FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

Electrical Engineering Department

Telecommunication Systems

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Laboratory Work 2:
Data link layer protocols with sliding window

Integrated Master in Electrical Engineering and Computers

http://tele1.dee.fct.unl.pt/st

Index

1. OBJECTIVE

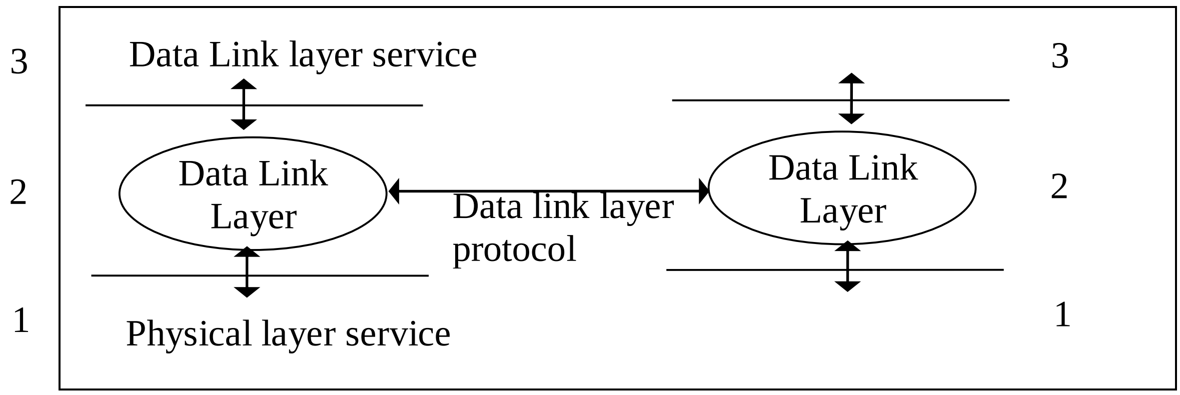
Familiarization with the sliding window data-link layer protocols, of type Stop & Wait, Go-Back-N and Selective Repeat.

The work consists in the development of a data-link layer protocol based on sliding window, of type Selective Repeat, in a phased manner. For this, it is provided a system simulator developed in the course using TCP sockets, which simulates the operation of the network protocol level and physical level.

> **Suggestions**: In certain parts of this document appears some text formatted differently that begins with the word "Suggestion". It is not mandatory to follow what is written there, but may be important for students or groups where there is not yet at ease with programming, data structures and algorithms.

2. SPECIFICATIONS

The aim is to develop a data-link layer protocol for a point-to-point physical connection, which interacts with the Network layer and Physical layer protocols, respectively through the interfaces of the services of the Logical and Physical layers. