

A Distributed Time Event Server

Due at 11:59pm on Monday, 23 May 2022

Often when programming applications, your program needs to arrange to be notified when certain times are reached. These timer events can be one shot, in that the event will occur at a single absolute time in the future; or they can be repeating events that should occur a specified interval apart **and** some number of times. For both types of timer requests, it should be possible for your application to cancel an individual event if you determine that it is no longer necessary.

You will be building a Distributed Time Server (DTS); each version provides an increasingly complex set of capabilities.

There are 4 parts to this project, the first 3 of which are mandatory, with the 4th being for extra credit. The objectives of the project are to give you experience writing a distributed server that meets a specification, practice using priority queues, maps, and queues to construct a significant application, and familiarity with different programming notions of time in Linux and C.

All coding must be done in the C programming language; it must be compilable and runnable in the Linux virtual machine environment. Unlike Project 1, you may use any library functions available from section 3 of the manual on your Debian virtual machine.

You should tackle this problem in four steps, outlined below. Each step should be in a separate source file, `dtsv?.c`, where `?` is replaced by 1, 2, 3, or 4. The solution at each step is graded separately.

The usage string for `dtsv?` is:

`usage: ./dtsv?`

where `?` is replaced by 1, 2, 3, or 4.

1 DTS echos the requests it receives

The goal of Part 1 is to develop the first version of the DTS such that it can echo back the requests it receives from the client program supplied in the starting archive. DTS v1 will perform the following steps:

- Initialize the BXP runtime¹ so that it can create and accept encrypted connection requests.
- Create a thread that will receive requests from client applications.
- Respond to each such request by echoing back the received request along with a status byte; the first byte of the response is '1' for success, '0' for failure. Thus, if the request is in the character array `query`, the response to send back would be created

¹ See section 5 below for a discussion of the BXP runtime that you will be using.

by `sprintf(response, "1%s", query);` for this version of DTS, you will never respond with a failure indication.

- Except for initialization failure, DTSv1 should never exit.

2 DTS parses the requests and sets the status byte appropriately

Successful completion of Part 1 gives you a basic DTS for which the network plumbing works correctly. DTSv2 now interprets each received request; it will still echo the received request, but it will set the status byte appropriately if it is a legal request or not.

The legal queries to the DTS server are strings of the following form:

```
OneShot|<clid>|<secs>|<usecs>|<host>|<service>|<port>
Repeat|<clid>|<msecs>|<repeats>|<host>|<service>|<port>
Cancel|<svid>
```

Thus, the legal things you can ask the server to do is register a *OneShot* request, register a *Repeat* request, and to *Cancel* a previous request. The parameters to these requests have the following meaning:

- `<clid>` - this is an id that the client application assigns to this request; when we finally get to version 4 of the project, the server will send a message containing that client id to a service in the client when its time has been reached.
- `<secs>` - this is the number of seconds since the Epoch at which the event should occur.
- `<usecs>` - this is the number of microseconds since the Epoch at which the event should occur.
- `<host>` - this is a string that has the IP address of the client so it can be called back.
- `<service>` - this is a string for the service within the client that should be called when the event occurs.
- `<port>` - this is an unsigned short for the UDP port at which the service in the client is listening.
- `<msecs>` - this is the number of milliseconds between repeats.
- `<repeats>` - this is the number of times that the event should repeat; a value of 0 indicates that it should go on forever.
- `<svid>` - this is an id assigned to the event by the server, and in v3 and v4 of the server is what is returned upon receipt of successful requests to the server.

In this version of DTS, you need to check that the first word in each request is one of the three legal strings ("OneShot", "Repeat", "Cancel") **and** that the number of arguments is correct. If both are true, `sprintf(response, "1%s", query);` otherwise, `sprintf(response, "0");`

3 DTS processes the command arguments, stores them in appropriate data structures, and processes the timer requests

Now we need to process the request arguments, store the information in appropriate data structures, and use a periodic timing capability to process each event at the correct time. In this version, *you will simply print out information about each event when it has elapsed*, instead of communicating that information to the requesting process (that's in part 4). The format to use when printing the event is **exactly** as follows:

```
printf("Event fired: %lu|%s|%s|%u\n", <clid>, <host>, <service>, <port>);
```

What is the appropriate data structure to use for keeping the events in time order? I suggest that a priority queue, where the priority is the time since the Epoch, would be the best choice. When your periodic timer fires, you can obtain the current time since the Epoch, and then harvest all entries in the priority queue whose time is less than or equal to the current time.

When you store an event in the queue, you will associate with that event a unique server id; this is necessary for you to be able to cancel that request if the client requests that action. Since you cannot remove anything from a priority queue except the minimum value, you will likely need another data structure that will permit you to find the event data structure associated with a particular server id. And since you cannot remove it from the priority queue, you will likely need a member in the request structure that is true if the event has been cancelled; that way, when the due time comes for the event, you will remove it; if it has been cancelled, you will just recycle any heap-allocated storage associated with it.

When your periodic timer indicates it is time to harvest requests from the priority queue, you will likely store the event structures in a Queue. It is reasonable to process this queue in another thread; since entries in the Queue are inserted by one thread, and removed by another, the Queue will have to be appropriately protected by pthread mutex and condition variables.

The return value to the client for OneShot and Repeat requests should be formatted `sprintf(response, "1%08lu", svid);` if Cancel is invoked, the svid argument will also be formatted as "%08lu".

4 DTS delivers each event to the requesting process

This version of the server, instead of just printing details of the event to be delivered, actually delivers an event to the requesting process. In the OneShot and Repeat

requests processed by the server, the client provides the <host>, <service>, and <port> arguments. These can be used by the server to connect back to the client to send it a notification that one of its events has fired. The pseudocode for this would be

```
bxpc = bxp_connect(host, port, service, 1, 1);
reqlen = (unsigned) (sprintf(req, "%lu", clid) + 1);
bxp_call(bxpc, Q_Arg(req), reqlen, resp, sizeof resp, &resplen);
bxp_disconnect(bxpc);
```

Connecting to and disconnecting from the client service is a fairly high overhead way to do this, and a solution that caches the BXPConnections in some way would be much more efficient.

dts-client, supplied in the starting archive, has a separate thread that reads the queries from these bxp_call() invocations, and prints out the information received.

5 The Buffer Exchange Protocol (BXP)

One often encounters the requirement for a simple request/response networking capability. One can craft such a system using TCP, but reliable stream protocols were designed to maximize bulk data throughput. Some RPC systems exist, but require that one define one's interface in an interface definition language, execute a stub compiler to generate client stubs and server skeletons, and run a number of auxiliary services in order to use the system.

This section describes a simple buffer-exchange (BXP) system over UDP; it is derived from a Simple RPC system documented at <https://github.com/jsventek/SRPC>. Each request/response is in terms of exchanging an outgoing char buffer, and an incoming char buffer, with the server. This document describes the C interface and implementation of this BXP system.

5.1 The C API

The API provided to C programmers is shown below. Both clients and servers invoke the bxp_init() method to initialize the PThread implementation of the architecture shown in Figures 1 and 2 below. The remaining methods are divided into two groups: those used by clients and those used by servers. The following listing shows the API; subsequent subsections show stylized code for a client, a server, and a client supporting a callback service using the API.

5.1.1 The BXP header file

```
/* BSD Header removed to conserve space */

/*
 * bxp - a simple UDP-based Buffer eXchange Protocol system
 */

#ifndef _BXP_H_
#define _BXP_H_

#include "BXP/endpoint.h"
```

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```
typedef void *BXPConnection;
typedef void *BXPService;

/*
 * query descriptor needed to detect buffer overrun problem
 */
struct qdecl {
    int size;
    char *buf;
};

/*
 * query buffers for bxp_call() MUST BE DECLARED
 * AND PASSED using these macros
 */
#define Q_Decl(QUERY,SIZE) char QUERY[SIZE]; \
                           const struct qdecl QUERY ## _struct = {SIZE,QUERY}
#define Q_Arg(QUERY) (&QUERY ## _struct)

/*
 * initialize BXP system - bind to 'port' if non-zero
 * otherwise port number assigned dynamically
 * if 'ifEncrypted' is true, creates public and private keys
 * returns 1 if successful, 0 if failure
 */
int bxp_init(unsigned short port, int ifEncrypted);

/*
 * the following methods are used by BXP clients
 */

/*
 * obtain our ip address (as a string) and port number
 */
void bxp_details(char *ipaddr, unsigned short *port);

/*
 * reverse lookup of ip address (as a string) to fully-qualified hostname
 */
void bxp_reverselu(char *ipaddr, char *hostname);

/*
 * send connect message to host:port with initial sequence number
 * svcName indicates the offered service of interest
 * requests an encrypted connection if ifEncrypted is 1/true
 * returns !NULL after target accepts connect request
 * else returns NULL (failure)
 */
BXPConnection bxp_connect(char *host, unsigned short port,
                          char *svcName, unsigned long seqno, ifEncrypted);

/*
 * make the next BXP call, waiting until response received
 * must be invoked as bxp_call(bxpc, Q_Arg(query), qlen, resp, rsize, &rlen)
 * upon successful return, 'resp' contains 'rlen' bytes of data
 * returns 1 if successful, 0 otherwise
 */
int bxp_call(BXPConnection bxpc, const struct qdecl *query, unsigned qlen,
             void *resp, unsigned rsize, unsigned *rlen);

/*
 * disconnect from target
 * no return
 */
void bxp_disconnect(BXPConnection bxpc);

/*
 * the following methods are used to offer and withdraw a named service
 */

/*
```

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```
* offer service named `svcName' in this process
* returns NULL if error
*/
BXPService *bxp_offer(char *svcName);

/*
 * withdraw service
 */
void bxp_withdraw(BXPService bxps);

/*
 * the following methods are used by a worker thread in a BXP server
 */

/*
 * obtain the next query message from `bxps' - blocks until message available
 * `len' is the size of `qb' to receive the data
 * upon return, ep has opaque sender information
 *         qb has query data
 *
 * returns actual length as function value
 * returns 0 if there is some massive failure in the system
 */
unsigned bxp_query(BXPService bxps, BXPEndpoint *ep, void *qb, unsigned len);

/*
 * send the next response message to the `ep'
 * `rb' contains the response to return to the caller
 * returns 1 if successful
 * returns 0 if there is a massive failure in the system
 */
int bxp_response(BXPService bxps, BXPEndpoint *ep, void *rb, unsigned len);

/*
 * shutdown the BXP system
 */
void bxp_shutdown(void);

#endif /* _BXP_H_ */
```

5.1.2 Client example

```
#include "BXP/bxp.h"
#include <assert.h>
#include <stdio.h>
#include <string.h>
#define UNUSED __attribute__((unused))

int main(UNUSED int argc, UNUSED char *argv[]) {
    BXPConnection bxp;
    char response[10000];
    Q_Decl(request, 10000);
    unsigned reqlen, rsplen;
    char buf[BUFSIZ];

    assert(bxp_init(0, 1));
    assert((bxp = bxp_connect("localhost", 5000, "Echo", 1, 1)));
    while (fgets(buf, BUFSIZ, stdin) != NULL) {
        strcpy(request, buf);
        reqlen = strlen(request) + 1;
        assert(bxp_call(bxp, Q_Arg(request), reqlen, response, 10000, &rsplen));
        if (response[0] == '0')
            fprintf(stderr, "Error response from server\n");
        else
            fputs(response+1, stdout);
    }
    bxp_disconnect(bxp);
}
```

5.1.3 Server example

```
#include "BXP/bxp.h"
#include <assert.h>
#include <stdio.h>
#include <string.h>
#define UNUSED __attribute__((unused))

int main(UNUSED int argc, UNUSED char *argv[]) {
    BXPEndpoint ep;
    BXPService svc;
    char query[10000], response[10001];
    unsigned qlen, rlen;

    assert(bxp_init(5000, 1));
    assert((svc = bxp_offer("Echo")));
    while ((qlen = bxp_query(svc, &ep, query, 10000)) > 0) {
        sprintf(response, "%s", query);
        rlen = strlen(response) + 1;
        assert(bxp_response(svc, &ep, response, rlen));
    }
    return 0;
}
```

