directory name – this document will refer to it as **$OPT** – and create the subdirectories as needed. In any case, make sure that you have read, write, and execute permission for all of the ION installation directories and that:
    - The directory **/$OPT/bin** is in your execution path.
    - The directory **/$OPT/lib** is in your $LD_LOADLIB_PATH.
2. Edit the Makefile in **ion/trunk/ici**:
    - Make sure PLATFORMS is set to the appropriate platform name, e.g., x86-redhat, sparc-sol9, etc.
    - Set OPT to your ION root directory name, if other than "/opt".
3. Then:

```
cd ion/trunk/ici
make
make install
```

2.1.3 Configure

Two types of files are used to provide the information needed to perform global configuration of the ION protocol stack: the ION system configuration (or **ionconfig**) file and the ION administration command (**ionrc**) file. For details, see the man pages for ionconfig(5) and ionrc(5) in Appendix A.

2.1.4 Run

The executable programs used in operation of the ici component of ION include:

- The **ionadmin** system configuration utility, invoked at node startup time and as needed thereafter.
- The **rfxclock** background daemon, which effects scheduled network configuration events.
- The **sdrmend** system repair utility, invoked as needed.
- The **sdrwatch** and **psmwatch** utilities for resource utilization monitoring, invoked as needed.

Each time it is executed, **ionadmin** computes a new congestion forecast and, if a congestion collapse is predicted, invokes the node's congestion alarm script (if any). **ionadmin** also establishes the node number for the local node and starts/stops the **rfxclock** task, among other functions. For further details, see the man pages for ionadmin(1), rfxclock(1), sdrmend(1), sdrwatch(1), and psmwatch(1) in Appendix A.

2.1.5 Test

Six test executables are provided to support testing and debugging of the ICI component of ION:

- The **file2sdr** and **sdr2file** programs exercise the SDR system.
- The **psmshell** program exercises the PSM system.
- The **file2sm**, **sm2file**, and **smlistsh** programs exercise the shared-memory linked list system.

For details, see the man pages for file2sdr(1), sdr2file(1), psmshell(1), file2sm(1), sm2file(1), and smlistsh(1) in Appendix A.

2.2 Licklider Transmission Protocol (LTP)

2.2.1 Build

To build LTP:

1. Make sure that the "ici" component of ION has been built for the platform on which you plan to run LTP.
2. Edit the Makefile in **ion/trunk/ltp**:
   - As for ici, make sure PLATFORMS is set to the name of platform on which you plan to run LTP.
   - Set OPT to the directory containing the bin, lib, include, etc. directories used for building ici.
3. Then:

```
cd ion/trunk/ltp
make
make install
```

2.2.2 Configure

The LTP administration command (**ltprc**) file provides the information needed to configure LTP on a given ION node. For details, see the man page for ltprc(5) in Appendix A.

2.2.3 Run

The executable programs used in operation of the ltp component of ION include:

- The **ltpadmin** protocol configuration utility, invoked at node startup time and as needed thereafter.
- The **<u>ltpclock</u>** background daemon, which effects scheduled LTP events such as segment retransmissions.
- The **ltpmeter** block management daemon, which segments blocks and effects LTP flow control.
- The **udplsi** and **udpslo** link service input and output tasks, which handle transmission of LTP segments encapsulated in UDP datagrams (mainly for testing purposes).

ltpadmin starts/stops the **ltpclock** task and, as mandated by configuration, the **udplsi** and **udplso** tasks.

For details, see the man pages for ltpadmin(1), ltpclock(1), ltpmeter(1), udplsi(1), and udplso(1) in Appendix A.

2.2.4 Test

Two test executables are provided to support testing and debugging of the LTP component of ION:

- **ltpdriver** is a continuous source of LTP segments.
- **ltpcounter** is an LTP block receiver that counts blocks as they arrive.

For details, see the man pages for ltpdriver(1) and ltpcounter(1) in Appendix A.

2.3 *Bundle Protocol (BP)*

2.3.1 Compile-time options

Declaring values for the following variables, by setting parameters that are provided to the C compiler (for example, `–DION_NOSTATS` or `–DBRSSEED=2134245356`), will alter the functionality of BP as noted below.

<u>BRSSEED=*xxxxxxxxxx*</u>

This option overrides the hard-coded default value of the "seed" from which all BRS authenticators are computed; it is the "shared secret" on which BRS authentication is built. The BRSSEED compile-time option is mandatory for any BP installation in which secure Bundle Relay Service is required. It must be set to the same value for all nodes that will participate in BRS-based bundle exchange.

<u>BRSTERM=*xx*</u>

This option sets the maximum number of seconds by which the current time at the BRS server may exceed the time tag in a BRS authentication message from a client; if this interval is exceeded, the authentication message is presumed to be a replay attack and is rejected. Small values of BRSTERM are safer than large ones, but they require that clocks be more closely synchronized. The default value is 5.

<u>ION_NOSTATS</u>

Setting this option prevents the logging of bundle processing statistics in status messages.

<u>KEEPALIVE_PERIOD=*xx*</u>

This option sets the number of seconds between transmission of keep-alive messages over any TCP or BRS convergence-layer protocol connection. The default value is 15.

<u>ION_BANDWIDTH_RESERVED</u>

Setting this option overrides strict priority order in bundle transmission, which is the default. Instead, bandwidth is shared between the priority-1 and priority-0 queues on a 2:1 ratio whenever there is no priority-2 traffic.

2.3.2 Build

To build BP:

1. Make sure that the "ici" and "dg" (see below) components of ION have been built for the platform on which you plan to run BP.
2. Edit the Makefile in **ion/trunk/bp**:
   - As for ici, make sure PLATFORMS is set to the name of platform on which you plan to run BP.
   - Set OPT to the directory containing the bin, lib, include, etc. directories used for building ici.
3. Then:

```
cd ion/trunk/bp
make
make install
```

2.3.3 Configure

The BP administration command (**bprc**) file provides the information needed to configure generic BP on a given ION node. The IPN scheme administration command (**ipnrc**) file provides information that configures static and default routes for endpoints whose IDs conform to the "ipn" scheme. The DTN scheme administration command (**dtnrc**) file provides information that configures static and default routes for endpoints whose IDs conform to the "dtn" scheme, as supported by the DTN2 reference implementation. For details, see the man pages for bprc(5), ipnrc(5), and dtnrc(5) in Appendix A.

2.3.4 Run

The executable programs used in operation of the bp component of ION include:

- The **bpadmin, ipnadmin,** and **dtnadmin** protocol configuration utilities, invoked at node startup time and as needed thereafter.
- The **bpclock** background daemon, which effects scheduled BP events such as TTL expirations and which also implements rate control.
- The **ipnfw** and **dtnfw** forwarding daemons, which compute routes for bundles addressed to "ipn"-scheme and "dtn"-scheme endpoints, respectively.
- The **ipnadminep** and **dtnadminep** administrative endpoint daemons, which handle custody acceptances, custody refusals, and status messages.
- The **brsscla** (server) and **brsccla** (client) Bundle Relay Service convergence-layer adapters.
- The **tcpcli** (input) and **tcpclo** (output) TCP convergence-layer adapters.
- The **udpcli** (input) and **udpclo** (output) UDP convergence-layer adapters.
- The **ltpcli** (input) and **ltpclo** (output) LTP convergence-layer adapters.
- The **dgrcla** Datagram Retransmission convergence-layer adapter.
- The **bpsendfile** utility, which sends a file of arbitrary size, encapsulated in a single bundle, to a specified BP endpoint.
- The **bpstats** utility, which prints a snapshot of currently accumulated BP processing statistics on the local node.
- The **bptrace** utility, which sends a bundle through the network to enable a forwarding trace based on bundle status reports.
- The **lgsend** and **lgagent** utilities, which are used for remote administration of ION nodes.

bpadmin starts/stops the **bpclock** task and, as mandated by configuration, the **ipnfw**, **dtnfw**, **ipnadminep**, **dtnadminep**, **brsscla**, **brsccla**, , **tcpcli**, **tcpclo**, **udpcli**, **udpclo**, **ltpcli**, **ltpclo**, and **dgrcla** tasks.

For details, see the man pages for bpadmin(1),ipnadmin(1), dtnadmin(1), bpclock(1), ipnfw(1), dtnfw(1), ipnadminep(1), dtnadminep(1), brsscla(1), brsccla(1), tcpcli(1), tcpclo(1), udpcli(1), udpclo(1), ltpcli(1), ltpclo(1), dgrcla(1), bpsendfile(1), bpstats(1), bptrace(1), lgsend(1), and lgagent(1) in Appendix A.

2.3.5 Test

Five test executables are provided to support testing and debugging of the BP component of ION:

- **bpdriver** is a continuous source of bundles.
- **bpcounter** is a bundle receiver that counts bundles as they arrive.
- **bpecho** is a bundle receiver that sends an "echo" acknowledgment bundle back to bpdriver upon reception of each bundle.
- **bpsource** is a simple console-like application for interactively sending text strings in bundles to a specified DTN endpoint, nominally a **bpsink** task.
- **bpsink** is a simple console-like application for receiving bundles and printing their contents.

For details, see the man pages for bpdriver(1), bpcounter(1), bpecho(1), bpsource(1), and bpsink(1) in Appendix A.

2.4 Datagram Retransmission (DGR)

2.4.1 Build

To build DGR:

1. Make sure that the “ici” component of ION has been built for the platform on which you plan to run DGR.
2. Edit the Makefile in **ion/trunk/dgr**:
   - As for ici, make sure PLATFORMS is set to the name of platform on which you plan to run DGR.
   - Set OPT to the directory containing the bin, lib, include, etc. directories used for building ici.
3. Then:

```
cd ion/trunk/dgr
make
make install
```

2.4.2 Configure

No additional configuration files are required for the operation of the DGR component of ION.

2.4.3 Run

No runtime executables are required for the operation of the DGR component of ION.

2.4.4 Test

Two test executables are provided to support testing and debugging of the DGR component of ION:

- **file2dgr** repeatedly reads a file of text lines and sends copies of those text lines via DGR to **dgr2file**, which writes them to a copy of the original file.

For details, see the man pages for file2dgr(1) and dgr2file(1) in Appendix A.

2.5 Asynchronous Message Service (AMS)

For operational details of the AMS system, please see sections 4 and 5 of the AMS Programmer's Guide.

Appendix A – ION “man” Pages

Executables (man section 1)

bpadmin
bpclock
bpcounter
bpdriver
bpecho
bpsendfile
bpsink
bpsource
bpstats
bptrace
brsccla
brsscla
dgr2file
dgrcla
dtnadmin
dtnadminep
dtnfw
file2dgr
file2sdr
file2sm
ionadmin
ipnadmin
ipnadminep
ipnfw
lgagent
lgsend
ltpadmin
ltpcli
ltpclo
ltpclock
ltpcounter
ltpdriver
ltpmeter
owltsim
owlttb
psmshell
psmwatch
rfxclock
sdr2file
sdrmend
sdrwatch
sm2file
smlistsh
tcpcli
tcpclo
udpcli
udpclo
udplsi
udplso

Libraries (man section 3)

bp
bpextensions
dgr
ion
llcv
ltp
lyst
memmgr
platform
psm
sdr
sdrhash
sdrlist
sdrstring
sdrtable
smlist
zco

Configuration files (man section 5)

bprc
dtnrc
ionconfig
ionrc
ipnrc
lgfile
ltprc

NAME

bp - Bundle Protocol communications library

SYNOPSIS

```
    #include "bp.h"
```

    [see description for available functions]

DESCRIPTION

The bp library provides functions enabling application software to use Bundle Protocol to send and receive information over a delay-tolerant network. It conforms to the Bundle Protocol specification as documented in Internet RFC 5050.

int bp_attach( )

Attaches the application to BP functionality on the local computer. Returns 0 on success, -1 on any error.

Note that all ION libraries and applications draw memory dynamically, as needed, from a shared pool of ION working memory. The size of the pool is established when ION node functionality is initialized by ionadmin(1). This is a precondition for initializing BP functionality by running bpadmin(1), which in turn is required in order for `bp_attach()` to succeed.

Sdr bp_get_sdr( )

Returns handle for the SDR data store used for BP, to enable creation and interrogation of bundle payloads (application data units).

void bp_detach( )

Terminates access to BP functionality on the local computer.

int bp_open(char *eid, BpSAP *ionsapPtr)

Opens the application's access to the BP endpoint identified by *eid*, so that the application can take delivery of bundles destined for the indicated endpoint and to send bundles whose source is the indicated endpoint. On success, places a value in **ionsapPtr* that can be supplied to future bp function invocations and returns 0. Returns -1 on any error.

int bp_send(BpSAP sap, int mode, char *destEid, char *reportToEid, int lifespan, int classOfService, BpCustodySwitch custodySwitch, unsigned char srrFlags, int ackRequested, Object adu)

Sends a bundle to the endpoint identified by *destEid*, from the source endpoint as provided to the `bp_open()` call that returned *sap*.

mode must be either BP_BLOCKING or BP_NONBLOCKING, as `bp_send()` does not support timeout intervals.

reportToEid identifies the endpoint to which any status reports pertaining to this bundle will be sent; if NULL, defaults to the source endpoint.

lifespan is the maximum number of seconds that the bundle can remain in-transit (undelivered) in the network prior to automatic deletion.

classOfService is the logical OR of the bundle's transmission priority (BP_BULK_PRIORITY, BP_STD_PRIORITY, or BP_EXPEDITED_PRIORITY) and any other applicable class-of-service flags (both of which are ION extensions that are not supported by other BP implementations):

> BP_MINIMUM_LATENCY designates the bundle as "critical" for the purposes of Contact Graph Routing.
>
> BP_BEST_EFFORT signifies that non-reliable convergence-layer protocols, as available, may be used to transmit the bundle. Notably, the bundle may be sent as "green" data rather than "red" data when issued via LTP.

custodySwitch indicates whether or not custody transfer is requested for this bundle and, if so, whether or not the source node itself is required to be the initial custodian. The valid values are SourceCustodyRequired, SourceCustodyOptional, NoCustodyRequired.

srrFlags, if non-zero, is the logical OR of the status reporting behaviors requested for this bundle: BP_RECEIVED_RPT, BP_CUSTODY_RPT, BP_FORWARDED_RPT, BP_DELIVERED_RPT, BP_DELETED_RPT.

ackRequested is a Boolean parameter indicating whether or not the recipient application should be notified that the source application requests some sort of application-specific end-to-end acknowledgment upon receipt of the bundle.

adu must be a "zero-copy object" reference, as returned by zco_create(), containing the application data that is to be conveyed as the bundle's payload.

The function returns 1 on success, 0 on transient failure, -1 on any other (i.e., system or application; permanent) error. If 1 is returned, then the ADU has been accepted and queued for transmission in a bundle.

If 0 is returned, then there is not currently enough space for acceptance and queuing of this ADU. (Note that this is possible only when *mode* is BP_NONBLOCKING.) The application may abandon this transmission attempt or may wait briefly and then try again.

int bp_track(Object bundle, Object trackingElt)

Adds *trackingElt* to the list of ``tracking" reference in *bundle*. *trackingElt* must be the address of an SDR list element – whose data is the address of this same bundle – within some list of bundles that is privately managed by the application. Upon destruction of the bundle this list element will automatically be deleted, thus removing the bundle from the application's privately managed list of bundles. This enables the application to keep track of bundles that it is operating on without risk of inadvertently de-referencing the address of a nonexistent bundle.

void bp_untrack(Object bundle, Object trackingElt)

Removes *trackingElt* from the list of ``tracking" reference in *bundle*, if it is in that list. Does not delete *tracknigElt* itself.

int bp_cancel(Object bundle)

Cancels transmission of *bundle*. If the indicated bundle is currently queued for forwarding, transmission, or retransmission, it is removed from the relevant queue and destroyed exactly as if its Time To Live had expired. Returns 0 on success, -1 on any error.

int bp_receive(BpSAP sap, BpDelivery *dlvBuffer, int timeoutSeconds)

Receives a bundle, or reports on some failure of bundle reception activity.

The "result" field of the dlvBuffer structure will be used to indicate the outcome of the data reception activity.

If at least one bundle destined for the endpoint for which this SAP is opened has not yet been delivered to the SAP, then the payload of the oldest such bundle will be returned in *dlvBuffer->adu* and *dlvBuffer->result* will be set to BpPayloadPresent. If there is no such bundle, `bp_receive()` blocks for up to *timeoutSeconds* while waiting for one to arrive.

If *timeoutSeconds* is BP_POLL (i.e., zero) and no bundle is awaiting delivery, or if *timeoutSeconds* is greater than zero but no bundle arrives before *timeoutSeconds* have elapsed, then *dlvBuffer->result* will be set to BpReceptionTimedOut. If *timeoutSeconds* is BP_BLOCKING (i.e., -1) then `bp_receive()` blocks until either a bundle arrives or the function is interrupted by an invocation of bp_interrupt().

dlvBuffer->result will be set to BpReceptionInterrupted in the event that the calling process received and handled some signal other than SIGALRM while waiting for a bundle.

The application data unit delivered in the data delivery structure, if any, will be a "zero-copy object" reference. Use zco reception functions (see `zco(3)`) to read the content of the application data unit.

Be sure to call `bp_release_delivery()` after every successful invocation of bp_receive().

The function returns 0 on success, -1 on any error.

void bp_interrupt(BpSAP sap)

Interrupts a `bp_receive()` invocation that is currently blocked. This function is designed to be called from a signal handler; for this purpose, *sap* may need to be obtained from a static variable.

void bp_release_delivery(BpDelivery *dlvBuffer, int releaseAdu)

Releases resources allocated to the indicated delivery. *releaseAdu* is a Boolean parameter: if non-zero, the ADU ZCO reference in *dlvBuffer* (if any) is destroyed, causing the ZCO itself to be destroyed if no other references to it remain.

void bp_close(BpSAP sap)

Terminates the application's access to the BP endpoint identified by the *eid* cited by the indicated service access point. The application relinquishes its ability to take delivery of bundles destined for the indicated endpoint and to send bundles whose source is the indicated endpoint.

SEE ALSO

bpadmin(1), lgsend(1), lgagent(1), bpextensions(3), bprc(5), lgfile(5)

NAME

bpadmin - ION Bundle Protocol (BP) administration interface

SYNOPSIS

bpadmin [*commands_filename* | .]

DESCRIPTION

bpadmin configures, starts, manages, and stops bundle protocol operations for the local ION node.

It operates in response to BP configuration commands found in the file *commands_filename*, if provided; if not, **bpadmin** prints a simple prompt (:) so that the user may type commands directly into standard input. If *commands_filename* is a period (.), the effect is the same as if a command file containing the single command 'x' were passed to **bpadmin** – that is, the ION node's **bpclock** task, forwarder tasks, and convergence layer adapter tasks are stopped.

The format of commands for *commands_filename* can be queried from **bpadmin** with the 'h' or '?' commands at the prompt. The commands are documented in bprc(5).

EXIT STATUS

0 **Successful completion of BP administration.**

EXAMPLES

bpadmin

Enter interactive BP configuration command entry mode.

bpadmin host1.bp

Execute all configuration commands in *host1.bp*, then terminate immediately.

bpadmin .

Stop all bundle protocol operations on the local node.

FILES

See bprc(5) for details of the BP configuration commands.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Note: all ION administration utilities expect source file input to be lines of ASCII text that are NL-delimited. If you edit the bprc file on a Windows machine, be sure to **use dos2unix to convert it to Unix text format** before presenting it to **bpadmin**. Otherwise **bpadmin** will detect syntax errors and will not function satisfactorily.

The following diagnostics may be issued to the logfile ion.log:

ION can't set custodian EID information.

> The *custodial_endpoint_id* specified in the BP initialization ('1') command is malformed. Remember that the format for this argument is ipn:*element_number*.0 and that the final 0 is required, as custodial/administration service is always service 0. Additional detail for this error is provided if one of the following other errors is present:
>
> > Malformed EID.
> >
> > Malformed custodian EID.

bpadmin can't attach to ION.

> There is no SDR data store for *bpadmin* to use. You should run `ionadmin(1)` first, to set up an SDR data store for ION.

Can't open command file...

> The *commands_filename* specified in the command line doesn't exist.

Various errors that don't cause **bpadmin** to fail but are noted in the **ion.log** log file may be caused by improperly formatted commands given at the prompt or in the *commands_filename* file. Please see `bprc(5)` for details.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ionadmin(1), bprc(5), ipnadmin(1), ipnrc(5), dtnadmin(1), dtnrc(5)

NAME

bpclock - Bundle Protocol (BP) daemon task for managing scheduled events

SYNOPSIS

bpclock

DESCRIPTION

bpclock is a background "daemon" task that periodically performs scheduled Bundle Protocol activities. It is spawned automatically by **bpadmin** in response to the 's' command that starts operation of Bundle Protocol on the local ION node, and it is terminated by **bpadmin** in response to an 'x' (STOP) command.

Once per second, **bpclock** takes the following action:

> First it (a) destroys all bundles whose TTLs have expired and (b) enqueues for re-forwarding all bundles that were expected to have been transmitted (by convergence-layer output tasks) by now but are still stuck in their assigned transmission queues.
>
> Then **bpclock** adjusts the transmission and reception "throttles" that control rates of LTP transmission to and reception from neighboring nodes, in response to data rate changes as noted in the RFX database by **rfxclock**.
>
> **bpclock** then checks for bundle origination activity that has been blocked due to insufficient allocated space for BP traffic in the ION data store: if space for bundle origination is now available, **bpclock** gives the bundle production throttle semaphore to unblock that activity.
>
> Finally, **bpclock** applies rate control to all convergence-layer protocol inducts and outducts:
>
> > For each induct, **bpclock** increases the current capacity of the duct by the applicable nominal data reception rate. If the revised current capacity is greater than zero, **bpclock** gives the throttle's semaphore to unblock data acquisition (which correspondingly reduces the current capacity of the duct) by the associated convergence layer input task.

For each outduct, **bpclock** increases the current capacity of the duct by the applicable nominal data transmission rate. If the revised current capacity is greater than zero, **bpclock** gives the throttle's semaphore to unblock data transmission (which correspondingly reduces the current capacity of the duct) by the associated convergence layer output task.

EXIT STATUS

0 **bpclock** terminated, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **bpclock**.

1 **bpclock** was unable to attach to Bundle Protocol operations, probably because **bpadmin** has not yet been run.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

bpclock can't attach to BP.

bpadmin has not yet initialized BP operations.

Can't dispatch events.

An unrecoverable database error was encountered. **bpclock** terminates.

Can't adjust throttles.

An unrecoverable database error was encountered. **bpclock** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), rfxclock(1)

NAME

bpcounter - Bundle Protocol reception test program

SYNOPSIS

bpcounter *ownEndpointId* [*maxCount*]

DESCRIPTION

bpcounter uses Bundle Protocol to receive application data units from a remote **bpdriver** application task. When the total number of application data units it has received exceeds *maxCount,* it terminates and prints its reception count. If *maxCount* is omitted, the default limit is 2 billion application data units.

EXIT STATUS

0
: **bpcounter** has terminated. Any problems encountered during operation will be noted in the **ion.log** log file.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **bpcounter** are written to the ION log file *ion.log*.

Can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

Can't open own endpoint.

> Another application has already opened *ownEndpointId*. Terminate that application and rerun.

bpcounter bundle reception failed.

> BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bpdriver(1), bpecho(1), bp(3)

NAME

bpdriver - Bundle Protocol transmission test program

SYNOPSIS

bpdriver *nbrOfCycles ownEndpointId destinationEndpointId* [*length*]

DESCRIPTION

bpdriver uses Bundle Protocol to send *nbrOfCycles* application data units of length indicated by *length*, to a counterpart application task that has opened the BP endpoint identified by *destinationEndpointId*.

If omitted, *length* defaults to 60000.

bpdriver normally runs in "echo" mode: after sending each bundle it waits for an acknowledgment bundle before sending the next one. For this purpose, the counterpart application task should be **bpecho**.

Alternatively **bpdriver** can run in "streaming" mode, i.e., without expecting or receiving acknowledgments. Streaming mode is enabled when *length* is specified as a negative number, in which case the additive inverse of *length* is used as the effective value of *length*. For this purpose, the counterpart application task should be **bpcounter**.

If the effective value of *length* is 1, the sizes of the transmitted service data units will be randomly selected multiples of 1024 in the range 1024 to 62464.

bpdriver normally runs with custody transfer disabled. To request custody transfer for all bundles sent by **bpdriver**, specify *nbrOfCycles* as a negative number; the additive inverse of *nbrOfCycles* will be used as its effective value in this case.

When all copies of the file have been sent, **bpdriver** prints a performance report.

EXIT STATUS

0 **bpdriver** has terminated. Any problems encountered during operation will be noted in the **ion.log** log file.

FILES

The service data units transmitted by **bpdriver** are sequences of text obtained from a file in the current working directory named "bpdriverAduFile", which **bpdriver** creates automatically.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **bpdriver** are written to the ION log file *ion.log*.

Can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

Can't open own endpoint.

> Another application has already opened *ownEndpointId*. Terminate that application and rerun.

Can't create ADU file

> Operating system error. Check errtext, correct problem, and rerun.

Error writing to ADU file

> Operating system error. Check errtext, correct problem, and rerun.

bpdriver can't create file ref.

> ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

bpdriver can't create ZCO.

> ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

bpdriver can't send message

> Bundle Protocol service to the remote endpoint has been stopped.

bpdriver reception failed

> **bpdriver** is in "echo" mode, and Bundle Protocol delivery service has been stopped.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bpcounter(1), bpecho(1), bp(3)

NAME

bpecho - Bundle Protocol reception test program

SYNOPSIS

bpecho *ownEndpointId*

DESCRIPTION

bpecho uses Bundle Protocol to receive application data units from a remote **bpdriver** application task. In response to each received application data unit it sends back an "echo" application data unit of length 2, the NULL-terminated string "x".

bpecho terminates upon receiving the SIGQUIT signal, i.e., ^C from the keyboard.

EXIT STATUS

0
: **bpecho** has terminated normally. Any problems encountered during operation will be noted in the **ion.log** log file.

1
: **bpecho** has terminated due to a BP reception failure. Details should be noted in the **ion.log** log file.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **bpecho** are written to the ION log file *ion.log*.

Can't attach to BP.

  bpadmin has not yet initialized Bundle Protocol operations.

Can't open own endpoint.

Another application has already opened *ownEndpointId*. Terminate that application and rerun.

bpecho bundle reception failed.

BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

No space for ZCO extent.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't create ZCO.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

bpecho can't send echo bundle.

BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bpdriver(1), bpcounter(1), bp(3)

NAME

bpextensions - interface for adding extensions to Bundle Protocol

SYNOPSIS

```
    #include "bpextensions.c"
```

DESCRIPTION

ION's interface for extending the Bundle Protocol enables the definition of external functions that insert *extension* blocks into outbound bundles (either before or after the payload block), parse and record extension blocks in inbound bundles, and modify extension blocks at key points in bundle processing. All extension-block handling is statically linked into ION at build time, but the addition of an extension never requires that any standard ION source code be modified.

Standard structures for recording extension blocks -- both in transient storage [memory] during bundle acquisition (AcqExtBlock) and in persistent storage [the ION database] during subsequent bundle processing (ExtensionBlock) -- are defined in the *bpP.h* header file. In each case, the extension block structure comprises a block *type* code, an array of *bytes* (the serialized form of the block, for transmission), the *length* of that array, optionally an extension-specific opaque *object* whose structure is designed to characterize the block in a manner that's convenient for the extension processing functions, and the *size* of that object.

The definition of each extension is asserted in an ExtensionDef structure, also as defined in the *bpP.h* header file. Each ExtensionDef must supply:

The name of the extension. (Used in some diagnostic messages.)

The extension's block type code.

An indication as to whether the local node is to insert this extension block before (0) or after (1) the payload block when new bundles are locally sourced.

A pointer to an **offer** function.

A pointer to a **release** function.

A pointer to an **accept** function.

A pointer to a **check** function.

A pointer to a **record** function.

A pointer to a **clear** function.

A pointer to a **copy** function.

A pointer to a function to be called when **forwarding** a bundle containing this sort of block.

A pointer to a function to be called when **taking custody** of a bundle containing this sort of block.

A pointer to a function to be called when **enqueuing** for transmission a bundle containing this sort of block.

A pointer to a function to be called when a convergence-layer adapter **dequeues** a bundle containing this sort of block, before transmitting it.

All extension definitions must be coded into an array of ExtensionDef structures named *extensions*. The order of appearance of extension definitions in the extensions array determines the order in which extension blocks will be inserted into locally sourced bundles.

The standard extensions array -- which is empty -- is in the *bpextensions.c* prototype source file. The procedure for extending the Bundle Protocol in ION is as follows:

1. Specify -DBP_EXTENDED in the Makefile's compiler command line when building the libbpP.c library module.

2. Create a copy of the prototype extensions file, named ``myextensions.c", in a directory that is made visible to the Makefile's libbpP.c compilation command line (by a -I parameter).

3. In the ``external function declarations" area of ``myextensions.c", add ``extern" function declarations identifying the functions that will implement your extension (or extensions).

4. Add one or more ExtensionDef structure initialization lines to the extensions array, referencing those declared functions.

5. Develop the implementations of those functions in one or more new source code files.

6. Add the object `file(s)` for the new extension implementation source file (or files) to the Makefile's command line for linking libbpP.so.

The function pointers supplied in each ExtensionDef must conform to the following specifications. NOTE that any function that modifies the *bytes* member of an

ExtensionBlock or AckExtBlock **must** set the corresponding *length* to the new length of the *bytes* array, if changed.

int (*BpExtBlkOfferFn)(ExtensionBlock *blk, Bundle *bundle)

Populates the indicated ExtensionBlock structure with *type*, *length*, *bytes*, *size*, and *object*, for inclusion in the indicated outbound bundle. This function is automatically called when a new bundle is locally sourced. The values of the extension block are typically expected to be a function of the state of the bundle, but this is extension-specific. If no internal object representing the state of the block is needed, the *object* and *size* members of *blk* must be set to zero. The block's *bytes* array and *object* (if present) must occupy space allocated from the ION database heap. Return zero on success, -1 on any system failure.

void (*BpExtBlkReleaseFn)(ExtensionBlock *blk)

Releases all ION database space occupied by the *object* member of *blk*. This function is automatically called when a bundle is destroyed. Note that incorrect implementation of this function may result in a database space leak.

int (*BpExtBlkRecordFn)(ExtensionBlock *blk, AcqExtBlock *acqblk)

Copies the *object* member of *acqblk* to ION database heap space and places the address of that non-volatile object in the *object* member of *blk*. This function is automatically called when an acquired bundle is accepted for forwarding and/or delivery. Return zero on success, -1 on any system failure.

int (*BpExtBlkCopyFn)(ExtensionBlock *newblk, ExtensionBlock *oldblk)

Copies the *object* member of *oldblk* to ION database heap space and places the address of that new non-volatile object in the *object* member of *newblk*. This function is automatically called when two copies of a bundle are needed, e.g., in the event that it must both be delivered to a local client and also fowarded to another node. Return zero on success, -1 on any system failure.

int (*BpExtBlkProcessFn)(ExtensionBlock *blk, Bundle *bundle)

Performs some extension-specific transformation of the data encapsulated in *blk* based on the state of *bundle*. The transformation to be performed will typically vary depending on whether the identified function is the one that is automatically invoked upon forwarding the bundle, upon taking custody of the bundle, upon enqueuing the bundle for transmission, or upon removing the bundle from the transmission queue. Return zero on success, -1 on any system failure.

int (*BpAcqExtBlkAcceptFn)(AcqExtBlock *acqblk, Bundle *bundle)

Populates the indicated AcqExtBlock structure with *type*, *length*, *bytes*, *size*, and *object* for retention as part of the indicated inbound bundle. This function is automatically called when an extension block of this type is encountered in the course of parsing and acquiring a bundle for local delivery and/or forwarding. If no internal object representing the state of the block is needed, the *object* member of *acqblk* must be set to NULL and the *size* member must be set to zero. If an *object* is needed for this block, it must occupy space that is allocated from ION working memory using **MTAKE**. Return 1 if the block is malformed (this will cause the bundle to be discarded), zero on success, -1 on any system failure.

int (*BpAcqExtBlkCheckFn)(AcqExtBlock *acqblk, AcqWorkArea *work)

Examines the bundle in *work* to determine whether or not it is authentic, in the context of the indicated extension block. Return 1 if the block is determined to be inauthentic (this will cause the bundle to be discarded), zero if no inauthenticity is detected, -1 on any system failure.

void (*BpAcqExtBlkClearFn)(AcqExtBlock *acqblk)

Uses **MRELEASE** to release all ION working memory occupied by the *object* member of *acqblk*. This function is automatically called when acquisition of a bundle is completed, whether or not the bundle is accepted. Note that incorrect implementation of this function may result in a working memory leak.

SEE ALSO

`bp(3)`

NAME

bprc - Bundle Protocol management commands file

DESCRIPTION

Bundle Protocol management commands are passed to **bpadmin** either in a file of text lines or interactively at **bpadmin**'s command prompt (:). Commands are interpreted line-by line, with exactly one command per line. The formats and effects of the Bundle Protocol management commands are described below.

GENERAL COMMANDS

?

The **help** command. This will display a listing of the commands and their formats. It is the same as the **h** command.

#

Comment line. Lines beginning with **#** are not interpreted.

e { 0 | 1 }

Echo control. Setting echo to 1 causes all output printed by bpadmin to be logged as well as sent to stdout. Setting echo to 0 disables this behavior.

1 *custodian_endpoint_ID*

The **initialize** command. Until this command is executed, Bundle Protocol is not in operation on the local ION node and most *bpadmin* commands will fail.

The command establishes the local ION node's administrative (custodian) endpoint ID to be the indicated *custodian_endpoint_ID*, which must conform to one of the endpoint ID "schemes" understood by the local ION node as declared in subsequent **add scheme** commands.

r '*command_text*'

The **run** command. This command will execute *command_text* as if it had been typed at a console prompt. It is used to, for example, run another administrative program.

s

The **start** command. This command starts all schemes and all protocols on the local node.

x

The **stop** command. This command stops all schemes and all protocols on the local node.

w { 0 | 1 | *activity_spec* }

The **BP watch** command. This command enables and disables production of a continuous stream of user-selected Bundle Protocol activity indication characters. A watch parameter of "1" selects all BP activity indication characters; "0" de-selects all BP activity indication characters; any other activity_spec such as "acz~" selects all activity indication characters in the string, de-selecting all others. BP will print each selected activity indication character to stdout every time a processing event of the associated type occurs:

a bundle is queued for forwarding

b bundle is queued for transmission

c bundle is popped from its transmission queue

m custody acceptance signal is received

w custody of bundle is accepted

x custody of bundle is refused

y bundle is accepted upon arrival

z bundle is queued for delivery to an application

~ bundle is abandoned (discarded) upon arrival

! bundle is destroyed due to TTL expiration

& custody refusal signal is received

custodial bundle is queued for re-forwarding due to CL protocol failure

h

The **help** command. This will display a listing of the commands and their formats. It is the same as the **?** command.

