



TRDP

Train Real Time Data Protocol

System Architecture & Design Specification

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DOCUMENT SUMMARY SHEET

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Participants

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V2	10 July 13	Bernd Löhr	Added more VOS, Statistics, Marshalling functional descriptions and diagrams. Added build settings for make, Lint, Visual C and Xcode

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1. Introduction

1.1. Purpose

This document describes the basic design of the TRDP protocol stack and may aid in extending and including further protocol features apart from process data handling.

1.2. Intended Audience

The intended audience is the programmers, who want to add additional features and/or want to support more target systems.

1.3. References/Related Documents

Reference	Number	Title
[1]	IEC51375-3-2	TRDP Protocol (Annex A)
[2]	TCN-TRDP2-D-BOM-033-xx	TRDP Reference Manual (generated from source code by Doxygen)
[3]	RFC4122	UUID (http://www.ietf.org/rfc/rfc4122.txt)

Table 1: References

1.4. Abbreviations and Definitions

Abbreviation	Definition
API	Application Programming Interface
ComID	Communication Identifier – determines message content (PD and MD)
IDE	Integrated Development Environment
MD	Message Data
PD	Process Data
POSIX	Portable Operating System Interface for uniX
OS	Operating System
QoS	Quality of Service (= Type of Service, TOS)
TAU	TRDP Application Utility (Function calling prefix)
TCP	Transmission Control Protocol
TLC	TRDP Light Common (Function calling prefix)
TLP	TRDP Light Process data (Function calling prefix)
TLM	TRDP Light Message data (Function calling prefix)
TOS	Type of Service, Ethernet header value
TTL	Time To Live
UDP	User Datagram Protocol
UUID	Universally Unique IDentifier
VOS	Virtual Operating System

Table 2: Abbreviations and Definitions

2. System Description

2.1.1. Overview

The TRDP prototype stack consists of the following functional groups:

- Application/Session layer handling
- Process Data handling (publish/subscribe)
- Optional Message Data handling
- Statistics handling
- Virtual Operating System

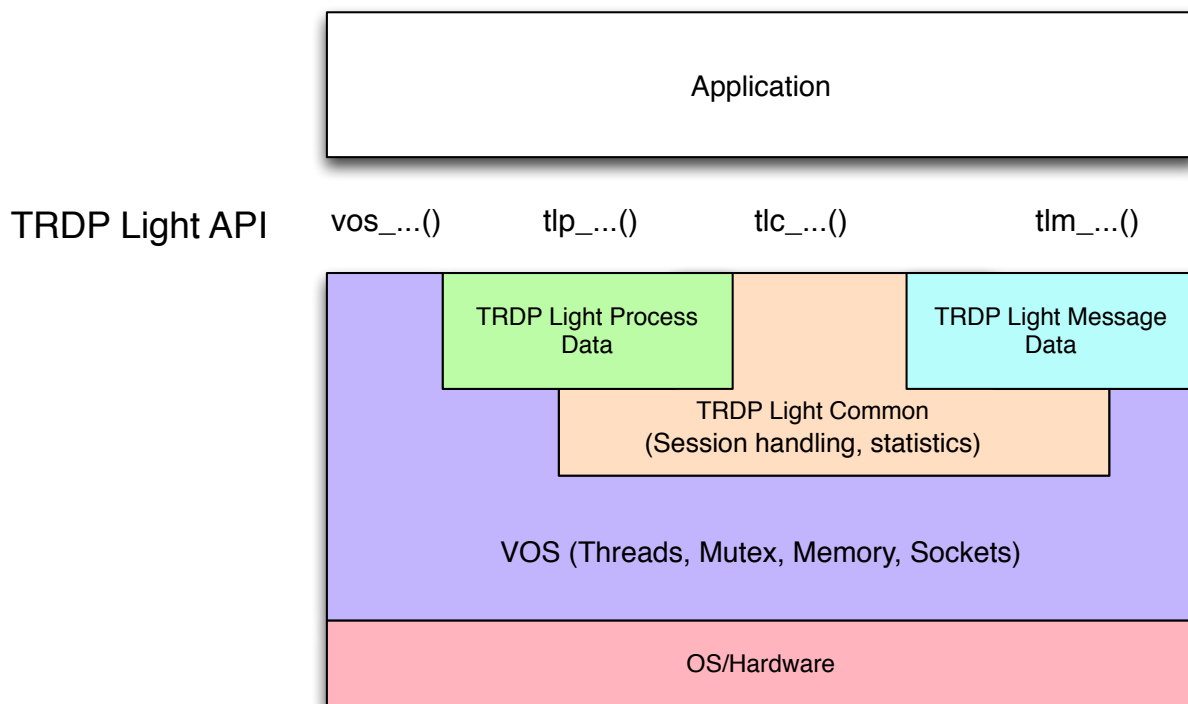


Figure 1: TRDP Functional Layers

2.1.2. Application Session layer handling

The application session layer functions handle the basic resource management – they register a session of a client application and control the overall behaviour and options for that session. The same application can have several sessions open at the same time.

Note: The term ‘session’ can either apply to the application’s session with the TRDP stack, or to a message data communication session (2.1.4). Within this chapter 2.1.2 the term ‘session’ will refer to the application’s session.

Each session is internally represented by an instance of the data object `TRDP_SESSION_T`. Sessions are maintained by a singly linked list and are protected by mutexes.

The first function an application must call before any other call to the protocol stack can succeed is `tlc_init()`.

`tlc_init()` will initialize the VOS memory subsystem using the supplied memory configuration parameters and will create a recursive mutex to protect concurrent access to the session queue. The selected memory scheme will be valid for all subsequently opened application sessions until `tlc_terminate()` is called.

`tlc_terminate()` will close all open sessions, release the allocated memory area and delete the mutex.

`tlc_openSession()` creates a new session element, initializes it with the supplied default parameters and creates a recursive session mutex to protect concurrent access to the session data.

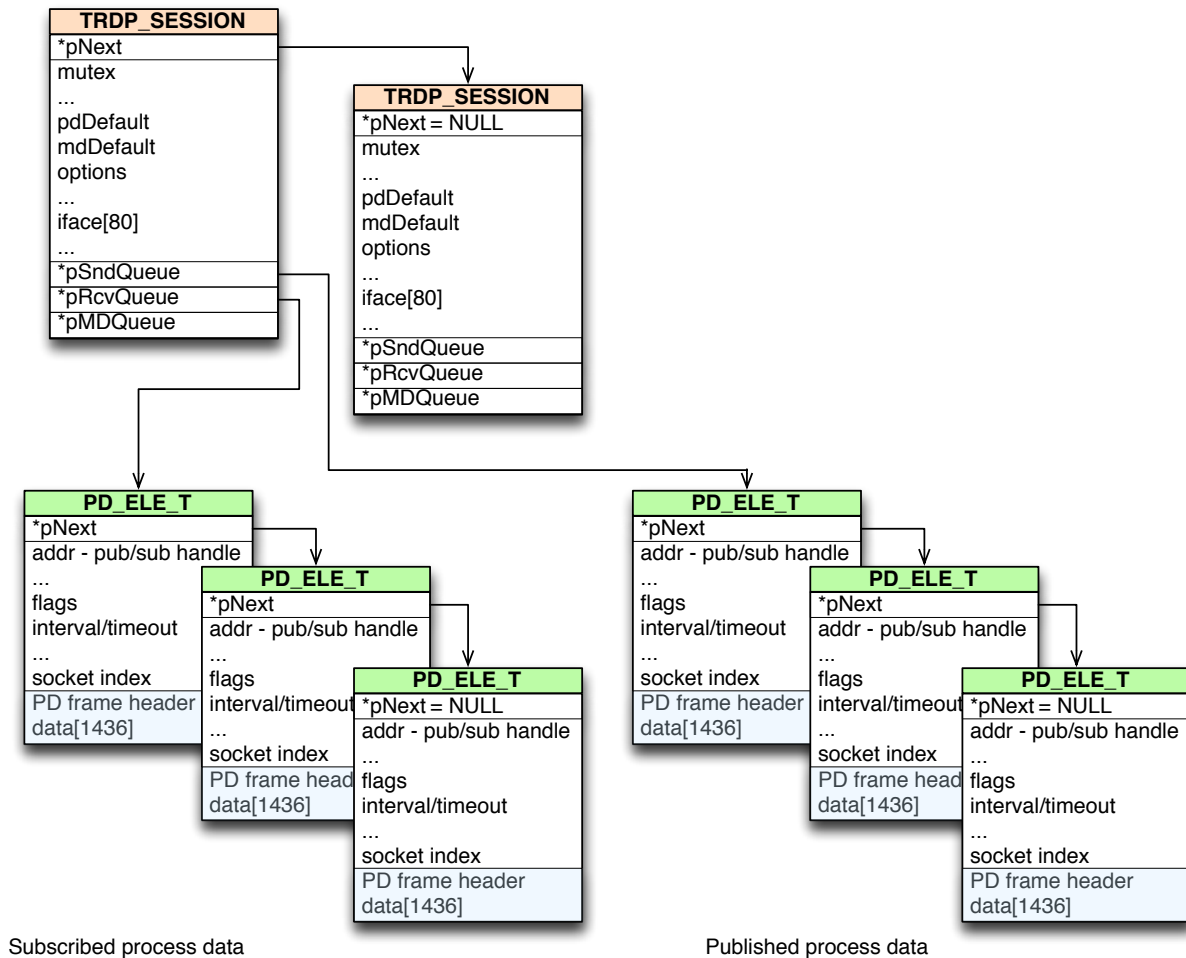
On successful initialization a session handle will be returned and will be used by the caller to select the right session when calling all session related functions (`tlp_...`, `tlm_...`, `tlc_setTopoCount`). If the application quits or doesn't need the session anymore, it should close it by calling `tlc_closeSession()` then `tlc_terminate()`.

The session handle is actually the opaque pointer to the memory area reserved for the session's internal management data (`TRDP_SESSION_T`) and must be checked for validity before dereferencing (using `isValidSession()`).

To allow different packet options mainly for PD, like different TTLs and QoS values, and opening sockets is quite expensive, the number of concurrent sockets should be limited. In `tlc_openSession()` a pool of socket descriptors is created and maintained. If a new publish call is done, the pool of already open sockets is searched for the same send parameters and source address. Either a new or an already open socket will be returned and a reference counter incremented. Handling of the socket pool is done through the functions `trdp_initSockets()`, `trdp_requestSocket()` and `trdp_releaseSocket()` in `trdp_utils.c`. A maximum of 80 sockets per session may be handled by default. The actual usable maximum number of sockets depends on the selected target system (VOS) and might probably be less. The VOS defined `VOS_MAX_SOCKET_CNT` determines the maximum socket count.

Each application session will handle network traffic on one selected interface, determined by its IP address, only. This allows for multi-session, multi-homing usage (but it might not be supported by every target). If a target does not support a certain option at runtime, a referring error message will be generated.

Figure 2 shows the basic data layout of a two-session application. The first session already has three publishers and three subscribers allocated, the second application session has none (Actually, every application session initially has one publisher for statistical data (ComID 35) and one subscription to ComID 31. See 2.1.6)


Figure 2: Main Data Structures

There are two additional, session related functions to mention:

`tlc_reinitSession` should be called by the application when it detects a link-up event.

It will re-join any multicast groups, which might have been dropped in between.

`tlc_setTopoCount` will set a new topology counter to be used to verify incoming traffic.

2.1.3. Process Data

For process data handling, two queues are maintained – a send and a receive queue. The send queue is filled or diminished by `tlp_publish()` resp. `tlp_unpublish()`, likewise the receive queue is filled or diminished by `tlp_subscribe()` and `tlp_unsubscribe()`.

2.1.3.1. Publish

On publishing, the caller supplies all necessary data to construct the PD header:

- `comId`
- current topology counter
- source and destination IP address
- interval
- send parameters
- pointer to initial data

`tlp_publish()` will request an adequate socket and will create and insert a new queue element into the send queue of the used session.

The needed data buffer is allocated through `vos_memAlloc()` and will be freed only when the PD is un-published.

Data is initially copied into the element data buffer by calling `tlp_put()`. Data can be updated at any time using `tlp_put()`. It will be sent only when `tlc_process()` is called, though! `tlp_put()` will copy the data into the internally managed data buffer by either doing a 1:1 memory copy or calling a supplied marshalling function to translate the local data representation into network format (see 2.1.7).

Any published packet can be sent using an interval (timeToGo, PUSH pattern) or on request (PULL pattern) or both. To prevent having discontinuous sequence counters in the case pushing of PDs is interrupted by PULL requests, two separate sequence counters must be maintained with each `PD_ELEMENT`.

Traffic shaping

If traffic shaping is enabled, the starting time values of all packets must be evenly distributed over the largest used interval. Re-scheduling of the packet send times must take place each time new a PD is published or un-published.

The duration of PD packets on a 100MBit/s network ranges from 3 μ s to 150 μ s max. Because a cyclic thread scheduling below 5ms would put a too heavy load on the system, and PD packets cannot become larger than 1472 (+ UDP header) bytes, we need not account for differences in packet sizes.

Another factor is the differences in intervals for different packets: We should only change the starting times of the packets within half the interval time. Otherwise a late addition of packets could lead to timeouts of already queued packets.

The input requirements for traffic shaping are contradictory: The outgoing traffic should be evenly distributed over the time but the intervals of the packets to send may be of any value. For this reason only the starting time of the packets may be adjusted. Packet agglomeration at repeating times cannot be avoided and depends on the ratio and range of the interval times of all pending PDs!

Scheduling will be computed based on the smallest interval time in `tlc_getInterval()`.

2.1.3.2. Subscribe

On subscribing, the functional flow is very similar to publishing; a new element is inserted into the receive queue instead and an eventual multicast group may be joined.

On `tlp_unsubscribe()` the subscription element will be released from the queue and the allocated memory (and the frame buffer) will be freed.

The data buffer for receiving PDs will always be allocated with the maximum data size (1436 + 36). This is different to message data handling, where the header will be peeked at first to find the announced data length, then a buffer of the correct size is allocated and the packet is read.

2.1.4. Message Data

Message data handling is a compile time option, which is controlled by `#define MD_SUPPORT=1`.

All message data handling and most MD related data definitions are guarded by `#if MD_SUPPORT` and the corresponding `#endif`.

Tbd

2.1.5. Processing

`tlc_process()` is the main work function. It is the only function where sending and receiving takes place. Depending on the selected mode, whether blocking/non-blocking, using the `select()` function or polling, receiving process and message data is done.

`tlc_process()` has to be called at least at the lowest time interval that has been defined when publishing process data. The send queue is checked for the next pending packet – if it is due, `trdp_pdSend()` or `trdp_mdSend()` will be called.

Next job is to look for timeouts of subscribed packets. If a late packet is detected, the `PD_ELE` entry is marked as overdue and, if callbacks are enabled, the supplied user function will be called.

If blocking mode is on (`select()` is used), the receive queue is scanned for the ready socket descriptor and `trdp_pdReceive()` is called, getting new packet data. Again, the user-supplied callback may be called.

After process data has been handled, optionally message data will be processed depending on the state of the transaction kept in the relevant `mdQueue` element.

Note: Callbacks will only be called from within `tlc_process()`. To avoid recursion, `tlc_process()` must not be called from within a callback.

To support the application in determining the right time to call `tlc_process()` and to minimize CPU usage through polling, the function `tlc_getInterval()` checks all queues for pending packets to send or receive and computes and returns the next time when `tlc_process()` must be called before any timing constraints may hit. The application should always call `tlc_getInterval()`, wait for the amount of the reported time and then call `tlc_process()` in its main loop.

The sample calling sequences in Figure 3 shows a basic functional flow for a publisher only. Before entering the main loop, the application has to open a session and publishes PD. The process data will not be sent immediately but a `PD_ELE_T` will be queued into the send queue. The send queue will be searched for pending packets in `tlc_getInterval()` to set the due time. The returned time value should be used by the application to wait before calling `tlc_process()`. If `MD_SUPPORT==1`, message data session timeouts must be considered as well.

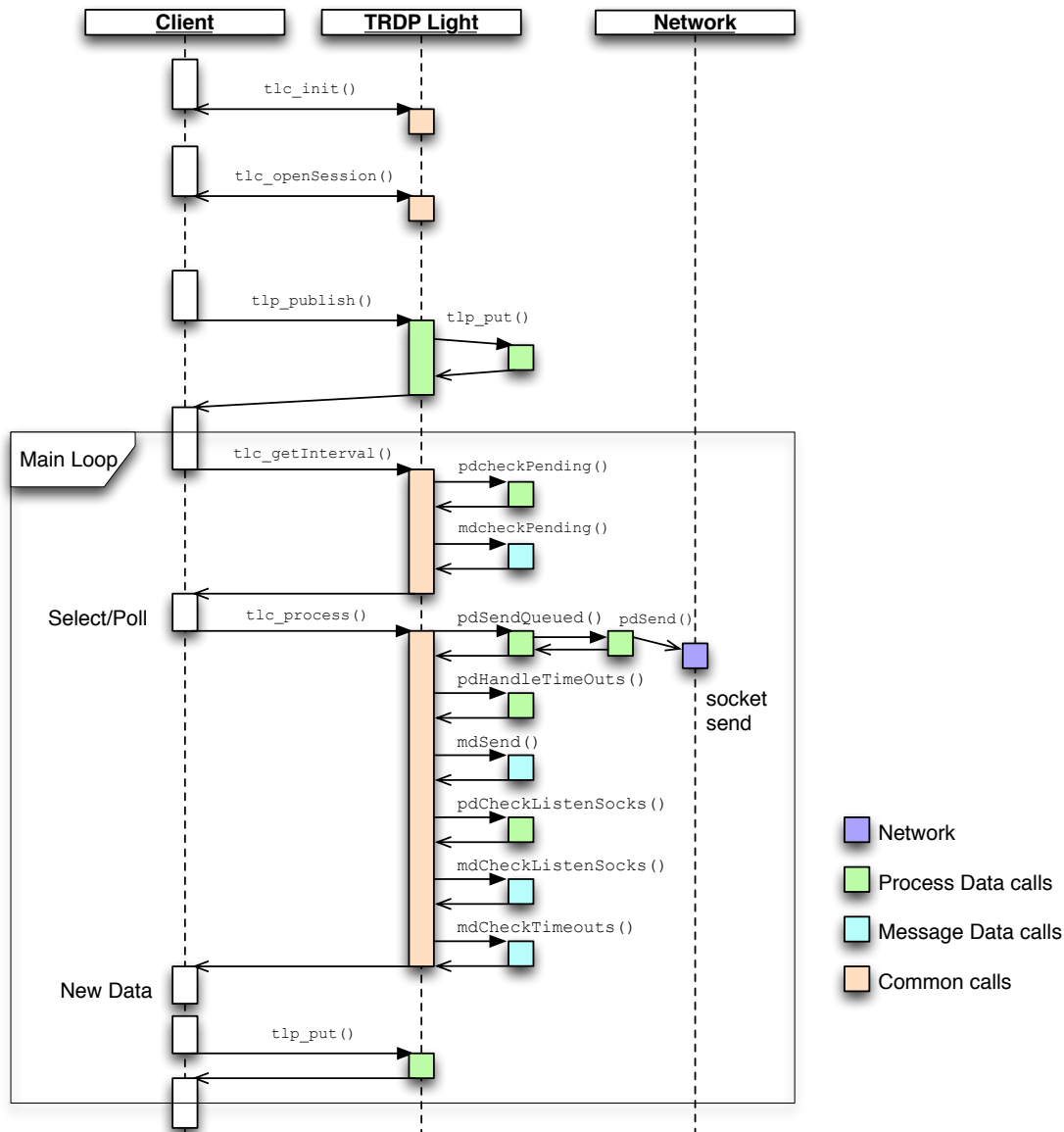


Figure 3: Publish and Send Process Data

When receiving data (subscribe), data can be fetched either by using callbacks (out of `tlc_process()`) or at any time by polling using `tlp_get()`.

Figure 4 shows a basic sending and receiving sequence of process data:

- `pdcheckPending()` and `mdcheckPending()` return in a file descriptor set which sockets are used and the minimum time when the next packets are due to be sent.
- `pdSendQueued()` walks through the list of published PDs and calls the socket send function (through `trdp_pdSend()` and `vos_sockSendUDP()`)
- `pdHandleTimeOuts()` detects missing PDs and might call back to indicate a timeout error
- `pdCheckListenSocks()` checks the supplied file descriptor set for read-ready sockets and reads the packet from the socket (via `pdReceive()` and `vos_sockReceiveUDP()`). In case of receive errors like FCS mismatch, I/O error

- etc. the user supplied callback function will be called. Internally the error will be saved in the PD_ELEMENT anyway.
- The md-prefixed functions will basically do the same for message data, except that there will be a listener queue, a receive queue and a send queue with special handling for TCP and UDP based communication sessions.

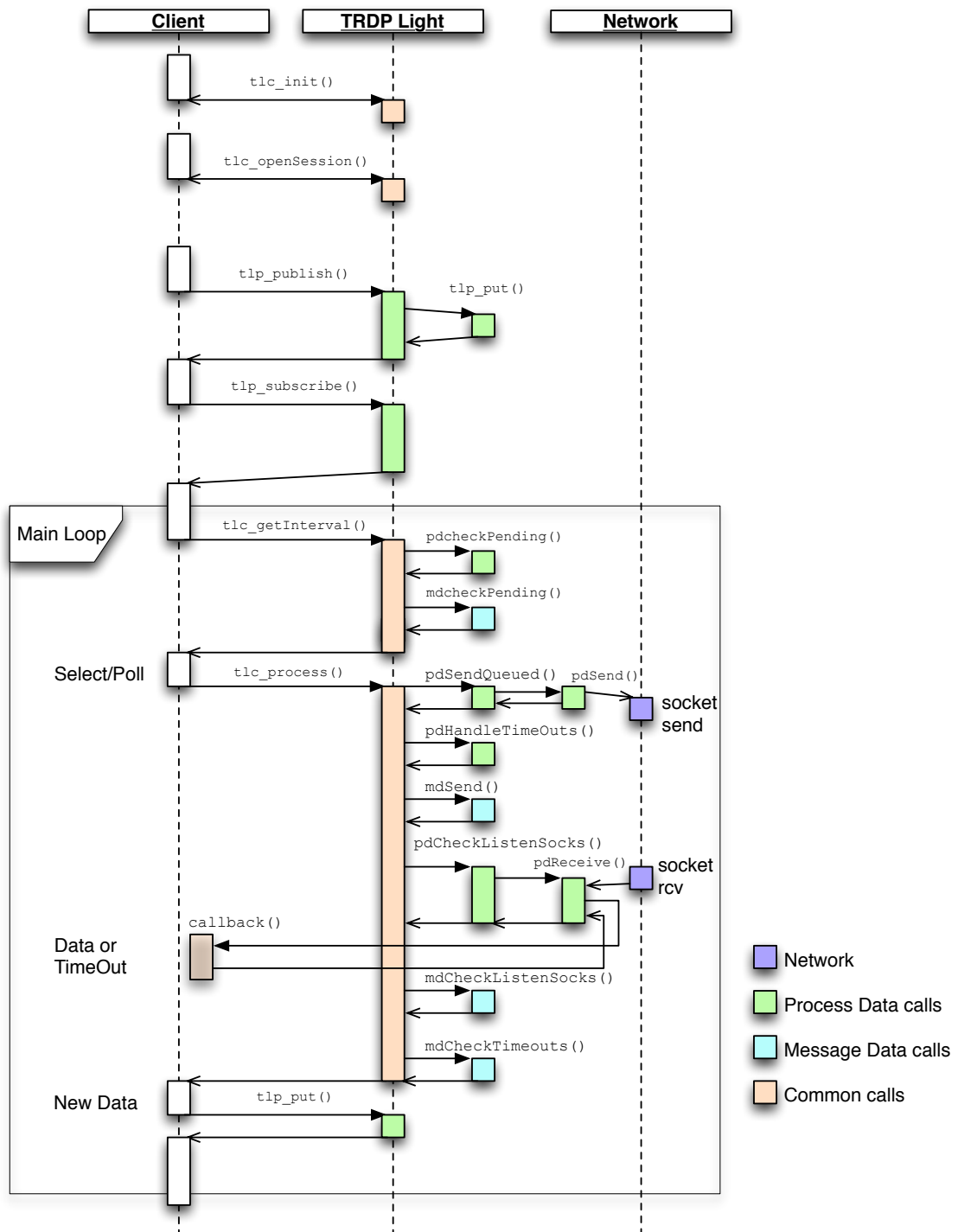


Figure 4: Sample Call Sequence for Subscription

If a callback is not provided by the user application (and non-blocking mode is set), it may collect new data by polling the `tlp_get()` function. `tlp_get()` will call `pdReceive()` repeatedly as long as data can be read from the PD socket. After testing for possible timeout of data, `tlp_get()` transfers the data to the user supplied buffer. Optionally, as with `tlp_put()`, a user supplied de-marshalling function will be used to copy the data while aligning and correcting the endianness to maintain the host system's data representation (see 2.1.7). If the timeout behaviour for this PD is set to `TRDP_TO_SET_TO_ZERO`, the user-supplied buffer is zeroed out (`memset()`).

Detailed description of the PD communication-related functions can be found in [2].

2.1.6. Statistics

All functions effectively taking part in communication will update the counters kept in their session variable `TRDP_STATISTICS_T stats`. Functions referring to statistics are collected in the file `trdp_stats.c`.

All receiving and sending functions have access to the session element of their context and can increment/decrement the corresponding statistics values while operating. Nevertheless some statistics values will be computed only on demand – either by the application calling `tlc_getStatistics()` or a remote client using a ComID 31 control packet to “PULL” ComID 35 statistics data. This applies to the time fields (`timeStamp`, `upTime`, `statisticTime`), the current memory usage and the actual number of publishers and subriptions.

In `trdp_pdReceive()`, when receiving a message of type ‘Pr’ with ComID 31, the statistics packet is updated and sent directly to the requester by setting the private element flag `TRDP_REQ_2B_SENT` and calling `pdSendQueued()`.