5.1.4 Client that establishes a callback service

```
#include "BXP/bxp.h"
#include <assert.h>
#include <stdio.h>
#include <string.h>
#include <pthread.h>
#define UNUSED __attribute__((unused))
#define SERVICE "Callback"

void *svcFxn(void *args) {
    BXPService *bxps = (BXPService *)args;
    BXPEndpoint ep;
    char query[1024], *resp = "1";
    unsigned qlen;

    while ((qlen = bxp_query(bxps, &ep, query, 1024)) > 0) {
        bxp_response(bxps, &ep, resp, 2);
        fputs(query, stdout);
    }
    return NULL;
}

int main(UNUSED int argc, UNUSED char *argv[]) {
    BXPConnection bxp;
    BXPService bxps;
    char response[10000];
    Q_Decl(request, 10000);
    unsigned reqlen, rsplen;
    char ipaddr[16];
    unsigned short svcPort;
    pthread_t svcThread;
    char buf[BUFSIZ];

    assert(bxp_init(0, 1));
    bxp_details(ipaddr, &svcPort);
    assert((bxps = bxp_offer(SERVICE)));
    assert((bxp = bxp_connect("localhost", 5000, "Echo-Callback", 1, 1)));
    assert(! pthread_create(&svcThread, NULL, svcFxn, (void *)bxps));
    while (fgets(buf, BUFSIZ, stdin) != NULL) {
        sprintf(request, "%s|%u|%s|%s", ipaddr, svcPort, SERVICE, buf);
        reqlen = strlen(request) + 1;
        assert(bxp_call(bxp, Q_Arg(request), reqlen, response, 10000, &rsplen));
        if (response[0] == '0')
            fprintf(stderr, "Error response from server\n");
    }
    bxp_disconnect(bxp);
}
```

```
}
```

5.1.5 Server that uses call back service of client

```
#include "BXP/bxp.h"
#include <assert.h>
#include <stdio.h>
#include <string.h>
#define UNUSED __attribute__((unused))

int extractWords(char *buf, char *sep, char *words[]) {
    int i;
    char *p;

    for (p = strtok(buf, sep), i = 0; p != NULL; p = strtok(NULL, sep), i++)
        words[i] = p;
    words[i] = NULL;
    return i;
}

int main(UNUSED int argc, UNUSED char *argv[]) {
    BXPEndpoint ep;
    BXPService svc;
    char query[10000], response[10001];
    unsigned qlen, rlen;

    assert(bxp_init(5000, 1));
    assert((svc = bxp_offer("Echo-Callback")));
    while ((qlen = bxp_query(svc, &ep, query, 10000)) > 0) {
        char *words[25];
        Q_Decl(out, BUFSIZ);
        char back[128];
        BXPConnection bxpc;
        unsigned port, backlen;
        (void) extractWords(query, "|", words);
        sscanf(words[1], "%u", &port);
        bxpc = bxp_connect(words[0], (unsigned short)port, words[2], 1, 1);
        strcpy(out, words[3]);
        bxpc_call(bxpc, Q_Arg(out), strlen(out)+1, back, sizeof back, &backlen);
        bxpc_disconnect(bxpc);
        sprintf(response, "1%s", query);
        rlen = strlen(response) + 1;
        assert(bxp_response(svc, &ep, response, rlen));
    }
    return 0;
}
```

5.1.6 Makefile for the previous four programs

```
CFLAGS=-W -Wall -pedantic -I/usr/local/include
LDFLAGS=-L/usr/local/lib
PROGRAMS=client server cbclient cbserver
LIBRARIES=-lBXP -lpthread

all: $(PROGRAMS)

client: client.o
    gcc $(LDFLAGS) -o $@ $^ $(LIBRARIES)

cbclient: cbclient.o
    gcc $(LDFLAGS) -o $@ $^ $(LIBRARIES)

server: server.o
    gcc $(LDFLAGS) -o $@ $^ $(LIBRARIES)

cbserver: cbserver.o
    gcc $(LDFLAGS) -o $@ $^ $(LIBRARIES)

client.o: client.c
cbclient.o: cbclient.c
```



```

server.o: server.c
cbserver.o: cbserver.c

clean:
    rm -f $(PROGRAMS) *.o

```

5.2 General Architecture

Each process wishing to use the BXP system consists of at least three threads:

- a receiving thread that retrieves UDP packets from the network, and places each one in an incoming queue
- a timer thread that processes retries of certain messages as well as being responsible for purging stale connections
- to provide a service, one or more worker threads; each such thread obtains an element from an incoming queue, performs some actions, and sends the response back to the requestor
- to use a service, one or more client threads; each such thread issues blocking requests to the selected service

The sending thread, timer thread, and worker threads sending a response also share connection state for each active connection.

The architecture in a server is displayed in Figure 1 below. The architecture in a client is shown in Figure 2.