SCHEME COMMANDS

a scheme *scheme_name scheme_nbr* '*forwarder_command*' '*admin_app_command*'

The **add scheme** command. This command declares an endpoint naming "scheme" for use in endpoint IDs, which are structured as URIs: *scheme_name*:*scheme-specific_part*. *scheme_nbr* must be -1 if the scheme is not CBHE-conformant. *forwarder_command* will be executed when the scheme is started on this node, to initiate operation of a forwarding daemon for this scheme. *admin_app_command* will also be executed when the scheme is started on this node, to initiate operation of a daemon that opens the custodian endpoint so that it can receive and process custody signals and bundle status reports.

c scheme *scheme_name* '*forwarder_command*' '*admin_app_command*'

The **change scheme** command. This command sets the indicated scheme's *forwarder_command* and *admin_app_command* to the strings provided as arguments.

d scheme *scheme_name*

The **delete scheme** command. This command deletes the scheme identified by *scheme_name*. The command will fail if any bundles identified in this scheme are pending forwarding, transmission, or delivery.

i scheme *scheme_name*

This command will print information (number and commands) about the endpoint naming scheme identified by *scheme_name*.

l scheme

This command lists all declared endpoint naming schemes.

s scheme *scheme_name*

The **start scheme** command. This command starts the forwarder and administrative endpoint tasks for the indicated scheme task on the local node.

x scheme *scheme_name*

The **stop scheme** command. This command stops the forwarder and administrative endpoint tasks for the indicated scheme task on the local node.

ENDPOINT COMMANDS

a endpoint *scheme_name ssp* { q | x } ['*recv_script*']

The **add endpoint** command. This command establishes a DTN endpoint named *scheme_name*:*ssp* on the local node. The remaining parameters indicate what is to be done when bundles destined for this endpoint arrive at a time when no application has got the endpoint open for bundle reception. If 'x', then such bundles are to be discarded silently and immediately. If 'q', then such bundles are to be enqueued for later delivery and, if *recv_script* is provided, *recv_script* is to be executed.

c endpoint *scheme_name ssp* { q | x } ['*recv_script*']

The **change endpoint** command. This command changes the action that is to be taken when bundles destined for this endpoint arrive at a time when no application has got the endpoint open for bundle reception, as described above.

d endpoint *scheme_name ssp*

The **delete endpoint** command. This command deletes the endpoint identified by *scheme_name* and *ssp*. The command will fail if any bundles are currently pending delivery to this endpoint.

i endpoint *scheme_name ssp*

This command will print information (disposition and script) about the endpoint identified by *scheme_name* and *ssp*.

l endpoint [*scheme_name*]

If *scheme_name* is specified, this command lists all local endpoints in the indicated scheme. Otherwise it lists all local endpoints, regardless of scheme name.

PROTOCOL COMMANDS

a protocol *protocol_name payload_bytes_per_frame overhead_bytes_per_frame* [*nominal_data_rate*]

The **add protocol** command. This command establishes access to the named convergence layer protocol at the local node. The *payload_bytes_per_frame* and *overhead_bytes_per_frame* arguments are used in calculating the estimated transmission capacity consumption of each bundle, to aid in route computation and congestion forecasting.

The optional *nominal_data_rate* argument overrides the hard-coded default continuous data rate for the indicated protocol, for purposes of rate control. For all CL protocols other than LTP, the protocol's applicable nominal continuous data rate is the data rate that is always used for rate control over links served by that protocol; data rates are not extracted from contact graph information. This is because only the LTP induct and outduct throttles can be dynamically adjusted in response to changes in data rate between the local node and its neighbors, because (currently) there is no mechanism for mapping neighbor node number to the duct name for any other CL protocol. For LTP, duct name is simply LTP engine number which, by convention, is identical to node number. For all other CL protocols, the nominal data rate in each induct and outduct throttle is initially set to the protocol's configured nominal data rate and is never subsequently modified.

d protocol ***protocol_name***

The **delete protocol** command. This command deletes the convergence layer protocol identified by *protocol_name*. The command will fail if any ducts are still locally declared for this protocol.

i protocol ***protocol_name***

This command will print information about the convergence layer protocol identified by *protocol_name*.

l protocol

This command lists all convergence layer protocols that can currently be utilized at the local node.

s protocol ***protocol_name***

The **start protocol** command. This command starts all induct and outduct tasks for inducts and outducts that have been defined for the indicated CL protocol on the local node.

x protocol ***protocol_name***

The **stop protocol** command. This command stops all induct and outduct tasks for inducts and outducts that have been defined for the indicated CL protocol on the local node.

INDUCT COMMANDS

a induct ***protocol_name duct_name*** **'*CLI_command*'**

The **add induct** command. This command establishes a "duct" for reception of bundles via the indicated CL protocol. The duct's data acquisition structure is used and populated by the "induct" task whose operation is initiated by *CLI_command* at the time the duct is started.

c induct ***protocol_name duct_name*** **'*CLI_command*'**

The **change induct** command. This command changes the command that is used to initiate operation of the induct task for the indicated duct.

d induct ***protocol_name duct_name***

The **delete induct** command. This command deletes the induct identified by *protocol_name* and *duct_name*. The command will fail if any bundles are currently pending acquisition via this induct.

i induct *protocol_name duct_name*

This command will print information (the CLI command) about the induct identified by *protocol_name* and *duct_name*.

l induct [*protocol_name*]

If *protocol_name* is specified, this command lists all inducts established locally for the indicated CL protocol. Otherwise it lists all locally established inducts, regardless of protocol.

s induct *protocol_name duct_name*

The **start induct** command. This command starts the indicated induct task as defined for the indicated CL protocol on the local node.

x induct *protocol_name duct_name*

The **stop induct** command. This command stops the indicated induct task as defined for the indicated CL protocol on the local node.

OUTDUCT COMMANDS

a outduct *protocol_name duct_name* '*CLO_command*'

The **add outduct** command. This command establishes a "duct" for transmission of bundles via the indicated CL protocol. The duct's data transmission structure is serviced by the "outduct" task whose operation is initiated by *CLO_command* at the time the duct is started.

c outduct *protocol_name duct_name* '*CLO_command*'

The **change outduct** command. This command changes the command that is used to initiate operation of the outduct task for the indicated duct.

d outduct *protocol_name duct_name*

The **delete outduct** command. This command deletes the outduct identified by *protocol_name* and *duct_name*. The command will fail if any bundles are currently pending transmission via this outduct.

i outduct *protocol_name duct_name*

This command will print information (the CLO command) about the outduct identified by *protocol_name* and *duct_name*.

l outduct [*protocol_name*]

If *protocol_name* is specified, this command lists all outducts established locally for the indicated CL protocol. Otherwise it lists all locally established outducts, regardless of protocol.

s outduct *protocol_name duct_name*

The **start outduct** command. This command starts the indicated outduct task as defined for the indicated CL protocol on the local node.

x outduct *protocol_name duct_name*

The **stop outduct** command. This command stops the indicated outduct task as defined for the indicated CL protocol on the local node.

EXAMPLES

a scheme ipn 1 'ipnfw' 'ipnadminep'

Declares the "ipn" scheme on the local node.

a protocol udp 1400 100 16384

Establishes access to the "udp" convergence layer protocol on the local node, estimating the number of payload bytes per ultimate (lowest-layer) frame to be 1400 with 100 bytes of total overhead (BP, UDP, IP, AOS) per lowest-layer frame, and setting the default nominal data rate to be 16384 bytes per second.

r 'ipnadmin ipnrc.flyby'

Runs the administrative program *ipnadmin* from within *bpadmin*.

SEE ALSO

bpadmin(1), ipnadmin(1), dtnadmin(1)

NAME

bpsendfile - Bundle Protocol (BP) file transmission utility

SYNOPSIS

bpsendfile *own_endpoint_ID destination_endpoint_ID file_name*

DESCRIPTION

bpsendfile uses `bp_send()` to issue a single bundle to a designated destination endpoint, containing the contents of the file identified by *file_name*, then terminates. The bundle is sent at standard priority with no custody transfer requested, with TTL of 300 seconds (5 minutes).

EXIT STATUS

0 **bpsendfile** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

Can't attach to BP.

 bpadmin has not yet initialized BP operations.

Can't open own endpoint.

 Another BP application task currently has *own_endpoint_ID* open for bundle origination and reception. Try again after that task has terminated. If no such task exists, it may have crashed while still holding the endpoint open; the easiest workaround is to select a different source endpoint.

Can't stat the file

Operating system error. Check errtext, correct problem, and rerun.

bpsendfile can't create file ref.

Probably an unrecoverable database error, in which case the local ION node must be terminated and re-initialized.

bpsendfile can't create ZCO.

Probably an unrecoverable database error, in which case the local ION node must be terminated and re-initialized.

bpsendfile can't send file in bundle.

BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bp(3)

NAME

bpsink - Bundle Protocol reception test program

SYNOPSIS

bpsink *ownEndpointId*

DESCRIPTION

bpsink uses Bundle Protocol to receive application data units from a remote **bpsource** application task. For each application data unit it receives, it prints the ADU's length and – if length is less than 80 – its text.

bpsink terminates upon receiving the SIGQUIT signal, i.e., ^C from the keyboard.

EXIT STATUS

0 **bpsink** has terminated. Any problems encountered during operation will be noted in the **ion.log** log file.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **bpsink** are written to the ION log file *ion.log*.

Can't attach to BP.

bpadmin has not yet initialized Bundle Protocol operations.

Can't open own endpoint.

Another application has already opened *ownEndpointId*. Terminate that application and rerun.

bpsink bundle reception failed.

BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't receive payload.

BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't handle delivery.

BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bpsource(1), bp(3)

NAME

bpsource - Bundle Protocol transmission test shell

SYNOPSIS

bpsource *destinationEndpointId*

DESCRIPTION

bpsource offers the user an interactive "shell" for testing Bundle Protocol data transmission. **bpsource** prints a prompt string (": ") to stdout, accepts a string of text from stdin, uses Bundle Protocol to send the string to a counterpart **bpsink** application task that has opened the BP endpoint identified by *destinationEndpointId*, then prints another prompt string and so on. The source endpoint ID for these bundles is the null endpoint ID, i.e., the bundles are anonymous. All bundles are sent with TTL = 300 seconds (5 minutes), standard priority, no custody transfer, and no status reports requested.

To terminate the program, enter a string consisting of a single exclamation point (!) character.

EXIT STATUS

0
: **bpsource** has terminated. Any problems encountered during operation will be noted in the **ion.log** log file.

FILES

The service data units transmitted by **bpsource** are sequences of text obtained from a file in the current working directory named "bpsourceAduFile", which **bpsource** creates automatically.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **bpsource** are written to the ION log file *ion.log*.

Can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

bpsource fgets failed

> Operating system error. Check errtext, correct problem, and rerun.

No space for ZCO extent.

> ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't create ZCO extent.

> ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

bpsource can't send ADU

> Bundle Protocol service to the remote endpoint has been stopped.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bpsink(1), bp(3)

NAME

bpstats - Bundle Protocol (BP) processing statistics query utility

SYNOPSIS

bpstats

DESCRIPTION

bpstats simply logs messages containing the current values of all BP processing statistics accumulators, then terminates.

EXIT STATUS

0 **bpstats** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

bpstats can't attach to BP.

  bpadmin has not yet initialized BP operations.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

N/A

NAME

bptrace - Bundle Protocol (BP) network trace utility

SYNOPSIS

bptrace *own_endpoint_ID destination_endpoint_ID report-to_endpoint_ID TTL priority* "*trace_text*" [*status_report_ flags*]

DESCRIPTION

bptrace uses `bp_send()` to issue a single bundle to a designated destination endpoint, with status reporting options enabled as selected by the user, then terminates. The status reports returned as the bundle makes its way through the network provide a view of the operation of the network as currently configured.

TTL indicates the number of seconds the trace bundle may remain in the network, undelivered, before it is automatically destroyed.

priority must be 0 (bulk), 1 (standard), or 2 (expedited).

trace_text can be any string of ASCII text.

status_report_flags must be a sequence of status report flags, separated by commas, with no embedded whitespace. Each status report flag must be one of the following: rcv, ct, fwd, dlv, del.

EXIT STATUS

0 **bptrace** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

bptrace can't attach to BP.

> **bpadmin** has not yet initialized BP operations.

bptrace can't open own endpoint.

> Another BP application task currently has *own_endpoint_ID* open for bundle origination and reception. Try again after that task has terminated. If no such task exists, it may have crashed while still holding the endpoint open; the easiest workaround is to select a different source endpoint.

No space for bptrace text.

> Probably an unrecoverable database error, in which case the local ION node must be terminated and re-initialized.

bptrace can't create ZCO.

> Probably an unrecoverable database error, in which case the local ION node must be terminated and re-initialized.

bptrace can't send message.

> BP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bp(3)

NAME

brsccla - BRSC-based BP convergence layer adapter (input and output) task

SYNOPSIS

brsccla server hostname[:server port nbr] own node nbr

DESCRIPTION

BRSC is the "client" side of the Bundle Relay Service (BRS) convergence layer protocol for BP. It is complemented by BRSS, the "server" side of the BRS convergence layer protocol for BP. BRS clients send bundles directly only to the server, regardless of their final destinations, and the server forwards them to other clients as necessary.

brsccla is a background "daemon" task comprising three threads: one that connects to the BRS server, spawns the other threads, and then handles BRSC protocol output by transmitting bundles over the connected socket to the BRS server; one that simply sends periodic "keepalive" messages over the connected socket to the server (to assure that local inactivity doesn't cause the connection to be lost); and one that handles BRSC protocol input from the connected server.

The output thread connects to the server's TCP socket at *server_hostname* and *server_port_nbr*, sends over the connected socket the client's *own_node_nbr* followed by a simple digital signature to authenticate itself, checks the authenticity of the similarly signed countersign returned by the server, spawns the keepalive and receiver threads, and then begins extracting bundles from the queues of bundles ready for transmission via BRSC and transmitting those bundles over the connected socket to the server. Each transmitted bundle is preceded by its length, a 32-bit unsigned integer in network byte order. The default value for *server_port_nbr*, if omitted, is 80.

The reception thread receives bundles over the connected socket and passes them to the bundle protocol agent on the local ION node. Each bundle received on the connection is preceded by its length, a 32-bit unsigned integer in network byte order.

The keepalive thread simply sends a "bundle length" value of zero (a 32-bit unsigned integer in network byte order) to the server once every 15 seconds.

Note that **brsccla** is not a "promiscuous" convergence layer daemon: it can transmit bundles only to the BRS server to which it is connected, so scheme configuration directives that cite this outduct need only provide the protocol name and the BRSC outduct name as specified on the command line when **brsccla** is started.

brsccla is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **brsccla** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the BRSC convergence layer protocol.

EXIT STATUS

0 **brsccla** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart the BRSC protocol.

1 **brsccla** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart the BRSC protocol.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

brsccla can't attach to BP.

bpadmin has not yet initialized Bundle Protocol operations.

No such brsc induct.

No BRSC induct with duct name matching *server_hostname*, *own_node_nbr*, and *server_port_nbr* has been added to the BP database. Use **bpadmin** to stop the BRSC convergence-layer protocol, add the induct, and then restart the BRSC protocol.

CLI task is already started for this duct.

Redundant initiation of **brsccla**.

No such brsc outduct.

No BRSC outduct with duct name matching *server_hostname*, *own_node_nbr*, and *server_port_nbr* has been added to the BP database. Use **bpadmin** to stop the

BRSC convergence-layer protocol, add the outduct, and then restart the BRSC protocol.

Can't connect to server.

Operating system error. Check errtext, correct problem, and restart BRSC.

Can't register with server.

Configuration error. Authentication has failed, probably because (a) the client and server were compiled with different BRSSEED values or (b) the clocks of the client and server differ by more than 5 seconds. Recompile as necessary, assure that the clocks are synchronized, and restart BRSC.

brsccla can't create receiver thread

Operating system error. Check errtext, correct problem, and restart BRSC.

brsccla can't create keepalive thread

Operating system error. Check errtext, correct problem, and restart BRSC.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), brsscla(1)

NAME

brsscla - BRSS-based BP convergence layer adapter (input and output) task

---

SYNOPSIS

brsscla *local_hostname*[:*local_port_nbr*]

DESCRIPTION

BRSS is the "server" side of the Bundle Relay Service (BRS) convergence layer protocol for BP. It is complemented by BRSC, the "client" side of the BRS convergence layer protocol for BP.

brsscla is a background "daemon" task that spawns two plus N threads: one that handles BRSS client connections and spawns sockets for continued data interchange with connected clients; one that handles BRSS protocol output by transmitting over those spawned sockets to the associated clients; and one input thread for each spawned socket, to handle BRSS protocol input from the associated connected client.

The connection thread simply accepts connections on a TCP socket bound to *local_hostname* and *local_port_nbr* and spawns reception threads. The default value for *local_port_nbr*, if omitted, is 80.

Each reception thread receives over the socket connection the node number of the connecting client, followed by a simple digital signature. It checks the authenticity of the client by checking the signature, then sends the client a similarly signed countersign to assure the client of its own authenticity, then commences receiving bundles over the connected socket. Each bundle received on the connection is preceded by its length, a 32-bit unsigned integer in network byte order. The received bundles are passed to the bundle protocol agent on the local ION node.

The output thread extracts bundles from the queues of bundles ready for transmission via BRSS to remote bundle protocol agents, finds the connected clients whose node numbers match the proximate node numbers assigned to the bundles by the routing daemons that enqueued them, and transmits the bundles over the sockets to those clients. Each transmitted bundle is preceded by its length, a 32-bit unsigned integer in network byte order.

Note that **brsscla** is a "promiscuous" convergence layer daemon, able to transmit bundles to any BRSS destination induct for which it has received a connection. Its duct name is the name of the corresponding induct, rather than the induct name of any single BRSS destination induct to which it might be dedicated, so scheme configuration directives that cite this outduct must provide destination induct IDs. For the BRS convergence-layer protocol, destination induct IDs are simply the node numbers of connected clients.

brsscla is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **brsscla** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the BRSS convergence layer protocol.

EXIT STATUS

0 **brsscla** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart the BRSS protocol.

1 **brsscla** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart the BRSS protocol.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

brsscla can't attach to BP.

bpadmin has not yet initialized Bundle Protocol operations.

No such brss induct.

No BRSS induct with duct name matching *local_hostname* and *local_port_nbr* has been added to the BP database. Use **bpadmin** to stop the BRSS convergence-layer protocol, add the induct, and then restart the BRSS protocol.

CLI task is already started for this duct.

Redundant initiation of **brsscla**.

No such brss outduct.

No BRSS outduct with duct name matching *local_hostname* and *local_port_nbr* has been added to the BP database. Use **bpadmin** to stop the BRSS convergence-layer protocol, add the outduct, and then restart the BRSS protocol.

Can't get IP address for host

Operating system error. Check errtext, correct problem, and restart BRSS.

Can't open TCP socket

Operating system error -- unable to open TCP socket for accepting connections. Check errtext, correct problem, and restart BRSS.

Can't initialize socket (note: must be root for port 80)

Operating system error. Check errtext, correct problem, and restart BRSS.

brsscla can't create sender thread

Operating system error. Check errtext, correct problem, and restart BRSS.

brsscla can't create access thread

Operating system error. Check errtext, correct problem, and restart BRSS.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), brsccla(1)

NAME

dgr2file - DGR reception test program

SYNOPSIS

dgr2file

DESCRIPTION

dgr2file uses DGR to receive multiple copies of the text of a file transmitted by **file2dgr**, writing each copy of the file to the current working directory. The name of each file written by **dgr2file** is file_copy_*cycleNbr*, where *cycleNbr* is initially zero and is increased by 1 every time **dgr2file** closes the file it is currently writing and opens a new one.

Upon receiving a DGR datagram from **file2dgr**, **dgr2file** extracts the content of the datagram (either a line of text from the file that is being transmitted by **file2dgr** or else an EOF string indicating the end of that file). It appends each extracted line of text to the local copy of that file that **dgr2file** is currently writing. When the extracted datagram content is an EOF string (the ASCII text "*** End of the file ***"), **dgr2file** closes the file it is writing, increments *cycleNbr*, opens a new copy of the file for writing, and prints the message "working on cycle *cycleNbr*."

dgr2file always receives datagrams at port 2101.

EXIT STATUS

0 **dgr2file** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

can't open dgr service

Operating system error. Check errtext, correct problem, and rerun.

can't open output file

Operating system error. Check errtext, correct problem, and rerun.

dgr_receive failed

Operating system error. Check errtext, correct problem, and rerun.

can't write to output file

Operating system error. Check errtext, correct problem, and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

file2dgr(1), dgr(3)

NAME

dgr - Datagram Retransmission system library

SYNOPSIS

```
#include "dgr.h"
```

[see description for available functions]

DESCRIPTION

The dgr library provides functions enabling application software to use the DGR system to send and receive information reliably over an IP-based network, using UDP/IP.

DGR differs from many reliable-UDP systems in two main ways:

- It uses adaptive timeout interval computation techniques borrowed from TCP to try to avoid introducing congestion into the network.
- It borrows the concurrent-session model of transmission from LTP (and ultimately from CFDP), rather than waiting for one datagram to be acknowledged before sending the next, to improve bandwidth utilization.

DgrRC dgr_open(unsigned short ownPortNbr, unsigned int ownIpAddress, char *memmgrName, Dgr *dgr)

Establishes the application's access to DGR communication service.

ownPortNbr is the port number to use for DGR service. If zero, a system-assigned UDP port number is used.

ownIpAddress is the Internet address of the network interface to use for DGR service. If zero, this argument defaults to the address of the interface identified by the local machine's host name.

memmgrName is the name of the memory manager (see `memmgr(3)`) to use for dynamic memory management in DGR. If NULL, defaults to the standard system `malloc()` and `free()` functions.

dgr is the location in which to store the service access pointer that must be supplied on subsequent DGR function invocations.

On any error, returns DgrFailed; check errno for the nature of the error.

void dgr_getsockname(Dgr dgr, unsigned short *portNbr, unsigned int *ipAddress)

States the port number and IP address of the UDP socket used for this DGR service access point.

void dgr_close(Dgr dgr)

Reverses dgr_open(), releasing resources where possible.

DgrRC dgr_send(Dgr dgr, unsigned short toPortNbr, unsigned int toIpAddress, int notificationFlags, char *content, int length)

Sends the indicated content, of length as indicated, to the remote DGR service access point identified by *toPortNbr* and *toIpAddress*. The message will be retransmitted as necessary until either it is acknowledged or DGR determines that it cannot be delivered.

notificationFlags, if non-zero, is the logical OR of the notification behaviors requested for this datagram. Available behaviors are DGR_NOTE_FAILED (a notice of datagram delivery failure will issued if delivery of the datagram fails) and DGR_NOTE_ACKED (a notice of datagram delivery success will be issued if delivery of the datagram succeeds). Notices are issued via `dgr_receive()` that is, the thread that calls `dgr_receive()` on this DGR service access point will receive these notices interspersed with inbound datagram contents.

length of content must be greater than zero and may be as great as 65535, but lengths greater than 8192 may not be supported by the local underlying UDP implementation; to minimize the chance of data loss when transmitting over the internet, length should not exceed 512.

On any error, returns DgrFailed; check errno for the nature of the error.

DgrRC dgr_receive(Dgr dgr, unsigned short *fromPortNbr, unsigned int *fromIpAddress, char *content, int *length, int *errnbr, int timeoutSeconds)

Delivers the oldest undelivered DGR event queued for delivery.

DGR events are of two type: (a) messages received from a remote DGR service access point and (b) notices of previously sent messages that DGR has determined either have been or cannot be delivered, as requested in the *notificationFlags* parameters provided to the `dgr_send()` calls that sent those messages.

In the former case, `dgr_receive()` will place the content of the inbound message in *content*, its length in *length*, and the IP address and port number of the sender in *fromIpAddress* and *fromPortNbr*, and it will return DgrDatagramReceived.

In the latter case, `dgr_receive()` will place the content of the affected **outbound** message in *content* and its length in *length*, will place the relevant errno (if any) in *errnbr*, and will return either DgrDatagramAcknowledged or DgrDatagramNotAcknowledged.

The *content* buffer should be at least 65535 bytes in length to enable delivery of the content of the received or delivered/undeliverable message.

timeoutSeconds controls blocking behavior. If *timeoutSeconds* is DGR_BLOCKING (i.e., -1), `dgr_receive()` will not return until (a) there is either an inbound message to deliver or an outbound message delivery result to report, or (b) the function is interrupted by means of dgr_interrupt(). If *timeoutSeconds* is DGR_POLL (i.e., zero), `dgr_receive()` returns immediately; if there is currently no inbound message to deliver and no outbound message delivery result to report, the function returns DgrTimedOut. For any other positive value of *timeoutSeconds*, `dgr_receive()` returns after the indicated number of seconds have lapsed (in which case the return value is DgrTimedOut), or when there is a message to deliver or a delivery result to report, or when the function is interrupted by means of dgr_interrupt(), whichever occurs first. When the function returns due to interruption by dgr_interrupt(), the return value is DgrInterrupted.

On any I/O error or other unrecoverable system error, returns DgrFailed; check errno for the nature of the error.

void dgr_interrupt(Dgr dgr)

Interrupts a `dgr_receive()` invocation that is currently blocked. Designed to be called from a signal handler; for this purpose, *dgr* man need to be obtained from a static variable.

SEE ALSO

ltp(3), file2dgr(1), dgr2file(1)

NAME

dgrcla - DGR-based BP convergence layer adapter (input and output) task

SYNOPSIS

dgrcla *local_hostname*[:*local_port_nbr*]

DESCRIPTION

dgrcla is a background "daemon" task that spawns two threads, one that handles DGR convergence layer protocol input and a second that handles DGR convergence layer protocol output.

The input thread receives DGR messages via a UDP socket bound to *local_hostname* and *local_port_nbr*, extracts bundles from those messages, and passes them to the bundle protocol agent on the local ION node. (*local_port_nbr* defaults to 5101 if not specified.)

The output thread extracts bundles from the queues of bundles ready for transmission via DGR to remote bundle protocol agents, encapsulates them in DGR messages, and sends those messages to the appropriate remote UDP sockets as indicated by the host names and UDP port numbers (destination induct names) associated with the bundles by the routing daemons that enqueued them.

Note that **dgrcla** is a "promiscuous" convergence layer daemon, able to transmit bundles to any DGR destination induct. Its duct name is the name of the corresponding induct, rather than the induct name of any single DGR destination induct to which it might be dedicated, so scheme configuration directives that cite this outduct must provide destination induct IDs. For the DGR convergence-layer protocol, destination induct IDs are identical to induct names, i.e., they are of the form *local_hostname*[:*local_port_nbr*].

dgrcla is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **dgrcla** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the DGR convergence layer protocol.

EXIT STATUS

0
: **dgrcla** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **dgrcla**.

1 **dgrcla** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart **dgrcla**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

dgrcla can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

No such dgr induct.

> No DGR induct with duct name matching *local_hostname* and *local_port_nbr* has been added to the BP database. Use **bpadmin** to stop the DGR convergence-layer protocol, add the induct, and then restart the DGR protocol.

CLI task is already started for this engine.

> Redundant initiation of **dgrcla**.

No such dgr induct.

> No DGR outduct with duct name matching *local_hostname* and *local_port_nbr* has been added to the BP database. Use **bpadmin** to stop the DGR convergence-layer protocol, add the outduct, and then restart the DGR protocol.

Can't get IP address for host

> Operating system error. Check errtext, correct problem, and restart DGR.

dgrcla can't open DGR service access point.

> DGR system error. Check prior messages in **ion.log** log file, correct problem, and then stop and restart the DGR protocol.

dgrcla can't create sender thread

> Operating system error. Check errtext, correct problem, and restart DGR.

dgrcla can't create receiver thread

> Operating system error. Check errtext, correct problem, and restart DGR.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5)

NAME

dtnadmin - baseline Delay-Tolerant Networking (DTN) scheme administration interface

SYNOPSIS

dtnadmin *node_name* [*commands_filename*]

DESCRIPTION

dtnadmin configures the local ION node's routing of bundles to endpoints whose IDs conform to the *dtn* endpoint ID scheme. *dtn* is a non-CBHE-conformant scheme. The structure of *dtn* endpoint IDs remains somewhat in flux at the time of this writing, but endpoint IDs in the *dtn* scheme historically have been strings of the form "dtn://*node_name*.dtn/*demux_token*", where *node_name* normally identifies a computer somewhere on the network and *demux_token* normally identifies a specific application processing point. Although the *dtn* endpoint ID scheme imposes more transmission overhead than the *ipn* scheme, ION provides support for *dtn* endpoint IDs to enable interoperation with other implementations of Bundle Protocol.

dtnadmin operates in response to DTN scheme configuration commands found in the file *commands_filename*, if provided; if not, **dtnadmin** prints a simple prompt (:) so that the user may type commands directly into standard input.

The format of commands for *commands_filename* can be queried from **dtnadmin** with the 'h' or '?' commands at the prompt. The commands are documented in dtnrc(5).

EXIT STATUS

0 Successful completion of DTN scheme administration.

1 Unsuccessful completion of DTN scheme administration, due to inability to attach to the Bundle Protocol system or to initialize the DTN scheme.

EXAMPLES

dtnadmin

Enter interactive DTN scheme configuration command entry mode.

dtnadmin host1.dtn

Execute all configuration commands in *host1.dtn*, then terminate immediately.

FILES

See `dtnrc(5)` for details of the DTN scheme configuration commands.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Note: all ION administration utilities expect source file input to be lines of ASCII text that are NL-delimited. If you edit the dtnrc file on a Windows machine, be sure to **use dos2unix to convert it to Unix text format** before presenting it to **dtnadmin**. Otherwise **dtnadmin** will detect syntax errors and will not function satisfactorily.

The following diagnostics may be issued to the logfile ion.log:

dtnadmin can't attach to BP.

Bundle Protocol has not been initialized on this computer. You need to run `bpadmin(1)` first.

dtnadmin can't initialize routing database.

There is no SDR data store for *dtnadmin* to use. Please run `ionadmin(1)` to start the local ION node.

Can't open command file...

The *commands_filename* specified in the command line doesn't exist.

Various errors that don't cause **dtnadmin** to fail but are noted in the **ion.log** log file may be caused by improperly formatted commands given at the prompt or in the *commands_filename* file. Please see `dtnrc(5)` for details.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

dtnrc(5)

NAME

dtnadminep - administrative endpoint task for the DTN scheme

SYNOPSIS

dtnadminep

DESCRIPTION

dtnadminep is a background "daemon" task that receives and processes administrative bundles (all custody signals and, nominally, all bundle status reports) that are sent to the DTN-scheme administrative endpoint on the local ION node, if and only if such an endpoint was established by **bpadmin**. It is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of Bundle Protocol on the local ION node, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **dtnadminep** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the DTN scheme.

dtnadminep responds to custody signals as specified in the Bundle Protocol specification, RFC 5050. It responds to bundle status reports by logging ASCII text messages describing the reported activity.

EXIT STATUS

0 **dtnadminep** terminated, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **dtnadminep**.

1 **dtnadminep** was unable to attach to Bundle Protocol operations or was unable to load the DTN scheme database, probably because **bpadmin** has not yet been run.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

dtnadminep can't attach to BP.

  bpadmin has not yet initialized BP operations.

dtnadminep can't load routing database.

  dtnadmin has not yet initialized the DTN scheme.

dtnadminep can't get admin EID.

  dtnadmin has not yet initialized the DTN scheme.

dtnadminep crashed.

  An unrecoverable database error was encountered. **dtnadminep** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), dtnadmin(1)

NAME

dtnfw - bundle route computation task for the DTN scheme

SYNOPSIS

dtnfw

DESCRIPTION

dtnfw is a background "daemon" task that pops bundles from the queue of bundle destined for DTN-scheme endpoints, computes proximate destinations for those bundles, and appends those bundles to the appropriate queues of bundles pending transmission to those computed proximate destinations.

For each possible proximate destination (that is, neighboring node) there is a separate queue for each possible level of bundle priority: 0, 1, 2. Each outbound bundle is appended to the queue matching the bundle's designated priority.

Proximate destination computation is affected by static routes as configured by dtnadmin(1).

dtnfw is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of Bundle Protocol on the local ION node, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **dtnfw** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the DTN scheme.

EXIT STATUS

0
: **dtnfw** terminated, for reasons noted in the **ion.log** log file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **dtnfw**.

1
: **dtnfw** could not commence operations, for reasons noted in the **ion.log** log file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart **dtnfw**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

dtnfw can't attach to BP.

> **bpadmin** has not yet initialized BP operations.

dtnfw can't load routing database.

> **dtnadmin** has not yet initialized the DTN scheme.

Can't create lists for route computation.

> An unrecoverable database error was encountered. **dtnfw** terminates.

'dtn' scheme is unknown.

> The DTN scheme was not added when **bpadmin** initialized BP operations. Use **bpadmin** to add and start the scheme.

Can't take forwarder semaphore.

> ION system error. **dtnfw** terminates.

Can't enqueue bundle.

> An unrecoverable database error was encountered. **dtnfw** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), dtnadmin(1), bprc(5), dtnrc(5)

NAME

dtnrc - DTN scheme configuration commands file

DESCRIPTION

DTN scheme configuration commands are passed to **dtnadmin** either in a file of text lines or interactively at **dtnadmin**'s command prompt (:). Commands are interpreted line-by line, with exactly one command per line.

DTN scheme configuration commands mainly establish static routing rules for forwarding bundles to DTN endpoints, identified by node names and demux names.

Static routes are expressed as **plan**s in the DTN scheme database. A plan that is established for a given node name associates a default routing **directive** with the named node, and that default directive may be overridden by more narrowly scoped **rule**s in specific circumstances: a different directive may apply when the destination endpoint ID specifies a particular demux name.

Each directive is a string of one of two possible forms:

> f *endpoint_ID*

...or...

> x *protocol_name*/*outduct_name*[,*destination_induct_name*]

The former form signifies that the bundle is to be forwarded to the indicated endpoint, requiring another iteration of the route computation procedure. The latter form signifies that the bundle is to be queued for transmission via the indicated convergence layer protocol outduct. *destination_induct_name* must be provided when the indicated outduct is "promiscuous", i.e., not configured for transmission only to a single neighboring node; this is protocol-specific.