2.1.7. Marshalling

The marshalling/un-marshalling functions are optional utilities independent from the rest of the TRDP stack, but are designed to be easily used as an integrated extension. When opening an application session, pointers to marshalling/un-marshalling functions can be provided to the TRDP stack, which in turn will use the provided functions to effectively copy data between the internal network data buffer and the applications data buffer on request only. This will work automatically when using `tlp_pdGet()` and `tlp_pdPut()`, but must be inserted separately when data is read using callbacks.

All marshalling-handling functions are defined in `tau_marshall.c` and are declared in the header file `tau_marshall.h`.

The marshalling functions need to know:

- the host compiler's alignment for all defined data types (VOS defined macro `ALIGNOF()`)
- the host compiler's size of all defined data types (operator `sizeof()`)
- the host computer's endianness – provided by a compile-time flag (`__BIG_ENDIAN__`)
- the structural definition of the packet to process (`comID`) – provided by the application

The `tau_initMarshall()` function must be called by the application before any other call to the marshalling subsystem. It will accept and maintain two application-supplied tables:

- a fixed number of `TRDP_COMID_DSID_MAP_T` elements provides the mapping between comIDs and datasetIDs
- a fixed number of `TRDP_DATASET_T` elements providing the structure of datasets.

Optionally an entry to allow cached access to datasets using a pointer to a dataset element structure will be maintained for every encountered dataset.

All of these tables will be accessed by the standard `qsort()/bsearch()` functions of the C-library, they must be mutable and must not be altered by the application after `tau_initMarshall()` processed them. Using the cached dataset pointer will save some calls to `bsearch()` on large datasets. Once a ComID /dataset match was found, the pointer to the dataset element definition is saved and allows direct access to the alignment information for both marshalling and de-marshalling.

Figure 5 shows an overview of the principle table structure:

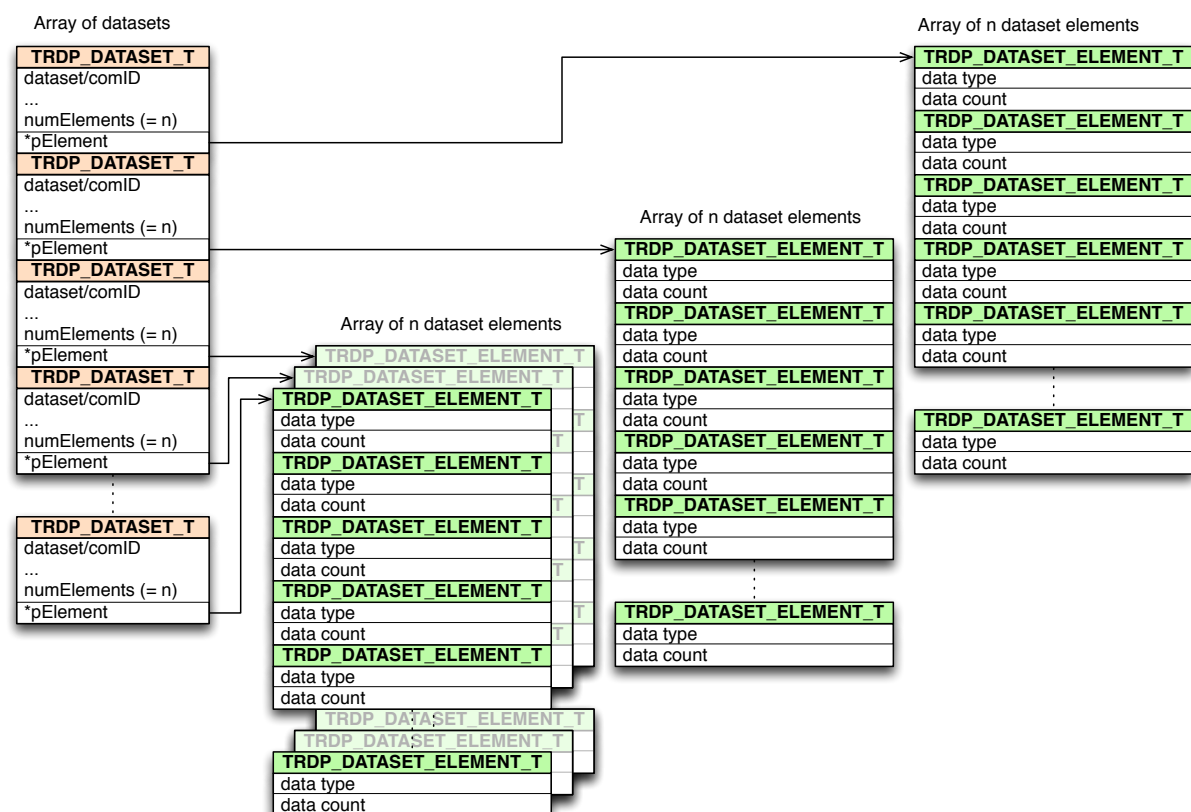


Figure 5: Structure of Dataset Tables

The relationship between ComID and datasetIDs is injective (with the exception of data-less ComIDs); datasets (structures) can include other datasets. Datasets contain one or more dataset elements, which in turn define one or more instances of one data type.

Data types (TRDP_DATA_TYPE_T) defined are:

- TRDP_BOOLEAN = 1, UINT8, 1 bit relevant
- TRDP_CHAR8 = 2, char, can be used also as UTF8
- TRDP_UTF16 = 3, Unicode UTF-16 character
- TRDP_INT8 = 4, Signed integer, 8 bit
- TRDP_INT16 = 5, Signed integer, 16 bit
- TRDP_INT32 = 6, Signed integer, 32 bit
- TRDP_INT64 = 7, Signed integer, 64 bit
- TRDP_UINT8 = 8, Unsigned integer, 8 bit
- TRDP_UINT16 = 9, Unsigned integer, 16 bit
- TRDP_UINT32 = 10, Unsigned integer, 32 bit
- TRDP_UINT64 = 11, Unsigned integer, 64 bit
- TRDP_REAL32 = 12, Floating point real, 32 bit
- TRDP_REAL64 = 13, Floating point real, 64 bit
- TRDP_TIMEDATE32 = 14, 32 bit UNIX time
- TRDP_TIMEDATE48 = 15, 48 bit TCN time (32 bit UNIX time and 16 bit ticks)
- TRDP_TIMEDATE64 = 16, 32 bit UNIX time + 32 bit micro-seconds (== struct timeval)
- TRDP_TYPE_MAX = 30, Values greater are considered nested datasets

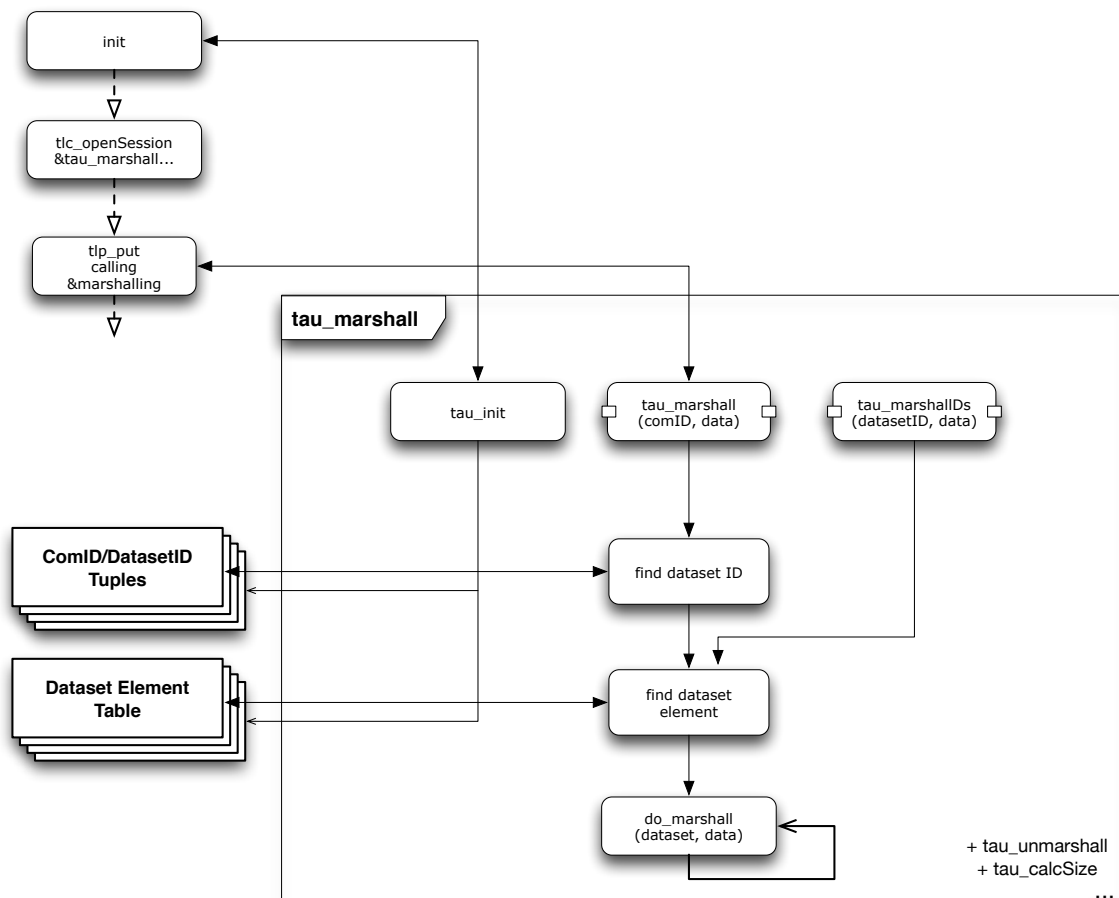


Figure 6: Marshalling Overview

When receiving packets over the network, ComIDs define the structure of the complete payload and they are the first and only identifier to find the right description for decoding. If other structures are nested inside, they must be identified through dataset IDs. Functions called by TRDP communication functions, like `tlp_get()` and `tlp_put()`, will supply comIDs to the marshalling functions, while functions called from within the marshalling system can provide dataset IDs only. This results in a two-step approach, where the first entry needs to find the matching dataset ID for a given ComID, while in the second step, also using `bsearch()`, the corresponding dataset element description is found. See Figure 6 for an overview of the functions involved and the principal interrelationship with each other. Un-marshalling and computing the marshalled size will work in the same way.