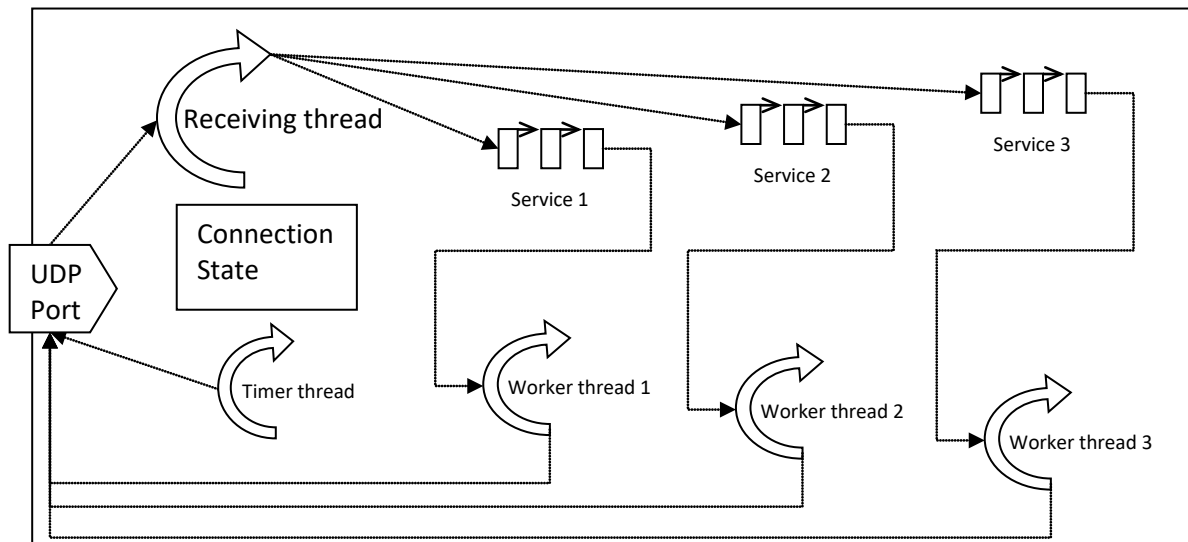


Figure 1: Server architecture of the Buffer eXchange Protocol system

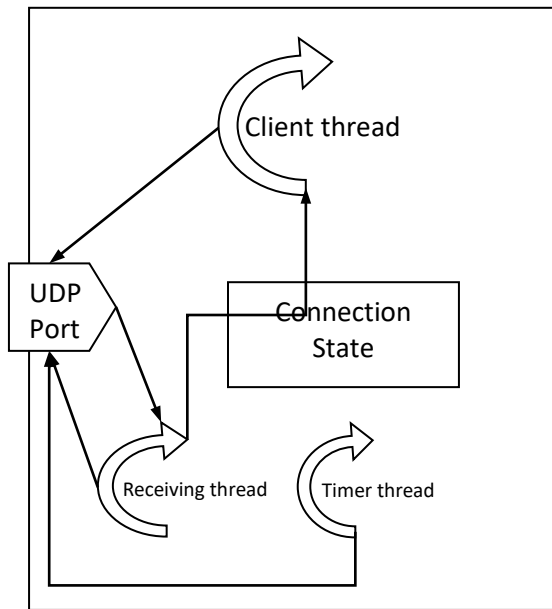


Figure 2: Client architecture of the Buffer eXchange Protocol system

5.3 Connection States

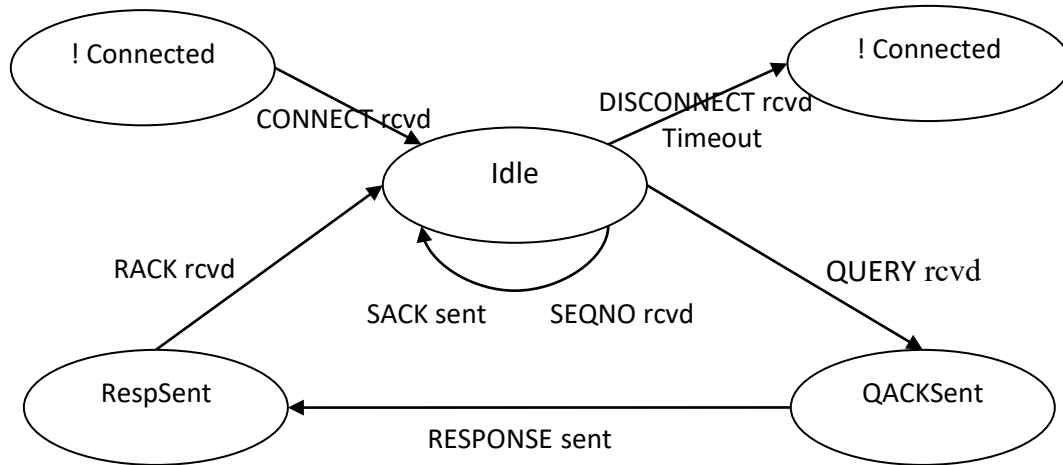
BXP communication is basically request/response. There is no absolute requirement to maintain connection state, but it does make it much easier to provide the best-effort semantics embodied in BXP interactions; additionally, it tends to make the system easier to build and maintain. And, finally, it provides the opportunity to successfully secure the connection using a combination of asymmetric and symmetric encryption.

Each process in an internet host is associated with one or more UDP ports. There is no technical reason to have more than one port, so the remainder of the discussion, as well as Figures 1 and 2 above, is in terms of a single port for a process.

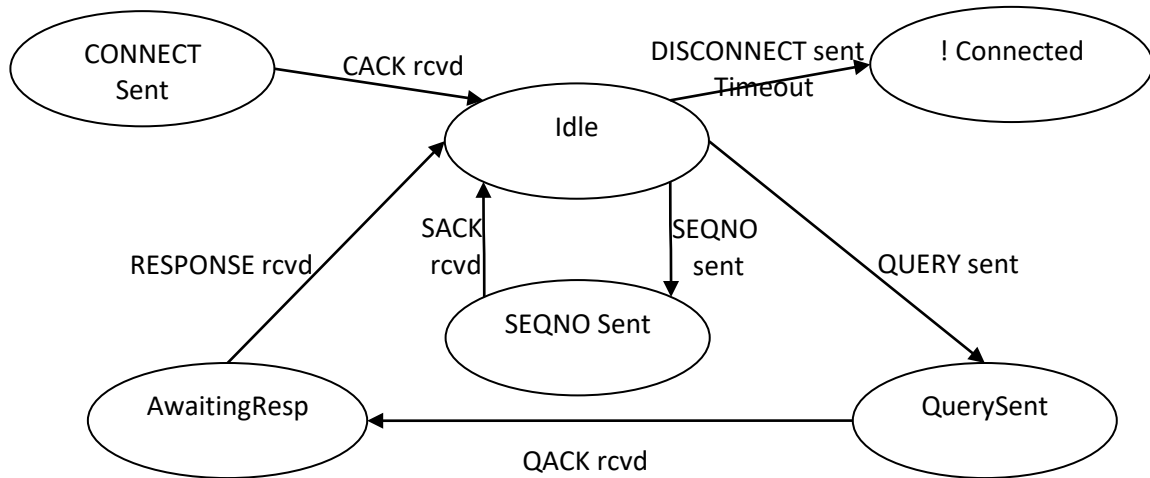
In general, a triple of identifiers is required to uniquely identify each connection:

- the IP address of the host upon which the process is running
- the UDP port number associated with the running process
- a multiplexing identifier within the process, usually one per active thread

Each connection goes through the following life cycle on the server side of a connection:



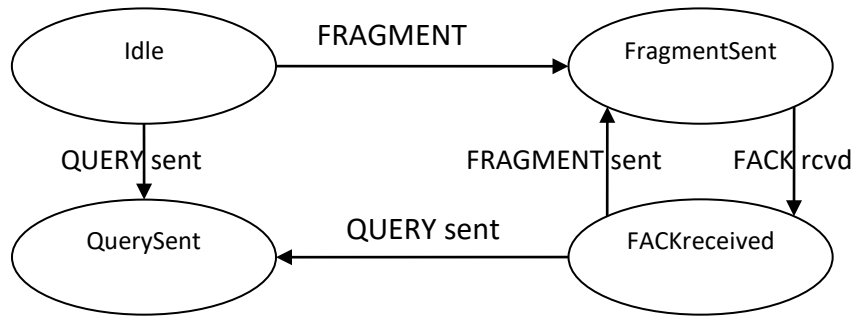
The equivalent life cycle diagram on the client side of a connection is as follows:



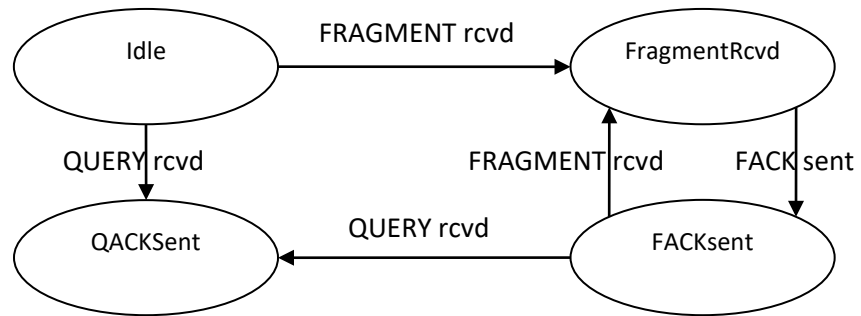
5.4 Fragmentation and Reassembly states

If the query or response buffer exceeds the size of a single UDP datagram, the buffer must be broken up into fragments and reassembled at the receiving end. Therefore, the actions labelled "QUERY sent", "QUERY rcvd", "RESPONSE sent", and "RESPONSE rcvd" in the state diagrams above are actually nested state machines.

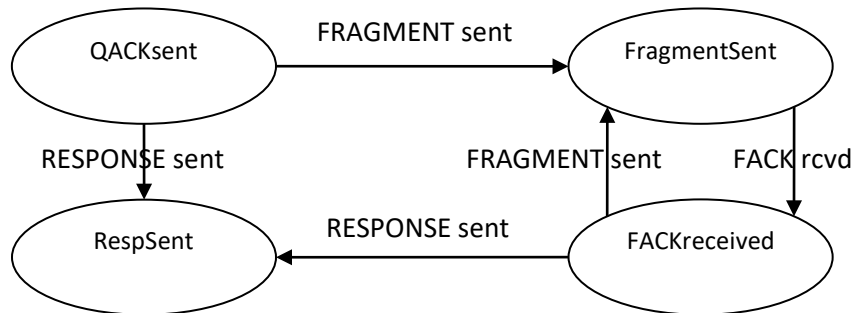
5.4.1 QUERY sent



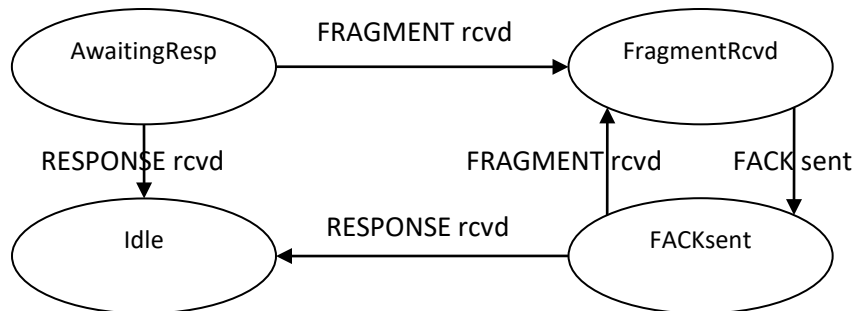
5.4.2 QUERY rcvd



5.4.3 RESPONSE sent



5.4.4 RESPONSE rcvd



5.5 Protocol Message Types

A number of protocol message types are shown as labels on the transitions in the life cycle diagrams in the previous section. Each of these is enumerated here, with pseudocode for the action taken by the state machine receiving such a message. Initially, we focus on messages sent by both requestors and responders. Then we focus on the messages sent by a requestor and received by a responder. Finally, we will look at the opposite direction.

N.B. You may ignore sections 5.5.1-5.5.3; they are provided for those students who may have an interest in what goes into a transport level protocol.

5.5.1 Both directions

- PING** Once a connection is established, connection state is kept by each participant. Participants have a habit of occasionally disappearing without gracefully terminating the connection. It is important that each participant is able to determine if its correspondent is still alive, terminating the connection if the answer to this question is in the negative. This is done using pings and ping acknowledgments to construct a failure detector. The receiving state machine does the following upon receipt of a PING message:
- If it has a connection record corresponding to that client identifier, it sends a PACK (Ping ACK) response to the sender.
 - If not, it drops the message
- PACK** The receiving state machine does the following upon receipt of a PACK message:
- If it has a connection record corresponding to that client identifier, it resets the `pingsTilPurge` and `ticksTilPing` fields of the connection record
 - If not, it drops the message.

5.5.2 Requestor → Responder

- CONNECT** Before a client makes a request of a server, it must first explicitly connect with the server. The client sends a CONNECT protocol message, which provides the client identifier [triple] to the server for naming the connection and an initial value for the sequence number that will be used for this connection.
- The receiving state machine does the following upon receipt of a CONNECT message:
- if it does NOT have any state associated with that client identifier, it creates a connection record for that client, marks it as IDLE, and sends a CACK (Connection ACK) response to the client
 - if it already has a connection record for that client, and it is in the IDLE state, it assumes that the CACK was lost, and resends it
 - if it already has a connection record for that client, and it is NOT in the IDLE state, it simply ignores the message, as the client state machine is obviously confused

- SEQNO The requestor can reset the sequence number at any time when the connection is in the IDLE state.
The receiving state machine does the following upon receipt of a SEQNO message:
- if it does NOT have any state associated with that client identifier, it drops the message, as the client state machine is confused
 - if it already has a connection record for that client, and it is in the IDLE state, it resets the sequence number to the value supplied in the SEQNO protocol message, and replies with a SACK message
 - if it is in the RESPONSE_SENT state, it assumes that the RACK message was not delivered, it sets the connection state to IDLE, and then acts according to the previous bullet
 - if it already has a connection record for that client, and it is NOT in the IDLE or RESPONSE_SENT state, it simply ignores the message, as the client state machine is obviously confused
- QUERY Clients issue queries over connections, expecting responses. The QUERY protocol message conveys a request for which the server is expected to provide a response.
The receiving state machine does the following upon receipt of a QUERY message:
- if it does NOT have a connection record for that client identifier, it drops the message, as the client state machine is obviously confused
 - if the connection record is in the IDLE state, the next actions depend upon the relationship between the sequence number in the received query and the sequence number stored in the connection record:
 - query number \leq record number
this is a replay of previously answered query; client state machine is confused, message is dropped
 - query number $>$ record number + 1
gaps are not allowed in sequence numbers, so this is illegal; again, client state machine is confused, message is dropped
 - have next legal query on this connection; takes the following steps
 - increment connection record sequence number
 - set state to QACKSent
 - send the QACK
 - place query in appropriate service queue
 - record is in the FACKSent state; action depends upon relationship between query sequence number and record sequence number and the fragment number
 - if query sequence number \neq record sequence number, client state machine is confused, drop message
 - if the fragment number is one more than the last received fragment, this QUERY message completes the buffered query; take the following actions:
 - append data to the previously allocated buffer
 - set state to QACKSent