The demux names that are used in DTN endpoint IDs may also be defined by DTN scheme configuration commands, but at the time of this writing these demux name definitions are not used and are not required.

The formats and effects of the DTN scheme configuration commands are described below.

GENERAL COMMANDS

?

The **help** command. This will display a listing of the commands and their formats. It is the same as the **h** command.

#

Comment line. Lines beginning with **#** are not interpreted.

e { 0 | 1 }

Echo control. Setting echo to 1 causes all output printed by dtnadmin to be logged as well as sent to stdout. Setting echo to 0 disables this behavior.

h

The **help** command. This will display a listing of the commands and their formats. It is the same as the **?** command.

DEMUX COMMANDS

a demux *demux_name*

The **add demux** command. This command declares a "demux" that may be cited in DTN endpoint IDs.

d demux *demux_name*

The **delete demux** command. This command deletes the demux identified by *demux_name*.

l demux

This command lists all declared demux names.

PLAN COMMANDS

a plan *node_name default_directive*

The **add plan** command. This command establishes a static route for the bundles destined for the node identified by *node_name*. A general plan must be in place for a node before any more specific routing rules are declared.

d plan *node_name*

The **delete plan** command. This command deletes the static route for the node identified by *node_name*, including all associated rules.

i plan *node_name*

This command will print information (the default directive and all specific rules) about the static route for the node identified by *node_name*.

l plan

This command lists all static routes established in the DTN database for the local node.

RULE COMMANDS

a rule *node_name demux_name directive*

The **add rule** command. This command establishes a rule, i.e., a directive that overrides the default directive of the plan for the node identified by *node_name* in the event that the demux name of the subject bundle's destination endpoint ID matches *demux_name*.

c rule *node_name demux_name directive*

The **change rule** command. This command changes the directive for the indicated rule.

d rule ***node_name demux_name***

The **delete rule** command. This command deletes the rule identified by *node_name* and *demux_name*.

i rule ***node_name demux_name***

This command will print information (the directive) about the rule identified by *node_name* and *demux_name*.

l rule ***node_name***

This command lists all rules in the plan for the indicated node.

EXAMPLES

a plan bbn2 f dtn://mitre1.dtn/fwd

Declares a static route from the local node to node "bbn2". By default, any bundle destined for any endpoint whose node name is "bbn2" will be forwarded to endpoint "dtn://mitre1.dtn/fwd".

a plan mitre1 x ltp/6

Declares a static route from the local node to node "mitre1". By default, any bundle destined for any endpoint whose node name is "mitre1" will be queued for transmission on LTP outduct 6.

a rule mitre1 fwd x ltp/18

Declares an overriding static routing rule for any bundle destined for node "mitre1" whose destination demux name is "fwd". Each such bundle must be queued for transmission on LTP outduct 18 rather than the default (LTP outduct 6).

SEE ALSO

dtnadmin(1)

NAME

file2dgr - DGR transmission test program

SYNOPSIS

file2dgr *remoteHostName fileName* [*nbrOfCycles*]

DESCRIPTION

file2dgr uses DGR to send *nbrOfCycles* copies of the text of the file named *fileName* to the **dgr2file** process running on the computer identified by *remoteHostName*. If not specified (or if less than 1), *nbrOfCycles* defaults to 1. After sending all lines of the file, **file2dgr** sends a datagram containing an EOF string (the ASCII text "*** End of the file ***") before reopening the file and starting transmission of the next copy.

When all copies of the file have been sent, **file2dgr** prints a performance report:

```
        Bytes sent = I<byteCount>, usec elapsed = I<elapsedTime>.
        Sending I<dataRate> bits per second.
```

EXIT STATUS

0 **file2dgr** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **file2dgr** are written to the ION log file *ion.log*.

Can't open dgr service.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't open input file

Operating system error. Check errtext, correct problem, and rerun.

Can't acquire DGR working memory.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't reopen input file

Operating system error. Check errtext, correct problem, and rerun.

Can't read from input file

Operating system error. Check errtext, correct problem, and rerun.

dgr_send failed.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

file2dgr(1), dgr(3)

NAME

file2sdr - SDR data ingestion test program

SYNOPSIS

file2sdr *configFlags fileName*

DESCRIPTION

file2sdr stress-tests SDR data ingestion by repeatedly writing all text lines of the file named *fileName* to one of a series of non-volatile linked lists created in a test SDR data store named "testsdr*configFlags*". By incorporating the data store configuration into the name (e.g., "testsdr14") we make it relatively easy to perform comparative testing on SDR data stores that are identical aside from their configuration settings.

The operation of **file2sdr** is cyclical: a new linked list is created each time the program finishes copying the file's text lines and starts over again. If you use ^C to terminate **file2sdr** and then restart it, the program resumes operation at the point where it left off.

After writing each line to the current linked list, **file2sdr** gives a semaphore to indicate that the list is now non-empty. This is mainly for the benefit of the complementary test program sdr2file(1).

At the end of each cycle **file2sdr** appends a final EOF line to the current linked list, containing the text "*** End of the file ***", and prints a brief performance report:

```
        Processing I<lineCount> lines per second.
```

EXIT STATUS

0 **file2sdr** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **file2sdr** are written to the ION log file *ion.log*.

Can't use sdr.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't create semaphore.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

SDR transaction failed.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't open input file

Operating system error. Check errtext, correct problem, and rerun.

Can't reopen input file

Operating system error. Check errtext, correct problem, and rerun.

Can't read from input file

Operating system error. Check errtext, correct problem, and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

sdr2file(1), sdr(3)

NAME

file2sm - shared-memory linked list data ingestion test program

SYNOPSIS

file2sm *fileName*

DESCRIPTION

file2sm stress-tests shared-memory linked list data ingestion by repeatedly writing all text lines of the file named *fileName* to a shared-memory linked list that is the root object of a PSM partition named "file2sm".

After writing each line to the linked list, **file2sm** gives a semaphore to indicate that the list is now non-empty. This is mainly for the benefit of the complementary test program sm2file(1).

The operation of **file2sm** is cyclical. After copying all text lines of the source file to the linked list, **file2sm** appends an EOF line to the linked list, containing the text "*** End of the file ***", and prints a brief performance report:

```
        Processing I<lineCount> lines per second.
```

Then it reopens the source file and starts appending the file's text lines to the linked list again.

EXIT STATUS

0 **file2sm** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Can't attach to shared memory

Operating system error. Check errtext, correct problem, and rerun.

Can't manage shared memory.

PSM error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't create shared memory list.

smlist error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't create semaphore.

ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

Can't open input file

Operating system error. Check errtext, correct problem, and rerun.

Can't reopen input file

Operating system error. Check errtext, correct problem, and rerun.

Can't read from input file

Operating system error. Check errtext, correct problem, and rerun.

Ran out of memory.

Nominal behavior. **sm2file** is not extracting data from the linked list quickly enough to prevent it from growing to consume all memory allocated to the test partition.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

sm2file(1), smlist(3), psm(3)

NAME

ion - Interplanetary Overlay Network common definitions and functions

SYNOPSIS

```
    #include "ion.h"
    [see description for available functions]
```

DESCRIPTION

The Interplanetary Overlay Network (ION) software distribution is an implementation of Delay-Tolerant Networking (DTN) architecture as described in Internet RFC 4838. It is designed to enable inexpensive insertion of DTN functionality into embedded systems such as robotic spacecraft. The intent of ION deployment in space flight mission systems is to reduce cost and risk in mission communications by simplifying the construction and operation of automated digital data communication networks spanning space links, planetary surface links, and terrestrial links.

The ION distribution comprises the following software packages:

- *ici* (Interplanetary Communication Infrastructure), a set of general-purpose libraries providing common functionality to the other packages.
- *ltp* (Licklider Transmission Protocol), a core DTN protocol that provides transmission reliability based on delay-tolerant acknowledgments, timeouts, and retransmissions.
- *bp* (Bundle Protocol), a core DTN protocol that provides delay-tolerant forwarding of data through a network in which continuous end-to-end connectivity is never assured, including support for delay-tolerant dynamic routing. The Bundle Protocol (BP) specification is defined in Internet RFC 5050.
- *dgr* (Datagram Retransmission), a library that enables data to be transmitted via UDP with reliability comparable to that provided by TCP.
- *ams* (Asynchronous Message Service), an application-layer service that is not part of the DTN architecture but utilizes underlying DTN protocols.

Taken together, the packages included in the ION software distribution constitute a communication capability characterized by the following operational features:

- Reliable conveyance of data over a DTN, i.e., a network in which it might never be possible for any node to have reliable information about the detailed current state of any other node.
- Built on this capability, reliable distribution of short messages to multiple recipients (subscribers) residing in such a network.
- Management of traffic through such a network.
- Facilities for monitoring the performance of the network.
- Robustness against node failure.

- Portability across heterogeneous computing platforms.
- High speed with low overhead.
- Easy integration with heterogeneous underlying communication infrastructure, ranging from Internet to dedicated spacecraft communication links.

While most of the ici package consists of libraries providing functionality that may be of general utility in any complex embedded software system, the functions and macros described below are specifically designed to support operations of ION's delay-tolerant networking protocol stack.

TIMESTAMPBUFSZ

This macro returns the recommended size of a buffer that is intended to contain a timestamp in ION-standard format:

yyyy/mm/dd-hh:mm:ss

int ionAttach( )

Attaches the invoking task to ION infrastructure as previously established by running the *ionadmin* utility program on the same computer. Returns zero on success, -1 on any error.

void ionProd(time_t fromTime, time_t toTime, unsigned long fromNode, unsigned long toNode, unsigned long xmitRate, unsigned int owlt)

This function is designed to be called from an operating environment command or a fault protection routine, to enable operation of a node to resume when all of its scheduled contacts are in the past (making it impossible to use a DTN communication contact to assert additional future communication contacts). The function asserts a single new unidirectional contact conforming to the arguments provided, including the applicable one-way light time. The result of executing the function is written to the ION log using standard ION status message logging functions.

NOTE that the ionProd() function must be invoked twice in order to establish bidirectional communication.

Sdr getIonsdr( )

Returns a pointer to the SDR management object, previously acquired by calling ionAttach(), or zero on any error.

PsmPartition getIonwm( )

Returns a pointer to the ION working memory partition, previously acquired by calling ionAttach(), or zero on any error.

int getIonMemoryMgr( )

Returns the memory manager ID for operations on ION's working memory partition, previously acquired by calling ionAttach(), or -1 on any error.

unsigned long getOwnNodeNbr( )

Returns the Bundle Protocol node number identifying this computer, as declared when ION was initialized by *ionadmin*.

time_t getUTCTime( )

Returns the current UTC time, as computed from local clock time and the computer's current offset from UTC as managed from *ionadmin*.

void writeTimestamp(time_t timestamp, char *timestampBuffer)

Expresses the time value in *timestamp* as a timestamp string in ION-standard format, as noted above, in *timestampBuffer*.

time_t readTimestamp(char *timestampBuffer, time_t referenceTime)

Parses the timestamp string in *timestampBuffer* and returns the corresponding time value (as would be returned by time(2)), or zero if the timestamp string cannot be parsed successfully. The timestamp string is normally expected to be an absolute time expression in ION-standard format as noted above. However, a relative time expression variant is also supported: if the first character of *timestampBuffer* is '+' then the remainder of the string is interpreted as a count of seconds; the sum of this value and the time value in *referenceTime* is returned.

STATUS MESSAGES

ION uses writeMemo(), putErrmsg(), and putSysErrmsg() to log several different types of standardized status messages.

Informational messages

These messages are generated to inform the user of the occurrence of events that are nominal but significant, such as the controlled termination of a daemon or the production of a congestion forecast. Each informational message has the following format:

{*yyyy/mm/dd hh:mm:ss*} [i] *text*

Warning messages

These messages are generated to inform the user of the occurrence of events that are off-nominal but are likely caused by configuration or operational errors rather than software failure. Each warning message has the following format:

{*yyyy/mm/dd hh:mm:ss*} [?] *text*

Diagnostic messages

These messages are produced by calling `putErrmsg()` or putSysErrmsg(). They are generated to inform the user of the occurrence of events that are off-nominal and might be due to errors in software. The location within the ION software at which the off-nominal condition was detected is indicated in the message:

{*yyyy/mm/dd hh:mm:ss*} at line *nnn* of *sourcefilename*, *text* (*argument*)

Note that the *argument* portion of the message (including its enclosing parentheses) will be provided only when an argument value seems potentially helpful in fault analysis.

Bundle Status Report (BSR) messages

A BSR message informs the user of the arrival of a BSR, a Bundle Protocol report on the status of some bundle. BSRs are issued in the course of processing bundles for which one or more status report request flags are set, and they are also issued when bundles for which custody transfer is requested are destroyed prior to delivery to their destination endpoints. A BSR message is generated by **ipnadminep** upon reception of a BSR. The time and place (node) at which the BSR was issued are indicated in the message:

> {*yyyy/mm/dd hh:mm:ss*} [s] (*sourceEID*)/*creationTimeSeconds*:*counter*/*fragmentOffset* status *flagsByte* at *time* on *endpointID*, '*reasonString*'.

Communication statistics messages
A network performance report is a set of eight communication statistics messages, one for each of eight different types of network activity. A report is issued every time contact transmission or reception starts or stops, except when there is no activity of any kind on the local node since the prior report. When a report is issued, statistic messages are generated to summarize all network activity detected since the prior report, after which all network activity counters and accumulators are reset to zero.

NOTE also that the **bpstats** utility program can be invoked to issue an interim network performance report at any time. Issuance of interim status reports does **not** cause network activity counters and accumulators to be reset to zero.

Statistics messages have the following format:

> {*yyyy/mm/dd hh:mm:ss*} [x] *xxx* from *tttttttt* to *TTTTTTTT*: (0) *aaaa bbbbbbbbbb* (1) *cccc dddddddddd* (2) *eeee ffffffffff* (@) *gggg hhhhhhhhhh*

xxx indicates the type of network activity that the message is reporting on. Statistics for eight different types of network activity are reported:

src
: This message reports on the bundles sourced at the local node during the indicated interval.

fwd
: This message reports on the bundles forwarded by the local node. When a bundle is re-forwarded due to custody transfer timeout it is counted a second time here.

xmt
: This message reports on the bundles passed to the convergence layer `protocol(s)` for transmission from this node. Again, a re-forwarded bundle that is then re-transmitted at the convergence layer is counted a second time here.

rcv
: This message reports on the bundles from other nodes that were received at the local node.

dlv

This message reports on the bundles delivered to applications via endpoints on the local node.

ctr

This message reports on the custody refusal signals received at the local node.

ctt

This message reports on the custodial bundles for which convergence-layer transmission failed at this node, nominally causing the bundles to be re-forwarded.

exp

This message reports on the bundles destroyed at this node due to TTL expiration.

tttttttt and *TTTTTTTT* indicate the start and end times of the interval for which statistics are being reported, expressed as a number of seconds since the start of the DTN epoch. *TTTTTTTT* is the current time and *tttttttt* is the time of the prior report.

Each of the four value pairs following the colon (:) reports on the number of bundles counted for the indicated type of network activity, for the indicated traffic flow, followed by the sum of the sizes of the payloads of all those bundles. The four traffic flows for which statistics are reported are ``(0)'' the priority-0 or ``bulk'' non-administrative traffic, ``(1)'' the priority-1 non-administrative traffic, ``(2)'' the priority-2 ``expedited'' non-administrative traffic, and ``(@)'' all administrative traffic regardless of priority.

Free-form messages

Other status messages are free-form, except that date and time are always noted just as for the documented status message types.

SEE ALSO

ionadmin(1), rfxclock(1), bpstats(1), llcv(3), lyst(3), memmgr(3), platform(3), psm(3), rfx(3), sdr(3), zco(3), ltp(3), bp(3), *AMS Programmer's Guide*

NAME

ionadmin - ION node administration interface

SYNOPSIS

ionadmin [*commands_filename* | .]

DESCRIPTION

ionadmin configures, starts, manages, and stops the ION node on the local computer.

It configures the node and sets (and reports on) global operational settings for the DTN protocol stack on the local computer in response to ION configuration commands found in *commands_filename,* if provided; if not, **ionadmin** prints a simple prompt (:) so that the user may type commands directly into standard input. If *commands_filename* is a period (.), the effect is the same as if a command file containing the single command 'x' were passed to **ionadmin** -- that is, the ION node's *rfxclock* task is stopped.

The format of commands for *commands_filename* can be queried from **ionadmin** by entering the command 'h' or '?' at the prompt. The commands are documented in ionrc(5).

Note that *ionadmin* always computes a congestion forecast immediately before exiting. The result of this forecast -- maximum projected occupancy of the DTN protocol traffic allocation in ION's SDR database -- is retained for application flow control purposes: if maximum projected occupancy is the entire protocol traffic allocation, then a message to this effect is logged and no new bundle origination by any application will be accepted until a subsequent forecast that predicts no congestion is computed. (Congestion forecasts are constrained by *horizon* times, which can be established by commands issued to *ionadmin*. One way to re-enable data origination temporarily while long-term traffic imbalances are being addressed is to declare a congestion forecast horizon in the near future, before congestion would occur if no adjustments were made.)

EXIT STATUS

0 Successful completion of ION node administration.

EXAMPLES

ionadmin

Enter interactive ION configuration command entry mode.

ionadmin host1.ion

Execute all configuration commands in *host1.ion*, then terminate immediately.

FILES

Status and diagnostic messages from **ionadmin** and from other software that utilizes the ION node are nominally written to a log file in the current working directory within which **ionadmin** was run. The log file is typically named **ion.log**.

See also ionconfig(5) and ionrc(5).

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Note: all ION administration utilities expect source file input to be lines of ASCII text that are NL-delimited. If you edit the ionrc file on a Windows machine, be sure to **use dos2unix to convert it to Unix text format** before presenting it to **ionadmin**. Otherwise **ionadmin** will detect syntax errors and will not function satisfactorily.

The following diagnostics may be issued to the log file:

Can't open command file...

The *commands_filename* specified in the command line doesn't exist.

ionadmin SDR definition failed.

A node initialization command was executed, but an SDR database already exists for the indicated node. It is likely that an ION node is already running on this computer or that destruction of a previously started the previous ION node was incomplete. For most ION installations, incomplete node destruction can be repaired by (a) killing all ION processes that are still running and then (b) using **ipcrm** to remove all SVr4 IPC objects owned by ION.

ionadmin can't get SDR parms.

A node initialization command was executed, but the *ion_config_filename* passed to that command contains improperly formatted commands. Please see `ionconfig(5)` for further details.

Various errors that don't cause **ionadmin** to fail but are noted in the log file may be caused by improperly formatted commands given at the prompt or in the *commands_filename*. Please see `ionrc(5)` for details.

BUGS

If the *ion_config_filename* parameter passed to a node initialization command refers to a nonexistent filename, then **ionadmin** uses default values are used rather than reporting an error in the command line argument.

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ionrc(5), ionconfig(5)

NAME

ionconfig - ION node configuration parameters file

DESCRIPTION

ION node configuration parameters are passed to **ionadmin** in a file of parameter name/value pairs:

> *parameter_name parameter_value*

Any line of the file that begins with a '#' character is considered a comment and is ignored.

ionadmin supplies default values for any parameters for which no value is provided in the node configuration parameters file.

The applicable parameters are as follows:

configFlags
: This is the bitwise "OR" of the flag values that characterize the SDR database to use for this ION node. The default value is 1. The SDR configuration flags are documented in detail in sdr(3). To recap:

1	The SDR is implemented in a region of shared memory. [Possibly with write-through to a file, for fault tolerance.]
2	The SDR is implemented as a file. [Possibly cached in a region of shared memory, for faster data retrieval.]
4	Transactions in the SDR are written ahead to a log, making them reversible.
8	SDR heap updates are not allowed to cross object boundaries.

heapKey
: This is the shared-memory key by which the pre-allocated block of shared dynamic memory to be used as heap space for this SDR can be located, if applicable. The default value is -1, i.e., not specified and not applicable.

pathName
: This is the fully qualified path name of the directory in which are located (a) the file to be used as heap space for this SDR (which will be created, if it doesn't already exist), in the event that the SDR is to be implemented in a file, and (b) the file to be used to log the database updates of each SDR transaction, in the event that transactions in this SDR are to be reversible. The default value is **/usr/ion**.

heapWords
: This is the number of words (of 32 bits each on a 32-bit machine, 64 bits each on a 64-bit machine) of nominally non-volatile storage to use for ION's SDR

database. If the SDR is to be implemented in shared memory and no *heapKey* is specified, a block of shared memory of this size will be allocated (e.g., by `malloc()`) at the time the node is created. If the SDR is to be implemented in a file and no file named **ion.sdr** exists in the directory identified by *pathName*, then a file of this name and size will be created in this directory and initialized to all binary zeroes. The default value is 250000 words (1 million bytes on a 32-bit computer).

wmAddress

This is the address of the block of dynamic memory -- volatile storage, which is not expected to persist across a system reboot -- to use for ION's working memory. If zero, the working memory block will be allocated from system memory (e.g., by `malloc()`) at the time the local ION node is created. The default value is zero.

wmSize

This is the size of the block of dynamic memory that will be used for ION's working memory. If *wmAddress* is zero, a block of system memory of this size will be allocated (e.g., by `malloc()`) at the time the node is created. The default value is 5000000 (5 million bytes).

EXAMPLE

configFlags 1

heapWords 2500000

heapKey -1

pathName 'usr/ion'

wmSize 5000000

wmAddress 0

SEE ALSO

ionadmin(1)

NAME

ionrc - ION node management commands file

DESCRIPTION

ION node management commands are passed to **ionadmin** either in a file of text lines or interactively at **ionadmin**'s command prompt (:). Commands are interpreted line-by line, with exactly one command per line. The formats and effects of the ION node management commands are described below.

TIME REPRESENTATION

For many ION node management commands, time values must be passed as arguments. Every time value may be represented in either of two formats. Absolute time is expressed as:

> *yyyy*/*mm*/*dd*-*hh*:*mm*:*ss*

Relative time (a number of seconds following the current *reference time*, which defaults to the current time at the moment *ionadmin* began execution but which can be overridden by the **at** command described below) is expressed as:

> +*ss*

COMMANDS

?

> The **help** command. This will display a listing of the commands and their formats. It is the same as the **h** command.

#

> Comment line. Lines beginning with **#** are not interpreted.

e { 0 | 1 }

> Echo control. Setting echo to 1 causes all output printed by ionadmin to be logged as well as sent to stdout. Setting echo to 0 disables this behavior.

1 *element_number* { *ion_config_filename* | '''' }

> The **initialize** command. Until this command is executed, the local ION node does not exist and most *ionadmin* commands will fail.
>
> The command configures the local node to be identified by *element_number*, a CBHE element number which functions as "node number", a unique identification number for the node in the delay-tolerant network. It also configures ION's data store (SDR) and shared working-memory region using either the settings found in

the *ion_config_filename* file or, if "" is supplied as the *ion_config_filename*, a set of default settings. Please see `ionconfig(5)` for details.

For example:

```
        1 19 ""
```

would initialize ION on the local computer, assigning the local ION node the node number 19 and using default values to configure the data store and shared working-memory region.

@ time

The **at** command. This is used to set the reference time that will be used for interpreting relative time values from now until the next revision of reference time. Note that the new reference time can be a relative time, i.e., an offset beyond the current reference time.

a contact *start_time stop_time source_node dest_node xmit_data_rate*

The **add contact** command. This command schedules a period of data transmission from *source_node* to *dest_node*. The period of transmission will begin at *start_time* and end at *stop_time*, and the rate of data transmission will be *xmit_data_rate* bytes/second.

d contact *start_time source_node dest_node*

The **delete contact** command. This command deletes the scheduled period of data transmission from *source_node* to *dest_node* starting at *start_time*.

i contact *start_time source_node dest_node*

This command will print information (the stop time and data rate) about the scheduled period of transmission from *source_node* to *dest_node* that starts at *start_time*.

l contact

This command lists all scheduled periods of data transmission.

a range *start_time stop_time one_node the_other_node distance*

The **add range** command. This command predicts a period of time during which the distance from *one_node* to *the_other_node* will be constant to within one light second. The period will begin at *start_time* and end at *stop_time*, and the distance between the nodes during that time will be *distance* light seconds.

d range *start_time one_node the_other_node*

The **delete range** command. This command deletes the predicted period of constant distance between *one_node* and *the_other_node* starting at *start_time*.

i range *start_time one_node the_other_node*

This command will print information (the stop time and range) about the predicted period of constant distance between *one_node* and *the_other_node* that starts at *start_time*.

l range

This command lists all predicted periods of constant distance.

m utcdelta *local_time_sec_after_UTC*

This management command sets ION's understanding of the current difference between correct UTC time and the time values reported by the clock for the local ION node's computer. This delta is automatically applied to locally obtained time values whenever ION needs to know the current time. For NTP-synchronized clocks in the Pacific time zone, the value of this delta should be -28800.

m clockerr *known_maximum_clock_error*

This management command sets ION's understanding of the accuracy of the scheduled start and stop times of planned contacts, in seconds. The default value is 1. When revising local data transmission and reception rates, *ionadmin* will adjust contact start and stop times by this interval to be sure not to send bundles that arrive before the neighbor expects data arrival or to discard bundles that arrive slightly before they were expected.

m production *planned_data_production_rate*

This management command sets ION's expectation of the mean rate of continuous data origination by local BP applications throughout the period of time over which congestion forecasts are computed. For nodes that function only as routers this variable will normally be zero, which is the default.

m consumption *planned_data_consumption_rate*

This management command sets ION's expectation of the mean rate of continuous data delivery to local BP applications throughout the period of time over which congestion forecasts are computed. For nodes that function only as routers this variable will normally be zero, which is the default.

m occupancy *data_store_occupancy_limit*

This management command sets the maximum number of bytes of storage space in ION's SDR non-volatile data store that can be used for the storage of bundles. The default value is 60% of the SDR data store's total heap size.

m horizon { 0 | *end_time_for_congestion_forecasts* }

This management command sets the end time for computed congestion forecasts. Setting congestion forecast horizon to zero sets the congestion forecast end time to infinite time in the future: if there is any predicted net growth in bundle storage space occupancy at all, following the end of the last scheduled contact, then eventual congestion will be predicted. The default value is zero, i.e., no end time.

m alarm '*congestion_alarm_command*'

This management command establishes a command which will automatically be executed whenever *ionadmin* predicts that the node will become congested at some future time. By default, there is no alarm command.

m usage

This management command simply prints ION's current data store occupancy (the number of bytes of space in the SDR non-volatile data store that are occupied by bundles), the limit on occupancy, and the maximum level of occupancy predicted by the most recent *ionadmin* congestion forecast computation.

r '*command_text*'

The **run** command. This command will execute *command_text* as if it had been typed at a console prompt. It is used to, for example, run another administrative program.

s

The **start** command. This command starts the *rfxclock* task on the local ION node.

x

The **stop** command. This command stops the *rfxclock* task on the local ION node.

h

The **help** command. This will display a listing of the commands and their formats. It is the same as the **?** command.

EXAMPLES

@ 2008/10/05-11:30:00

Sets the reference time to 1130 (UTC) on 5 October 2008.

a range +1 2009/01/01-00:00:00 1 2 12

Predicts that the distance between nodes 1 and 2 (endpoint IDs ipn:1.0 and ipn:2.0) will remain constant at 12 light seconds over the interval that begins 1 second after the reference time and ends at the end of calendar year 2009.

a contact +60 +7260 1 2 10000

Schedules a period of transmission at 10,000 bytes/second from node 1 to node 2, starting 60 seconds after the reference time and ending exactly two hours (7200 seconds) after it starts.

SEE ALSO

ionadmin(1), rfxclock(1)

NAME

ipnadmin - Interplanetary Internet (IPN) scheme administration interface

SYNOPSIS

ipnadmin [*commands_filename*]

DESCRIPTION

ipnadmin configures the local ION node's routing of bundles to endpoints whose IDs conform to the *ipn* endpoint ID scheme. *ipn* is a CBHE-conformant scheme; that is, every endpoint ID in the *ipn* scheme is a string of the form "ipn:*element_number*.*service_number*" where *element_number* is an ION "node number" and *service_number* identifies a specific application processing point.

ipnadmin operates in response to IPN scheme configuration commands found in the file *commands_filename*, if provided; if not, **ipnadmin** prints a simple prompt (:) so that the user may type commands directly into standard input.

The format of commands for *commands_filename* can be queried from **ipnadmin** with the 'h' or '?' commands at the prompt. The commands are documented in ipnrc(5).

EXIT STATUS

0 Successful completion of IPN scheme administration.

1 Unsuccessful completion of IPN scheme administration, due to inability to attach to the Bundle Protocol system or to initialize the IPN scheme.

EXAMPLES

ipnadmin

Enter interactive IPN scheme configuration command entry mode.

ipnadmin host1.ipn

Execute all configuration commands in *host1.ipn*, then terminate immediately.

FILES

See `ipnrc(5)` for details of the IPN scheme configuration commands.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Note: all ION administration utilities expect source file input to be lines of ASCII text that are NL-delimited. If you edit the ipnrc file on a Windows machine, be sure to **use dos2unix to convert it to Unix text format** before presenting it to **ipnadmin**. Otherwise **ipnadmin** will detect syntax errors and will not function satisfactorily.

The following diagnostics may be issued to the logfile ion.log:

ipnadmin can't attach to BP.

> Bundle Protocol has not been initialized on this computer. You need to run `bpadmin(1)` first.

ipnadmin can't initialize routing database.

> There is no SDR data store for *dtnadmin* to use. Please run `ionadmin(1)` to start the local ION node.

Can't open command file...

> The *commands_filename* specified in the command line doesn't exist.

Various errors that don't cause **ipnadmin** to fail but are noted in the **ion.log** log file may be caused by improperly formatted commands given at the prompt or in the *commands_filename* file. Please see `ipnrc(5)` for details.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ipnrc(5)

NAME

ipnadminep - administrative endpoint task for the IPN scheme

SYNOPSIS

ipnadminep

DESCRIPTION

ipnadminep is a background "daemon" task that receives and processes administrative bundles (all custody signals and, nominally, all bundle status reports) that are sent to the IPN-scheme administrative endpoint on the local ION node, if and only if such an endpoint was established by **bpadmin**. It is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of Bundle Protocol on the local ION node, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **ipnadminep** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the IPN scheme.

ipnadminep responds to custody signals as specified in the Bundle Protocol specification, RFC 5050. It responds to bundle status reports by logging ASCII text messages describing the reported activity.

EXIT STATUS

0 **ipnadminep** terminated, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **ipnadminep**.

1 **ipnadminep** was unable to attach to Bundle Protocol operations or was unable to load the IPN scheme database, probably because **bpadmin** has not yet been run.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

ipnadminep can't attach to BP.

> **bpadmin** has not yet initialized BP operations.

ipnadminep can't load routing database.

> **ipnadmin** has not yet initialized the IPN scheme.

ipnadminep crashed.

> An unrecoverable database error was encountered. **ipnadminep** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), ipnadmin(1), bprc(5)

NAME

ipnfw - bundle route computation task for the IPN scheme

SYNOPSIS

ipnfw

DESCRIPTION

ipnfw is a background "daemon" task that pops bundles from the queue of bundle destined for IPN-scheme endpoints, computes proximate destinations for those bundles, and appends those bundles to the appropriate queues of bundles pending transmission to those computed proximate destinations.

For each possible proximate destination (that is, neighboring node) there is a separate queue for each possible level of bundle priority: 0, 1, 2. Each outbound bundle is appended to the queue matching the bundle's designated priority.

Proximate destination computation is affected by static and default routes as configured by `ipnadmin(1)` and by contact graphs as managed by `ionadmin(1)` and rfxclock(1).

ipnfw is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of Bundle Protocol on the local ION node, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **ipnfw** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the IPN scheme.

EXIT STATUS

0
: **ipnfw** terminated, for reasons noted in the **ion.log** log file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **ipnfw**.

1
: **ipnfw** could not commence operations, for reasons noted in the **ion.log** log file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart **ipnfw**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

ipnfw can't attach to BP.

> **bpadmin** has not yet initialized BP operations.

ipnfw can't load routing database.

> **ipnadmin** has not yet initialized the IPN scheme.

Can't create lists for route computation.

> An unrecoverable database error was encountered. **ipnfw** terminates.

'ipn' scheme is unknown.

> The IPN scheme was not added when **bpadmin** initialized BP operations. Use **bpadmin** to add and start the scheme.

Can't take forwarder semaphore.

> ION system error. **ipnfw** terminates.

Can't exclude sender from routes.

> An unrecoverable database error was encountered. **ipnfw** terminates.

Can't enqueue bundle.

> An unrecoverable database error was encountered. **ipnfw** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), ipnadmin(1), bprc(5), ipnrc(5)

NAME

ipnrc - IPN scheme configuration commands file

DESCRIPTION

IPN scheme configuration commands are passed to **ipnadmin** either in a file of text lines or interactively at **ipnadmin**'s command prompt (:). Commands are interpreted line-by line, with exactly one command per line.

IPN scheme configuration commands (a) establish egress plans for transmission to neighboring nodes and (b) establish static and default routing rules for forwarding bundles to specified destination nodes..

The egress **plan** established for a given node associates a default egress **directive** with that node, and that default directive may be overridden by more narrowly scoped **rule**s in specific circumstances: a different directive may apply when the source endpoint for the subject bundle identifies a specific node, a specific service, or both.

Each directive is a string of the form "x *protocol_name*/*outduct_name*[,*destination_induct_name*]", signifying that the bundle is to be queued for transmission via the indicated convergence layer protocol outduct. *destination_induct_name* must be provided when the indicated outduct is "promiscuous", i.e., not configured for transmission only to a single neighboring node; this is protocol-specific.

The circumstances that characterize a specific rule within a general plan are expressed in a **qualifier**, a string of the form "*source_service_number source_element_number*" where either *source_service_number* or *source_element_number* may be an asterisk character (*) signifying "all".

Note that egress plans **must** be established for all neighboring nodes, regardless of whether or not contact graph routing is used for computing dynamic routes to distant nodes. This is by definition: if there isn’t an egress plan to a node, it can’t be considered a neighbor.

Static and default routes are expressed as **groups** in the IPN scheme database. A group is a range of node numbers identifying a set of nodes for which defined default routing behavior is established: whenever a bundle is to be forwarded to a node whose number is in the group's node number range **and** it has not been possible to compute a dynamic route to that node from the contact schedules that have been provided to the local node, BP will simply forward the bundle to the **gateway** node associated with this group. A static route is a group whose range is a single node number. The gateway node for any group might or might not be a neighbor; if it is not a neighbor (i.e., there is no egress plan defined for this node), then the static or default route for the gateway itself must be computed to enable forwarding, and so on. Ultimately, static/default routing must resolve to an egress directive; otherwise, routing fails. Multiple groups may encompass the same node number, in which case the gateway associated with the most restrictive group (the one with the smallest range) is always selected.