2.1.7.1. Marshalling function

`tau_marshall()` converts data structures in native representation, i.e. natural alignment of data types with host endianness, into a packed representation using network (big endian) byte order. It uses `bsearch()` to find the dataset corresponding to the supplied ComID and calls the actual marshalling function (`do_marshall()`), which can call itself recursively for nested datasets. The recursion depth is limited to 5. Figure 7 shows the simplified workflow:

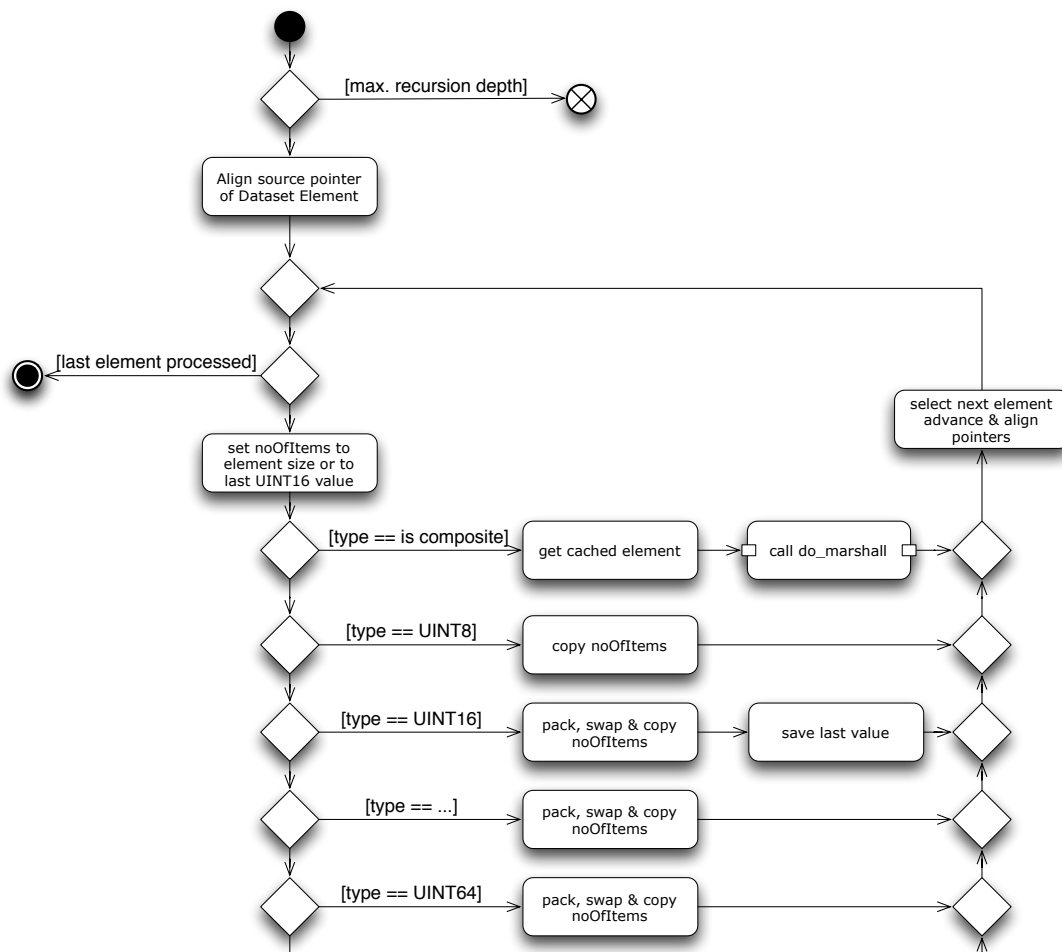


Figure 7: Activity Diagram of Marshalling Function

After checking the recursion depth, we first align the source pointer to the natural alignment of the host's structure data type. Looping over the supplied dataset elements, for each entry we branch depending on the value of the type field. If it is a composite type (i.e. a dataset), we call ourselves recursively. For basic data types we do a packed copy and swapping according to the host compiler's settings.

There are two exceptions to this:

- Byte values (TRDP_BOOLEAN, TRDP_CHAR8, TRDP_INT8, TRDP_UINT8) need no special treatment, just copying
- The last TRDP_UINT16 value is always kept and used as size parameter in case of a dynamic array definition.

2.1.7.2. Un-marshalling function

`tau_unmarshall()` converts data structures in packed representation in network (big endian) byte order into the native representation, i.e. natural alignment of data types with host endianness of the host system. It also uses `bsearch()` to find the dataset corresponding to the supplied ComID and calls the actual un-marshalling function (`do_unmarshall()`), which can call itself recursively for nested datasets. The recursion depth is limited to 5. The flow of control is the same as for marshalling, except that instead of accessing naturally aligned source data, the target pointer must be aligned and the data will be un-packed.

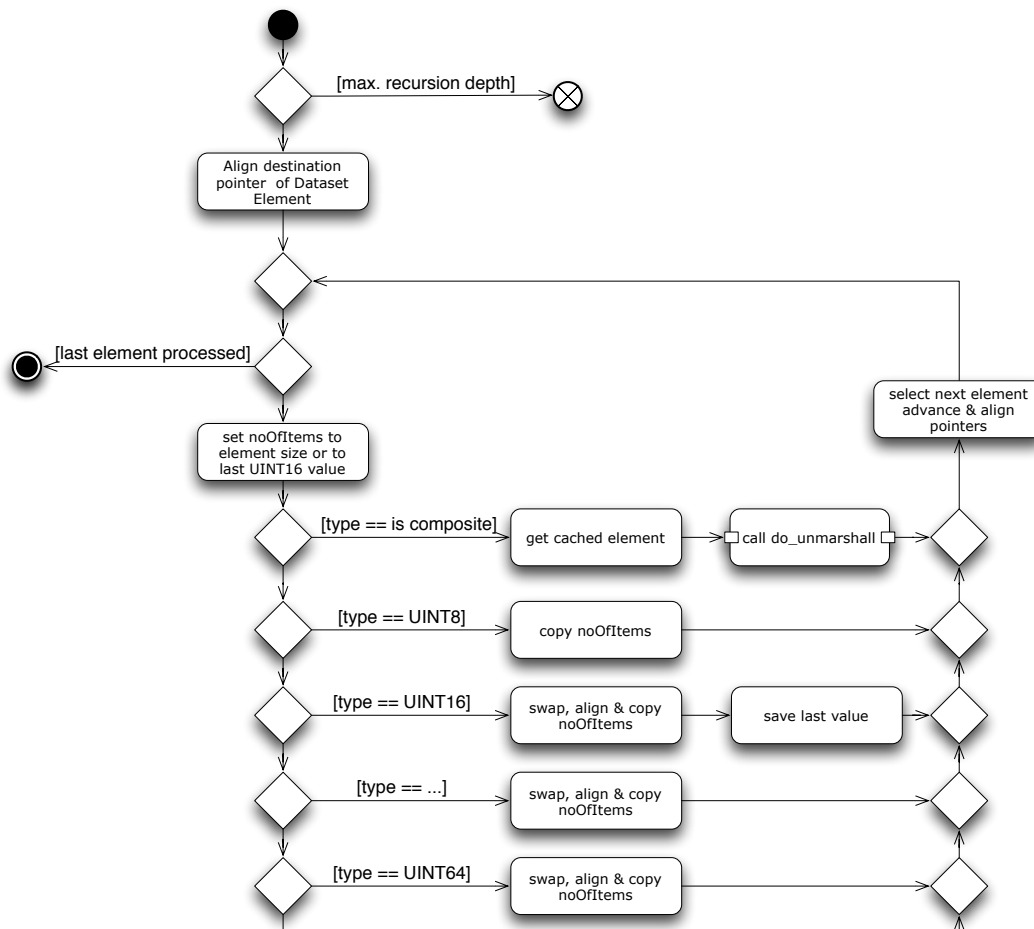


Figure 8: Activity Diagram of Un-Marshalling Function

2.1.7.3. Compute Data Size

Calculating the needed marshalled data size is supported by `tau_calcDatasetSize()` and `tau_calcDatasetSizeByComId()`. The effort is nearly the same as real marshalling; just the copy phase is left out of the program flow. The same flow diagram applies.