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- send the QACK
 - place the completed buffer in the appropriate service queue
 - if the fragment numbers are equal, FACK was lost, resend FACK
- record is in the QACKSent state; again, action depends upon relationship between query sequence number and record sequence number
 - if query sequence number \neq record sequence number, client state machine is confused, drop message
 - QACK was lost, resend QACK
- record is in the RespSent state; as before, sequence number relationships are important
 - query sequence number $=$ record sequence number – apparently, client NEVER received QACK, nor has it received the Response that we sent causing us to be in the RespSent state; resend the response, remaining in this state
 - query sequence number $=$ record sequence number + 1 – client has received the response, but we have not received the RACK acknowledging receipt of the previous response; change the state of the connection record to IDLE, then process this QUERY as described for the IDLE state above
 - any other query sequence number - client state machine is confused, so drop the message

FRAGMENT If the query is too large to fit into a single UDP packet, and is broken up into $n-1$ fragments, with the last fragment sent as a QUERY message. The FRAGMENT protocol message conveys a fragment that must be reassembled by the responder.

The receiving state machine does the following upon receipt of a FRAGMENT message:

- if it does NOT have a connection record for that client identifier, it drops the message, as the client state machine is obviously confused
- if the connection record is in the IDLE state, the next actions depend upon the relationship between the sequence number in the received fragment and the sequence number stored in the connection record, as well as the fragment number:
 - query number \leq record number
this is a replay of previously answered query; client state machine is confused, message is dropped
 - query number $>$ record number + 1
gaps are not allowed in sequence numbers, so this is illegal; again, client state machine is confused, message is dropped
 - if the fragment number is 1, we have the first fragment of the next legal query on this connection; take the following steps
 - increment connection record sequence number
 - allocate buffer to hold ENTIRE query
 - copy packet data into beginning of that buffer
 - set state to FACKSent
 - send the FACK

- record is in the FACKSent state; again, action depends upon relationship between fragment sequence number and record sequence number
 - if query sequence number == record sequence number and the fragment numbers in the packet and the record are equal, the FACK was lost, resend the FACK
 - if the sequence numbers are equal, and the packet fragment number is one larger than the last sent, then we have received the next fragment; take the following steps:
 - copy fragment data into query buffer
 - set state to FACKSent
 - send the FACK
 - client state machine is confused, drop the message
- record is in the RespSent state; as before, sequence number relationships are important
 - query sequence number == record sequence number + 1 and fragment number is 1 – client has received the response, but we have not received the RACK acknowledging receipt of the previous response; change the state of the connection record to IDLE, then process this FRAGMENT as described for the IDLE state above
 - any other query sequence number or fragment number - client state machine is confused, so drop the message

RACK The RACK protocol message acknowledges receipt of the response previously sent.

The receiving state machine does the following upon receipt of a RACK message:

- if it does NOT have a connection record for that client identifier, it drops the message, as the client state machine is obviously confused
- if the record is in the IDLE state, the client state machine is confused, and the message is dropped
- if record is in the QACKSent state, the client state machine is confused, and the message is dropped
- record is in the RespSent state; actions depend upon the sequence number relationship
 - query sequence number == record sequence number – normal behaviour, the client is acknowledging receipt of the response; change the state of the connection record to IDLE
 - any other query sequence number - client state machine is confused, so drop the message

DISCONNECT The DISCONNECT protocol message declares the client's desire to terminate the connection.

The receiving state machine does the following upon receipt of a DISCONNECT message:

- it always generates a corresponding DACK and sends it back
- if it has a connection record, it sets the connection record state to TIMEDOUT

5.5.3 Responder → Requestor

- CACK** When the user invokes `bxp_connect()`, a connection record is created, recording the specified starting sequence number and setting the state to `CONNECTSent`.
The receiving state machine does the following upon receipt of a CACK message:
- if it does NOT have any state associated with that server identifier, it drops the message, as the server state machine is confused
 - if it already has a connection record for that client, and it is in the `CONNECTSent` state, it changes the state to `IDLE` and returns to the calling client
 - if it already has a connection record for that client, and it is in some other state, it simply ignores the message, as the server state machine is confused
- SACK** After sending a `SEQNO`, the client state machine expects to receive a SACK message.
The receiving state machine does the following upon receipt of a SACK message:
- if it does NOT have any state associated with that server identifier, it drops the message, as the server state machine is confused
 - if it is in the `IDLE` state, it drops the SACK message, as the server state machine is confused
 - If it is the `SeqnoSent` state, it sets the connection state to `IDLE`
- QACK** After sending a `QUERY`, the client state machine expects to receive a QACK message.
The receiving state machine does the following upon receipt of a QACK message:
- if it does NOT have any state associated with that server identifier, it drops the message, as the server state machine is confused
 - if it is in the `IDLE` state, it drops the QACK message, as the server state machine is confused
 - If it is the `QuerySent` state, action depends upon the relationships between the sequence numbers
 - if the sequence numbers are identical, then change the record state to `AwaitingResponse`
 - for any other sequence numbers, drop the message as the server state machine is confused
 - if it is in the `AwaitingResponse` state, drop the message
- RESPONSE** After processing the `QUERY`, the server sends a `RESPONSE` message.
The receiving state machine does the following upon receipt of a `RESPONSE` message:
- if it does NOT have any state associated with that server identifier, it drops the message, as the server state machine is confused

- if it is in the IDLE state, it drops the message, as the server state machine is confused
- If it is the QuerySent state, action depends upon the relationships between the sequence numbers
 - if the sequence numbers are identical, then it appears that we never received a QACK message, but have received the RESPONSE corresponding to the outstanding QUERY; change the record state to IDLE, send the RACK, and enable delivery of the response to the caller
 - for any other sequence numbers, drop the message as the server state machine is confused
- if it is in the AwaitingResponse state, and the sequence numbers are identical, change the record state to IDLE and enable delivery of the response to the caller; otherwise, drop the message
- if it is in the FACKSent state and this is the last fragment of the response and the sequence numbers are identical, append the message data to the previously allocated buffer, change record state to IDLE, send the RACK, and enable delivery of the response to the caller

FRAGMENT If the response is too large to fit into a single UDP packet, and is broken up into n-1 fragments, with the last fragment sent as a RESPONSE message.