The service numbers that are used in IPN endpoint IDs may also be defined by IPN scheme configuration commands, but at the time of this writing these service number definitions are not used and are not required.

The formats and effects of the IPN scheme configuration commands are described below.

GENERAL COMMANDS

?

The **help** command. This will display a listing of the commands and their formats. It is the same as the **h** command.

#

Comment line. Lines beginning with **#** are not interpreted.

e { 0 | 1 }

Echo control. Setting echo to 1 causes all output printed by ipnadmin to be logged as well as sent to stdout. Setting echo to 0 disables this behavior.

h

The **help** command. This will display a listing of the commands and their formats. It is the same as the **?** command.

SERVICE COMMANDS

a service *service_nbr service_name*

The **add service** command. This command declares a "service" that may be cited in IPN endpoint IDs. Services are identified by service numbers but may have associated informational names.

c service *service_nbr service_name*

The **change service** command. This command sets the indicated service's *service_name* to the string provided.

d service *service_nbr*

The **delete service** command. This command deletes the service identified by *service_nbr*.

i service *service_nbr*

This command will print information (service name) about the service identified by *service_nbr*.

l service

This command lists all declared services.

PLAN COMMANDS

a plan *element_nbr element_name default_directive*

The **add plan** command. This command establishes an egress plan for the bundles that must be transmitted to the neighboring node identified by *element_nbr*. A general plan must be in place for a node before any more specific routing rules are declared.

d plan *element_nbr*

The **delete plan** command. This command deletes the egress plan for the node identified by *element_nbr*, including all associated rules.

i plan *element_nbr*

This command will print information (the default directive and all specific rules) about the egress plan for the node identified by *element_nbr*.

l plan

This command lists all egress plans established in the IPN database for the local node.

RULE COMMANDS

a rule *element_nbr qualifier directive*

The **add rule** command. This command establishes a rule, i.e., a directive that overrides the default directive of the egress plan for the node identified by *element_nbr* in the event that the source endpoint ID of the subject bundle matches *qualifier*.

c rule *element_nbr qualifier directive*

The **change rule** command. This command changes the directive for the indicated rule.

d rule *element_nbr qualifier*

The **delete rule** command. This command deletes the rule identified by *element_nbr* and *qualifier*.

i rule *element_nbr qualifier*

This command will print information (the directive) about the rule identified by *element_nbr* and *qualifier*.

l rule *element_nbr*

This command lists all rules in the plan for the indicated node.

GROUP COMMANDS

a group *first_element_nbr last_element_nbr gateway_element_nbr*

The **add group** command. This command establishes a "group" for static and default routing as described above.

c group *first_element_nbr last_element_nbr gateway_element_nbr*

The **change group** command. This command changes the gateway element number for the group identified by *first_element_nbr* and ***last_element_nbr***.

d group *first_element_nbr last_element_nbr*

The **delete group** command. This command deletes the group identified by *first_element_nbr* and ***last_element_nbr***.

i group *first_element_nbr last_element_nbr*

This command will print information (the last element number and gateway element number) about the group identified by *first_element_nbr* and ***last_element_nbr***.

l group

This command lists all groups defined in the IPN database for the local node.

EXAMPLES

a plan 18 Odyssey x ltp/6

Declares the egress plan to ue for transmission from the local node to neighboring node 18, nicknamed "Odyssey". Any bundle for which the computed “next hop” node is node 18 will be queued for transmission on LTP outduct 6.

a rule 18 * 9 x ltp/18

Declares an egress plan override that applies to transmission to node 18 of any bundle whose source is node 9, regardless of the service that was the source of the bundle. Each such bundle must be queued for transmission on LTP outduct 18 rather than the default (LTP outduct 6).

a group 1 999 18

Declares a default route for bundles destined for all nodes whose numbers are in the range 1 through 999 inclusive: absent any other routing decision, such bundles are to be forwarded to node 18.

SEE ALSO

ipnadmin(1)

NAME

lgagent - ION Load/Go remote agent program

SYNOPSIS

lgagent *own_endpoint_ID*

DESCRIPTION

ION Load/Go is a system for management of an ION-based network, enabling the execution of ION administrative programs at remote nodes. The system comprises two programs, **lgsend** and **lgagent**.

The **lgagent** task on a given node opens the indicated ION endpoint for bundle reception, receives the extracted payloads of Load/Go bundles sent to it by **lgsend** as run on one or more remote nodes, and processes those payloads, which are the text of Load/Go source files.

Load/Go source file content is limited to newline-terminated lines of ASCII characters. More specifically, the text of any Load/Go source file is a sequence of *line sets* of two types: *file capsules* and *directives*. Any Load/Go source file may contain any number of file capsules and any number of directives, freely intermingled in any order, but the typical structure of a Load/Go source file is simply a single file capsule followed by a single directive.

When **lgagent** identifies a file capsule, it copies all of the capsule's text lines to a new file that it creates in the current working directory. When **lgagent** identifies a directive, it executes the directive by passing the text of the directive to the `pseudoshell()` function (see platform(3)). **lgagent** processes the line sets of a Load/Go source file in the order in which they appear in the file, so the text of a directive may reference a file that was created as the result of processing a prior file capsule in the same source file.

EXIT STATUS

0 Load/Go remote agent processing has terminated.

FILES

lgfile contains the Load/Go file capsules and directives that are to be processed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

lgagent: can't attach to BP.

> Bundle Protocol is not running on this computer. Run `bpadmin(1)` to start BP.

lgagent: can't open own endpoint.

> *own_endpoint_ID* is not a declared endpoint on the local ION node. Run `bpadmin(1)` to add it.

lgagent: bundle reception failed.

> ION system problem. Investigate and correct before restarting.

lgagent cannot continue.

> lgagent processing problem. See earlier diagnostic messages for details. Investigate and correct before restarting.

lgagent: no space for bundle content.

> ION system problem: have exhausted available SDR data store reserves.

lgagent: can't receive bundle content.

> ION system problem: have exhausted available SDR data store reserves.

lgagent: can't handle bundle delivery.

> ION system problem. Investigate and correct before restarting.

lgagent: pseudoshell failed.

> Error in directive line, usually an attempt to execute a non-existent administration program (e.g., a misspelled program name). Terminates processing of source file content.

A variety of other diagnostics noting source file parsing problems may also be reported. These errors are non-fatal but they terminate the processing of the source file content from the most recently received bundle.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

lgsend(1), lgfile(5)

NAME

lgfile - ION Load/Go source file

DESCRIPTION

The ION Load/Go system enables the execution of ION administrative programs at remote nodes:

- The **lgsend** program reads a Load/Go source file from a local file system, encapsulates the text of that source file in a bundle, and sends the bundle to a designated DTN endpoint on the remote node.
- An **lgagent** task running on the remote node, which has opened that DTN endpoint for bundle reception, receives the extracted payload of the bundle – the text of the Load/Go source file – and processes it.

Load/Go source file content is limited to newline-terminated lines of ASCII characters. More specifically, the text of any Load/Go source file is a sequence of *line sets* of two types: *file capsules* and *directives*. Any Load/Go source file may contain any number of file capsules and any number of directives, freely intermingled in any order, but the typical structure of a Load/Go source file is simply a single file capsule followed by a single directive.

Each *file capsule* is structured as a single start-of-capsule line, followed by zero or more capsule text lines, followed by a single end-of-capsule line. Each start-of-capsule line is of this form:

> [*file_name*

Each capsule text line can be any line of ASCII text that does not begin with an opening ([) or closing (]) bracket character.

A text line that begins with a closing bracket character (]) is interpreted as an end-of-capsule line.

A *directive* is any line of text that is not one of the lines of a file capsule and that is of this form:

> !*directive_text*

When **lgagent** identifies a file capsule, it copies all of the capsule's text lines to a new file named *file_name* that it creates in the current working directory. When **lgagent** identifies a directive, it executes the directive by passing *directive_text* to the `pseudoshell()` function (see platform(3)). **lgagent** processes the line sets of a Load/Go source file in the order in which they appear in the file, so the *directive_text* of a directive may reference a file that was created as the result of processing a prior file capsule line set in the same source file.

Note that lgfile directives are passed to `pseudoshell`, which on a VxWorks platform will always spawn a new task; the first argument in *directive_text* must be a symbol that VxWorks can resolve to a function, not a shell command. Also note that the arguments in *directive_text* will be actual task arguments, not shell command-line arguments, so they should never be enclosed in double-quote characters (“). However, any argument that contains embedded whitespace must be enclosed in single-quote characters (‘) so that `pseudoshell` can parse it correctly.

EXAMPLES

Presenting the following lines of source file text to **lgsend**:

```
[cmd33.bprc
x protocol ltp
]
!bpadmin cmd33.bprc
```

should cause the receiving node to halt the operation of the LTP convergence-layer protocol.

SEE ALSO

lgsend(1), lgagent(1), platform(3)

NAME

lgsend - ION Load/Go command program

SYNOPSIS

lgsend *command_file_name own_endpoint_ID destination_endpoint_ID*

DESCRIPTION

ION Load/Go is a system for management of an ION-based network, enabling the execution of ION administrative programs at remote nodes. The system comprises two programs, **lgsend** and **lgagent**.

The **lgsend** program reads a Load/Go source file from a local file system, encapsulates the text of that source file in a bundle, and sends the bundle to an **lgagent** task that is waiting for data at a designated DTN endpoint on the remote node.

To do so, it first reads all lines of the Load/Go source file identified by *command_file_name* into a temporary buffer in ION's SDR data store, concatenating the lines of the file and retaining all newline characters. Then it invokes the `bp_send()` function to create and send a bundle whose payload is this temporary buffer, whose destination is *destination_endpoint_ID*, and whose source endpoint ID is *own_endpoint_ID*. Then it terminates.

EXIT STATUS

0	Load/Go file transmission succeeded.
1	Load/Go file transmission failed. Examine **ion.log** to determine the cause of the failure, then re-run.

FILES

lgfile contains the Load/Go file capsules and directive that are to be sent to the remote node.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

lgsend: can't attach to BP.

> Bundle Protocol is not running on this computer. Run `bpadmin(1)` to start BP.

lgsend: can't open own endpoint.

> *own_endpoint_ID* is not a declared endpoint on the local ION node. Run `bpadmin(1)` to add it.

lgsend: can't open file of LG commands: *error description*

> *command_file_name* doesn't identify a file that can be opened. Correct spelling of file name or file's access permissions.

lgsend: can't get size of LG command file: *error description*

> Operating system problem. Investigate and correct before rerunning.

lgsend: LG cmd file size > 64000.

> Load/Go command file is too large. Split it into multiple files if possible.

lgsend: no space for application data unit.

> ION system problem: have exhausted available SDR data store reserves.

lgsend: fgets failed: *error description*

> Operating system problem. Investigate and correct before rerunning.

lgsend: can't create application data unit.

> ION system problem: have exhausted available SDR data store reserves.

lgsend: can't send bundle.

> ION system problem. Investigate and correct before rerunning.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

lgagent(1), lgfile(5)

NAME

llcv - library for manipulating linked-list condition variable objects

SYNOPSIS

```
    #include "llcv.h"

    typedef struct llcv_str
    {
        Lyst            list;
        pthread_mutex_t mutex;
        pthread_cond_t  cv;
    } *Llcv;

    typedef int (*LlcvPredicate)(Llcv);
```

[see description for available functions]

DESCRIPTION

A "linked-list condition variable" object (LLCV) is an inter-thread communication mechanism that pairs a process-private linked list in memory with a condition variable as provided by the pthreads library. LLCVs echo in thread programming the standard ION inter-process or inter-task communication model that pairs shared-memory semaphores with linked lists in shared memory or shared non-volatile storage. As in the semaphore/list model, variable-length messages may be transmitted; the resources allocated to the communication mechanism grow and shrink to accommodate changes in data rate; the rate at which messages are issued is completely decoupled from the rate at which messages are received and processed. That is, there is no flow control, no blocking, and therefore no possibility of deadlock or "deadly embrace". Traffic spikes are handled without impact on processing rate, provided sufficient memory is provided to accommodate the peak backlog.

An LLCV comprises a Lyst, a mutex, and a condition variable. The Lyst may be in either private or shared memory, but the Lyst itself is not shared with other processes. The reader thread waits on the condition variable until signaled by a writer that some condition is now true. The standard Lyst API functions are used to populate and drain the linked list. In order to protect linked list integrity, each thread must call `llcv_lock()` before operating on the Lyst and `llcv_unlock()` afterwards. The other llcv functions merely effect flow signaling in a way that makes it unnecessary for the reader to poll or busy-wait on the Lyst.

Llcv llcv_open(Lyst list, Llcv llcv)

Opens an LLCV, initializing as necessary. The *list* argument must point to an existing Lyst, which may reside in either private or shared dynamic memory. *llcv* must point to an existing llcv_str management object, which may reside in either static or dynamic (private or shared) memory -- but *NOT* in stack space. Returns *llcv* on success, NULL on any error.

void llcv_lock(Llcv llcv)
: Locks the LLCV's Lyst so that it may be updated or examined safely by the calling thread. Fails silently on any error.

void llcv_unlock(Llcv llcv)
: Unlocks the LLCV's Lyst so that another thread may lock and update or examine it. Fails silently on any error.

int llcv_wait(Llcv llcv, LlcvPredicate cond, int microseconds)
: Returns when the Lyst encapsulated within the LLCV meets the indicated condition. If *microseconds* is non-negative, will return -1 and set *errno* to ETIMEDOUT when the indicated number of microseconds has passed, if and only if the indicated condition has not been met by that time. Negative values of the microseconds argument other than LLCV_BLOCKING (defined as -1) are illegal. Returns -1 on any error.

void llcv_signal(Llcv llcv, LlcvPredicate cond)
: Locks the indicated LLCV's Lyst; tests (evaluates) the indicated condition with regard to that LLCV; if the condition is true, signals to the waiting reader on this LLCV (if any) that the Lyst encapsulated in the indicated LLCV now meets the indicated condition; and unlocks the Lyst.

void llcv_signal_while_locked(Llcv llcv, LlcvPredicate cond)
: Same as `llcv_signal()` except does not lock the Llcv's mutex before signaling or unlock afterwards. For use when the Llcv is already locked; prevents deadlock.

void llcv_close(Llcv llcv)
: Destroys the indicated LLCV's mutex and condition variable. Fails silently (and has no effect) if a reader is currently waiting on the Llcv.

int llcv_lyst_is_empty(Llcv Llcv)
: A built-in "convenience" predicate, for use when calling llcv_wait(), llcv_signal(), or llcv_signal_while_locked(). Returns true if the length of the indicated LLCV's encapsulated Lyst is zero, false otherwise.

int llcv_lyst_not_empty(Llcv Llcv)
: A built-in "convenience" predicate, for use when calling llcv_wait(), llcv_signal(), or llcv_signal_while_locked(). Returns true if the length of the LLCV's encapsulated Lyst is non-zero, false otherwise.

SEE ALSO

lyst(3)

NAME

ltp - Licklider Transmission Protocol (LTP) communications library

SYNOPSIS

```
#include "ltp.h"

typedef enum
{
    LtpNoNotice = 0,
    LtpExportSessionStart,
    LtpXmitComplete,
    LtpExportSessionCanceled,
    LtpExportSessionComplete,
    LtpRecvGreenSegment,
    LtpRecvRedPart,
    LtpImportSessionCanceled
} LtpNoticeType;
```

[see description for available functions]

DESCRIPTION

The ltp library provides functions enabling application software to use LTP to send and receive information reliably over a long-latency link. It conforms to the LTP specification as documented by the Delay-Tolerant Networking Research Group of the Internet Research Task Force.

The LTP notion of **engine ID** corresponds closely to the Internet notion of a host, and in ION engine IDs are normally indistinguishable from node numbers (and from the "element numbers" in Bundle Protocol endpoint IDs conforming to the "ipn" scheme).

The LTP notion of **client ID** corresponds closely to the Internet notion of "protocol number" as used in the Internet Protocol. It enables data from multiple applications – clients – to be multiplexed over a single reliable link. However, for ION operations we normally use LTP exclusively for the transmission of Bundle Protocol data, identified by client ID = 1.

int ltp_init()

Attaches the application to LTP functionality on the local computer. Returns 0 on success, -1 on any error.

int ltp_send(unsigned long destinationEngineId, unsigned long clientId, Object clientServiceData, unsigned int redLength, LtpSessionId *sessionId)

Sends a client service data unit to the application that is waiting for data tagged with the indicated *clientId* as received at the remote LTP engine identified by *destinationEngineId*.

clientServiceData must be a "zero-copy object" reference as returned by zco_create(). Note that LTP will privately make and destroy its own reference to the client service data object; the application is free to destroy its reference at any time.

redLength indicates the number of leading bytes of data in *clientServiceData* that are to be sent reliably, i.e., with selective retransmission in response to explicit or implicit negative acknowledgment as necessary. All remaining bytes of data in *clientServiceData* will be sent as "green" data, i.e., unreliably. If *redLength* is zero, the entire client service data unit will be sent unreliably. If the entire client service data unit is to be sent reliably, *redLength* may be simply be set to LTP_ALL_RED (i.e., -1).

On success, the function populates **sessionId* with the source engine ID and the "session number" assigned to transmission of this client service data unit and returns zero. The session number may be used to link future LTP processing events, such as transmission cancellation, to the affected client service data. `ltp_send()` returns -1 on any error.

int ltp_open(unsigned long clientId)

Establishes the application's exclusive access to received service data units tagged with the indicated client service data ID. At any time, only a single application task is permitted to receive service data units for any single client service data ID.

Returns 0 on success, -1 on any error (e.g., the indicated client service is already being held open by some other application task).

int ltp_get_notice(unsigned long clientId, LtpNoticeType *type, LtpSessionId *sessionId, unsigned char *reasonCode, unsigned char *endOfBlock, unsigned long *dataOffset, unsigned long *dataLength, char **data)

Receives notices of LTP processing events pertaining to the flow of service data units tagged with the indicated client service ID. The nature of each event is indicated by **type*. Additional parameters characterizing the event are returned in **sessionId*, **reasonCode*, **endOfBlock*, **dataOffset*, **dataLength*, and ***data* as relevant.

Note that what is returned in ***data* when the notice is an LtpRecvRedPart is the red part of an aggregated block of client service data units. The block may contain one or more service data objects. Extraction of individual service data objects from the aggregated block is the responsibility of the application. A simple way to do this is to prepend the length of the service data object to the object itself (using `zco_prepend_header()`) before calling ltp_send(), so that the receiving application can alternate extraction of object lengths and objects from the delivered block's red part.

`ltp_get_notice()` always blocks indefinitely until an LTP processing event is delivered.

Returns zero on success, -1 on any error.

void ltp_interrupt(unsigned long clientId)

Interrupts an `ltp_get_notice()` invocation. This function is designed to be called from a signal handler; for this purpose, *clientId* may need to be obtained from a static variable.

void ltp_release_data(char *data)

Releases resources temporarily allocated from ION working memory to hold client service data in the case of an LtpRecvRedPart or LtpRecvGreenSegment event.

void ltp_close(unsigned long clientId)

Terminates the application's exclusive access to received service data units tagged with the indicated client service data ID.

SEE ALSO

ltpadmin(1), ltprc(5)

NAME

ltpadmin - ION Licklider Transmission Protocol (LTP) administration interface

SYNOPSIS

ltpadmin [*commands_filename* | .]

DESCRIPTION

ltpadmin configures, starts, manages, and stops LTP operations for the local ION node.

It operates in response to LTP configuration commands found in the file *commands_filename*, if provided; if not, **ltpadmin** prints a simple prompt (:) so that the user may type commands directly into standard input. If *commands_filename* is a period (.), the effect is the same as if a command file containing the single command 'x' were passed to **ltpadmin** – that is, the ION node's **ltpclock** task, **ltpmeter** tasks, and link service adapter tasks are stopped.

The format of commands for *commands_filename* can be queried from **ltpadmin** with the 'h' or '?' commands at the prompt. The commands are documented in ltprc(5).

EXIT STATUS

0 Successful completion of LTP administration.

EXAMPLES

ltpadmin

Enter interactive LTP configuration command entry mode.

ltpadmin host1.ltp

Execute all configuration commands in *host1.ltp*, then terminate immediately.

ltpadmin .

Stop all LTP operations on the local node.

FILES

See `ltprc(5)` for details of the LTP configuration commands.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Note: all ION administration utilities expect source file input to be lines of ASCII text that are NL-delimited. If you edit the ltprc file on a Windows machine, be sure to **use dos2unix to convert it to Unix text format** before presenting it to **ltpadmin**. Otherwise **ltpadmin** will detect syntax errors and will not function satisfactorily.

The following diagnostics may be issued to the logfile ion.log:

ltpadmin can't attach to ION.

> There is no SDR data store for *ltpadmin* to use. You should run `ionadmin(1)` first, to set up an SDR data store for ION.

Can't open command file...

> The *commands_filename* specified in the command line doesn't exist.

Various errors that don't cause **ltpadmin** to fail but are noted in the **ion.log** log file may be caused by improperly formatted commands given at the prompt or in the *commands_filename* file. Please see `ltprc(5)` for details.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ltpmeter(1), ltprc(5)

NAME

ltpcli - LTP-based BP convergence layer input task

SYNOPSIS

ltpcli *local_node_nbr*

DESCRIPTION

ltpcli is a background "daemon" task that receives LTP data transmission blocks, extracts bundles from the received blocks, and passes them to the bundle protocol agent on the local ION node.

ltpcli is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol; the text of the command that is used to spawn the task must be provided at the time the "ltp" convergence layer protocol is added to the BP database. The convergence layer input task is terminated by **bpadmin** in response to an 'x' (STOP) command. **ltpcli** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the LTP convergence layer protocol.

EXIT STATUS

0 **ltpcli** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **ltpcli**.

1 **ltpcli** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart **ltpcli**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

ltpcli can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

No such ltp duct.

> No LTP induct matching *local_node_nbr* has been added to the BP database. Use **bpadmin** to stop the LTP convergence-layer protocol, add the induct, and then restart the LTP protocol.

CLI task is already started for this duct.

> Redundant initiation of **ltpcli**.

ltpcli can't initialize LTP.

> **ltpadmin** has not yet initialized LTP operations.

ltpcli can't open client access.

> Another task has already opened the client service for BP over LTP.

ltpcli can't create receiver thread

> Operating system error. Check errtext, correct problem, and restart LTP.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), ltpadmin(1), ltprc(5), ltpclo(1)

NAME

ltpclo - LTP-based BP convergence layer adapter output task

SYNOPSIS

ltpclo *remote_node_nbr*

DESCRIPTION

ltpclo is a background "daemon" task that extracts bundles from the queues of segments ready for transmission via LTP to the remote bundle protocol agent identified by *remote_node_nbr* and passes them to the local LTP engine for aggregation, segmentation, and transmission to the remote node.

Note that **ltpclo** is not a "promiscuous" convergence layer daemon: it can transmit bundles only to the node for which it is configured, so scheme configuration directives that cite this outduct need only provide the protocol name and the outduct name (the remote node number) as specified on the command line when **ltpclo** is started.

ltpclo is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **ltpclo** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the LTP convergence layer protocol.

EXIT STATUS

0 **ltpclo** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart the BRSC protocol.

1 **ltpclo** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart the BRSC protocol.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

ltpclo can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

No such ltp duct.

> No LTP outduct with duct name matching *remote_node_nbr* has been added to the BP database. Use **bpadmin** to stop the LTP convergence-layer protocol, add the outduct, and then restart the LTP protocol.

CLO task is already started for this duct.

> Redundant initiation of **ltpclo**.

ltpclo can't initialize LTP.

> **ltpadmin** has not yet initialized LTP operations.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), ltpadmin(1), ltprc(5), ltpcli(1)

NAME

ltpclock - LTP daemon task for managing scheduled events

SYNOPSIS

ltpclock

DESCRIPTION

ltpclock is a background "daemon" task that periodically performs scheduled LTP activities. It is spawned automatically by **ltpadmin** in response to the 's' command that starts operation of the LTP protocol, and it is terminated by **ltpadmin** in response to an 'x' (STOP) command.

Once per second, **ltpclock** takes the following action:

> First it retransmits all unacknowledged checkpoint segments, report segments, and cancellation segments whose computed timeout intervals have expired.
>
> Then **ltpclock** infers link state changes ("link cues") from data rate changes as noted in the RFX database by **rfxclock**:
>
> > If the rate of transmission to a neighbor was zero but is now non-zero, then transmission to that neighbor is unblocked. The applicable "buffer empty" semaphore is given if no outbound block is being constructed (enabling start of a new transmission session) and the "segments ready" semaphore is given if the outbound segment queue is non-empty (enabling transmission of segments by the link service output task).
> >
> > If the rate of transmission to a neighbor was non-zero but is now zero, then transmission to that neighbor is blocked – i.e., the semaphores triggering transmission will no longer be given.
> >
> > If the imputed rate of transmission from a neighbor was non-zero but is now zero, then all timers affecting segment retransmission to that neighbor are suspended. This has the effect of extending the interval of each affected timer by the length of time that the timers remain suspended.
> >
> > If the imputed rate of transmission from a neighbor was zero but is now non-zero, then all timers affecting segment retransmission to that neighbor are resumed.

EXIT STATUS

0 **ltpclock** terminated, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **ltpadmin** to restart **ltpclock**.

1 **ltpclock** was unable to attach to LTP protocol operations, probably because **ltpadmin** has not yet been run.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

ltpclock can't initialize LTP.

ltpadmin has not yet initialized LTP protocol operations.

Can't dispatch events.

An unrecoverable database error was encountered. **ltpclock** terminates.

Can't manage links.

An unrecoverable database error was encountered. **ltpclock** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ltpadmin(1), rfxclock(1)

NAME

ltpcounter - LTP reception test program

SYNOPSIS

ltpcounter [*max_nbr_of_bytes*]

DESCRIPTION

ltpcounter uses LTP to receive service data units flagged with client service number 1 from a remote **ltpdriver** client service process. When the total number of bytes of client service data it has received exceeds *max_nbr_of_bytes*, it terminates and prints reception and cancellation statistics. If *max_nbr_of_bytes* is omitted, the default limit is 2 billion bytes.

While receiving data, **ltpcounter** prints a 'v' character every 5 seconds to indicate that it is still alive.

EXIT STATUS

0 **ltpcounter** has terminated. Any problems encountered during operation will be noted in the **ion.log** log file.

1 **ltpcounter** was unable to start, because it could not attach to the LTP protocol on the local node or could not open access to client service 1. In the former case, run **ltpadmin** to start LTP and try again. In the latter case, some other client service task has already opened access to client service 1. If no such task is currently running (e.g., it crashed while holding the client service open), use **ltpadmin** to stop and restart the LTP protocol.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **ltpcounter** are written to the ION log file *ion.log*.

ltpcounter can't initialize LTP.

> **ltpadmin** has not yet initialized LTP protocol operations.

ltpcounter can't open client access.

> Another task has opened access to service client 1 and has not yet relinquished it.

Can't get LTP notice.

> LTP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ltpadmin(1), ltpdriver(1), ltp(3)

NAME

ltpdriver - LTP transmission test program

SYNOPSIS

ltpdriver *nbrOfCycles remote_engine_nbr* [*length*]

DESCRIPTION

ltpdriver uses LTP to send *nbrOfCycles* service data units of length indicated by *length*, flagged with client service number 1, to the **ltpcounter** client service process attached to the remote LTP engine identified by *remote_engine_nbr*. If omitted, *length* defaults to 60000. If *length* is 1, the sizes of the transmitted service data units will be randomly selected multiples of 1024 in the range 1024 to 62464.

When all copies of the file have been sent, **ltpdriver** prints a performance report.

EXIT STATUS

0 **ltpdriver** has terminated. Any problems encountered during operation will be noted in the **ion.log** log file.

1 **ltpdriver** was unable to start, because it could not attach to the LTP protocol on the local node. Run **ltpadmin** to start LTP, then try again.

FILES

The service data units transmitted by **ltpdriver** are sequences of text obtained from a file in the current working directory named "ltpdriverAduFile", which **ltpdriver** creates automatically.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Diagnostic messages produced by **ltpdriver** are written to the ION log file *ion.log*.

ltpdriver can't initialize LTP.

> **ltpadmin** has not yet initialized LTP protocol operations.

Can't create ADU file

> Operating system error. Check errtext, correct problem, and rerun.

Error writing to ADU file

> Operating system error. Check errtext, correct problem, and rerun.

ltpdriver can't create file ref.

> ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

ltpdriver can't create ZCO.

> ION system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

ltpdriver can't send message.

> LTP span to the remote engine has been stopped.

ltp_send failed.

> LTP system error. Check for earlier diagnostic messages describing the cause of the error; correct problem and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ltpadmin(1), ltpcounter(1), ltp(3)

NAME

ltpmeter - LTP daemon task for aggregating and segmenting transmission blocks

SYNOPSIS

ltpmeter *remote_engine_nbr*

DESCRIPTION

ltpmeter is a background "daemon" task that manages the presentation of LTP segments to link service output tasks. Each "span" of LTP data interchange between the local LTP engine and a neighboring LTP engine requires its own **ltpmeter** task. All **ltpmeter** tasks are spawned automatically by **ltpadmin** in response to the 's' command that starts operation of the LTP protocol, and they are all terminated by **ltpadmin** in response to an 'x' (STOP) command.

ltpmeter waits until its span's current transmission block (the data to be transmitted during the transmission session that is currently being constructed) is ready for transmission, then divides the data in the span's block buffer into segments and enqueues the segments for transmission by the span's link service output task (giving the segments semaphore to unblock the link service output task as necessary), then reinitializes the span's block buffer and starts another session (giving the "buffer empty" semaphore to unblock the client service task -- nominally **ltpclo**, the LTP convergence layer output task for Bundle Protocol -- as necessary).

ltpmeter determines that the current transmission block is ready for transmission by waiting for two conditions to be concurrently true:

- **Link service is not backlogged.**

  There must be at most two previously segmented blocks that have not yet been transmitted by the span's link service output task. By waiting for this condition to be true, **ltpmeter** delays block transmission long enough to enable the aggregation of multiple client service data units in the block buffer. The condition is signaled by the span's EOB semaphore, given by the link service output task.

- **Block buffer is not empty.**

  The block buffer must contain data. The condition is signaled by the span's "buffer not empty" semaphore, given by the client service task.

The initiation of a new session may also be blocked: the total number of transmission sessions that the local LTP engine may have open at a single time is limited (this is LTP flow control), and while the engine is at this limit no new sessions can be started.

Availability of a session from the session pool is signaled by the session semaphore, which is given whenever a session is completed or canceled.

EXIT STATUS

0 **ltpmeter** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **ltpadmin** to restart **ltpmeter**.

1 **ltpmeter** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **ltpadmin** to restart **ltpmeter**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

ltpmeter can't initialize LTP.

ltpadmin has not yet initialized LTP protocol operations.

No such engine in database.

remote_engine_nbr is invalid, or the applicable span has not yet been added to the LTP database by **ltpadmin**.

ltpmeter task is already started for this engine.

Redundant initiation of **ltpmeter**.

ltpmeter can't start new session.

An unrecoverable database error was encountered. **ltpmeter** terminates.

Can't take eobSemaphore.

An unrecoverable database error was encountered. **ltpmeter** terminates.

Can't take bufNonEmptySemaphore.

An unrecoverable database error was encountered. **ltpmeter** terminates.

Can't create extents list.

An unrecoverable database error was encountered. **ltpmeter** terminates.

Can't post ExportSessionStart notice.

An unrecoverable database error was encountered. **ltpmeter** terminates.

Can't finish session.

An unrecoverable database error was encountered. **ltpmeter** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ltpadmin(1), rfxclock(1)

NAME

ltprc - Licklider Transmission Protocol management commands file

DESCRIPTION

LTP management commands are passed to **ltpadmin** either in a file of text lines or interactively at **ltpadmin**'s command prompt (:). Commands are interpreted line-by line, with exactly one command per line. The formats and effects of the LTP management commands are described below.

COMMANDS

?

The **help** command. This will display a listing of the commands and their formats. It is the same as the **h** command.

#

Comment line. Lines beginning with **#** are not interpreted.

e { 0 | 1 }

Echo control. Setting echo to 1 causes all output printed by ltpadmin to be logged as well as sent to stdout. Setting echo to 0 disables this behavior.

1 *max_nbr_of_sessions block_size_limit*

The **initialize** command. Until this command is executed, LTP is not in operation on the local ION node and most *ltpadmin* commands will fail.

The command establishes the size of the local LTP engine's retransmission "window", the product of *max_nbr_of_sessions* and *block_size_limit*. The LTP window imposes flow control on LTP transmission, preventing the allocation of all available space in the ION node's data store to LTP transmission sessions.

A typical value for *max_nbr_of_sessions*, assuming that each session is sized to be about one second's worth of transmission, would the sum of the maximum anticipated round-trip times (in seconds) on all "spans" on which this LTP engine will operate, plus 20% margin for sessions that persist longer than a single RTT because they require retransmission.

a span *peer_engine_nbr max_segment_size nominal_block_size* '*LSO_command*' [*queuing latency*]

The **add span** command. This command declares that a *span* of potential LTP data interchange exists between the local LTP engine and the indicated (neighboring) LTP engine.

max_segment_size and *nominal_block_size* are both expressed as numbers of bytes of data. *max_segment_size* limits the size of each of the segments into which each outbound data *block* will be divided; typically this limit will be the maximum number of bytes that can be encapsulated within a single transmission frame of the underlying *link service*.

nominal_block_size limits the number of LTP service data units (e.g., bundles) that can be aggregated into a single block: when the sum of the sizes of all service data units aggregated into a block exceeds this limit, aggregation into this block must cease and the block must be segmented and transmitted. A typical value for *nominal_block_size* would be the number of bytes that would be transmitted in one second at the maximum data rate (in either direction) anticipated on this span, or the *block_size_limit* established at LTP engine initialization, whichever is less.