2.1.7.4. Alignment

Critical for the correct (un-) marshalling function is the pointer/object alignment. There are some compilers which support the operator `alignof()`, but unfortunately the most common compiler family, gcc, has an incorrect implementation since V 3.2. The VOS supported `ALIGNOF()` macro circumvents this behaviour by being defined compiler dependent and using the `offsetof` operator for gcc. To verify correct implementation for different targets/compiler an alignment test function (`vos_initRuntimeConsts()`) is called during VOS initialization and will return an error (and logging output) if the `ALIGNOF` macro does not work as expected.

2.1.8. VOS – Virtual Operating System

All calls to system dependent services like memory, network, CPU (threading) are mapped to an abstraction layer. Target dependent implementations are located in directories named after their targets. For version 1.0 of the TRDP protocol stack, two major targets are supported:

- A Windows 32 Bit target using winsock2
- A generic POSIX target with branches for Linux, Darwin and QNX

Creating and selecting a specific target involves making changes to the `Makefile` and/or IDE project settings, see 2.2.1 and 2.2.3.

The VOS subsystem consists of:

- Type definitions
- Memory/Queue functions
- Utilities: crc32, debugging output, alignment
- Networking/Socket functions
- Threading/Time/Mutex/Semaphore functions
- Shared Memory functions

and can principally be used without the TRDP stack.

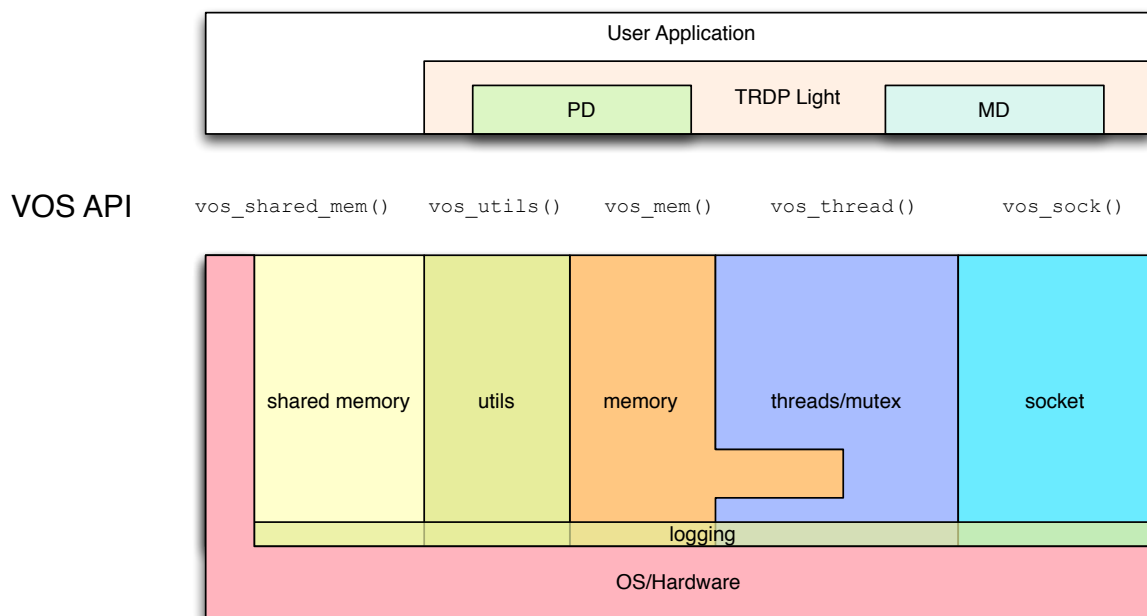


Figure 9: VOS Functional Layers

The TRDP Light stack does not use the shared memory subsystem itself – it is provided to support the implementation of traffic stores (e.g. the ladder system). Also semaphores and

thread calls are not used, but all TRDP API functions are prepared for multi-threading by always taking a mutex before accessing non-local variables.

The indentation of the memory and the threads/mutex sections in Figure 9 shall indicate VOS memory functions using VOS mutexes and VOS mutexes using the VOS memory functions.

Applications, which want to use the VOS functions, will include the appropriate header files located in `vos/api`. The first call to the VOS system must be `vos_init()`, which will be called by `tlc_init()` if the TRDP stack is used.

The exact calling parameters and function prototypes are defined in the corresponding header files and in the Doxygen-generated reference manual [2].

2.1.8.1. Types

The VOS subsystem defines system independent data types, which are used throughout the API and inside the TRDP stack. Also some error codes are defined, which match the ones used in TRDP. Data types inside the particular implementations will use the target system's definitions. These data types are declared in the file `vos_types.h`.

2.1.8.2. Memory

One of the major target independent VOS features is the memory subsystem. It provides the management of fixed, pre-set block sizes of memory blocks from a user supplied area of memory.

This avoids wasting memory on small systems, where (because of MISRA rules) the use of the target system's dynamic memory allocation scheme is not allowed and fixed sized tables would be used instead.

The VOS memory subsystem circumvents this by implementing a pseudo-dynamic scheme, where the application (via `tlc_init()`) must pre-set:

- a memory area of defined size to be used
- a list of pre-allocated blocks to minimize fragmentation (optional)

Via `#defines`, the list of block sizes to manage is adjusted to TRDP's needs, i.e. to fit closely the size of the memory structures of PD publishers, subscribers, MD listeners and maximum packet size. This can be changed during compile time.

For regular systems (with Message Data support), the following block sizes are defined and can be allocated:

48, 72, 128, 180, 256, 512, 1024, 1480, 2048, 4096, 11520,
16384, 32768, 65536, 131072 Bytes

Default pre-allocations are 10 x 1480, 2 x 4096, 4 x 32768 Bytes

Small systems (`MD_SUPPORT == 0`) will provide:

32, 48, 128, 180, 256, 512, 1024, 1480, 2048, 4096, 11520,
16384, 32768, 65536, 131072 Bytes

Default pre-allocations are 8 x 1480, 1 x 11520 Bytes

All of these definitions and function prototypes are declared in the file `vos_mem.h`.

Memory Init

`vos_memInit()` initializes its global variables and creates a memory mutex, which controls access to the memory subsystem and allows the use of the memory subsystem with multithreading. The VOS-based mutex implementation might use itself the memory subsystem – a possible lock must be avoided by using static memory for the memory mutex. Three options can be selected by calling the function with different parameter values:

- if the supplied memory area pointer is NULL and the area size is zero, the subsystem is disabled and the `vos_memAlloc()` and `vos_memFree()` calls will be redirected to `malloc()` resp. `free()` of the host system. This mode is only recommended for use in debugging/testing environments. No pre-allocation will take place.
- If the supplied memory area pointer is NULL, but the area size is not zero, the memory area is allocated once using `malloc()` and then managed internally.
- Else the supplied memory area and size will be used.

Next the list of blocks to pre-allocate is traversed and pre-allocated if they would occupy less than half of the supplied memory area. Otherwise pre-allocation must not take place.

Memory Block Allocation

`vos_memAlloc()` will reserve a memory block for use by the caller until `vos_memFree()` is called for the same block.

Allocation is done by following these steps:

- Round up the demanded memory size to multiples of 32Bit.
- Find the closest size equal or greater than the requested size.
- Take the memory mutex.
- Try to allocate any returned memory blocks with the closest size equal or greater than the requested size.
- Try to create a new block from the free, unblocked memory area with a fixed size from the set of memory block sizes that is equal or greater than the requested size.
- Try to allocate any returned memory blocks with a greater size.
- Release the mutex.
- Still no suitable block found? Return error.

The content of the returned memory block is set to all 0s (using `memset()`).

Memory Block De-Allocation

If the stack or user application does not need the memory area any more it releases it by calling `vos_memFree()`. After getting the memory mutex it will add this memory block to the list of available memory blocks, which can then be reused later.

If system memory allocation was used (`vos_memInit()` called with NULL-pointer, but parameter `size > 0`), the allocated memory will be free'd.

Statistics

To be able to track memory usage during development and deployment, the `vos_memCount()` function returns the number of used memory blocks, free memory blocks, total memory used, number of failed memory allocations and the list of memory block sizes.

Sort/Search

`vos_qsort()` and `vos_bsearch()` are wrappers for the standard library's `qsort` and `bsearch` functions and use the same parameters. If available, they can be mapped directly to the target supplied function.