The FRAGMENT protocol message conveys a fragment that must be reassembled by the requestor.

The receiving state machine does the following upon receipt of a FRAGMENT message:

- if it does NOT have a connection record for that client identifier, it drops the message, as the client state machine is obviously confused
- if the connection record is in the AwaitingResponse state, the next actions depend upon the relationship between the sequence number in the received fragment and the sequence number stored in the connection record, as well as the fragment number:
 - if the sequence numbers are equal, and the fragment number is 1, we have the first fragment of the next legal response on this connection; take the following steps
 - allocate buffer to hold ENTIRE response
 - copy packet data into beginning of that buffer
 - set state to FACKSent
 - send the FACK
- record is in the FACKSent state; again, action depends upon relationship between fragment sequence number and record sequence number
 - if query sequence number == record sequence number and the fragment numbers in the packet and the record are equal, the FACK was lost, resend the FACK
 - if the sequence numbers are equal, and the packet fragment number is one larger than the last sent, then we have received the next fragment; take the following steps:
 - copy fragment data into response buffer

- set state to FACKSent
 - send the FACK
 - otherwise, client state machine is confused, drop the message
- record is in the QuerySent state; as before, sequence number relationships are important
 - query sequence number == record sequence number and fragment number is 1 – we somehow missed the QACK for the current QUERY, and this is the first fragment of the response; change the state of the connection record to AwaitingResponse, then process this FRAGMENT as described for the AwaitingResponse state above
 - any other query sequence number or fragment number - client state machine is confused, so drop the message

DACK After sending a DISCONNECT, the client state machine expects to receive a DACK message.

The receiving state machine does the following upon receipt of a DACK message:

- if it does NOT have any state associated with that server identifier, it drops the message, as the server state machine is confused
- Otherwise, it sets the state of the connection to TIMEDOUT

5.6 *Persistence, timeouts, and other miscellany*

UDP does not provide guaranteed delivery of packets, so any reliable protocol constructed over UDP must implement mechanisms to mask transient delivery failures of individual packets. This is accomplished using two devices in this protocol:

- As may be evident from the discussion in the previous section, the receiving state machines attempt to be very flexible in what they accept; in particular, there are a couple of situations where even though the explicit acknowledgement scheme is violated, the protocol is able to function correctly in the absence of these particular ACK messages.
- Successful message delivery (as determined by explicit ACKs or the short circuits discussed in the previous bullet) is facilitated by attempting retransmission of each outbound packet according to an exponentially increasing time schedule. After an implementation-defined maximum number of retransmission attempts, the implementation will assume that the failure is not transient, and will set the state of the connection to TIMEDOUT.
- If a PACK is not received after an implementation-defined number of PINGs, the connection state is set to TIMEDOUT. Note that regular messaging activity on the connection always resets the failure detector fields in the connection record, so PINGs are only sent if the connection has been idle (not necessarily in the ST_IDLE state ☺).
- The sequence number sequence will need to wrap; the responsibility for resetting the sequence number is with the client/requestor; when it determines that it must reset the sequence number, it sends a SEQNO protocol message, expecting a SACK response.
- All harvesting of stale connections is done by the timer thread; the next timer pass after a connection has been set to TIMEDOUT will remove such connection records from the table and return any allocated resources.

6 Starting archives

6.1 *P3start.tgz*

This archive contains the following files:

echoclient.c A client that you can use to test out *dtsv1.c* and *dtsv2.c*.

dts-client.c A client that you can use to test out *dtsv3.c* and *dtsv4.c*.

Makefile Has targets to compile and link *echoclient*, *dts-client*, *dtsv1*, *dtsv2*, *dtsv3*, and *dtsv4*.

6.2 *Installing BXP*

P3BXP-INTEL.tgz and *P3BXP-ARM.tgz* are available on Canvas. You should download the archive appropriate to your architecture; extract the contents of the archive - it will create a *bxp* directory in your current directory when you invoke *tar*. *cd* into *bxp*, then issue the following three commands to bash:

```
% sudo make installheaders
% sudo make installlibrary
% sudo make installmanpages
```

6.3 *Reinstalling the ADT headers, library, and man pages*

P3ADTS-INTEL.tgz and *P3ADTS-ARM.tgz* are also available on Canvas; I realized that the *min()* method on priority queues should have an additional argument, returning both the priority and the value for the minimum element in the priority queue. You should create a directory named *adts* somewhere on your system, download the archive appropriate to your architecture into that directory, and extract the contents of the archive into that directory. Assuming that your current directory is the *adts* directory, then issue the following three commands to bash:

```
% sudo make installheaders
% sudo make installlibrary
% sudo make installmanpages
```

7 Developing Your Code

The best way to develop your code is in Linux running inside the virtual machine image provided to you. This way, if you crash the system, it is straightforward to restart. This also gives you the benefit of taking snapshots of system state right before you do something potentially risky or hazardous, so that if something goes horribly awry you can easily roll back to a safe state. You should use your Bitbucket GIT repositories for keeping track of your programming work. As a reference, you can perform the command line steps below to create a new project directory and upload it to your *uoregon-cis415* repository.

```
% cd /path/to/your/uoregon-cis415
% mkdir project3
% echo "This is a test file." >project1/testFile.txt
% git add project3
% git commit -m "Initial commit of project3"
% git push -u origin master
```

Any subsequent changes or additions can be saved via the add, commit, and push commands.

7.1 Testing Your Code

In `P3start.tgz`, I have provided the source for two programs that you can use to test your server: `echoclient.c` and `dts-client.c`; `echoclient` can be used to test `dtsv1` and `dtsv2`, while `dts-client` can be used to test `dtsv3` and `dtsv4`. You will have to read over the source code for `echoclient` and `dts-client` to see how to invoke them. I have provided a `Makefile` in the archive that will build these two programs; it also has targets to build `dtsv1`, `dtsv2`, `dtsv3`, and `dtsv4`.

7.2 Checking for memory leaks in your code

The buffer exchange protocol uses `malloc()/free()` quite a bit while implementing the state machines shown in sections 5.3 and 5.4 above. In addition, your server should run forever, so you have to terminate it when running it under `valgrind`, thus making the summary message you receive when you `^C` out of the server less than useful.