LSO_command is script text that will be executed when LTP is started on this node, to initiate operation of a link service output task for this span. Note that " *peer_engine_nbr*" will automatically be appended to *LSO_command* by **ltpadmin** before the command is executed, so only the link-service-specific portion of the command should be provided in the *LSO_command* string itself.

queuing_latency is the estimated number of seconds that we expect to lapse between reception of a segment at this node and transmission of an acknowledging segment, due to processing delay in the node. (See the **m ownqtime** command below.) The default value is 1.

c span ***peer_engine_nbr max_segment_size nominal_block_size*** **'*LSO_command*'**
The **change span** command. This command sets the indicated span's *max_segment_size, nominal_block_size* and *LSO_command* to the values provided as arguments.

d span ***peer_engine_nbr***
The **delete span** command. This command deletes the span identified by *peer_engine_nbr*. The command will fail if any outbound segments for this span are pending transmission or any inbound blocks from the peer engine are incomplete.

i span ***peer_engine_nbr***
This command will print information (max segment size, nominal block size, and LSO command) about the span identified by *peer_engine_nbr*.

l span
This command lists all declared LTP data interchange spans.

s '*LSI command*'
The **start** command. This command starts link service output tasks for all LTP spans (to remote engines) from the local LTP engine, and it starts the link service input task for the local engine.

m screening { y | n }
The **manage screening** command. This command enables or disables the screening of received LTP segments per the periods of scheduled reception in the node's contact graph. By default, screening is enabled – that is, LTP segments from a given remote LTP engine (ION node) are silently discarded whenever they

arrive during an interval when the contact graph says the data rate from that engine to the local LTP engine is zero. Note that when screening is enabled the ranges declared in the contact graph must be accurate; otherwise, segments will be arriving at times other than the scheduled contact intervals and will be discarded.

m ownqtime *own_queuing_latency*

The **manage own queuing latency** command. This command sets the number of seconds of predicted additional latency attributable to processing delay within the local engine itself that should be included whenever LTP computes the nominal round-trip time for an exchange of data with any remote engine. The default value is 1.

x

The **stop** command. This command stops all link service input and output tasks for the local LTP engine.

w { 0 | 1 | ***activity_spec*** **}**

The **LTP watch** command. This command enables and disables production of a continuous stream of user-selected LTP activity indication characters. A watch parameter of "1" selects all LTP activity indication characters; "0" de-selects all LTP activity indication characters; any other activity_spec such as "df{]" selects all activity indication characters in the string, de-selecting all others. LTP will print each selected activity indication character to stdout every time a processing event of the associated type occurs:

d bundle appended to block for next session

e segment of block is queued for transmission

f block has been fully segmented for transmission

g segment popped from transmission queue

h positive ACK received for block, session ended

s segment received

t block has been fully received

@ negative ACK received for block, segments retransmitted

= unacknowledged checkpoint was retransmitted

+ unacknowledged report segment was retransmitted

{ export session canceled locally (by sender)

} import session canceled by remote sender

[import session canceled locally (by receiver)

] export session canceled by remote receiver

h

The **help** command. This will display a listing of the commands and their formats. It is the same as the **?** command.

EXAMPLES

a span 19 1024 32768 'udplso node19.ohio.edu:5001'

Declares a data interchange span between the local LTP engine and the remote engine (ION node) numbered 19. Maximum segment size for this span is set to 1024 bytes, nominal block size is 32768 bytes, and the link service output task that is initiated when LTP is started on the local ION node will execute the *udplso* program as indicated.

m screening n

Disables strict enforcement of the contact schedule.

SEE ALSO

ltpadmin(1), udplsi(1), udplso(1)

NAME

lyst - library for manipulating generalized doubly linked lists

SYNOPSIS

```
#include "lyst.h"

typedef int  (*LystCompareFn)(void *s1, void *s2);

typedef void (*LystCallback)(LystElt elt, void *userdata);
```

[see description for available functions]

DESCRIPTION

The "lyst" library uses two types of objects, *Lyst* objects and *LystElt* objects. A Lyst knows how many elements it contains, its first and last elements, the memory manager used to create/destroy the Lyst and its elements, and how the elements are sorted. A LystElt knows its content (normally a pointer to an item in memory), what Lyst it belongs to, and the LystElts before and after it in that Lyst.

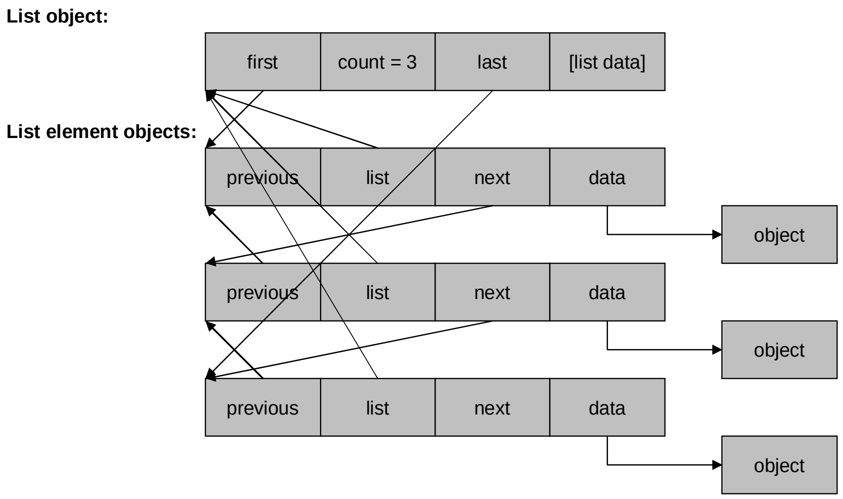


Figure 15 Lyst data objects structure

Lyst lyst_create(void)

Create and return a new Lyst object without any elements in it. All operations performed on this Lyst will use the allocation/deallocation functions of the default memory manager "std" (see memmgr(3)). Returns NULL on any failure.

Lyst lyst_create_using(unsigned memmgrId)

Create and return a new Lyst object without any elements in it. All operations performed on this Lyst will use the allocation/deallocation functions of the specified memory manager (see memmgr(3)). Returns NULL on any failure.

void lyst_clear(Lyst list)

Clear a Lyst, i.e. free all elements of *list*, calling the Lyst's deletion function if defined, but without destroying the Lyst itself.

void lyst_destroy(Lyst list)

Destroy a Lyst. Will free all elements of *list*, calling the Lyst's deletion function if defined.

void lyst_compare_set(Lyst list, LystCompareFn compareFn)
LystCompareFn lyst_compare_get(Lyst list)

Set/get comparison function for specified Lyst. Comparison functions are called with two Lyst element data pointers, and must return a negative integer if first is less than second, 0 if both are equal, and a positive integer if first is greater than second (i.e., same return values as strcmp(3)). The comparison function is used by the lyst_insert(), lyst_search(), lyst_sort(), and `lyst_sorted()` functions.

void lyst_direction_set(Lyst list, LystSortDirection direction)

Set sort direction (either LIST_SORT_ASCENDING or LIST_SORT_DESCENDING) for specified Lyst. If no comparison function is set, then this controls whether new elements are added to the end or beginning (respectively) of the Lyst when `lyst_insert()` is called.

void lyst_delete_set(Lyst list, LystCallback deleteFn, void *userdata)

Set user deletion function for specified Lyst. This function is automatically called whenever an element of the Lyst is deleted, to perform any user-required processing. When automatically called, the deletion function is passed two arguments: the element being deleted and the *userdata* pointer specified in the `lyst_delete_set()` call.

void lyst_insert_set(Lyst list, LystCallback insertFn, void *userdata)

Set user insertion function for specified Lyst. This function is automatically called whenever a Lyst element is inserted into the Lyst, to perform any user-required processing. When automatically called, the insertion function is passed two arguments: the element being inserted and the *userdata* pointer specified in the `lyst_insert_set()` call.

unsigned long lyst_length(Lyst list)

Return the number of elements in the Lyst.

LystElt lyst_insert(Lyst list, void *data)

Create a new element whose content is the pointer value *data* and insert it into the Lyst. Uses the Lyst's comparison function to select insertion point, if defined; otherwise adds the new element at the beginning or end of the Lyst, depending on the Lyst sort direction setting. Returns a pointer to the newly created element, or NULL on any failure.

LystElt lyst_insert_first(Lyst list, void *data)
LystElt lyst_insert_last(Lyst list, void *data)

Create a new element and insert it at the beginning/end of the Lyst. If these functions are used when inserting elements into a Lyst with a defined comparison function, then the Lyst may get out of order and future calls to `lyst_insert()` can put new elements in unpredictable locations. Returns a pointer to the newly created element, or NULL on any failure.

LystElt lyst_insert_before(LystElt element, void *data)

LystElt lyst_insert_after(LystElt element, void *data)

Create a new element and insert it before/after the specified element. If these functions are used when inserting elements into a Lyst with a defined comparison function, then the Lyst may get out of order and future calls to lyst_insert can put new elements in unpredictable locations. Returns a pointer to the newly created element, or NULL on any failure.

void lyst_delete(LystElt element)

Delete the specified element from its Lyst and deallocate its memory. Calls the user delete function if defined.

LystElt lyst_first(Lyst list) =item LystElt lyst_last(Lyst list)

Return a pointer to the first/last element of a Lyst.

LystElt lyst_next(LystElt element)
LystElt lyst_prev(LystElt element)

Return a pointer to the element following/preceding the specified element.

LystElt lyst_search(LystElt element, void *searchValue)

Find the first matching element in a Lyst starting with the specified element. Returns NULL if no matches are found. Uses the Lyst's comparison function if defined, otherwise searches from the given element to the end of the Lyst.

Lyst lyst_lyst(LystElt element)

Return the Lyst to which the specified element belongs.

void* lyst_data(LystElt element)
void* lyst_data_set(LystElt element, void *data)

Get/set the pointer value content of the specified Lyst element. The set routine returns the element's previous content, and the delete function is *not* called. If the `lyst_data_set()` function is used on an element of a Lyst with a defined comparison function, then the Lyst may get out of order and future calls to `lyst_insert()` can put new elements in unpredictable locations.

void lyst_sort(Lyst list)

Sort the Lyst based on the current comparison function and sort direction. A stable insertion sort is used that is very fast when the elements are already in order.

int lyst_sorted(Lyst list)

Determine whether or not the Lyst is sorted based on the current comparison function and sort direction.

void lyst_apply(Lyst list, LystCallback applyFn, void *userdata)

Apply the function *applyFn* automatically to each element in the Lyst. When automatically called, *applyFn* is passed two arguments: a pointer to an element, and the *userdata* argument specified in the call to lyst_apply(). *applyFn* should not delete or reorder the elements in the Lyst.

SEE ALSO

memmgr(3), psm(3)

NAME

memmgr - memory manager abstraction functions

SYNOPSIS

```
    #include "memmgr.h"
    typedef void *(* MemAllocator)
        (char *fileName, int lineNbr, size_t size);
    typedef void (* MemDeallocator)
        (char *fileName, int lineNbr, void * blk);
    typedef void *(* MemAtoPConverter) (unsigned int address);
    typedef unsigned int (* MemPtoAConverter) (void * pointer);
    unsigned int memmgr_add       (char *name,
                                   MemAllocator take,
                                   MemDeallocator release,
                                   MemAtoPConverter AtoP,
                                   MemPtoAConverter PtoA);
    int memmgr_find               (char *name);
    char *memmgr_name             (int mgrId);
    MemAllocator memmgr_take      (int mgrId);
    MemDeallocator memmgr_release (int mgrId);
    MemAtoPConverter memmgr_AtoP  (int mgrId);
    MemPtoAConverter memmgr_PtoA  (int mgrId;
    int memory_open               (int memKey,
                                   unsigned long memSize,
                                   char **memPtr,
                                   int *smId,
                                   char *partitionName,
                                   PsmPartition *partition,
                                   int *memMgr,
                                   MemAllocator afn,
                                   MemDeallocator ffn,
                                   MemAtoPConverter apfn,
                                   MemPtoAConverter pafn);
    void memory_destroy           (int smId,
                                   PsmPartition *partition);
```

DESCRIPTION

"memmgr" is an abstraction layer for administration of memory management. It enables multiple memory managers to coexist in a single application. Each memory manager specification is required to include pointers to a memory allocation function, a memory deallocation function, and functions for translating between local memory pointers and "addresses", which are abstract memory locations that have private meaning to the manager. The allocation function is expected to return a block of memory of size "size" (in bytes), initialized to all binary zeroes. The *fileName* and *lineNbr* arguments to the allocation and deallocation functions are expected to be the values of __FILE__ and __LINE__ at the point at which the functions are called; this supports any memory usage tracing via `sptrace(3)` that may be implemented by the underlying memory management system.

Memory managers are identified by number and by name. The identifying number for a memory manager is an index into a private, fixed-length array of up to 8 memory manager configuration structures; that is, memory manager number must be in the range 0-7. However, memory manager numbers are assigned dynamically and not always predictably. To enable multiple applications to use the same memory manager for a given segment of shared memory, a memory manager may be located by a predefined name of up to 15 characters that is known to all the applications.

The memory manager with manager number 0 is always available; its name is "std". Its memory allocation function is calloc(), its deallocation function is free(), and its pointer/address translation functions are merely casts.

unsigned int memmgr_add(char *name, MemAllocator take, MemDeallocator release, MemAtoPConverter AtoP, MemPtoAConverter PtoA)

> Add a memory manager to the memory manager array, if not already defined; attempting to add a previously added memory manager is not considered an error. *name* is the name of the memory manager. *take* is a pointer to the manager's memory allocation function; *release* is a pointer to the manager's memory deallocation function. *AtoP* is a pointer to the manager's function for converting an address to a local memory pointer; *PtoA* is a pointer to the manager's pointer-to-address converter function. Returns the memory manager ID number assigned to the named manager, or -1 on any error.
>
> *NOTE*: `memmgr_add()` is NOT thread-safe. In a multithreaded execution image (e.g., VxWorks), all memory managers should be loaded *before* any subordinate threads or tasks are spawned.

int memmgr_find(char *name)

> Return the memmgr ID of the named manager, or -1 if not found.

char *memmgr_name(int mgrId)

> Return the name of the manager given by *mgrId*.

MemAllocator memmgr_take(int mgrId)

> Return the allocator function pointer for the manager given by *mgrId*.

memDeallocator memmgr_release(int mgrId)

> Return the deallocator function pointer for the manager given by *mgrId*.

MemAtoPConverter memmgr_AtoP(int mgrId)

> Return the address-to-pointer converter function pointer for the manager given by *mgrId*.

MemPtoAConverter memmgr_PtoA(int mgrId)

> Return the pointer-to-address converter function pointer for the manager given by *mgrId*.

int memory_open(int memKey, unsigned long memSize, char **memPtr, int *smId, char *partitionName, PsmPartition *partition, int *memMgr, MemAllocator afn, MemDeallocator ffn, MemAtoPConverter apfn, MemPtoAConverter pafn);

> `memory_open()` opens one avenue of access to a PSM managed region of shared memory, initializing as necessary.

In order for multiple tasks to share access to this memory region, all must cite the same *memkey* and *partitionName* when they call memory_open(). If shared access is not necessary, then *memKey* can be SM_NO_KEY and *partitionName* can be any valid partition name.

If it is known that a prior invocation of `memory_open()` has already initialized the region, then *memSize* can be zero and *memPtr* must be NULL. Otherwise *memSize* is required and the required value of *memPtr* depends on whether or not the memory that is to be shared and managed has already been allocated (e.g., it's a fixed region of bus memory). If so, then the memory pointer variable that *memPtr* points to must contain the address of that memory region. Otherwise, **memPtr* must contain NULL.

`memory_open()` will allocate system memory as necessary and will in any case return the address of the shared memory region in **memPtr*.

If the shared memory is newly allocated or otherwise not yet under PSM management, then `memory_open()` will invoke `psm_manage()` to manage the shared memory region. It will also add a catalogue for the managed shared memory region as necessary.

If *memMgr* is non-NULL, then `memory_open()` will additionally call `memmgr_add()` to establish a new memory manager for this managed shared memory region, as necessary. The index of the applicable memory manager will be returned in *memMgr*. If that memory manager is newly created, then the supplied *afn*, *ffn*, *apfn*, and *pafn* functions (which can be written with reference to the memory manager index value returned in *memMgr*) have been established as the memory management functions for local private access to this managed shared memory region.

Returns 0 on success, -1 on any error.

void memory_destroy(int smId, PsmPartition *partition);

`memory_open()` terminates all access to a PSM managed region of shared memory, invoking `psm_erase()` to destroy the partition and `sm_ShmDestroy()` to destroy the shared memory object.

EXAMPLE

```
/* this example uses the calloc/free memory manager, which is
 * called "std", and is always defined in memmgr. */
 #include "memmgr.h"
 main()
 {
     int mgrId;
     MemAllocator myalloc;
     MemDeallocator myfree;
     char *newBlock;
     mgrId = memmgr_find("std");
```

```
        myalloc = memmgr_take(mgrId);
        myfree = memmgr_release(mgrId);
        ...
        newBlock = myalloc(5000);
        ...
        myfree(newBlock);
    }
```

SEE ALSO

psm(3)

NAME

owltsim - one-way light time transmission delay simulator

SYNOPSIS

owltsim *config_filename* [-v]

DESCRIPTION

owltsim delays delivery of data between pairs of ION nodes by specified lengths of time, simulating the signal propagation delay imposed by distance between the nodes.

Its operation is configured by delay simulation configuration lines in the file identified by *config_filename*. A pair of threads is created for each line in the file: one that receives UDP datagrams on a specified port and queues them in a linked list, and a second that later removes queued datagrams from the linked list and sends them on to a specified UDP port on a specified network host.

Each configuration line must be of the following form:

> *to from my_port# dest_host dest_port# owlt modulus*

***to* identifies the receiving node.**
> This parameter is purely informational, intended to enable **owltsim**'s printed messages more helpful to the user.

***from* identifies the sending node.**
> A value of '*' may be used to indicate ``all nodes''. Again, this parameter is purely informational, intended to enable **owltsim**'s printed messages more helpful to the user.

***my_port#* identifies owltsim's receiving port for this traffic.**

***dest_host* is a hostname identifying the computer to which owltsim will transmit this traffic.**

***dest_port#* identifies the port to which owltsim will transmit this traffic.**

***owlt* specifies the number of seconds to wait before forwarding each received datagram.**

***modulus* controls the artificial random data loss imposed on this traffic by owltsim.**
> A value of '0' specifies ``no random data loss''. Any other modulus value N causes **owltsim** to randomly drop (i.e., not transmit upon expiration of the delay interval) one out of every N packets.

The optional **-v** (``verbose'') parameter causes **owltsim** to print a message whenever it receives, sends, or drops (due to artificial random data loss) a datagram.

Note that error conditions may cause one delay simulation (a pair of threads) to terminate without terminating any others.

owltsim is designed to run indefinitely. To terminate the program, just use control-C to kill it.

EXIT STATUS

1. **Nominal termination.**
2. **Termination due to an error condition, as noted in printed messages.**

EXAMPLES

Here is a sample owltsim configuration file:

1. **7 5502 ptl02.jpl.nasa.gov 5001 75 0**
2. **2 5507 ptl07.jpl.nasa.gov 5001 75 16**

This file indicates that **owltsim** will receive on port 5502 the ION traffic from node 2 that is destined for node 7, which will receive it at port 5001 on the computer named ptl02.jpl.nasa.gov; 75 seconds of delay (simulating a distance of 75 light seconds) will be imposed on this transmission activity, and **owltsim** will not simulate any random data loss.

In the reverse direction, **owltsim** will receive on port 5507 the ION traffic from node 7 that is destined for node 2, which will receive it at port 5001 on the computer named ptl07.jpl.nasa.gov; 75 seconds of delay will again be imposed on this transmission activity, and **owltsim** will randomly discard (i.e., not transmit upon expiration of the transmission delay interval) one datagram out of every 16 received at this port.

FILES

Not applicable.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be printed to stdout:

owltsim can't open configuration file

The program terminates.

owltsim failed on fscanf

Failure on reading the configuration file. The program terminates.

owltsim stopped malformed config file line *line_number*.

Failure on parsing the configuration file. The program terminates.

owltsim can't spawn receiver thread

The program terminates.

owltsim out of memory.

The program terminates.

owltsim can't open reception socket

The program terminates.

owltsim can't initialize reception socket

The program terminates.

owltsim can't open transmission socket

The program terminates.

owltsim can't initialize transmission socket

The program terminates.

owltsim can't spawn timer thread

The program terminates.

owltsim can't acquire datagram

Datagram transmission failed. This causes the threads for the affected delay simulation to terminate, without terminating any other threads.

owltsim failed on send

Datagram transmission failed. This causes the threads for the affected delay simulation to terminate, without terminating any other threads.

at *time* owltsim LOST a dg of length *length* from *sending node* destined for *receiving node* due to ECONNREFUSED.

This is an informational message. Due to an apparent bug in Internet protocol implementation, transmission of a datagram on a connected UDP socket occasionally fails. **owltsim** does not attempt to retransmit the affected datagram.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

udplsi(1), `udplso(1)`

NAME

owlttb - one-way light time transmission delay simulator

SYNOPSIS

owlttb *own_uplink_port# own_downlink_port# dest_uplink_IP_address dest_uplink_port# dest_downlink_IP_address dest_downlink_port# owlt_sec.* [-v]

DESCRIPTION

owlttb delays delivery of data between an NTTI and a NetAcquire box (or two, one for uplink and one for downlink) by a specified length of time, simulating the signal propagation delay imposed by distance between the nodes.

Its operation is configured by the command-line parameters, except that the delay interval itself may be changed while the program is running. **owlttb** offers a command prompt (:), and when a new value of one-way light time is entered at this prompt the new delay interval takes effect immediately.

***own_uplink_port#* identifies the port on owlttb accepts the NTTI's TCP connection for uplink traffic (i.e., data destined for the NetAcquire box).**

***own_downlink_port#* identifies the port on owlttb accepts the NTTI's TCP connection for downlink traffic (i.e., data issued by the NetAcquire box).**

***dest_uplink_IP_address* is the IP address (a dotted string) identifying the NetAcquire box to which owlttb will transmit uplink traffic.**

***dest_uplink_port#* identifies the TCP port to which owlttb will connect in order to transmit uplink traffic to NetAcquire.**

***dest_downlink_IP_address* is the IP address (a dotted string) identifying the NetAcquire box from which owlttb will receive downlink traffic.**

***dest_downlink_port#* identifies the TCP port to which owlttb will connect in order to receive downlink traffic from NetAcquire.**

***owlt* specifies the number of seconds to wait before forwarding each received segment of TCP traffic.**

The optional **-v** (``verbose'') parameter causes **owlttb** to print a message whenever it receives, sends, or discards (due to absence of a connected downlink client) a segment of TCP traffic.

owlttb is designed to run indefinitely. To terminate the program, just use control-C to kill it or enter ``q'' at the prompt.

EXIT STATUS

1. **Nominal termination.**
2. **Termination due to an error condition, as noted in printed messages.**

EXAMPLES

Here is a sample owlttb command:

owlttb 2901 2902 137.7.8.19 10001 137.7.8.19 10002 75

This command indicates that **owlttb** will accept an uplink traffic connection on port 2901, forwarding the received uplink traffic to port 10001 on the NetAcquire box at 137.7.8.19, and it will accept a downlink traffic connection on port 2902, delivering over that connection all downlink traffic that it receives from connecting to port 10002 on the NetAcquire box at 137.7.8.19. 75 seconds of delay (simulating a distance of 75 light seconds) will be imposed on this transmission activity.

FILES

Not applicable.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be printed to stdout:

owlttb can't spawn uplink thread

The program terminates.

owlttb can't spawn uplink sender thread

The program terminates.

owlttb can't spawn downlink thread

The program terminates.

owlttb can't spawn downlink receiver thread

The program terminates.

owlttb can't spawn downlink sender thread

The program terminates.

owlttb fgets failed

The program terminates.

owlttb out of memory.

The program terminates.

owlttb lost uplink client.

This is an informational message. The NTTI may reconnect at any time.

owlttb lost downlink client

This is an informational message. The NTTI may reconnect at any time.

owlttb can't open TCP socket to NetAcquire

The program terminates.

owlttb can't connect TCP socket to NetAcquire

The program terminates.

owlttb `write()` error on socket

The program terminates if it was writing to NetAcquire; otherwise it simply recognizes that the client NTTI has disconnected.

owlttb `read()` error on socket

The program terminates.

owlttb can't open uplink dialup socket

The program terminates.

owlttb can't initialize uplink dialup socket

The program terminates.

owlttb can't open downlink dialup socket

The program terminates.

owlttb can't initialize downlink dialup socket

The program terminates.

owlttb `accept()` failed

The program terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

NAME

platform - C software portability definitions and functions

SYNOPSIS

```
    #include "platform.h"
```

[see description for available functions]

DESCRIPTION

platform is a library of functions that simplify the porting of software written in C. It provides an API that enables application code to access the resources of an abstract POSIX-compliant "least common denominator" operating system -- typically a large subset of the resources of the actual underlying operating system.

Most of the functionality provided by the platform library is aimed at making communication code portable: common functions for shared memory, semaphores, and IP sockets are provided. The implementation of the abstract O/S API varies according to the actual operating system on which the application runs, but the API's behavior is always the same; applications that invoke the platform library functions rather than native O/S system calls may forego some O/S-specific capability, but they gain portability at little if any cost in performance.

The platform.h header file #includes many of the most frequently needed header files: sys/types.h, errno.h, string.h, stdio.h, sys/socket.h, signal.h, dirent.h, netinet/in.h, unistd.h, stdlib.h, sys/time.h, sys/resource.h, malloc.h, sys/param.h, netdb.h, sys/uni.h, and fcntl.h. Beyond this, *platform* attempts to enhance compatibility by providing standard macros, type definitions, external references, or function implementations that are missing from a few supported O/S's but supported by all others. Finally, entirely new, generic functions are provided to establish a common body of functionality that subsumes significantly different O/S-specific capabilities.

PLATFORM COMPATIBILITY PATCHES

The platform library "patches" the APIs of supported O/S's to guarantee that all of the following items may be utilized by application software:

- The strchr(), strrchr(), strcasecmp(), and strncasecmp() functions.
- The unlink(), getpid(), and gettimeofday() functions.
- The select() function.
- The FD_BITMAP macro (used by select()).
- The MAXHOSTNAMELEN macro.
- The NULL macro.
- The timer_t type definition.

PLATFORM GENERIC MACROS AND FUNCTIONS

The generic macros and functions in this section may be used in place of comparable O/S-specific functions, to enhance the portability of code. (The implementations of these macros and functions are no-ops in environments in which they are inapplicable, so they're always safe to call.)

FDTABLE_SIZE

The FDTABLE_SIZE macro returns the total number of file descriptors defined for the process (or VxWorks target).

ION_PATH_DELIMITER

The ION_PATH_DELIMITER macro returns the ASCII character – either '/' or '\' – that as used as a directory delimiter in path names for the file system used by the local platform.

void snooze(unsigned int seconds)

Suspends execution of the invoking task or process for the indicated number of seconds.

void microsnooze(unsigned int microseconds)

Suspends execution of the invoking task or process for the indicated number of microseconds.

void getCurrentTime(struct timeval *time)

Returns the current local time in a timeval structure (see gettimeofday(3C)).

void findToken(char **cursorPtr, char **token)

Locates the next non-whitespace lexical token in a character array, starting at **cursorPtr*. The function NULL-terminates that token within the array and places a pointer to the token in **token*. Also accommodates tokens enclosed within matching single quotes, which may contain embedded spaces and escaped single-quote characters. If no token is found, **token* contains NULL on return from this function.

void *acquireSystemMemory(size_t size)

Uses `memalign()` to allocate a block of system memory of length *size*, starting at an address that is guaranteed to be an integral multiple of the size of a pointer to void, and initializes the entire block to binary zeroes. Returns the starting address of the allocated block on success; returns NULL on any error.

int createFile(const char *name, int flags)

Creates a file of the indicated name, using the indicated file creation flags. This function provides common file creation functionality across VxWorks and Unix platforms, invoking `creat()` under VxWorks and `open()` elsewhere. For return values, see `creat(2)` and open(2).

unsigned int getInternetAddress(char *hostName)

Returns the host number of the indicated host machine.

char *getInternetHostName(unsigned int hostNbr, char *buffer)

Writes the host name of the indicated host machine into *buffer* and returns *buffer*, or returns NULL on any error. The size of *buffer* should be (MAXHOSTNAMELEN + 1).

int getNameOfHost(char *buffer, int bufferLength)

Writes the first (*bufferLength* - 1) characters of the host name of the local machine into *buffer*. Returns 0 on success, -1 on any error.

void parseSocketSpec(char *socketSpec, unsigned short *portNbr, unsigned int *hostNbr)

Parses *socketSpec*, extracting host number (IP address) and port number from the string. *socketSpec* is expected to be of the form "{ @ | hostname }[:<portnbr>]", where @ signifies "the host name of the local machine". If host number can be determined, writes it into **hostNbr*; otherwise writes 0 into **hostNbr*. If port number is supplied and is in the range 1024 to 65535, writes it into **portNbr*; otherwise writes 0 into **portNbr*.

char *getNameOfUser(char *buffer)

Writes the user name of the invoking task or process into *buffer* and returns *buffer*. The size of *buffer* must be at least *L_cuserid*, a constant defined in the stdio.h header file. Returns *buffer*.

int reUseAddress(int fd)

Makes the address that is bound to the socket identified by *fd* reusable, so that the socket can be closed and immediately reopened and re-bound to the same port number. Returns 0 on success, -1 on any error.

int makeIoNonBlocking(int fd)

Makes I/O on the socket identified by *fd* non-blocking; returns -1 on failure. An attempt to read on a non-blocking socket when no data are pending, or to write on it when its output buffer is full, will not block; it will instead return -1 and cause errno to be set to EWOULDBLOCK.

int watchSocket(int fd)

Turns on the "linger" and "keepalive" options for the socket identified by *fd*. See `socket(2)` for details. Returns 0 on success, -1 on any failure.

void closeOnExec(int fd)

Ensures that *fd* will NOT be open in any child process fork()ed from the invoking process. Has no effect on a VxWorks platform.

EXCEPTION REPORTING

The functions in this section offer platform-independent capabilities for reporting on processing exceptions.

The underlying mechanism for ICI's exception reporting is a pair of functions that record error messages in a privately managed pool of static memory. These functions -- `postErrmsg()` and `postSysErrmsg()` -- are designed to return very rapidly with no possibility of failing, themselves. Nonetheless are they not safe to call from an interrupt service routing (ISR). Although each merely copies its text to the next available location in the error message memory pool, that pool is protected by a mutex; multiple processes might be queued up to take that mutex, so the total time to execute the function is non-deterministic.

Built on top of `postErrmsg()` and `postSysErrmsg()` are the `putErrmsg()` and `putSysErrmsg()` functions, which may take longer to return. Each one simply calls the corresponding "post" function but then calls the `writeErrmsgMemos()` function, which calls `writeMemo()` to print (or otherwise deliver) each message currently posted to the pool and then destroys all of those posted messages, emptying the pool.

Recommended general policy on using the ICI exception reporting functions (which the functions in the ION distribution libraries are supposed to adhere to) is as follows:

> When returning a value that indicates successful operation of the function – even if the result might suggest an operational failure at a higher level (e.g., an object identified by a given string is not found, through no failure of the search function) – do NOT invoke putErrmsg().
>
> Use putErrmsg() and putSysErrmsg() only when functions are unable to proceed to normal completion. Use writeMemo() if you want to log a message.
>
> Whenever returning a value that indicates the failure of a function, such as NULL or -1:
>
> > If the failure is due to a condition that was detected locally by code within the function that has failed (i.e., it was not reported in the return value from any system call or function call), then set errno to an appropriate standard value such as EINVAL and use putSysErrmsg (or postSysErrmg if pressed for time) to describe the nature of the failure condition. The text of the error message should normally start with a capital letter and should NOT end with a period.
> >
> > If the failure is due to the failure of a system call or some other non-ION function, assume that errno has already been set by the function at the lowest layer of the call stack; simply use putSysErrmsg (or postSysErrmsg if in a hurry) to describe the nature of the activity that failed. The text of the error message should normally start with a capital letter and should NOT end with a period.
> >
> > If the failure is due to the reported failure of some ION function, use putErrmsg (or postErrmsg) to note the failure before returning. This will aid in tracing the failure through the function stack in which the failure was detected. DON'T set errno. The text of the error message should normally start with a capital letter and SHOULD end with a period.
>
> When a failure in a called function is reported to "driver" code in an application program, before continuing or exiting use writeErrmsgMemos() to empty the message pool and print a simple stack trace identifying the failure.

char *system_error_msg( )

> Returns a brief text message describing the current system error, as identified by the current value of errno.

void setLogger(Logger usersLoggerName)

Sets the user function to be used for writing messages to a user-defined "log" medium. The logger function's calling sequence must match the following prototype:

```
        void    usersLoggerName(char *msg);
```

The default Logger function simply writes the message to standard output.

void writeMemo(char *msg)

Writes one log message, using the currently defined message logging function.

void writeErrMemo(char *msg)

Writes a log message like writeMemo(), accompanied by text describing the current system error.

char *itoa(int value)

Returns a string representation of the signed integer in *value*, nominally for immediate use as an argument to putErrmsg(). [Note that the string is constructed in a static buffer; this function is not thread-safe.]

char *utoa(unsigned int value)

Returns a string representation of the unsigned integer in *value*, nominally for immediate use as an argument to putErrmsg(). [Note that the string is constructed in a static buffer; this function is not thread-safe.]

void postErrmsg(char *text, char *argument)

Constructs an error message noting the name of the source file containing the line at which this function was called, the line number, the *text* of the message, and -- if not NULL -- a single textual *argument* that can be used to give more specific information about the nature of the reported failure (such as the value of one of the arguments to the failed function). The error message is appended to the list of messages in a privately managed pool of static memory, ERRMSGS_BUFSIZE bytes in length.

If *text* is NULL or is a string of zero length or begins with a newline character (i.e., **text* == '\0' or '\n'), the function returns immediately and no error message is recorded.

The errmsgs pool is designed to be large enough to contain error messages from all levels of the calling stack at the time that an error is encountered. If the remaining unused space in the pool is less than the size of the new error message, however, the error message is silently omitted. In this case, provided at least two bytes of unused space remain in the pool, a message comprising a single newline character is appended to the list to indicate that a message was omitted due to excessive length.

void postSysErrmsg(char *text, char *arg)

Like `postErrmsg()` except that the error message constructed by the function additionally contains text describing the current system error. *text* is truncated as necessary to assure that the sum of its length and that of the description of the current system error does not exceed 1021 bytes.

int getErrmsg(char *buffer)

Copies the oldest error message in the message pool into *buffer* and removes that message from the pool, making room for new messages. Returns zero if the message pool cannot be locked for update or there are no more messages in the pool; otherwise returns the length of the message copied into *buffer*. Note that, for safety, the size of *buffer* should be ERRMSGS_BUFSIZE.