String functions

`vos_strnicmp()` implements a case insensitive comparison and expects UTF8 encoded, zero terminated character strings. `vos_strncpy()` is the same as the standard `strncpy()` function and will usually be mapped to that function.

Queue/Mailbox

The functions `vos_queueCreate()`, `vos_queueSend()`, `vos_queueReceive()`, `vos_queueDestroy()` implement a mutex and semaphore protected queue, stack or priority queue, which can be used for inter-task communication by the application. The basic TRDP light stack does not use VOS supported queuing.

2.1.8.3. Utilities

The utility functions include the `vos_init()` function, which initializes the VOS subsystem and supplies a pointer to the user defined logging output function.

It will be the first call of an application after being instantiated. `trdp_init()`, as the main user of VOS will call `vos_init()` before calling `vos_memInit()` and passes the logging function pointer along. All error, debug and logging output will be routed via this function.

Four levels of logging output are defined:

Name	Value	Comment
VOS_LOG_ERROR	0	This is a critical error
VOS_LOG_WARNING	1	This is a warning
VOS_LOG_INFO	2	This is an informal message
VOS_LOG_DBG	3	This is a debug info

Every type of logging output is always generated – the application can decide, whether to print or ignore a specific level of message.

`vos_init()` will also call `vos_initRuntimeConsts()`, which will compute the alignment of various data types and compare these results with the result of the `ALIGNOF` macro. On any discrepancy, initialization will fail. This will aid in porting to new platforms and compilers. This code maybe omitted for small systems by defining `MD_SUPPORT=0`.

In addition, the thread and network subsystem's initialization functions will be called (`vos_threadInit()` and `vos_sockInit()`).

`vos_terminate()` will release all resources of the VOS subsystem by calling the corresponding `...Term()` functions and will release the allocated memory area (`vos_memDelete(NULL)`).

The `crc32` function `vos_crc32()` implements the computation of the frame check sum according to IEEE802.3 and uses the pre-computed table from [1] .

2.1.8.4. Network

Socket and network related functions are declared in `vos_sock.h`.

Network Utilities

There are the common byte swapping functions `ntoh` (network to host) and `hton` (host to network) for 16 and 32 Bit unsigned values:

`vos_ntohs()`, `vos_ntohl()`, `vos_htons()`, `vos_htonl()`

These functions must not swap endianness if the host data format is Big Endian (= network byte order).

The utility function `vos_dottedIP()` converts an IP address in the form of 10.0.0.1 into its number equivalent in host endianness (e.g. 0x0A000001). If available, the POSIX function `inet_addr()` may be used by the target implementation. `vos_ipDotted()` is the counter part function.

`vos_isMulticast()` returns TRUE if the supplied IP address is in the range 224.0.0.0 and 239.255.255.255.

`vos_getMacAddress()` returns the MAC address for a specified network interface; if no interface name is provided (pointer is NULL), the MAC address of the default interface will be returned. The realization of this function is highly target dependent: Even on the POSIX target, there are different implementations for Linux and BSD (QNX, Darwin).

On Linux, a socket must be opened and the MAC address can be retrieved with `ioctl`. On BSD, the list returned by `getifaddr()` must be traversed. On Windows, the NetBIOS's enumeration function is used.

`vos_getInterfaces()` is similar to `vos_getMacAddress()` in terms of target dependency – in fact it also returns the MAC addresses of all interfaces. Note that the application will provide the array and `vos_getInterfaces()` fills the supplied array up to value of `pAddrCnt`. On return, the number of interfaces found is returned in `pAddrCnt`.

`vos_select()` is a wrapper for the standard `select()` function. For small systems, this could be defined as no-op (only polling mode supported)

Socket Functions

Before calling any of the socket functions, the application will call `vos_sockInit()`. Any initialization of the socket subsystem can be done here. For POSIX, nothing special needs to be done; the Windows implementation will prepare the WinSock2 library.

`vos_sockTerm()` will release any resources of the socket subsystem.

`vos_sockOpenUDP/TCP()` creates and returns a new socket for the particular protocol (UDP `SOCK_DGRAM` and TCP `SOCK_STREAM`) and sets the supplied socket options through `vos_sockSetOptions()`. To be able to send UDP messages of 64kB en bloc, the send and receive buffers might need to be enlarged. `vos_sockClose()` closes the corresponding socket.

`vos_sockSetOptions()` sets the socket options according to the supplied values. Not all options may be settable for a particular implementation – `reuseAddrPort` for instance might be mapped to either re-use port or re-use address. Blocking mode might not be available and will force the application to poll the sockets; QoS and multicast TTL might prohibit reliable train wide communication, if not settable. To allow destination address filtering, `IP_PKTINFO` or `IP_RECVDSTADDR` must be enabled for `recv_message`. This might not be necessary for systems with only one interface.

`vos_sockSetMulticastIf()` allows to determine sending multicast through a particular interface. This overrides the system's default interface.

`vos_sockJoinMC()` and `vos_sockLeaveMC()` will subscribe/unsubscribe to a particular multicast group on a particular interface. Usually, each socket has a maximum of multicast groups it can join. The constant definition `VOS_MAX_MULTICAST_CNT` limits the TRDP stack's joins per socket. If more groups are needed, the TRDP stack will open another socket with the same options (if `reuseAddrPort` is set and possible).

`vos_sockSend()` for UDP and TCP will try to send the supplied data by taking interruptions by signals (on multi-tasking systems) and blocking into account. The TCP version must also check for a lost connection and return the appropriate error (`VOS_NOCONN_ERR`).

`vos_sockReceiveUDP()` uses the `recvmsg()` call with setting up the scatter/gather list. This is necessary (under POSIX and Windows) to get the destination IP address of the packet when multiple interfaces (or multi-homing) are present. Under the Windows XP operating system, the address of the `WSARecvMsg` function must be obtained using a `WSAIoctl` call first, because this function is not accessible through the WinSock2 interface.

The `vos_sockReceiveUDP()` function must provide a way of peeking at the data to allow the caller to determine the necessary (big) buffer size from the header. The MD part of the TRDP stack uses this to avoid allocation of a buffer of the maximum packet size (64k).

`vos_sockBind()` binds the provided socket to a particular address and port. `vos_sockListen()` is a wrapper for the standard socket listening function to wait for remote clients to connect. `vos_sockAccept()` handles incoming connection requests for TCP. Intermittent signals and aborting connections must be caught and handled.

`vos_sockConnect()` tries to set up a TCP connection to the remote site. It will return no error if the connection was already established.

`vos_sockReceiveTCP()` reads data from the socket into the supplied buffer. It must return `VOS_BLOCK_ERR` if no data could be read in non-blocking mode and `VOS_NODATA_ERR` if the connection was reset while reading the socket.

See [2] for exact call parameters and valid return codes of all socket related functions.

2.1.8.5. CPU Resources

`vos_thread.h` declares (and partially defines) timer, threading and mutex/semaphore related functions.

Time

`vos_getTime()` returns the system's current time in the `VOS_TIME_T` format, which is equal to `struct timeval` on *ix target systems. It should return a monotonic clock value to prevent jitter or unsolicited transmissions or timeouts of PD data in case the clock setting changes during operation. `vos_getTimeStamp()` is used for logging output and should output the system's real time (not monotonic) to have a traceable listing of logging information. The string format is

`yyyymmdd-hhmmss.mmm` (year, month, day, hours, minutes, seconds, milliseconds)

Several helper functions are declared to handle the computations with the `VOS_TIME_T` format and are used through out the TRDP stack. They all take pointers to `VOS_TIME_T` as parameters:

`vos_clearTime()` sets the `timeval` to `{0,0}`, `vos_addTime()` adds and `vos_subTime()` subtracts the second to/from the first value; `vos_mulTime()` multiplies and `vos_divTime()` divides the first value by the second. They all save the result in the first value.

`vos_cmpTime()` returns -1, 0, +1 if the second value is smaller, equal resp. greater than the first value.

`vos_getUuid()` will return a 16 Byte long universal unique identifier, which is suitable to be used as session identifier. If the target system does not provide a system generated UUID, a substitute with at least the following features must be provided:

- Unique device ID (usually the MAC address of the default interface)
- Unique time stamp (using local monotonic time stamp)
- Incrementing usage count

The standardized format of the UUID is given in [3].

Threads

The thread handling subsystem is not used by the TRDP light stack, but is provided as a utility for higher layers (i.e. the application). All TRDP API session functions are mutex-protected and can therefore work in multithreaded environments. `VOS_MAX_THREAD_CNT` limits the maximum number of concurrent threads to 100.

In the current VOS implementations (POSIX & Windows XP), the `pthread` library is used to implement the thread-related functions. For simple single-threaded targets, these functions

along with the mutex and semaphore functions could be defined as no-ops. They must not return error codes other than `VOS_NO_ERR`, though.

`vos_threadInit()` initializes the thread subsystem and should be called by the application before calling any other thread related function.