`valgrind` enables you to display a leak check summary within your program by doing the following:

1. At the top of your source file, add `"#include <valgrind/valgrind.h>"` to the list of included files.
2. Wherever you wish to generate a leak check summary, include the following statement
`VALGRIND_MONITOR_COMMAND("leak_check summary");`

If you are not running your program under `valgrind`, this statement will not generate any output. If you are running your program under `valgrind`, a leak summary will be generated on standard error each time you execute this statement. The leak summary will look like the following:

```
==pid#== LEAK SUMMARY:
==pid#==    definitely lost: 0 (+0) bytes in 0 (+0) blocks
==pid#==    indirectly lost: 0 (+0) bytes in 0 (+0) blocks
==pid#==    possibly lost: 1,088 (+0) bytes in 4 (+0) blocks
==pid#==    still reachable: 5,952 (+124) bytes in 35 (+5) blocks
==pid#==    suppressed: 0 (+0) bytes in 0 (+0) blocks
==pid#== To see details of leaked memory, give 'full' arg to leak_check
==pid#==
```

How can you use this feature in `uspsv3` to check for your memory leaks? I suggest the following:

- After you have created all of the ADT instances you need, have initialized BXP, created the thread to process the requests, and that thread has offered the "DSP" service - this establishes the heap memory baseline.

- After you have processed each client request received (either determined there is an error, or you have entered an event in the priority queue).
- After you have completed each OneShot event.
- After you have completed all repeats of a Repeat event.

If the “definitely lost” line of each summary continues to read 0 for each of these summaries, your processing is not leaking any memory. Since this server is supposed to run forever, it is especially important that your code leak no memory. This is how I will be assessing the “No memory leaks or error messages” in the grading rubric.

7.3 Helping your Classmate

This is an individual assignment. You should be reading the manuals and man pages, hunting for information, and learning those things that enable you to do the project. However, it is important for everyone to make progress and hopefully obtain the same level of knowledge by the project’s end. If you get stuck, seek out help to get unstuck. Sometimes just having another pair of eyes looking at your code is all you need. If you cannot obtain help from the TA, the LAs, or the instructor, it is possible that a classmate can be of assistance.

In your status report on the project, you should provide the names of classmates that you have assisted, with an indication of the type of help you provided. You should also indicate the names of classmates from whom you have received help, and the nature of that assistance.

Each of your source files must start with an “authorship statement”, contained in C comments, as follows:

state your name, your login, and the title of the assignment (CIS 415 Project 3)

state either “This is my own work.” or “This is my own work except that ...”, as appropriate.

Note that this is not a license to collude. We will be checking for collusion; better to turn in an incomplete solution that is your own than a copy of someone else’s work. We have very good tools for detecting collusion.

8 Submission²

You will submit your solutions electronically by uploading a gzipped tar archive via Canvas.

Your TGZ archive should be named `<duckid>-project3.tgz`, where `<duckid>` is your “duckid”. It should contain `dtsv1.c`, `dtsv2.c`, `dtsv3.c`, `dtsv4.c`, a **Makefile** for creating executables named `dtsv1`, `dtsv2`, `dtsv3`, and `dtsv4`, and a document named `report.txt`, describing the state of your solution, and documenting anything of which we should be aware when marking your submission. If you have created any additional `.c` or `.h` files upon which `dtsv[1-4]` depend, be sure to include them in the archive, as well.

² A 75% penalty will be assessed if you do not follow these submission instructions. See the handout for Project 0 if you do not remember how to create the gzipped tar archive for submission.

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Within the archive, these files should **not** be contained in a folder. Thus, if I upload “jsventek-project3.tgz”, then I should see something like the following when I execute the following command:

```
$ tar -ztvf jsventek-project1.tgz
-rw-r--r-- jsventek/group      1021 2016-10-30 16:37 Makefile
-rw-r--r-- jsventek/group      3670 2016-10-30 16:30 dtsv1.c
-rw-r--r-- jsventek/group      5125 2016-10-30 16:37 dtsv2.c
-rw-r--r-- jsventek/group      6531 2016-10-30 16:37 dtsv3.c
-rw-r--r-- jsventek/group      8127 2016-10-30 16:37 dtsv4.c
-rw-r--r-- jsventek/group      1536 2016-10-30 16:30 report.txt
```

as well as any other files that you have included.

Each of your source files must start with an “authorship statement”, contained in C comments, as follows:

- state your name, your duckid, and the title of the assignment (CIS 415 Project 3)
- state either “This is my own work.” or “This is my own work except that ...”, as appropriate.

We will be compiling your code and testing against unseen commands. We will also be checking for collusion; better to turn in an incomplete solution that is your own than a copy of someone else’s work. We have very good tools for detecting collusion.

Rubric for CIS 415, Project 3

Your submission will be marked on a 100 point scale. I place substantial emphasis upon **WORKING** submissions, and you will note that a large fraction of the points is reserved for this aspect. It is to your advantage to ensure that whatever you submit compiles, links, and runs correctly. The information returned to you will indicate the number of points awarded for the submission.

You must be sure that your code works correctly on your virtual machine, regardless of which platform you use for development and testing. Leave enough time in your development to fully test on the virtual machine before submission.

Version	Points	Description
(10)	10	Your report – honestly describes the state of your submission
DTS v1	8	for workable solution initializes BXP runtime create a thread to receive requests from echoclient <ul style="list-style-type: none"> • offer DTS service • forever <ul style="list-style-type: none"> - fetch query from service - format correct response - send response back to client
(20)	1	if it successfully compiles
	1	if it compiles with no warnings
	1	if it successfully links
	1	if it links with no warnings
	6	if it works correctly
	2	if there are no memory leaks
DTS v2	8	for workable solution Correctly parses query strings echoes back correct query strings with success status byte responds with failure status byte if incorrect command or incorrect number of additional arguments.
(20)	1	if it successfully compiles
	1	if it compiles with no warnings
	1	if it successfully links
	1	if it links with no warnings
	6	if it works correctly
	2	if there are no memory leaks

Version	Points	Description
DTS v3 (50)	20	for workable solution correct data structures for event queue fine-grained timer structure correct implementation of OneShot correct implementation of Repeat correct implementation of Cancel correct printout when event transpires
	1	if it successfully compiles
	1	if it compiles with no warnings
	1	if it successfully links
	1	if it links with no warnings
	20	if it works correctly
	6	if there are no memory leaks
DTS v4 (20)	8	for workable solution - working version of dstv3 PLUS sends event notification to client caches BXPConnections
	1	if it compiles with no warnings
	1	if it links with no warnings
	8	if it works correctly
	2	if there are no memory leaks