Note that a returned error message comprising only a single newline character always signifies an error message that was silently omitted because there wasn't enough space left on the message pool to contain it.

void writeErrmsgMemos( )

Calls `getErrmsg()` repeatedly until the message pool is empty, using `writeMemo()` to log all the messages in the pool. Messages that were omitted due to excessive length are indicated by logged lines of the form "[message omitted due to excessive length]".

void putErrmsg(char *text, char *argument)

The `putErrmsg()` function merely calls `postErrmsg()` and then writeErrmsgMemos().

void putSysErrmsg(char *text, char *arg)

The `putSysErrmsg()` function merely calls `postSysErrmsg()` and then writeErrmsgMemos().

void discardErrmsgs( )

Calls `getErrmsg()` repeatedly until the message pool is empty, discarding all of the messages.

SELF-DELIMITING NUMERIC VALUES (SDNV)

The functions in this section encode and decode SDNVs, portable variable-length numeric variables that expand to whatever size is necessary to contain the values they contain. SDNVs are used extensively in the LTP and ION libraries.

void encodeSdnv(Sdnv *sdnvBuffer, unsigned long value)

Determines the number of octets of SDNV text needed to contain the value, places that number in the *length* field of the SDNV buffer, and encodes the value in SDNV format into the first *length* octets of the *text* field of the SDNV buffer.

int decodeSdnv(unsigned long *value, unsigned char *sdnvText)

Determines the length of the SDNV located at *sdnvText* and returns this number after extracting the SDNV's value from those octets and storing it in *value*. Returns 0 if the encoded number value will not fit into an unsigned long.

PRIVATE MUTEXES

The functions in this section provide platform-independent management of mutexes for synchronizing operations of threads or tasks in a common private address space.

int initResourceLock(ResourceLock *lock)

Establishes an inter-thread lock for use in locking some resource. Returns 0 if successful, -1 if not.

void killResourceLock(ResourceLock *lock)

Deletes the resource lock referred to by *lock*.

void lockResource(ResourceLock *lock)

Checks the state of *lock*. If the lock is already owned by a different thread, the call blocks until the other thread relinquishes the lock. If the lock is unowned, it is given to the current thread and the lock count is set to 1. If the lock is already owned by this thread, the lock count is incremented by 1.

void unlockResource(ResourceLock *lock)

If called by the current owner of *lock*, decrements *lock*'s lock count by 1; if zero, relinquishes the lock so it may be taken by other threads. Care must be taken to make sure that one, and only one, `unlockResource()` call is issued for each `lockResource()` call issued on a given resource lock.

SHARED MEMORY IPC DEVICES

The functions in this section provide platform-independent management of IPC mechanisms for synchronizing operations of threads, tasks, or processes that may occupy different address spaces but share access to a common system (nominally, processor) memory.

NOTE that this is distinct from the VxWorks "VxMP" capability enabling tasks to share access to bus memory or dual-ported board memory from multiple processors. The "platform" system will support IPC devices that utilize this capability at some time in the future, but that support is not yet implemented.

int sm_ipc_init( )

Acquires and initializes shared-memory IPC management resources. Must be called before any other shared-memory IPC function is called. Returns 0 on success, -1 on any failure.

void sm_ipc_stop( )

Releases shared-memory IPC management resources, disabling the shared-memory IPC functions until `sm_ipc_init()` is called again.

int sm_GetUniqueKey( )

Some of the "sm_" (shared memory) functions described below associate new communication objects with *key* values that uniquely identify them, so that different processes can access them independently. Key values are typically defined as constants in application code. However, when a new communication object is required for which no specific need was anticipated in the application, the `sm_GetUniqueKey()` function can be invoked to obtain a new, arbitrary key value that is known not to be already in use.

sm_SemId sm_SemCreate(int key, int semType)

Creates a shared-memory semaphore that can be used to synchronize activity among tasks or processes residing in a common system memory but possibly multiple address spaces; returns a reference handle for that semaphore, or SM_SEM_NONE on any failure. If *key* refers to an existing semaphore, returns the handle of that semaphore. If *key* is the constant value SM_NO_KEY, automatically obtains an unused key. On VxWorks platforms, *semType* determines the order in which the semaphore is given to multiple tasks that attempt to take it while it is already taken: if set to SM_SEM_PRIORITY then the semaphore is given to tasks in task priority sequence (i.e., the highest-priority task waiting for it receives it when it is released), while otherwise (SM_SEM_FIFO) the semaphore is given to tasks in the order in which they attempted to take it. On all other platforms, only SM_SEM_FIFO behavior is supported and *semType* is ignored.

int sm_SemTake(sm_SemId semId)

Blocks until the indicated semaphore is no longer taken by any other task or process, then takes it. Return 0 on success, -1 on any error.

void sm_SemGive(sm_SemId semId)

Gives the indicated semaphore, so that another task or process can take it.

void sm_SemEnd(sm_SemId semId)

This function is used to pass a termination signal to whatever task is currently blocked on taking the indicated semaphore, if any. It sets to 1 the "ended" flag associated with this semaphore, so that a test for `sm_SemEnded()` will return 1, and it gives the semaphore so that the blocked task will have an opportunity to test that flag.

int sm_SemEnded(sm_SemId semId)

This function returns 1 if the "ended" flag associated with the indicated semaphore has been set to 1; returns zero otherwise. When the function returns 1 it also gives the semaphore so that any other tasks that might be pended on the same semaphore are also given an opportunity to test it and discover that it has been ended.

int sm_SemUnend(sm_SemId semId)

This function is used to reset an ended semaphore, so that a restarted subsystem can reuse that semaphore rather than delete it and allocate a new one.

int sm_SemUnwedge(sm_SemId semId, int interval)

Used to release semaphores that have been taken but never released, possibly because the tasks or processes that took them crashed before releasing them. Spawns a "smunwedge" thread that attempts to take the semaphore identified by *semId* and, if successful, releases the semaphore and announces that the semaphore is released. If the smunwedge thread fails to announce release of the semaphore within *interval* seconds, the semaphore is unilaterally released by the parent thread. Returns 1 if the semaphore was wedged and had to be released, 0 if the semaphore was not wedged, -1 on any error.

void sm_SemDelete(sm_SemId semId)

Destroys the indicated semaphore.

sm_SemId sm_GetTaskSemaphore(int taskId)

Returns the ID of the semaphore that is dedicated to the private use of the indicated task, or SM_SEM_NONE on any error.

This function implements the concept that for each task there can always be one dedicated semaphore, which the task can always use for its own purposes, whose key value may be known a priori because the key of the semaphore is based on the task's ID. The design of the function rests on the assumption that each task's ID, whether a VxWorks task ID or a Unix process ID, maps to a number that is out of the range of all possible key values that are arbitrarily produced by sm_GetUniqueKey(). For VxWorks, we assume this to be true because task ID is a pointer to task state in memory which we assume not to exceed 2GB; the unique key counter starts at 2GB. For Unix, we assume this to be true because process ID is an index into a process table whose size is less than 64K; unique keys are formed by shifting process ID left 16 bits and adding the value of an incremented counter which is always greater than zero.

int sm_ShmAttach(int key, int size, char **shmPtr, int *id)

Attaches to a segment of memory to which tasks or processes residing in a common system memory, but possibly multiple address spaces, all have access.

This function registers the invoking task or process as a user of the shared memory segment identified by *key*. If *key* is the constant value SM_NO_KEY, automatically sets *key* to some unused key value. If a shared memory segment identified by *key* already exists, then *size* may be zero and the value of **shmPtr* is ignored. Otherwise the size of the shared memory segment must be provided in *size* and a new shared memory segment is created in a manner that is dependent on **shmPtr*: if **shmPtr* is NULL then *size* bytes of shared memory are dynamically acquired, allocated, and assigned to the newly created shared memory segment; otherwise the memory located at *shmPtr* is assumed to have been pre-allocated and is merely assigned to the newly created shared memory segment.

On success, stores the unique shared memory ID of the segment in **id* for possible future destruction, stores a pointer to the segment's assigned memory in **shmPtr*, and returns 1 (if the segment is newly created) or 0 (otherwise). Returns -1 on any error.

void sm_ShmDetach(char *shmPtr)

Unregisters the invoking task or process as a user of the shared memory starting at *shmPtr*.

void sm_ShmDestroy(int id)

Destroys the shared memory segment identified by *id*, releasing any memory that was allocated when the segment was created.

PORTABLE MULTI-TASKING

int sm_TaskIdSelf( )

Returns the unique identifying number of the invoking task or process.

int sm_TaskExists(int taskId)

Returns non-zero if a task or process identified by *taskId* is currently running on the local processor, zero otherwise.

void sm_TaskVarAdd(int *var)

Establishes the static variable *var* as a "task variable" belonging to the invoking task, so that it can be referenced as an external variable in application code; all tasks running that code will have their own private values for *var* even if they are in the same address space. Not applicable for UNIX, since every UNIX process already has its own private value for every static variable.

void sm_TaskSuspend( )

Indefinitely suspends execution of the invoking task or process. Helpful if you want to freeze an application at the point at which an error is detected, then use a debugger to examine its state.

void sm_TaskDelay(int seconds)

Same as snooze(3).

void sm_TaskYield( )

Relinquishes CPU temporarily for use by other tasks.

int sm_TaskSpawn(char *name, char *arg1, char *arg2, char *arg3, char *arg4, char *arg5, char *arg6, char *arg7, char *arg8, char *arg9, char *arg10, int priority, int stackSize)

Spawns/forks a new task/process, passing it up to ten command-line arguments. *name* is the name of the function (VxWorks) or executable image (UNIX) to be executed in the new task/process.

For UNIX, *name* must be the name of some executable program in the $PATH of the invoking process.

For VxWorks, *name* must be the name of some function named in an application-defined private symbol table (if PRIVATE_SYMTAB is defined) or the system symbol table (otherwise). If PRIVATE_SYMTAB is defined, the application must provide a suitable adaptation of the symtab.c source file, which implements the private symbol table.

"priority" and "stackSize" are ignored under UNIX. Under VxWorks, if zero they default to the values in the application-defined private symbol table if provided, or otherwise to ICI_PRIORITY (nominally 100) and 32768 respectively.

Returns the task/process ID of the new task/process on success, or -1 on any error.

void sm_TaskDelete(int taskId)

Terminates the indicated task or process.

int pseudoshell(char *script)

Parses *script* into a command name and up to 10 arguments, then passes the command name and arguments to `sm_TaskSpawn()` for execution. The `sm_TaskSpawn()` function is invoked with priority and stack size both set to zero, causing default values (possibly from an application-defined private symbol table) to be used. Tokens in *script* are normally whitespace-delimited, but a token that is enclosed in single-quote characters (') may contain embedded whitespace and may contain escaped single-quote characters ("\'"). On any parsing failure returns -1; otherwise returns the value returned by sm_TaskSpawn().

USER'S GUIDE

Compiling an application that uses "platform"

Just be sure to "#include "platform.h"" at the top of each source file that includes any platform function calls.

Linking/loading an application that uses "platform"

In a Solaris environment, link with these libraries:

```
-lplatform -socket -nsl -posix4 –c
```

In a Linux environment, simply link with platform:

```
-lplatform
```

In a VxWorks environment, use

```
ld 1, 0, "libplatform.o"
```

to load platform on the target before loading applications.

SEE ALSO

gettimeofday(3C)

NAME

psm - Personal Space Management

SYNOPSIS

```
#include "psm.h"
typedef enum { Okay, Redundant, Refused } PsmMgtOutcome;
typedef unsigned long PsmAddress;
typedef struct psm_str
{
        char            *space;
        int             freeNeeded;
        struct psm_str  *trace;
        int             traceArea[3];
} PsmView, *PsmPartition;
```

[see description for available functions]

DESCRIPTION

PSM is a library of functions that support personal space management, that is, user management of an application-configured memory partition. PSM is designed to be faster and more efficient than malloc/free (for details, see the DETAILED DESCRIPTION below), but more importantly it provides a memory management abstraction that insulates applications from differences in the management of private versus shared memory.

PSM is often used to manage shared memory partitions. On most operating systems, separate tasks that connect to a common shared memory partition are given the same base address with which to access the partition. On some systems (such as Solaris) this is not necessarily the case; an absolute address within such a shared partition will be mapped to different pointer values in different tasks. If a pointer value is stored within shared memory and used without conversion by multiple tasks, segment violations will occur.

PSM gets around this problem by providing functions for translating between local pointer values and relative addresses within the shared memory partition. For complete portability, applications which store addresses in shared memory should store these addresses as PSM relative addresses and convert them to local pointer values before using them. The PsmAddress data type is provided for this purpose, along with the conversion functions `psa()` and psp().

PsmMgtOutcome psm_manage(char *start, unsigned int length, char *name, PsmPartition *partitionPointer)

Puts the *length* bytes of memory at *start* under PSM management, associating this memory partition with the identifying string *name* (which is required and which can have a maximum string length of 31). PSM can manage any contiguous range of addresses to which the application has access, typically a block of heap memory returned by a malloc call.

Every other PSM API function must be passed a pointer to a local "partition" state structure characterizing the PSM-managed memory to which the function is to be applied. The partition state structure itself may be pre-allocated in static or local (or shared) memory by the application, in which case a pointer to that structure must be passed to `psm_manage()` as the value of **partitionPointer*; if **partitionPointer* is null, `psm_manage()` will use `malloc()` to allocate this structure dynamically from local memory and will store a pointer to the structure in **partitionPointer*.

`psm_manage()` formats the managed memory as necessary and returns a value of type PsmMgtOutcome. A return value of Redundant means that the memory at *start* is already under PSM management with the same name and size. A return value of Refused means that PSM was unable to put the memory at *start* under PSM management as directed; a diagnostic message was posted to the message pool (see discussion of `putErrmsg()` in platform(3)).

char *psm_name(PsmPartition partition)

Returns the name associated with the partition at the time it was put under management.

char *psm_space(PsmPartition partition)

Returns the address of the space managed by PSM for *partition*. This function is provided to enable the application to do an operating-system release (such as `free()`) of this memory when the managed partition is no longer needed. *NOTE* that calling `psm_erase()` or `psm_unmanage()` [or any other PSM function, for that matter] after releasing that space is virtually guaranteed to result in a segmentation fault or other seriously bad behavior.

void *psp(PsmPartition partition, PsmAddress address)

address is an offset within the space managed for the partition. Returns the conversion of that offset into a locally usable pointer.

PsmAddress psa(PsmPartition partition, void *pointer)

Returns the conversion of *pointer* into an offset within the space managed for the partition.

PsmAddress psm_malloc(PsmPartition partition, unsigned int length)

Allocates a block of memory from the "large pool" of the indicated partition. (See the DETAILED DESCRIPTION below.) *length* is the size of the block to allocate; the maximum size is 1/2 of the total address space (i.e., 2G for a 32-bit machine). Returns NULL if no free block could be found. The block returned is aligned on a doubleword boundary.

void psm_panic(PsmPartition partition)

Forces the "large pool" memory allocation algorithm to hunt laboriously for free blocks in buckets that may not contain any. This setting remains in force for the indicated partition until a subsequent `psm_relax()` call reverses it.

void psm_relax(PsmPartition partition)

Reverses psm_panic(). Lets the "large pool" memory allocation algorithm return NULL when no free block can be found easily.

PsmAddress psm_zalloc(PsmPartition partition, unsigned int length)

Allocates a block of memory from the "small pool" of the indicated partition, if possible; if the requested block size -- *length* -- is too large for small pool allocation (which is limited to 64 words, i.e., 256 bytes for a 32-bit machine), or if no small pool space is available and the size of the small pool cannot be increased, then allocates from the large pool instead. Small pool allocation is performed by an especially speedy algorithm, and minimum space is consumed in memory management overhead for small-pool blocks. Returns NULL if no free block could be found. The block returned is aligned on a word boundary.

void psm_free(PsmPartition partition, PsmAddress block)

Frees for subsequent re-allocation the indicated block of memory from the indicated partition. *block* may have been allocated by either `psm_malloc()` or psm_zalloc().

int psm_set_root(PsmPartition partition, PsmAddress root)

Sets the "root" word of the indicated partition (a word at a fixed, private location in the PSM bookkeeping data area) to the indicated value. This function is typically useful in a shared-memory environment, such as a VxWorks address space, in which a task wants to retrieve from the indicated partition some data that was inserted into the partition by some other task; the partition root word enables multiple tasks to navigate the same data in the same PSM partition in shared memory. The argument is normally a pointer to something like a linked list of the linked lists that populate the partition; in particular, it is likely to be an object catalog (see psm_add_catlg()). Returns 0 on success, -1 on any failure (e.g., the partition already has a root object, in which case `psm_erase_root()` must be called before psm_set_root()).

PsmAddress psm_get_root(PsmPartition partition)

Retrieves the current value of the root word of the indicated partition.

void psm_erase_root(PsmPartition partition)

Erases the current value of the root word of the indicated partition.

PsmAddress psm_add_catlg(PsmPartition partition)

Allocates space for an object catalog in the indicated partition and establishes the new catalog as the partition's root object. Returns 0 on success, -1 on any failure (e.g., the partition already has some other root object).

int psm_catlg(PsmPartition partition, char *objName, PsmAddress objLocation)

Inserts an entry for the indicated object into the catalog that is the root object for this partition. The length of *objName* cannot exceed 32 bytes, and *objName* must be unique in the catalog. Returns 0 on success, -1 on any failure.

void psm_uncatlg(PsmPartition partition, char *objName)

Removes the entry for the named object from the catalog that is the root object for this partition, if that object is found in the catalog.

PsmAddress psm_locate(PsmPartition partition, char *objName)

Returns the address associated with *objName* in the catalog that is the root object for this partition, if that object is found in the catalog. If *objName* is not in the catalog, returns zero.

void psm_usage(PsmPartition partition, PsmUsageSummary *summary)

Loads the indicated PsmUsageSummary structure with a snapshot of the indicated partition's usage status. PsmUsageSummary is defined by:

```
typedef struct {
    char            partitionName[32];
    unsigned int    partitionSize;
    unsigned int    smallPoolSize;
    unsigned int    smallPoolFreeBlockCount[SMALL_SIZES];
    unsigned int    smallPoolFree;
    unsigned int    smallPoolAllocated;
    unsigned int    largePoolSize;
    unsigned int    largePoolFreeBlockCount[LARGE_ORDERS];
    unsigned int    largePoolFree;
    unsigned int    largePoolAllocated;
    unsigned int    unusedSize;
} PsmUsageSummary;
```

void psm_report(PsmUsageSummary *summary)

Sends to stdout the content of *summary*, a snapshot of a partition's usage status.

void psm_unmanage(PsmPartition partition)

Terminates local PSM management of the memory in *partition* and destroys the partition state structure **partition*, but doesn't erase anything in the managed memory; PSM management can be re-established by a subsequent call to psm_manage().

void psm_erase(PsmPartition partition)

Unmanages the indicated partition and additionally discards all information in the managed memory, preventing re-management of the partition.

MEMORY USAGE TRACING

If PSM_TRACE is defined at the time the PSM source code is compiled, the system includes built-in support for simple tracing of memory usage: memory allocations are logged, and memory deallocations are matched to logged allocations, "closing" them. This enables memory leaks and some other kinds of memory access problems to be readily investigated.

int psm_start_trace(PsmPartition partition, int traceLogSize, char *traceLogAddress)

Begins an episode of PSM memory usage tracing. *traceLogSize* is the number of bytes of shared memory to use for trace activity logging; the frequency with which "closed" trace log events must be deleted will vary inversely with the amount of memory allocated for the trace log. *traceLogAddress* is normally NULL, causing the trace system to allocate *traceLogSize* bytes of shared memory dynamically for trace logging; if non-NULL, it must point to *traceLogSize* bytes of shared memory that have been pre-allocated by the application for this purpose. Returns 0 on success, -1 on any failure.

void psm_print_trace(PsmPartition partition, int verbose)

Prints a cumulative trace report and current usage report for *partition*. If *verbose* is zero, only exceptions (notably, trace log events that remain open -- potential memory leaks) are printed; otherwise all activity in the trace log is printed.

void psm_clear_trace(PsmPartition partition)

Deletes all closed trace log events from the log, freeing up memory for additional tracing.

void psm_stop_trace(PsmPartition partition)

Ends the current episode of PSM memory usage tracing. If the shared memory used for the trace log was allocated by psm_start_trace(), releases that shared memory.

EXAMPLE

For an example of the use of psm, see the file psmshell.c in the PSM source directory.

USER'S GUIDE

Compiling a PSM application

Just be sure to "#include "psm.h"" at the top of each source file that includes any PSM function calls.

Linking/loading a PSM application

In a UNIX environment, link with libpsm.a.

In a VxWorks environment, use

```
ld 1, 0, "libpsm.o"
```

to load PSM on the target before loading any PSM applications.

Typical usage:

a. Call `psm_manage()` to initiate management of the partition.

b. Call `psm_malloc()` (and/or `psm_zalloc()`) to allocate space in the partition; call `psm_free()` to release space for later re-allocation.

c. When `psm_malloc()` returns NULL and you're willing to wait a while for a more exhaustive free block search, call `psm_panic()` before retrying psm_malloc(). When you're no longer so desperate for space, call psm_relax().

d. To store a vital pointer in the single predefined location in the partition that PSM reserves for this purpose, call psm_set_root(); to retrieve that pointer, call psm_get_root().

e. To get a snapshot of the current configuration of the partition, call psm_usage(). To print this snapshot to stdout, call psm_report().

f. When you're done with the partition but want to leave it in its current state for future re-management (e.g., if the partition is in shared memory), call psm_unmanage(). If you're done with the partition forever, call psm_erase().

DETAILED DESCRIPTION

PSM supports user management of an application-configured memory partition. The partition is functionally divided into two pools of variable size: a "small pool" of low-overhead blocks aligned on 4-byte boundaries that can each contain up to 256 bytes of user data, and a "large pool" of high-overhead blocks aligned on 8-byte boundaries that can each contain up to 2GB of user data.

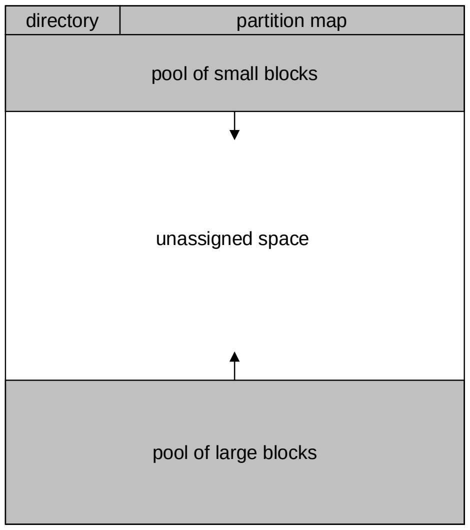


Figure 16 PSM memory pools

Space in the small pool is allocated in any one of 64 different block sizes; each possible block size is (4i + n) where i is a "block list index" from 1 through 64 and n is the length of the PSM overhead information per block [4 bytes on a 32-bit machine]. Given a user request for a block of size q where q is in the range 1 through 256 inclusive, we return the first block on the j'th small-pool free list where j = (q - 1) / 4. If there is no such block, we increase the size of the small pool [incrementing its upper limit by (4 * (j + 1)) + n], initialize the increase as a free block from list j, and return that block. No attempt is made to consolidate physically adjacent blocks when they are freed or to bisect large blocks to satisfy requests for small ones; if there is no free block of the requested size and the size of the small pool cannot be increased without encroaching on the large pool (or if the requested size exceeds 256), we attempt to allocate a large-pool block as described below. The differences between small-pool and large-pool blocks are transparent to the user, and small-pool and large-pool blocks can be freely intermixed in an application.

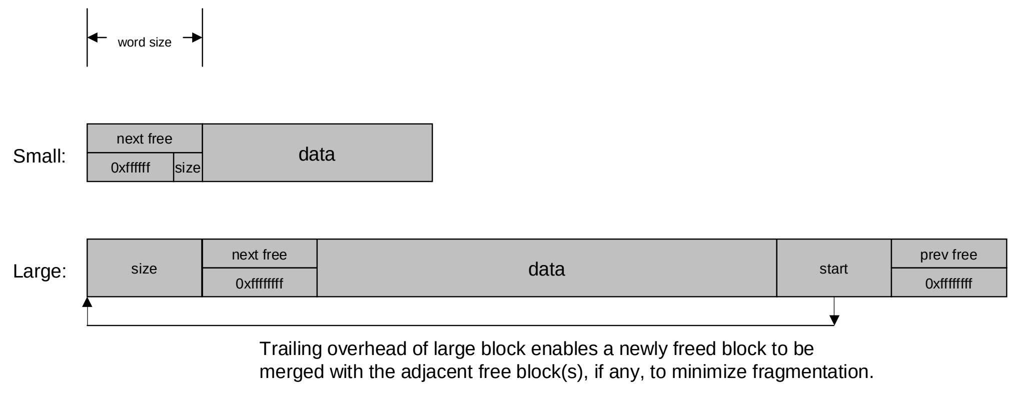

word size
Small:
next free
0xffffff
size
data
Large:
size
next free
0xffffffff
data
start
prev free
0xffffffff
Trailing overhead of large block enables a newly freed block to be merged with the adjacent free block(s), if any, to minimize fragmentation.

Figure 17 PSM memory block structures

Small-pool blocks are allocated and freed very rapidly, and space overhead consumption is small, but capacity per block is limited and space assigned to small-pool blocks of a given size is never again available for any other purpose. The small pool is designed to satisfy requests for allocation of a stable overall population of small, volatile objects such as List and ListElt structures (see lyst(3)).

Space in the large pool is allocated from any one of 29 buckets, one for each power of 2 in the range 8 through 2G. The size of each block can be expressed as (n + 8i + m) where i is any integer in the range 1 through 256M, n is the size of the block's leading overhead area [8 bytes on a 32-bit machine], and m is the size of the block's trailing overhead area [also 8 bytes on a 32-bit machine]. Given a user request for a block of size q where q is in the range 1 through 2G inclusive, we first compute r as the smallest multiple of 8 that is greater than or equal to q. We then allocate the first block in bucket t such that 2 ** (t + 3) is the smallest power of 2 that is greater than r [or, if r is a power of 2, the first block in bucket t such that 2 ** (t + 3) = r]. That is, we try to allocate blocks of size 8 from bucket 0 [2**3 = 8], blocks of size 16 from bucket 1 [2**4 = 16], blocks of size 24 from bucket 2 [2**5 = 32, 32 > 24], blocks of size 32 from bucket 2 [2**5 = 32], and so on. t is the first bucket whose free blocks are ALL guaranteed to be at least as large as r; bucket t - 1 may also contain some blocks that are as large as r (e.g., bucket 1 will contain blocks of size 24 as well as blocks of size 16), but we would have to do a possibly time consuming sequential search through the free blocks in that bucket to find a match, because free blocks within a bucket are stored in no particular order.

If bucket t is empty, we allocate the first block from the first non-empty bucket corresponding to a greater power of two; if all eligible bucket are empty, we increase the size of the large pool [decrementing its lower limit by (r + 16)], initialize the increase as a free block and "free" it, and try again. If the size of the large pool cannot be increased without encroaching on the small pool, then if we are desperate we search sequentially through all blocks in bucket t - 1 (some of which may be of size r or greater) and allocate the first block that is big enough, if any. Otherwise, no block is returned.

Having selected a free block to allocate, we remove the allocated block from the free list, split off as a new free block all bytes in excess of (r + 16) bytes [unless that excess is too small to form a legal-size block], and return the remainder to the user. When a block is freed, it is automatically consolidated with the physically preceding block (if that block is free) and the physically subsequent block (if that block is free).

Large-pool blocks are allocated and freed quite rapidly; capacity is effectively unlimited; space overhead consumption is very high for extremely small objects but becomes an insignificant fraction of block size as block size increases. The large pool is designed to serve as a general-purpose heap with minimal fragmentation whose overhead is best justified when used to store relatively large, long-lived objects such as image packets.

The general goal of this memory allocation scheme is to satisfy memory management requests rapidly and yet minimize the chance of refusing a memory allocation request when adequate unused space exists but is inaccessible (because it is fragmentary or is buried as unused space in a block that is larger than necessary). The size of a small-pool block delivered to satisfy a request for q bytes will never exceed q + 3 (alignment), plus 4 bytes of overhead. The size of a large-pool block delivered to satisfy a request for q bytes will never exceed q + 7 (alignment) + 20 (the maximum excess that can't be split off as a separate free block), plus 16 bytes of overhead.

Neither the small pool nor the large pool ever decrease in size, but large-pool space previously allocated and freed is available for small-pool allocation requests if no small-pool space is available. Small-pool space previously allocated and freed cannot easily be reassigned to the large pool, though, because blocks in the large pool must be physically contiguous to support defragmentation. No such reassignment algorithm has yet been developed.

SEE ALSO

lyst(3)

NAME

psmshell - PSM memory management test shell

SYNOPSIS

psmshell *partition_size*

DESCRIPTION

psmshell allocates a region of *partition_size* bytes of system memory, places it under PSM management, and offers the user an interactive "shell" for testing various PSM management functions.

psmshell prints a prompt string (": ") to stdout, accepts a command from stdin, executes the command (possibly printing a diagnostic message), then prints another prompt string and so on.

The locations of objects allocated from the PSM-managed region of memory are referred to as "cells" in psmshell operations. That is, when an object is to be allocated, a cell number in the range 0-99 must be specified as the notional "handle" for that object, for use in future commands.

The following commands are supported:

h
: The **help** command. Causes **psmshell** to print a summary of available commands. Same effect as the **?** command.

?
: Another **help** command. Causes **psmshell** to print a summary of available commands. Same effect as the **h** command.

m *cell_nbr size*
: The **malloc** command. Allocates a large-pool object of the indicated size and associates that object with *cell_nbr*.

z *cell_nbr size*
: The **zalloc** command. Allocates a small-pool object of the indicated size and associates that object with *cell_nbr*.

p *cell_nbr*
: The **print** command. Prints the address (i.e., the offset within the managed block of memory) of the object associated with *cell_nbr*.

f *cell_nbr*
: The **free** command. Frees the object associated with *cell_nbr*, returning the space formerly occupied by that object to the appropriate free block list.

u

The **usage** command. Prints a partition usage report, as per psm_report(3).

q

The **quit** command. Frees the allocated system memory in the managed block and terminates **psmshell**.

EXIT STATUS

0 **mshell** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

IPC initialization failed.

ION system error. Investigate, correct problem, and try again.

psmshell: can't allocate space; quitting.

Insufficient available system memory for selected partition size.

psmshell: can't allocate test variables; quitting.

Insufficient available system memory for selected partition size.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

psm(3)

NAME

psmwatch - PSM memory partition activity monitor

SYNOPSIS

psmwatch *partition_name interval count* [verbose]

DESCRIPTION

For *count* iterations, **psmwatch** sleeps *interval* seconds and then invokes the `psm_print_trace()` function (see `psm(3)`) to report on PSM dynamic memory management activity in the PSM-managed memory partition identified by *partition_name* during that interval. If the optional **verbose** parameter is specified, the printed PSM activity trace will be verbose as described in psm(3).

psmwatch is helpful for detecting and diagnosing memory leaks.

EXIT STATUS

0 **psmwatch** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

Can't attach to psm.

ION system error. One possible cause is that ION has not yet been initialized on the local computer; run `ionadmin(1)` to correct this.

Can't start trace.

Insufficient ION working memory to contain trace information. Reinitialize ION with more memory.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

psm(3), sdrwatch(1)

NAME

rfxclock - ION daemon task for managing scheduled events

SYNOPSIS

rfxclock

DESCRIPTION

rfxclock is a background "daemon" task that periodically applies scheduled changes in node connectivity and range to the ION node's database. It is spawned automatically by **ionadmin** in response to the 's' command that starts operation of the ION node infrastructure, and it is terminated by **ionadmin** in response to an 'x' (STOP) command.

Once per second, **rfxclock** takes the following action:

> For each neighboring node that has been refusing custody of bundles sent to it to be forwarded to some destination node, to which no such bundle has been sent for at least N seconds (where N is twice the one-way light time from the local node to this neighbor), **rfxclock** turns on a *probeIsDue* flag authorizing transmission of the next such bundle in hopes of learning that this neighbor is now able to accept custody.
>
> Then **rfxclock** purges the database of all range and contact information that is no longer applicable, based on the stop times of the records.
>
> Finally, **rfxclock** applies to the database all range and contact information that is currently applicable, i.e., those records whose start times are before the current time and whose stop times are in the future.

EXIT STATUS

0 **rfxclock** terminated, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **ionadmin** to restart **rfxclock**.

1 **rfxclock** was unable to attach to the local ION node, probably because **ionadmin** has not yet been run.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

rfxclock can't attach to ION.

> **ionadmin** has not yet initialized the ION database.

Can't apply ranges.

> An unrecoverable database error was encountered. **rfxclock** terminates.

Can't apply contacts.

> An unrecoverable database error was encountered. **rfxclock** terminates.

Can't purge ranges.

> An unrecoverable database error was encountered. **rfxclock** terminates.

Can't purge contacts.

> An unrecoverable database error was encountered. **rfxclock** terminates.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ionadmin(1)

NAME

sdr2file - SDR data extraction test program

SYNOPSIS

sdr2file *configFlags*

DESCRIPTION

sdr2file stress-tests SDR data extraction by retrieving and deleting all text file lines inserted into a test SDR data store named "testsdr*configFlags*" by the complementary test program file2sdr(1).

The operation of **sdr2file** echoes the cyclical operation of **file2sdr**: each linked list created by **file2sdr** is used to create in the current working directory a copy of **file2sdr**'s original source text file. The name of each file written by **sdr2file** is file_copy_*cycleNbr*, where *cycleNbr* identifies the linked list from which the file's text lines were obtained.

sdr2file may catch up with the data ingestion activity of **file2sdr**, in which case it blocks (taking the **file2sdr** test semaphore) until the linked list it is currently draining is no longer empty.

EXIT STATUS

0 **sdr2file** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

Can't use sdr.

ION system error. Check for diagnostics in the ION log file *ion.log*.

Can't create semaphore.

> ION system error. Check for diagnostics in the ION log file *ion.log*.

SDR transaction failed.

> ION system error. Check for diagnostics in the ION log file *ion.log*.

Can't open output file

> Operating system error. Check errtext, correct problem, and rerun.

can't write to output file

> Operating system error. Check errtext, correct problem, and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

file2sdr(1), sdr(3)

NAME

sdr - Simple Data Recorder library

SYNOPSIS

```
    #include "sdr.h"
```

[see below for available functions]

DESCRIPTION

SDR is a library of functions that support the use of an abstract data recording device called an "SDR" ("simple data recorder") for persistent storage of data. The SDR abstraction insulates software not only from the specific characteristics of any single data storage device but also from some kinds of persistent data storage and retrieval chores. The underlying principle is that an SDR provides standardized support for user data organization at object granularity, with direct access to persistent user data objects, rather than supporting user data organization only at "file" granularity and requiring the user to implement access to the data objects accreted within those files.