`vos_threadTerm()` releases all resources taken by the thread subsystem. It will not terminate any threads, though.

`vos_threadCreate()` is the major thread function and creates a new thread using the supplied parameters like

- policy (`VOS_THREAD_POLICY_FIFO`, `VOS_THREAD_POLICY_RR`, `VOS_THREAD_POLICY_OTHER`)
- priority (1...255 (highest, default 0))
- interval (for cyclic threads)
- stack size (default is 16kB)

and the run function plus argument pointer. Optionally (for debugging purpose) a name can be provided.

Note: Policies other than `VOS_THREAD_POLICY_OTHER` will probably require ‘root’ permissions of the calling application on POSIX systems.

On successful invocation of the new thread, a handle will be returned to the caller. This is needed to identify the thread in further calls to `vos_threadTerminate()` or `vos_threadIsActive()`.

In the current POSIX and Windows implementations, the created threads are detached, meaning: There is no need to join the thread with the main thread before exiting the application.

`vos_threadDelay()` does not depend on threads as such, but will exempt the calling thread or task from execution for the provided time value. If the delay parameter is zero, the function should yield process time to other tasks, if any. On non-multitasking systems, the delay must be implemented using busy-waiting.

Mutex

All TRDP API functions, which access session or global variables, are protected by recursive mutexes. The memory space used will be allocated using `vos_memAlloc()` and a pointer to this area is used as a handle for all calls (un/locking, deleting). An exception to this is the creation of the local mutex used to protect the memory subsystem itself, where the caller (`vos_memInit()`) must allocate the memory for the handle. A valid handle should be identified by a magic number to avoid passing a false pointer to any of the mutex related functions.

`vos_mutexCreate()` creates a recursive mutex, which is unlocked on success. The memory for the mutex is allocated internally.

`vos_mutexLocalCreate()` does the same, but uses a pointer to an already allocated memory area. This function is not exposed to TRDP or the application.

`vos_mutexDelete()` destroys a mutex created by `vos_mutexCreate()` and releases the used memory.

`vos_mutexLocalDelete()` destroys a local memory mutex created using `vos_mutexLocalCreate()`. The caller must release the used memory.

`vos_mutexLock()` and `vos_mutexTryLock()` will lock the mutex. The first version will block until the lock is acquired. The second version returns `VOS_MUTEX_ERR` if the lock couldn't be acquired. They both return `VOS_NO_ERR` if successful.

`vos_mutexUnlock()` will unlock the mutex.

The POSIX and the Windows XP implementation use the `pthread`-supplied mutexes.

Semaphore

To support thread-safe mail boxing and message queues, four basic semaphore-handling routines are supported:

`vos_semaCreate()` creates a semaphore and returns a handle to `VOS_SEMA_T` as reference. The semaphore will optionally be taken, depending on the provided parameter.

`vos_semaDelete()` destroys the semaphore and releases associated memory.

`vos_semaTake()` tries to take the semaphore; depending on the value of the timeout parameter, if timeout is

- 0 (zero): do not wait, return immediately with error `VOS_SEMA_ERR` if semaphore could not be taken
- `0xFFFFFFFF`: wait forever for the semaphore, return `VOS_NO_ERR`
- `1...4294967294`: wait for the semaphore up to timeout value, return with error `VOS_SEMA_ERR` on timeout, on success `VOS_NO_ERR`

`vos_semaGive()` releases the semaphore.

The POSIX and the Windows XP implementation use the `sem_` prefixed semaphore functions (POSIX Realtime Extension).

2.1.9. Source Files

File	Content
tau_addr.h	TRDP address resolution declarations
tau_marshall.h	TRDP marshalling declarations
tau_tti.h	TRDP train topology info interface declarations
tau_xml.h	TRDP configuration interface declarations
trdp_if.c	TRDP Light interface functions
trdp_if_light.h	TRDP Light interface declarations (API)
trdp_mdcom.c	Functions for MD communication
trdp_mdcom.h	Functions for MD communication
trdp_pdcom.c	Functions for PD communication
trdp_pdcom.h	Functions for PD communication
trdp_private.h	Typedefs for TRDP communication
trdp_types.h	Typedefs for TRDP communication
trdp_utils.c	Common utilities for TRDP communication
trdp_utils.h	Common utilities for TRDP communication
api/vos_mem.h	Memory and queue functions declarations
api/vos_shared_mem.h	Shared memory functions declarations
api/vos_sock.h	Typedefs for OS abstraction
api/vos_thread.h	Multitasking functions declarations
api/vos_types.h	Declaration of VOS common data types
api/vos_utils.h	Logging, alignment functions declarations
common/vos_mem.c	Memory functions definitions
common/vos_utils.c	Logging, alignment functions
<target>/vos_private.h	Target dependend declarations and defines
<target>/vos_shared_mem.c	Target impl. of shared memory functions
<target>/vos_sock.c	Target implementation of network function
<target>/vos_thread.c	Target implementation of multitasking functions

2.2. Build System

2.2.1. Predefines

Several compile time options can be set to define a specific behaviour or feature set for the build targets. The following `#defines` are used and checked throughout the TRDP and VOS sources:

Name	Meaning	Defined/set in	Evaluated in
MD_SUPPORT	Defines inclusion of message data handling functions in the TRDP library. if 1 or not defined -> MD support is enabled if 0 and defined -> MD support is disabled, reduced resource usage	command line option for make, Makefile, IDE build settings, trdp_if_light.h	trdp_utils.c trdp_if.c trdp_private.h vos_sock.h vos_mem.h
DEBUG	Defines generation of symbolics (supressing STRIP command) and compiler optimizations	Environment variable / command line option for make	Makefile
POSIX	Selects includes and source path for POSIX compatible targets	Makefile, IDE build settings	Makefile vos_types.h vos_mem.c vos_sock.c vos_thread.c vos_shared_mem.c
WIN32	Selects includes and source path for Windows XP compatible targets	IDE build settings	trdp_proto.h trdp_types.h trdp_private.h vos_types.h vos_utils.h vos_mem.c vos_sock.h vos_sock.c vos_thread.c vos_shared_mem.c
VXWORKS	Selects includes and source path for vxWorks compatible targets	Makefile	Makefile vos_types.h vos_mem.c vos_sock.h vos_sock.c vos_thread.c vos_shared_mem.c

Name	Meaning	Defined/set in	Evaluated in
__linux__ __APPLE__ __QNXNTO__	Sub-target defines for the POSIX platform. Differences in network and thread handling are taken into account.	Compiler/system includes	Makefile vos_types.h vos_private.h vos_sock.c vos_thread.c
__BIG_ENDIAN__ __ARMEB__ __AARCH64EB__ __MIPSEB__	Defines the host endianness; if any of these is 1, the host is considered to be big endian	Compiler/system includes	vos_utils.c tau_marshall.c

2.2.2. Command Line

On the top level of the project, a Makefile allows the generation of the TRDP library and several test and example utilities. To support multiple targets, a configuration folder with target & compiler specific includes exists. To select a certain target or build setting, a configuration file `config.mk` inside the configuration folder will be created/overwritten by the make command

```
Make <TARGET>_config
```

where <TARGET> needs to be replaced by a real target name. Currently at least a native Linux X86 target exists (`POSIX_X86_config`).

With the command

```
Make help
```

the possible targets and options are listed. To add more targets and tool-chains, a file in the `config` directory must be created, where several path and configuration variables for each target can be set.

To generate the documentation from the source files, ‘Doxygen’ version 1.5 or higher must be installed on the host system. Depending on your installation it might be necessary to adjust a path in the file `Doxyfile` on the same level. To be able to generate the PDF version of the reference manual, “Ghostscript” (for the `eps2pdf` utility) is also needed.

For special configurations (e.g. Ladder) different make files can be used and should exist in the project’s root directory.

2.2.3. IDE

2.2.3.1. Xcode

The folder `Xcode` contains the project file bundle `trdp.xcodeproj` for the Mac OS X Xcode IDE version 3.2 with several predefined targets and demo projects.

2.2.3.2. Visual C

`Win32TRDP_VS2010.sln` in the folder `VisualC` is a project file for Microsoft’s Visual C IDE 2010. Several predefined targets support building of a TRDP static and dynamic library and several test and demo applications.

2.2.4. *Lint*

Under `test/lint`, MS-DOS batch files for use with Gimpel Software's PC-lint are hosted, `Lint_posix.bat` and `Lint_win.bat`. Before invoking these files, the path to `lint-nt.exe` has to be set according to the installed location of PC-lint.

To be able to 'lint' the POSIX version of the VOS as well, a set of Linux header files is included in the compressed file `posix.zip`, which must be unpacked before usage. The standard headers originate from an Ubuntu 8.04 system (i486-linux-gnu gcc V 4.2.4).

The files `std_win.lnt` resp. `std_posix.lnt` contain source path definitions, exemptions and rules.

Output from the lint runs is saved into file `_LINT_WIN.TMP` resp. `_LINT_POS.TMP`