The SDR library is designed to provide some of the same kinds of directory services as a file system together with support for complex data structures that provide more operational flexibility than files. (As an example of this flexibility, consider how much easier and faster it is to delete a given element from the middle of a linked list than it is to delete a range of bytes from the middle of a text file.) The intent is to enable the software developer to take maximum advantage of the high speed and direct byte addressability of a non-volatile flat address space in the management of persistent data. The SDR equivalent of a "record" of data is simply a block of nominally persistent memory allocated from this address space. The SDR equivalent of a "file" is a *collection* object. Like files, collections can have names, can be located by name within persistent storage, and can impose structure on the data items they encompass. But, as discussed later, SDR collection objects can impose structures other than the strict FIFO accretion of records or bytes that characterizes a file.

The notional data recorder managed by the SDR library takes the form of a single array of randomly accessible, contiguous, nominally persistent memory locations called a *heap*. Physically, the heap may be implemented as a region of shared memory, as a single file of predefined size, or both -- that is, the heap may be a region of shared memory that is automatically mirrored in a file.

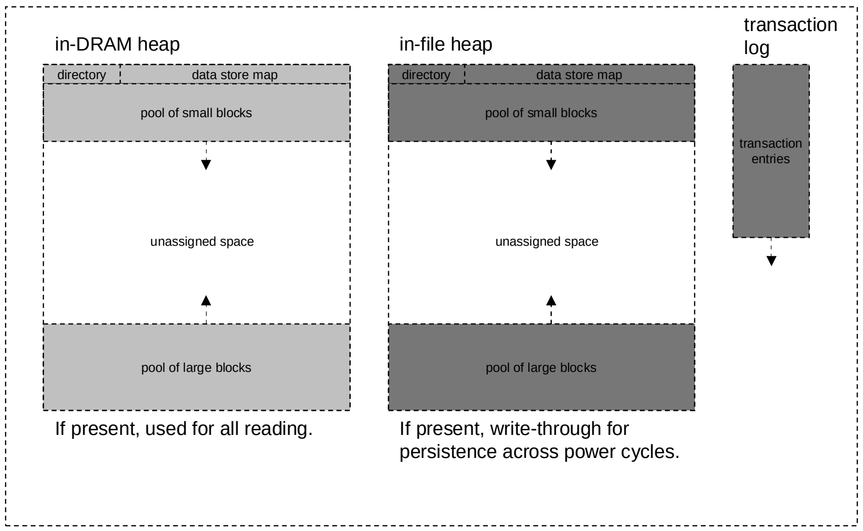


Figure 18 SDR data store structure

SDR services that manage SDR data are provided in several layers, each of which relies on the services implemented at lower levels:

> At the highest level, a cataloguing service enables retrieval of persistent objects by name.
>
> Services that manage three types of persistent data collections are provided for use both by applications and by the cataloguing service: linked lists, self-delimiting tables (which function as arrays that remember their own dimensions), and self-delimiting strings (short character arrays that remember their lengths, for speedier retrieval).
>
> Basic SDR heap space management services, analogous to `malloc()` and `free`(), enable the creation and destruction of objects of arbitrary type.
>
> Farther down the service stack are memcpy-like low-level functions for reading from and writing to the heap.
>
> Protection of SDR data integrity across a series of reads and writes is provided by a *transaction* mechanism.

SDR persistent data are referenced in application code by Object values and Address values, both of which are simply displacements (offsets) within SDR address space. The difference between the two is that an Object is always the address of a block of heap space returned by some call to `sdr_malloc`(), while an Address can refer to any byte in the address space. That is, an Address is the SDR functional equivalent of a C pointer in DRAM, and some Addresses point to Objects.

Before using SDR services, the services must be loaded to the target machine and initialized by invoking the `sdr_initialize()` function and the management profiles of one or more SDR's must be loaded by invoking the `sdr_load_profile()` function. These steps are normally performed only once, at application load time.

An application gains access to an SDR by passing the name of the SDR to the `sdr_start_using()` function, which returns an Sdr pointer. Most other SDR library functions take an Sdr pointer as first argument.

All writing to an SDR heap must occur during a *transaction* that was initiated by the task issuing the write. Transactions are single-threaded; if task B wants to start a transaction while a transaction begun by task A is still in progress, it must wait until A's transaction is either ended or cancelled. A transaction is begun by calling sdr_begin_xn(). The current transaction is normally ended by calling the `sdr_end_xn()` function, which returns an error return code value in the event that any serious SDR-related processing error was encountered in the course of the transaction. Transactions may safely be nested, provided that every level of transaction activity that is begun is properly ended.

The current transaction may instead be cancelled by calling sdr_cancel_xn(), which is normally used to indicate that some sort of serious SDR-related processing error has been encountered. Canceling a transaction reverses all SDR update activity performed up to that point within the scope of the transaction -- and, if the canceled transaction is an inner, nested transaction, all SDR update activity performed within the scope of every outer transaction encompassing that transaction *and* every other transaction nested within any of those outer transactions -- provided the SDR was configured for transaction *reversibility*. When an SDR is configured for reversibility, all heap write operations performed during a transaction are recorded in a log file that is retained until the end of the transaction. Each log file entry notes the location at which the write operation was performed, the length of data written, and the content of the overwritten heap bytes prior to the write operation. Canceling the transaction causes the log entries to be read and processed in reverse order, restoring all overwritten data. Ending the transaction, on the other hand, simply causes the log to be discarded.

If a log file exists at the time that the profile for an SDR is loaded (typically during application initialization), the transaction that was being logged is automatically canceled and reversed. This ensures that, for example, a power failure that occurs in the middle of a transaction will never wreck the SDR's data integrity: either all updates issued during a given transaction are reflected in the current database content or none are.

As a further measure to protect SDR data integrity, an SDR may additionally be configured for *object bounding*. When an SDR is configured to be "bounded", every heap write operation is restricted to the extent of a single object allocated from heap space; that is, it's impossible to overwrite part of one object by writing beyond the end of another. To enable the library to enforce this mechanism, application code is prohibited from writing anywhere but within the extent of an object that either (a) was allocated from managed heap space during the same transaction (directly or indirectly via some collection management function) or (b) was *staged* -- identified as an update target -- during the same transaction (again, either directly or via some collection management function).

Note that both transaction reversibility and object bounding consume processing cycles and inhibit performance to some degree. Determining the right balance between operational safety and processing speed is left to the user.

Note also that, since SDR transactions are single-threaded, they can additionally be used as a general mechanism for simply implementing "critical sections" in software that is already using SDR for other purposes: the beginning of a transaction marks the start of code that can't be executed concurrently by multiple tasks. To support this use of the SDR transaction mechanism, the additional transaction termination function `sdr_exit_xn()` is provided. `sdr_exit_xn()` simply ends a transaction without either signaling an error or checking for errors. Like `sdr_cancel_xn`(), `sdr_exit_xn()` has no return value; unlike `sdr_cancel_xn`(), it assures that ending an inner, nested transaction does not cause the outer transaction to be aborted and backed out. But this capability must be used carefully: the protection of SDR data integrity requires that transactions which are ended by `sdr_exit_xn()` must not encompass any SDR update activity whatsoever.

The heap space management functions of the SDR library are adapted directly from the Personal Space Management (*psm*) function library. The manual page for `psm(3)` explains the algorithms used and the rationale behind them. The principal difference between PSM memory management and SDR heap management is that, for performance reasons, SDR reserves the "small pool" for its own use only; all user data space is allocated from the "large pool", via the `sdr_malloc()` function.

RETURN VALUES AND ERROR HANDLING

Whenever an SDR function call fails, a diagnostic message explaining the failure of the function is recorded in the error message pool managed by the "platform" system (see the discussion of `putErrmsg()` in platform(3)).

The failure of any function invoked in the course of an SDR transaction causes all subsequent SDR activity in that transaction to fail immediately. This can streamline SDR application code somewhat: it may not be necessary to check the return value of every SDR function call executed during a transaction. If the `sdr_end_xn()` call returns zero, all updates performed during the transaction must have succeeded.

SYSTEM ADMINISTRATION FUNCTIONS

int sdr_initialize(int wmSize, char *wmPtr, int wmKey, char *wmName)

Initializes the SDR system. `sdr_initialize()` must be called once every time the computer on which the system runs is rebooted, before any call to any other SDR library function.

This function attaches to a pool of shared memory, managed by PSM (see psm(3), that enables SDR library operations. If the SDR system is to access a common pool of shared memory with one or more other systems, the key of that shared memory segment must be provided in *wmKey* and the PSM partition name associated with that memory segment must be provided in *wmName*; otherwise *wmKey* must be zero and *wmName* must be NULL, causing `sdr_initialize()` to assign default values. If a shared memory segment identified by the effective value of *wmKey* already exists, then *wmSize* may be zero and the value of *wmPtr* is ignored. Otherwise the size of the shared memory pool must be provided in *wmSize* and a new shared memory segment is created in a manner that is dependent on *wmPtr*: if *wmPtr* is NULL then *wmSize* bytes of shared memory are dynamically acquired, allocated, and assigned to the newly created shared memory segment; otherwise the memory located at *wmPtr* is assumed to have been pre-allocated and is merely assigned to the newly created shared memory segment.

`sdr_initialize()` also creates a semaphore to serialize access to the SDR system's private array of SDR profiles.

Returns 0 on success, -1 on any failure.

void sdr_wm_usage(PsmUsageSummary *summary)

Loads *summary* with a snapshot of the usage of the SDR system's private working memory. To print the snapshot, use psm_report(). (See `psm(3).)`

void sdr_shutdown( )

Ends all access to all SDRs (see sdr_stop_using()), detaches from the SDR system's working memory (releasing the memory if it was dynamically allocated by sdr_initialize()), and destroys the SDR system's private semaphore. After sdr_shutdown(), `sdr_initialize()` must be called again before any call to any other SDR library function.

DATABASE ADMINISTRATION FUNCTIONS

int sdr_load_profile(char *name, int configFlags, long heapWords, int memKey, char *pathName)

Loads the profile for an SDR into the system's private list of SDR profiles. Although SDRs themselves are persistent, SDR profiles are not: in order for an application to access an SDR, `sdr_load_profile()` must have been called to load the profile of the SDR since the last invocation of sdr_initialize().

name is the name of the SDR, required for any subsequent `sdr_start_using()` call.

configFlags specifies the configuration of the SDR, the bitwise "or" of some combination of the following:

SDR_IN_DRAM

SDR is implemented as a region of shared memory.

SDR_IN_FILE

SDR is implemented as a file.

SDR_REVERSIBLE

SDR transactions are logged and are reversed if canceled.

SDR_BOUNDED

Heap updates are not allowed to cross object boundaries.

heapWords specifies the size of the heap in words; word size depends on machine architecture, i.e., a word is 4 bytes on a 32-bit machine, 8 bytes on a 64-bit machine. Note that each SDR prepends to the heap a "map" of predefined, fixed size. The total amount of space occupied by an SDR in memory and/or in a file is the sum of the size of the map plus the product of word size and *heapWords*.

memKey is ignored if *configFlags* does not include SDR_IN_DRAM. It should normally be SM_NO_KEY, causing the shared memory region for the SDR to be allocated dynamically and shared using a dynamically selected shared memory key. If specified, *memKey* must be a shared memory key identifying a pre-allocated region of shared memory whose length is equal to the total SDR size, shared via the indicated key.

pathName is ignored if *configFlags* includes neither SDR_REVERSIBLE nor SDR_IN_FILE. It is the fully qualified name of the directory into which the SDR's log file and/or database file will be written. The name of the log file (if any) will be "<sdrname>.sdrlog". The name of the database file (if any) will be "<sdrname>.sdr"; this file will be automatically created and filled with zeros if it does not exist at the time the SDR's profile is loaded.

Returns 0 on success, -1 on any error.

int sdr_reload_profile(char *name, int configFlags, long heapWords, int memKey, char *pathName)

For use when the state of an SDR is thought to be inconsistent, perhaps due to crash of a program that had a transaction open. Unloads the profile for the SDR, forcing the reversal of any transaction that is currently in progress when the SDR's profile is re-loaded. Then calls `sdr_load_profile()` to re-load the profile for the SDR. Same return values as sdr_load_profile.

Sdr sdr_start_using(char *name)

Locates SDR profile by *name* and returns a handle that can be used for all functions that operate on that SDR. On any failure, returns NULL.

char *sdr_name(Sdr sdr)

Returns the name of the sdr.

long sdr_heap_size(Sdr sdr)

Returns the total size of the SDR heap, in bytes.

void sdr_stop_using(Sdr sdr)

Terminates access to the SDR via this handle. Other users of the SDR are not affected. Frees the Sdr object.

DATABASE TRANSACTION FUNCTIONS

void sdr_begin_xn(Sdr sdr)

Initiates a transaction. Note that transactions are single-threaded; any task that calls `sdr_begin_xn()` is suspended until all previously requested transactions have been ended or canceled.

int sdr_in_xn(Sdr sdr)

Returns 1 if called in the course of a transaction, 0 otherwise.

void sdr_cancel_xn(Sdr sdr)

Cancels the current transaction. If reversibility is enabled for the SDR, canceling a transaction reverses all heap modifications performed during that transaction.

int sdr_end_xn(Sdr sdr)

Ends the current transaction. Returns 0 if the transaction completed without any error; returns -1 if any operation performed in the course of the transaction failed, in which case the transaction was automatically canceled.

DATABASE I/O FUNCTIONS

void sdr_read(Sdr sdr, char *into, Address from, int length)

Copies *length* characters at *from* (a location in the indicated SDR) to the memory location given by *into*. The data are copied from the shared memory region in which the SDR resides, if any; otherwise they are read from the file in which the SDR resides.

void sdr_peek(sdr, variable, from)

`sdr_peek()` is a macro that uses `sdr_read()` to load *variable* from the indicated address in the SDR database; the size of *variable* is used as the number of bytes to copy.

void sdr_write(Sdr sdr, Address into, char *from, int length)

Copies *length* characters at *from* (a location in memory) to the SDR heap location given by *into*. Can only be performed during a transaction, and if the SDR is configured for object bounding then heap locations *into* through (*into* + (*length* - 1)) must be within the extent of some object that was either allocated or staged within the same transaction. The data are copied both to the shared memory region in which the SDR resides, if any, and also to the file in which the SDR resides, if any.

void sdr_poke(sdr, into, variable)

`sdr_peek()` is a macro that uses `sdr_write()` to store *variable* at the indicated address in the SDR database; the size of *variable* is used as the number of bytes to copy.

char *sdr_pointer(Sdr sdr, Address address)

Returns a pointer to the indicated location in the heap - a "heap pointer" - or NULL if the indicated address is invalid. NOTE that this function *cannot be used* if the SDR does not reside in a shared memory region.

Providing an alternative to using sdr_read() to retrieve objects into local memory, sdr_pointer() can help make SDR-based applications run very quickly, but it must be used WITH GREAT CAUTION! Never use a direct pointer into the heap when not within a transaction, because you will have no assurance at any time that the object pointed to by that pointer has not changed (or is even still there). And NEVER de-reference a heap pointer in order to write directly into the heap: this makes transaction reversal impossible. Whenever writing to the SDR, always use sdr_write().

Address sdr_address(Sdr sdr, char *pointer)

Returns the address within the SDR heap of the indicated location, which must be (or be derived from) a heap pointer as returned by sdr_pointer(). Returns zero if the indicated location is not greater than the start of the heap mirror. NOTE that this function *cannot be used* if the SDR does not reside in a shared memory region.

void sdr_get(sdr, variable, heap_pointer)

sdr_get() is a macro that uses sdr_read() to load *variable* from the SDR address given by *heap_pointer*; *heap_pointer* must be (or be derived from) a heap pointer as returned by sdr_pointer(). The size of *variable* is used as the number of bytes to copy.

void sdr_set(sdr, heap_pointer, variable)

sdr_set() is a macro that uses sdr_write() to store *variable* at the SDR address given by *heap_pointer*; *heap_pointer* must be (or be derived from) a heap pointer as returned by sdr_pointer(). The size of *variable* is used as the number of bytes to copy.

HEAP SPACE MANAGEMENT FUNCTIONS

Object sdr_malloc(Sdr sdr, unsigned long size)

Allocates a block of space from the of the indicated SDR's heap. *size* is the size of the block to allocate; the maximum size is 1/2 of the maximum address space size (i.e., 2G for a 32-bit machine). Returns block address if successful, zero if block could not be allocated.

Object sdr_insert(Sdr sdr, char *from, unsigned long size)

Uses sdr_malloc() to obtain a block of space of size *size* and, if this allocation is successful, uses sdr_write() to copy *size* bytes of data from memory at *from* into the newly allocated block. Returns block address if successful, zero if block could not be allocated.

Object sdr_stow(sdr, variable)

sdr_stow() is a macro that uses sdr_insert() to insert a copy of *variable* into the database. The size of *variable* is used as the number of bytes to copy.

int sdr_object_length(Sdr sdr, Object object)

Returns the number of bytes of heap space allocated to the application data at *object*.

void sdr_free(Sdr sdr, Object object)

Frees for subsequent re-allocation the heap space occupied by *object*.

void sdr_stage(Sdr sdr, char *into, Object from, int length)

Like sdr_read(), this function will copy *length* characters at *from* (a location in the heap of the indicated SDR) to the memory location given by *into*. Unlike sdr_get(), `sdr_stage()` requires that *from* be the address of some allocated object, not just any location within the heap. sdr_stage(), when called from within a transaction, notifies the SDR library that the indicated object may be updated later in the transaction; this enables the library to retrieve the object's size for later reference in validating attempts to write into some location within the object. If *length* is zero, the object's size is privately retrieved by SDR but none of the object's content is copied into memory.

long sdr_unused(Sdr sdr)

Returns number of bytes of heap space not yet allocated to either the large or small objects pool.

void sdr_usage(Sdr sdr, SdrUsageSummary *summary)

Loads the indicated SdrUsageSummary structure with a snapshot of the SDR's usage status. SdrUsageSummary is defined by:

```
    typedef struct
    {
            char            sdrName[MAX_SDR_NAME + 1];
            unsigned int    sdrSize;
            unsigned int    smallPoolSize;
            unsigned int    smallPoolFreeBlockCount[SMALL_SIZES];
            unsigned int    smallPoolFree;
            unsigned int    smallPoolAllocated;
            unsigned int    largePoolSize;
            unsigned int
largePoolFreeBlockCount[LARGE_ORDERS];
            unsigned int    largePoolFree;
            unsigned int    largePoolAllocated;
            unsigned int    unusedSize;
    } SdrUsageSummary;
```

void sdr_report(SdrUsageSummary *summary)

Sends to stdout a printed summary of the SDR's usage status.

HEAP SPACE USAGE TRACING

If SDR_TRACE is defined at the time the SDR source code is compiled, the system includes built-in support for simple tracing of SDR heap space usage: heap space allocations are logged, and heap space deallocations are matched to logged allocations, "closing" them. This enables heap space leaks and some other kinds of SDR heap access problems to be readily investigated.

int sdr_start_trace(Sdr sdr, int traceLogSize, char *traceLogAddress)

Begins an episode of SDR heap space usage tracing. *traceLogSize* is the number of bytes of shared memory to use for trace activity logging; the frequency with which "closed" trace log events must be deleted will vary inversely with the amount of memory allocated for the trace log. *traceLogAddress* is normally NULL, causing the trace system to allocate *traceLogSize* bytes of shared memory dynamically for trace logging; if non-NULL, it must point to *traceLogSize* bytes of shared memory that have been pre-allocated by the application for this purpose. Returns 0 on success, -1 on any failure.

void sdr_print_trace(Sdr sdr, int verbose)

Prints a cumulative trace report and current usage report for *sdr*. If *verbose* is zero, only exceptions (notably, trace log events that remain open -- potential SDR heap space leaks) are printed; otherwise all activity in the trace log is printed.

void sdr_clear_trace(Sdr sdr)

Deletes all closed trace log events from the log, freeing up memory for additional tracing.

void sdr_stop_trace(Sdr sdr)

Ends the current episode of SDR heap space usage tracing. If the shared memory used for the trace log was allocated by sdr_start_trace(), releases that shared memory.

CATALOGUE FUNCTIONS

The SDR catalogue functions are used to maintain the catalogue of the names, types, and addresses of objects within an SDR. The catalogue service includes functions for creating, deleting and finding catalogue entries and a function for navigating through catalogue entries sequentially.

void sdr_catlg(Sdr sdr, char *name, int type, Object object)

Associates *object* with *name* in the indicated SDR's catalogue and notes the *type* that was declared for this object. *type* is optional and has no significance other than that conferred on it by the application.

The SDR catalogue is flat, not hierarchical like a directory tree, and all names must be unique. The length of *name* is limited to15 characters.

Object sdr_find(Sdr sdr, char *name, int *type)

Locates the Object associated with *name* in the indicated SDR's catalogue and returns its address; also reports the catalogued type of the object in **type* if *type* is non-NULL. Returns zero if no object is currently catalogued under this name.

void sdr_uncatlg(Sdr sdr, char *name)

Dissociates from *name* whatever object in the indicated SDR's catalogue is currently catalogued under that name.

Object sdr_read_catlg(Sdr sdr, char *name, int *type, Object *object, Object previous_entry)

Used to navigate through catalogue entries sequentially. If *previous_entry* is zero, reads the first entry in the indicated SDR's catalogue; otherwise, reads the next catalogue entry following the one located at *previous_entry*. In either case, returns zero if no such catalogue entry exists; otherwise, copies that entry's name, type, and catalogued object address into *name*, **type*, and **object*, and then returns the address of the catalogue entry (which may be used as *previous_entry* in a subsequent call to sdr_read_catlg()).

USER'S GUIDE

Compiling an SDR application

Just be sure to "#include "sdr.h"" at the top of each source file that includes any SDR function calls.

For UNIX applications, link with "-lsdr".

Loading an SDR application (VxWorks)

```
ld < "libsdr.o"
```

After the library has been loaded, you can begin loading SDR applications.

SEE ALSO

sdrlist(3), sdrstring(3), sdrtable(3)

NAME

sdrhash - Simple Data Recorder hash table management functions

SYNOPSIS

```
    #include "sdr.h"
    Object  sdr_hash_create        (Sdr sdr, int keyLength,
                                        int estNbrOfEntries,
                                        int meanSearchLength);
    int     sdr_hash_insert        (Sdr sdr, Object hash, char *key,
                                        Address value);
    int     sdr_hash_retrieve      (Sdr sdr, Object hash, char *key,
                                        Address *value);
    int     sdr_hash_revise        (Sdr sdr, Object hash, char *key,
                                        Address value);
    int     sdr_hash_remove        (Sdr sdr, Object hash, char *key);
    int     sdr_hash_destroy       (Sdr sdr, Object hash);
```

DESCRIPTION

The SDR hash functions manage hash table objects in an SDR.

Hash tables associate values with keys. A value is always in the form of an SDR Address, nominally the address of some stored object identified by the associated key, but the actual significance of a value may be anything that fits into a *long*. A key is always an array of from 1 to 255 bytes, which may have any semantics at all.

Keys must be unique; no two distinct entries in an SDR hash table may have the same key. Any attempt to insert a duplicate entry in an SDR hash table will be rejected.

All keys must be of the same length, and that length must be declared at the time the hash table is created. Invoking a hash table function with a key that is shorter than the declared length will have unpredictable results.

An SDR hash table is an array of linked lists. The location of a given value in the hash table is automatically determined by computing a "hash" of the key, dividing the hash by the number of linked lists in the array, using the remainder as an index to the corresponding linked list, and then sequentially searching through the list entries until the entry with the matching key is found.

The number of linked lists in the array is automatically computed at the time the hash table is created, based on the estimated maximum number of entries you expect to store in the table and the mean linked list length (i.e., mean search time) you prefer. Increasing the maximum number of entries in the table and decreasing the mean linked list length both tend to increase the amount of SDR heap space occupied by the hash table.

Object sdr_hash_create(Sdr sdr, int keyLength, int estNbrOfEntries, int meanSearchLength)

Creates an SDR hash table. Returns the SDR address of the new hash table on success, zero on any error.

int sdr_hash_insert(Sdr sdr, Object hash, char *key, Address value)

Inserts an entry into the hash table identified by *hash*. Returns zero on success, -1 on any error.

int sdr_hash_retrieve(Sdr sdr, Object hash, char *key, Address *value)

Searches for the value associated with *key* in this hash table, storing it in *value* if found. Returns 1 if the entry matching *key* was found, zero if no such entry exists, -1 on any other failure.

int sdr_hash_revise(Sdr sdr, Object hash, char *key, Address value)

Searches for the hash table entry matching *key* in this hash table, replacing the associated value with *value* if found. Returns 1 if the entry matching *key* was found, zero if no such entry exists, -1 on any other failure.

int sdr_hash_remove(Sdr sdr, Object hash, char *key)

Searches for the hash table entry matching *key* in this hash table, deleting it if it is found. Returns 1 if the entry matching *key* was found, zero if no such entry exists, -1 on any other failure.

void sdr_hash_destroy(Sdr sdr, Object hash);

Destroys *hash*, destroying all entries in all linked lists of the array and destroying the hash table array structure itself. DO NOT use `sdr_free()` to destroy a hash table, as this would leave the hash table's content allocated yet unreferenced.

SEE ALSO

sdr(3), sdrlist(3), sdrtable(3)

NAME

sdrlist - Simple Data Recorder list management functions

SYNOPSIS

```
#include "sdr.h"
typedef int (*SdrListCompareFn)(Sdr sdr, Address eltData,
                   void *argData);
typedef void (*SdrListDeleteFn)(Sdr sdr, Object elt,
                   void *argument);
```

[see description for available functions]

DESCRIPTION

The SDR list management functions manage doubly-linked lists in managed SDR heap space. The functions manage two kinds of objects: lists and list elements. A list knows how many elements it contains and what its start and end elements are. An element knows what list it belongs to and the elements before and after it in the list. An element also knows its content, which is normally the SDR Address of some object in the SDR heap. A list may be sorted, which speeds the process of searching for a particular element.

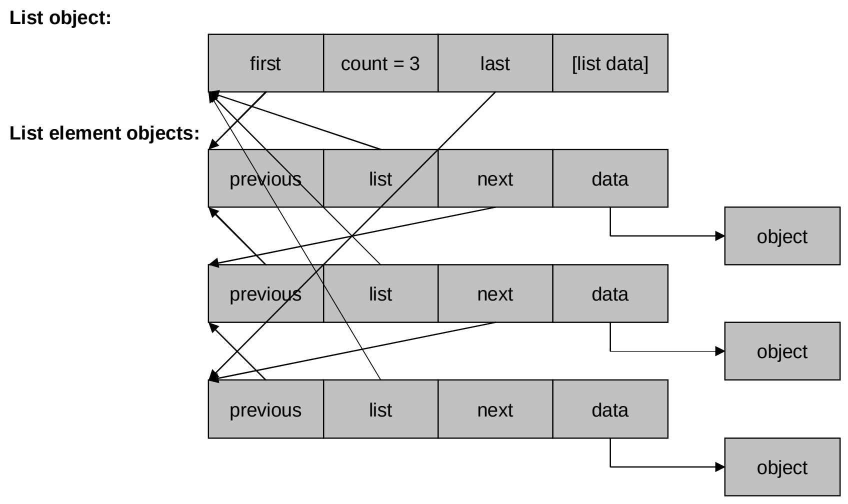


Figure 19 smlist data structures

Object sdr_list_create(Sdr sdr)

Creates a new list object in the SDR; the new list object initially contains no list elements. Returns the address of the new list, or zero on any error.

void sdr_list_destroy(Sdr sdr, Object list, SdrListDeleteFn fn, void *arg)

Destroys a list, freeing all elements of list. If *fn* is non-NULL, that function is called once for each freed element; when called, *fn* is passed the Address that is the element's data and the *argument* pointer passed to sdr_list_destroy().

Do not use *sdr_free* to destroy an SDR list, as this would leave the elements of the list allocated yet unreferenced.

int sdr_list_length(Sdr sdr, Object list)

Returns the number of elements in the list, or -1 on any error.

void sdr_list_user_data_set(Sdr sdr, Object list, Address userData)

Sets the "user data" word of *list* to *userData*. Note that *userData* is nominally an Address but can in fact be any value that occupies a single word. It is typically used to point to an SDR object that somehow characterizes the list as a whole, such as a name.

Address sdr_list_user_data(Sdr sdr, Object list)

Returns the value of the "user data" word of *list*, or zero on any error.

Object sdr_list_insert(Sdr sdr, Object list, Address data, SdrListCompareFn fn, void *arg)

Creates a new list element whose data value is *data* and inserts that element into the list. If *fn* is NULL, the new list element is simply appended to the list; otherwise, the new list element is inserted after the last element in the list whose data value is "less than or equal to" the data value of the new element according to the collating sequence established by *fn*. Returns the address of the newly created element, or zero on any error.

Object sdr_list_insert_first(Sdr sdr, Object list, Address data)
Object sdr_list_insert_last(Sdr sdr, Object list, Address data)

Creates a new element and inserts it at the front/end of the list. This function should not be used to insert a new element into any ordered list; use `sdr_list_insert()` instead. Returns the address of the newly created list element on success, or zero on any error.

Object sdr_list_insert_before(Sdr sdr, Object elt, Address data)
Object sdr_list_insert_after(Sdr sdr, Object elt, Address data)

Creates a new element and inserts it before/after the specified list element. This function should not be used to insert a new element into any ordered list; use `sdr_list_insert()` instead. Returns the address of the newly created list element, or zero on any error.

void sdr_list_delete(Sdr sdr, Object elt, SdrListDeleteFn fn, void *arg)

Delete *elt* from the list it is in. If *fn* is non-NULL, that function will be called upon deletion of *elt*; when called, that function is passed the Address that is the list element's data value and the *arg* pointer passed to sdr_list_delete().

Object sdr_list_first(Sdr sdr, Object list)
Object sdr_list_last(Sdr sdr, Object list)

Returns the address of the first/last element of *list*, or zero on any error.

Object sdr_list_next(Sdr sdr, Object elt)
Object sdr_list_prev(Sdr sdr, Object elt)

Returns the address of the element following/preceding *elt* in that element's list, or zero on any error.

Object sdr_list_search(Sdr sdr, Object elt, int reverse, SdrListCompareFn fn, void *arg);

Search a list for an element which matches the given argument, starting at the indicated initial list element. If the *compare* function is non-NULL, the list is assumed to be sorted in the order implied by that function and the function is automatically called once for each element of the list until it returns a value that is greater than or equal to zero (where zero indicates an exact match and a value greater than zero indicates that the list contains no matching element); each time *compare* is called it is passed the Address that is the element's data value and the *arg* value passed to sm_list_search(). If *reverse* is non-zero, then the list is searched in reverse order (starting at the indicated initial list element) and the search ends when *compare* returns a value that is less than or equal to zero. If *compare* is NULL, then the entire list is searched (in either forward or reverse order, as directed) until an element is located whose data value is equal to ((Address) *arg*). Returns the address of the matching element if one is found, 0 otherwise.

Object sdr_list_list(Sdr sdr, Object elt)

Returns the address of the list to which *elt* belongs, or 0 on any error.

Address sdr_list_data(Sdr sdr, Object elt)

Returns the Address that is the data value of *elt*, or 0 on any error.

Address sdr_list_data_set(Sdr sdr, Object elt, Address data)

Sets the data value for *elt* to *data*, replacing the original value. Returns the original data value for *elt*, or 0 on any error. The original data value for *elt* may or may not have been the address of an object in heap data space; even if it was, that object was NOT deleted.

Warning: changing the data value of an element of an ordered list may ruin the ordering of the list.

USAGE

When inserting elements or searching a list, the user may optionally provide a compare function of the form:

```
    int user_comp_name(Sdr sdr, Address eltData, void *argData);
```

When provided, this function is automatically called by the sdrlist function being invoked; when the function is called it is passed the content of a list element (*eltData*, nominally the Address of an item in the SDR's heap space) and an argument, *argData*, which is nominally the address in local memory of some other item in the same format. The user-supplied function normally compares some key values of the two data items and returns 0 if they are equal, an integer less than 0 if *eltData*'s key value is less than that of *argData*, and an integer greater than 0 if *eltData*'s key value is greater than that of *argData*. These return values will produce a list in ascending order. If the user desires the list to be in descending order, the function must reverse the signs of these return values.

When deleting an element or destroying a list, the user may optionally provide a delete function of the form:

```
    void user_delete_name(Sdr sdr, Address eltData, void *argData)
```

When provided, this function is automatically called by the sdrlist function being invoked; when the function is called it is passed the content of a list element (*eltData*, nominally the Address of an item in the SDR's heap space) and an argument, *argData*, which if non-NULL is normally the address in local memory of a data item providing context for the list element deletion. The user-supplied function performs any application-specific cleanup associated with deleting the element, such as freeing the element's content data item and/or other SDR heap space associated with the element.

SEE ALSO

lyst(3), sdr(3), sdrstring(3), sdrtable(3), smlist(3)

NAME

sdrmend - SDR corruption repair utility

SYNOPSIS

sdrmend *sdr_name config_flags heap_words heap_key path_name*

DESCRIPTION

The **sdrmend** program simply invokes the `sdr_reload_profile()` function (see `sdr(3)`) to effect necessary repairs in a potentially corrupt SDR, e.g., due to the demise of a program that had an SDR transaction in progress at the moment it crashed.

Note that **sdrmend** need not be run to repair ION's data store in the event of a hardware reboot: restarting ION will automatically reload the data store's profile. **sdrmend** is needed only when it is desired to repair the data store without requiring all ION software to terminate and restart.

EXIT STATUS

0	**sdrmend** has terminated successfully.
1	**sdrmend** has terminated unsuccessfully. See diagnostic messages in the **ion.log** log file for details.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

Can't initialize the SDR system.

Probable operations error: ION appears not to be initialized, in which case there is no point in running **sdrmend**.

Can't reload profile for SDR.

ION system error. See earlier diagnostic messages posted to **ion.log** for details. In this event it is unlikely that **sdrmend** can be run successfully, and it is also unlikely that it would have any effect if it did run successfully.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

sdr(3), ionadmin(1)

NAME

sdrstring - Simple Data Recorder string functions

SYNOPSIS

```
    #include "sdr.h"
    Object sdr_string_create (Sdr sdr, char *from);
    Object sdr_string_dup    (Sdr sdr, Object from);
    int    sdr_string_length (Sdr sdr, Object string);
    int    sdr_string_read   (Sdr sdr, char *into, Object string);
```

DESCRIPTION

SDR strings are used to record strings of up to 255 ASCII characters in the heap space of an SDR. Unlike standard C strings, which are terminated by a zero byte, SDR strings record the length of the string as part of the string object.

To store strings longer than 255 characters, use `sdr_malloc()` and `sdr_put()` instead of these functions.

Object sdr_string_create(Sdr sdr, char *from)

Creates a "self-delimited string" in the heap of the indicated SDR, allocating the required space and copying the indicated content. *from* must be a standard C string for which `strlen()` must not exceed 255; if it does, or if insufficient SDR space is available, 0 is returned. Otherwise the address of the newly created SDR string object is returned. To destroy, just use sdr_free().

Object sdr_string_dup(Sdr sdr, Object from)

Creates a duplicate of the SDR string whose address is *from*, allocating the required space and copying the original string's content. If insufficient SDR space is available, 0 is returned. Otherwise the address of the newly created copy of the original SDR string object is returned. To destroy, use sdr_free().

int sdr_string_length(Sdr sdr, Object string)

Returns the length of the indicated self-delimited string (as would be returned by strlen()), or -1 on any error.

int sdr_string_read(Sdr sdr, char *into, Object string)

Retrieves the content of the indicated self-delimited string into memory as a standard C string (NULL terminated). Length of *into* should normally be SDRSTRING_BUFSZ (i.e., 256) to allow for the largest possible SDR string (255 characters) plus the terminating NULL. Returns length of string (as would be returned by strlen()), or -1 on any error.

SEE ALSO

sdr(3), sdrlist(3), sdrtable(3), string(3)

NAME

sdrtable - Simple Data Recorder table management functions

SYNOPSIS

```
    #include "sdr.h"
    Object  sdr_table_create        (Sdr sdr, int rowSize,
                                        int rowCount);
    int     sdr_table_user_data_set (Sdr sdr, Object table,
                                        Address userData);
    Address sdr_table_user_data     (Sdr sdr, Object table);
    int     sdr_table_dimensions    (Sdr sdr, Object table,
                                        int *rowSize,
                                        int *rowCount);
    int     sdr_table_stage         (Sdr sdr, Object table);
    Address sdr_table_row           (Sdr sdr, Object table,
                                        unsigned int rowNbr);
    int     sdr_table_destroy       (Sdr sdr, Object table);
```

DESCRIPTION

The SDR table functions manage table objects in the SDR. An SDR table comprises N rows of M bytes each, plus optionally one word of user data (which is nominally the address of some other object in the SDR's heap space). When a table is created, the number of rows in the table and the length of each row are specified; they remain fixed for the life of the table. The table functions merely maintain information about the table structure and its location in the SDR and calculate row addresses; other SDR functions such as `sdr_read()` and `sdr_write()` are used to read and write the contents of the table's rows. In particular, the format of the rows of a table is left entirely up to the user.

Object sdr_table_create(Sdr sdr, int rowSize, int rowCount)
: Creates a "self-delimited table", comprising *rowCount* rows of *rowSize* bytes each, in the heap space of the indicated SDR. Note that the content of the table, a two-dimensional array, is a single SDR heap space object of size (*rowCount* x *rowSize*). Returns the address of the new table on success, zero on any error.

void sdr_table_user_data_set(Sdr sdr, Object table, Address userData)
: Sets the "user data" word of *table* to *userData*. Note that *userData* is nominally an Address but can in fact be any value that occupies a single word. It is typically used to point to an SDR object that somehow characterizes the table as a whole, such as an SDR string containing a name.

Address sdr_table_user_data(Sdr sdr, Object table)
: Returns the value of the "user data" word of *table*, or zero on any error.

void sdr_table_dimensions(Sdr sdr, Object table, int *rowSize, int *rowCount)
: Reports on the row size and row count of the indicated table, as specified when the table was created.

void sdr_table_stage(Sdr sdr, Object table)

Stages *table* so that the array it encapsulates may be updated; see the discussion of `sdr_stage()` in sdr(3). The effect of this function is the same as:

```
   sdr_stage(sdr, NULL, (Object) sdr_table_row(sdr, table, 0), 0)
```

Address sdr_table_row(Sdr sdr, Object table, unsigned int rowNbr)

Returns the address of the *rowNbr*th row of *table*, for use in reading or writing the content of this row; returns -1 on any error.

void sdr_table_destroy(Sdr sdr, Object table)

Destroys *table*, releasing all bytes of all rows and destroying the table structure itself. DO NOT use `sdr_free()` to destroy a table, as this would leave the table's content allocated yet unreferenced.

SEE ALSO

sdr(3), sdrlist(3), sdrstring(3)

NAME

sdrwatch - SDR non-volatile data store activity monitor

SYNOPSIS

sdrwatch *sdr_name interval count* [verbose]

DESCRIPTION

For *count* iterations, **sdrwatch** sleeps *interval* seconds and then invokes the `sdr_print_trace()` function (see `sdr(3)`) to report on SDR data storage management activity in the SDR data store identified by *sdr_name* during that interval. If the optional **verbose** parameter is specified, the printed SDR activity trace will be verbose as described in sdr(3).

sdrwatch is helpful for detecting and diagnosing storage space leaks.

EXIT STATUS

0 **sdrwatch** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

Can't attach to sdr.

ION system error. One possible cause is that ION has not yet been initialized on the local computer; run `ionadmin(1)` to correct this.

Can't start trace.

Insufficient ION working memory to contain trace information. Reinitialize ION with more memory.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

sdr(3), psmwatch(1)

NAME

sm2file - shared-memory linked list data extraction test program

SYNOPSIS

sm2file

DESCRIPTION

sm2file stress-tests shared-memory linked list data extraction by retrieving and deleting all text file lines inserted into a shared-memory linked list that is the root object of a PSM partition named "file2sm".

The operation of **sm2file** echoes the cyclical operation of **file2sm**: the EOF lines inserted into the linked list by **file2sm** punctuate the writing of files that are copies of **file2sm**'s original source text file. The name of each file written by **sm2file** is file_copy_*cycleNbr*, where *cycleNbr* is, in effect, the count of EOF lines encountered in the linked list up to the point at which the writing of this file began.

sm2file may catch up with the data ingestion activity of **file2sm**, in which case it blocks (taking the **file2sm** test semaphore) until the linked list is no longer empty.

EXIT STATUS

0 **sm2file** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

can't attach to shared memory

Operating system error. Check errtext, correct problem, and rerun.

Can't manage shared memory.

PSM error. Check for earlier diagnostics describing the cause of the error; correct problem and rerun.

Can't create shared memory list.

PSM error. Check for earlier diagnostics describing the cause of the error; correct problem and rerun.

Can't create semaphore.

ION system error. Check for earlier diagnostics describing the cause of the error; correct problem and rerun.

Can't open output file

Operating system error. Check errtext, correct problem, and rerun.

can't write to output file

Operating system error. Check errtext, correct problem, and rerun.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

file2sm(1), smlist(3), psm(3)

NAME

smlist - shared memory list management library

SYNOPSIS

```
    #include "smlist.h"

    typedef int (*SmListCompareFn)
        (PsmPartition partition, PsmAddress eltData, void *argData);

    typedef void (*SmListDeleteFn)
        (PsmPartition partition, PsmAddress eltData, void *argument);
```

[see description for available functions]

DESCRIPTION

The smlist library provides functions to create, manipulate and destroy doubly-linked lists in shared memory. As with lyst(3), smlist uses two types of objects, *list* objects and *element* objects. However, as these objects are stored in shared memory which is managed by psm(3), pointers to these objects are carried as PsmAddress values. A list knows how many elements it contains and what its first and last elements are. An element knows what list it belongs to and the elements before and after it in its list. An element also knows its content, which is normally the PsmAddress of some object in shared memory.

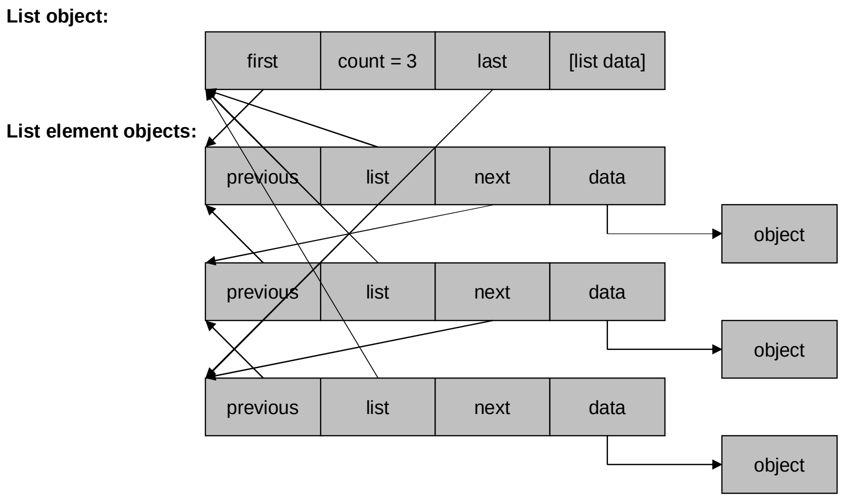


Figure 20 sdrlist data structures

PsmAddress sm_list_create(PsmPartition partition)

Create a new list object without any elements in it, within the memory segment identified by *partition*. Returns the PsmAddress of the list, or 0 on any error.

void sm_list_unwedge(PsmPartition partition, PsmAddress list, int interval)

Unwedge, as necessary, the mutex semaphore protecting shared access to the indicated list. For details, see the explanation of the `sm_SemUnwedge()` function in platform(3).

void sm_list_clear(PsmPartition partition, PsmAddress list, SmListDeleteFn delete, void *argument);

Empty a list. Frees each element of the list. If the *delete* function is non-NULL, that function is called once for each freed element; when called, that function is passed the PsmAddress that is the element's data and the *argument* pointer passed to sm_list_clear().

void sm_list_destroy(PsmPartition partition, PsmAddress list, SmListDeleteFn delete, void *argument);

Destroy a list. Same as sm_list_clear(), but additionally frees the list structure itself.

void sm_list_user_data_set(PsmPartition partition, PsmAddress list, PsmAddress userData);

Set the value of a user data variable associated with the list as a whole. This value may be used for any purpose; it is typically used to store the PsmAddress of a shared memory block containing data (e.g., state data) which the user wishes to associate with the list.

PsmAddress sm_list_user_data(PsmPartition partition, PsmAddress list);

Return the value of the user data variable associated with the list as a whole, or 0 on any error.

int sm_list_length(PsmPartition partition, PsmAddress list);

Return the number of elements in the list.

PsmAddress sm_list_insert(PsmPartition partition, PsmAddress list, PsmAddress data, SmListCompareFn compare, void *arg);

Create a new list element whose data value is *data* and insert it into the given list. If the *compare* function is NULL, the new list element is simply appended to the list; otherwise, the new list element is inserted after the last element in the list whose data value is "less than or equal to" the data value of the new element according to the collating sequence established by *compare*. Returns the PsmAddress of the new element, or 0 on any error.

PsmAddress sm_list_insert_first(PsmPartition partition, PsmAddress list, PsmAddress data);

PsmAddress sm_list_insert_last(PsmPartition partition, PsmAddress list, PsmAddress data);

Create a new list element and insert it at the start/end of a list. Returns the PsmAddress of the new element on success, or 0 on any error. Disregards any established sort order in the list.

PsmAddress sm_list_insert_before(PsmPartition partition, PsmAddress elt, PsmAddress data);

PsmAddress sm_list_insert_after(PsmPartition partition, PsmAddress elt, PsmAddress data);

Create a new list element and insert it before/after a given element. Returns the PsmAddress of the new element on success, or 0 on any error. Disregards any established sort order in the list.

void sm_list_delete(PsmPartition partition, PsmAddress elt, SmListDeleteFn delete, void *argument);

Delete an element from a list. If the *delete* function is non-NULL, that function is called upon deletion of *elt*; when called, that function is passed the PsmAddress that is the element's data value and the *argument* pointer passed to sm_list_delete().

PsmAddress sm_list_first(PsmPartition partition, PsmAddress list);
PsmAddress sm_list_last(PsmPartition partition, PsmAddress list);

Return the PsmAddress of the first/last element in *list*, or 0 on any error.

PsmAddress sm_list_next(PsmPartition partition, PsmAddress elt);
PsmAddress sm_list_prev(PsmPartition partition, PsmAddress elt);

Return the PsmAddress of the element following/preceding *elt* in that element's list, or 0 on any error.

PsmAddress sm_list_search(PsmPartition partition, PsmAddress elt, SmListCompareFn compare, void *arg);

Search a list for an element which matches the given argument. If the *compare* function is non-NULL, the list is assumed to be sorted in the order implied by that function and the function is automatically called once for each element of the list until it returns a value that is greater than or equal to zero (where zero indicates an exact match and a value greater than zero indicates that the list contains no matching element); each time *compare* is called it is passed the PsmAddress that is the element's data value and the *arg* value passed to sm_list_search(). If *compare* is NULL, then the entire list is searched until an element is located whose data value is equal to ((PsmAddress) *arg*). Returns the PsmAddress of the matching element if one is found, 0 otherwise.

PsmAddress sm_list_list(PsmPartition partition, PsmAddress elt);

Return the PsmAddress of the list to which *elt* belongs, or 0 on any error.

PsmAddress sm_list_data(PsmPartition partition, PsmAddress elt);

Return the PsmAddress that is the data value for *elt*, or 0 on any error.

PsmAddress sm_list_data_set(PsmPartition partition, PsmAddress elt, PsmAddress data);

Set the data value for *elt* to *data*, replacing the original value. Returns the original data value for *elt*, or 0 on any error. The original data value for *elt* may or may not have been the address of an object in memory; even if it was, that object was NOT deleted.

Warning: changing the data value of an element of an ordered list may ruin the ordering of the list.

USAGE

A user normally creates an element and adds it to a list by doing the following:

1. obtaining a shared memory block to contain the element's data;
2. converting the shared memory block's PsmAddress to a character pointer;
3. using that pointer to write the data into the shared memory block;
4. calling one of the *sm_list_insert* functions to create the element structure (which will include the shared memory block's PsmAddress) and insert it into the list.

When inserting elements or searching a list, the user may optionally provide a compare function of the form:

```
    int user_comp_name(PsmPartition partition, PsmAddress eltData,
                       void *argData);
```

When provided, this function is automatically called by the smlist function being invoked; when the function is called it is passed the content of a list element (*eltData*, nominally the PsmAddress of an item in shared memory) and an argument, *argData*, which is nominally the address in local memory of some other item in the same format. The user-supplied function normally compares some key values of the two data items and returns 0 if they are equal, an integer less than 0 if *eltData*'s key value is less than that of *argData*, and an integer greater than 0 if *eltData*'s key value is greater than that of *argData*. These return values will produce a list in ascending order. If the user desires the list to be in descending order, the function must reverse the signs of these return values.

When deleting an element or destroying a list, the user may optionally provide a delete function of the form:

```
    void user_delete_name(PsmPartition partition, PsmAddress eltData,
                          void *argData)
```

When provided, this function is automatically called by the smlist function being invoked; when the function is called it is passed the content of a list element (*eltData*, nominally the PsmAddress of an item in shared memory) and an argument, *argData*, which if non-NULL is normally the address in local memory of a data item providing context for the list element deletion. The user-supplied function performs any application-specific cleanup associated with deleting the element, such as freeing the element's content data item and/or other memory associated with the element.

EXAMPLE

For an example of the use of smlist, see the file smlistsh.c in the utils directory of ICI.

SEE ALSO

lyst(3), platform(3), psm(3)

NAME

smlistsh - shared-memory linked list test shell

SYNOPSIS

smlistsh *partition_size*

DESCRIPTION

smlistsh attaches to a region of system memory (allocating it if necessary, and placing it under PSM management as necessary) and offers the user an interactive "shell" for testing various shared-memory linked list management functions.

smlistsh prints a prompt string (": ") to stdout, accepts a command from stdin, executes the command (possibly printing a diagnostic message), then prints another prompt string and so on.

The following commands are supported:

h

The **help** command. Causes **smlistsh** to print a summary of available commands. Same effect as the **?** command.

?

Another **help** command. Causes **smlistsh** to print a summary of available commands. Same effect as the **h** command.

k

The **key** command. Computes and prints an unused shared-memory key, for possible use in attaching to a shared-memory region.

+ *key_value size*

The **attach** command. Attaches **smlistsh** to a region of shared memory. *key_value* identifies an existing shared-memory region, in the event that you want to attach to an existing shared-memory region (possibly created by another **smlistsh** process running on the same computer). To create and attach to a new shared-memory region that other processes can attach to, use a *key_value* as returned by the **key** command and supply the *size* of the new region. If you want to create and attach to a new shared-memory region that is for strictly private use, use -1 as key and supply the *size* of the new region.

-

The **detach** command. Detaches **smlistsh** from the region of shared memory it is currently using, but does not free any memory.

n

The **new** command. Creates a new shared-memory list to operate on, within the currently attached shared-memory region. Prints the address of the list.

s ***list_address***

The **share** command. Selects an existing shared-memory list to operate on, within the currently attached shared-memory region.

a ***element_value***

The **append** command. Appends a new list element, containing *element_value*, to the list on which **smlistsh** is currently operating.

p ***element_value***

The **prepend** command. Prepends a new list element, containing *element_value*, to the list on which **smlistsh** is currently operating.

w

The **walk** command. Prints the addresses and contents of all elements of the list on which **smlistsh** is currently operating.

f ***element_value***

The **find** command. Finds the list element that contains *element_value*, within the list on which **smlistsh** is currently operating, and prints the address of that list element.

d ***element_address***

The **delete** command. Deletes the list element located at *element_address*.

r

The **report** command. Prints a partition usage report, as per psm_report(3).

q

The **quit** command. Detaches **smlistsh** from the region of shared memory it is currently using (without freeing any memory) and terminates **smlistsh**.

EXIT STATUS

0 **smlistsh** has terminated.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

No diagnostics apply.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

psm(3)

NAME

tcpcli - TCP-based BP convergence layer input task

SYNOPSIS

tcpcli *local_hostname*[:*local_port_nbr*]

DESCRIPTION

tcpcli is a background "daemon" task comprising 1 + N threads: one that handles TCP connections from remote **tcpclo** tasks, spawning sockets for data reception from those tasks, plus one input thread for each spawned socket to handle data reception over that socket.

The connection thread simply accepts connections on a TCP socket bound to *local_hostname* and *local_port_nbr* and spawns reception threads. The default value for *local_port_nbr*, if omitted, is 5000.

Each reception thread receives bundles over the associated connected socket. Each bundle received on the connection is preceded by its length, a 32-bit unsigned integer in network byte order. The received bundles are passed to the bundle protocol agent on the local ION node.

tcpcli is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol; the text of the command that is used to spawn the task must be provided at the time the "tcp" convergence layer protocol is added to the BP database. The convergence layer input task is terminated by **bpadmin** in response to an 'x' (STOP) command. **tcpcli** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the TCP convergence layer protocol.

EXIT STATUS

0 **tcpcli** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **tcpcli**.

1 **tcpcli** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart **tcpcli**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

tcpcli can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

No such tcp duct.

> No TCP induct matching *local_hostname* and *local_port_nbr* has been added to the BP database. Use **bpadmin** to stop the TCP convergence-layer protocol, add the induct, and then restart the TCP protocol.

CLI task is already started for this duct.

> Redundant initiation of **tcpcli**.

Can't get IP address for host

> Operating system error. Check errtext, correct problem, and restart TCP.

Can't open TCP socket

> Operating system error. Check errtext, correct problem, and restart TCP.

Can't initialize socket

> Operating system error. Check errtext, correct problem, and restart TCP.

tcpcli can't create access thread

> Operating system error. Check errtext, correct problem, and restart TCP.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), tcpclo(1)

NAME

tcpclo - TCP-based BP convergence layer adapter output task

SYNOPSIS

tcpclo *remote_hostname*[:*remote_port_nbr*]

DESCRIPTION

tcpclo is a background "daemon" task that connects to a remote node's TCP socket at *remote_hostname* and *remote_port_nbr* and then begins extracting bundles from the queues of bundles ready for transmission via TCP to this remote bundle protocol agent and transmitting those bundles over the connected socket to that node. Each transmitted bundle is preceded by its length, a 32-bit unsigned integer in network byte order. If not specified, *remote_port_nbr* defaults to 5000.

Note that **tcpclo** is not a "promiscuous" convergence layer daemon: it can transmit bundles only to the node to which it is connected, so scheme configuration directives that cite this outduct need only provide the protocol name and the outduct name as specified on the command line when **tcpclo** is started.

tcpclo is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **tcpclo** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the TCP convergence layer protocol.

EXIT STATUS

0
: **tcpclo** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart the BRSC protocol.

1
: **tcpclo** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart the BRSC protocol.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

tcpclo can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

No such tcp duct.

> No TCP outduct with duct name matching *remote_hostname* and *remote_port_nbr* has been added to the BP database. Use **bpadmin** to stop the TCP convergence-layer protocol, add the outduct, and then restart the TCP protocol.

CLO task is already started for this duct.

> Redundant initiation of **tcpclo**.

Can't get IP address for host

> Operating system error. Check errtext, correct problem, and restart TCP.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), tcpcli(1)

NAME

udpcli - UDP-based BP convergence layer input task

SYNOPSIS

udpcli *local_hostname*[:*local_port_nbr*]

DESCRIPTION

udpcli is a background "daemon" task that receives UDP datagrams via a UDP socket bound to *local_hostname* and *local_port_nbr*, extracts bundles from those datagrams, and passes them to the bundle protocol agent on the local ION node.

If not specified, port number defaults to 5001.

The convergence layer input task is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol; the text of the command that is used to spawn the task must be provided at the time the "udp" convergence layer protocol is added to the BP database. The convergence layer input task is terminated by **bpadmin** in response to an 'x' (STOP) command. **udpcli** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the UDP convergence layer protocol.

EXIT STATUS

0 **udpcli** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **udpcli**.

1 **udpcli** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart **udpcli**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

udpcli can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

No such udp duct.

> No UDP induct matching *local_hostname* and *local_port_nbr* has been added to the BP database. Use **bpadmin** to stop the UDP convergence-layer protocol, add the induct, and then restart the UDP protocol.

CLI task is already started for this duct.

> Redundant initiation of **udpcli**.

Can't get IP address for host

> Operating system error. Check errtext, correct problem, and restart UDP.

Can't open UDP socket

> Operating system error. Check errtext, correct problem, and restart UDP.

Can't initialize socket

> Operating system error. Check errtext, correct problem, and restart UDP.

udpcli can't create receiver thread

> Operating system error. Check errtext, correct problem, and restart UDP.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), udpclo(1)

NAME

udpclo - UDP-based BP convergence layer output task

SYNOPSIS

udpclo

DESCRIPTION

udpclo is a background "daemon" task that extracts bundles from the queues of bundles ready for transmission via UDP to remote bundle protocol agents, encapsulates them in UDP datagrams, and sends those datagrams to the appropriate remote UDP sockets as indicated by the host names and UDP port numbers (destination induct names) associated with the bundles by the routing daemons that enqueued them.

Note that **udpclo** is a "promiscuous" CLO daemon, able to transmit bundles to any UDP destination induct. Its duct name is '*' rather than the induct name of any single UDP destination induct to which it might be dedicated, so scheme configuration directives that cite this outduct must provide destination induct IDs. For the UDP convergence-layer protocol, destination induct IDs are identical to induct names, i.e., they are of the form *local_hostname*[:*local_port_nbr*].

udpclo is spawned automatically by **bpadmin** in response to the 's' (START) command that starts operation of the Bundle Protocol, and it is terminated by **bpadmin** in response to an 'x' (STOP) command. **udpclo** can also be spawned and terminated in response to START and STOP commands that pertain specifically to the UDP convergence layer protocol.

EXIT STATUS

0 **udpclo** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **bpadmin** to restart **udpclo**.

1 **udpclo** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **bpadmin** to restart **udpclo**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

udpclo can't attach to BP.

> **bpadmin** has not yet initialized Bundle Protocol operations.

No memory for UDP buffer in udpclo.

> ION system error. Check errtext, correct problem, and restart UDP.

No such udp duct.

> No UDP outduct with duct name '*' has been added to the BP database. Use **bpadmin** to stop the UDP convergence-layer protocol, add the outduct, and then restart the UDP protocol.

CLO task is already started for this engine.

> Redundant initiation of **udpclo**.

CLO can't open UDP socket

> Operating system error. Check errtext, correct problem, and restart **udpclo**.

CLO `write()` error on socket

> Operating system error. Check errtext, correct problem, and restart **udpclo**.

Bundle is too big for UDP CLA.

> Configuration error: bundles that are too large for UDP transmission (i.e., larger than 65535 bytes) are being enqueued for **udpclo**. Change routing.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

bpadmin(1), bprc(5), udpcli(1)

NAME

udplsi - UDP-based LTP link service input task

SYNOPSIS

udplsi {*local_hostname* | @}[:*local_port_nbr*]

DESCRIPTION

udplsi is a background "daemon" task that receives UDP datagrams via a UDP socket bound to *local_hostname* and *local_port_nbr*, extracts LTP segments from those datagrams, and passes them to the local LTP engine. Host name "@" signifies that the host name returned by `hostname(1)` is to be used as the socket's host name. If not specified, port number defaults to 5001.

The link service input task is spawned automatically by **ltpadmin** in response to the 's' command that starts operation of the LTP protocol; the text of the command that is used to spawn the task must be provided as a parameter to the 's' command. The link service input task is terminated by **ltpadmin** in response to an 'x' (STOP) command.

EXIT STATUS

0 **udplsi** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **ltpadmin** to restart **udplsi**.

1 **udplsi** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **ltpadmin** to restart **udplsi**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

udplsi can't initialize LTP.

> **ltpadmin** has not yet initialized LTP protocol operations.

LSI task is already started.

> Redundant initiation of **udplsi**.

LSI can't open UDP socket

> Operating system error. Check errtext, correct problem, and restart **udplsi**.

LSI can't initialize socket

> Operating system error. Check errtext, correct problem, and restart **udplsi**.

LSI can't create receiver thread

> Operating system error. Check errtext, correct problem, and restart **udplsi**.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ltpadmin(1), udplso(1)

NAME

udplso - UDP-based LTP link service output task

SYNOPSIS

udplso {*remote_engine_hostname* | @}[:*remote_port_nbr*] *remote_engine_nbr*

DESCRIPTION

udplso is a background "daemon" task that extracts LTP segments from the queue of segments bound for the indicated remote LTP engine, encapsulates them in UDP datagrams, and sends those datagrams to the indicated UDP port on the indicated host. If not specified, port number defaults to 5001.

Each "span" of LTP data interchange between the local LTP engine and a neighboring LTP engine requires its own link service output task, such as **udplso**. All link service output tasks are spawned automatically by **ltpadmin** in response to the 's' command that starts operation of the LTP protocol, and they are all terminated by **ltpadmin** in response to an 'x' (STOP) command.

EXIT STATUS

0 **udplso** terminated normally, for reasons noted in the **ion.log** file. If this termination was not commanded, investigate and solve the problem identified in the log file and use **ltpadmin** to restart **udplso**.

1 **udplso** terminated abnormally, for reasons noted in the **ion.log** file. Investigate and solve the problem identified in the log file, then use **ltpadmin** to restart **udplso**.

FILES

No configuration files are needed.

ENVIRONMENT

No environment variables apply.

DIAGNOSTICS

The following diagnostics may be issued to the **ion.log** log file:

udplso can't initialize LTP.

> **ltpadmin** has not yet initialized LTP protocol operations.

No such engine in database.

> *remote_engine_nbr* is invalid, or the applicable span has not yet been added to the LTP database by **ltpadmin**.

LSO task is already started for this engine.

> Redundant initiation of **udplso**.

LSO can't open UDP socket

> Operating system error. Check errtext, correct problem, and restart **udplso**.

LSO can't connect UDP socket

> Operating system error. Check errtext, correct problem, and restart **udplso**.

Segment is too big for UDP LSO.

> Configuration error: segments that are too large for UDP transmission (i.e., larger than 65535 bytes) are being enqueued for **udplso**. Use **ltpadmin** to change maximum segment size for this span.

BUGS

Report bugs to <ion-bugs@korgano.eecs.ohiou.edu>

SEE ALSO

ltpadmin(1), ltpmeter(1), udplsi(1)

NAME

zco - library for manipulating zero-copy objects

SYNOPSIS

```
#include "zco.h"

typedef enum
{
    ZcoFileSource = 1,
    ZcoSdrSource
} ZcoMedium;
```

[see description for available functions]

DESCRIPTION

"Zero-copy objects" (ZCOs) are abstract data access representations designed to minimize I/O in the encapsulation of application source data within one or more layers of communication protocol structure. ZCOs are constructed within the heap space of an SDR to which implementations of all layers of the stack must have access. Each ZCO contains information enabling access to the source data object, together with (a) a linked list of zero or more "extents" that reference portions of this source data object and (b) linked lists of protocol header and trailer capsules. The concatenation of the headers (in ascending stack sequence), source data object extents, and trailers (in descending stack sequence) is what is to be transmitted.

The source data object may be either a file (identified by pathname stored in a "file reference" object in SDR heap) or an array of bytes in SDR heap space (identified by SDR address). Each protocol header or trailer capsule indicates the length and the address (within SDR heap space) of a single protocol header or trailer at some layer of the stack.

ZCOs are not directly exposed to applications. Instead, applications operate on ZcoReferences; multiple ZcoReferences may, invisibly to the applications, refer to the same ZCO. When the last reference to a given ZCO is destroyed -- either explicitly or (when the entire ZCO has been read and copied via this reference) implicitly -- the ZCO itself is automatically destroyed.

But NOTE: to reduce code size and complexity and minimize processing overhead, the ZCO functions are NOT mutexed. It is in general NOT SAFE for multiple threads or processes to be operating on the same ZCO concurrently, whether using the same Zco reference or multiple references. However, multiple threads or processes of overlying protocol (e.g., multiple final destination endpoints) MAY safely use different ZcoReferences to receive the source data of a ZCO concurrently once the length of that data -- with regard to that layer of protocol -- has been firmly established.

Note also that ZCO can more broadly be used as a general-purpose reference counting system for non-volatile data objects, where a need for such a system is identified.

Object zco_create_file_ref(Sdr sdr, char *pathName, char *cleanupScript)

> Creates and returns a new file reference object, which can be used as the source data extent location for creating a ZCO whose source data object is the file identified by *pathName*. *cleanupScript*, if not NULL, is invoked at the time that the last ZCO that cites this file reference is destroyed [normally upon delivery either down to the "ZCO transition layer" of the protocol stack or up to a ZCO-capable application]. Maximum length of *cleanupScript* is 255. Returns SDR location of file reference object on success, 0 on any error.

void zco_destroy_file_ref(Sdr sdr, Object fileRef)

> If the file reference object residing at location *fileRef* within the indicated Sdr is no longer in use (no longer referenced by any ZCO), destroys this file reference object immediately. Otherwise, flags this file reference object for destruction as soon as the last reference to it is removed.

Object zco_create(Sdr sdr, ZcoMedium firstExtentSourceMedium, Object firstExtentLocation, unsigned int firstExtentOffset, unsigned int firstExtentLength)

> Creates a new ZCO. *firstExtentLocation* and *firstExtentLength* must either both be zero (indicating that `zco_append_extent()` will be used to insert the first source data extent later) or else both be non-zero. If *firstExtentLocation* is non-zero, then (a) *firstExtentLocation* must be the SDR location of a file reference object if *firstExtentSourceMedium* is ZcoFileSource and must otherwise be the SDR location of the source data itself, and (b) *firstExtentOffset* indicates how many leading bytes of the source data object should be skipped over when adding the initial source data extent to the new ZCO. On success, returns the SDR location of the first reference to the new ZCO. Returns 0 on any error.

void zco_append_extent(Sdr sdr, Object zcoRef, ZcoMedium sourceMedium, Object location, unsigned int offset, unsigned int length)

> Appends the indicated source data extent to the indicated ZCO, as described for zco_create(). Both the *location* and *length* of the source data must be non-zero.

void zco_prepend_header(Sdr sdr, Object zcoRef, char *header, unsigned int length)
void zco_append_trailer(Sdr sdr, Object zcoRef, char *trailer, unsigned int length)
void zco_discard_first_header(Sdr sdr, Object zcoRef)
void zco_discard_last_trailer(Sdr sdr, Object zcoRef)

> These functions attach and remove the ZCO's headers and trailers. *header* and *trailer* are assumed to be arrays of octets, not necessarily text. Attaching a header or trailer causes it to be written to the SDR.

Object zco_add_reference(Sdr sdr, Object zcoRef)

> Creates an additional reference to the referenced ZCO and adds 1 to that ZCO's reference count. Returns SDR location of the new ZcoReference on success, 0 on any error.

void zco_destroy_reference(Sdr sdr, Object zcoRef)

> Explicitly destroys the indicated Zco reference. When the ZCO's last reference is destroyed, the ZCO itself is automatically destroyed.

unsigned int zco_length(Sdr sdr, Object zcoRef)

Returns length of entire ZCO, including all headers and trailers and all source data extents.

unsigned int zco_source_data_length(Sdr sdr, Object zcoRef)

Returns length of entire ZCO minus the lengths of all attached headers and trailers.

void zco_start_transmitting(Sdr sdr, Object zcoRef, ZcoReader *reader)

Used by underlying protocol layer to start extraction of an outbound ZCO's bytes (both from header and trailer capsules and from source data extents) for "transmission" -- i.e., the copying of bytes into a memory buffer for delivery to some non-ZCO-aware protocol implementation. Initializes reading after the last byte of the total concatenated ZCO object that has already been read via this ZCO reference, if any. Populates *reader*, which is used to keep track of "transmission" progress via this ZCO reference.

int zco_transmit(Sdr sdr, ZcoReader *reader, unsigned int length, char *buffer)

Copies *length* as-yet-uncopied bytes of the total concatenated ZCO (referenced by *reader*) into *buffer*. Returns the number of bytes copied, or -1 on any error.

void zco_stop_transmitting(Sdr sdr, ZcoReader *reader)

Terminates extraction of this outbound ZCO's bytes for transmission.

void zco_start_receiving(Sdr sdr, Object zcoRef, ZcoReader *reader)

Used by overlying protocol layer to start extraction of an inbound ZCO's bytes for "reception" -- i.e., the copying of bytes into a memory buffer for delivery to a protocol header parser, to a protocol trailer parser, or to the ultimate recipient (application). Initializes reading of headers, source data, and trailers after the last byte of such content that has already been read via this ZCO reference, if any. Populates *reader*, which is used to keep track of "reception" progress via this ZCO reference.

int zco_receive_source(Sdr sdr, ZcoReader *reader, unsigned int length, char *buffer)

Copies *length* as-yet-uncopied bytes of source data from ZCO extents into *buffer*. Returns number of bytes copied, or -1 on any error.

void zco_stop_receiving(Sdr sdr, ZcoReader *reader)

Terminates extraction of this inbound ZCO's bytes for reception.

SEE ALSO

sdr(3)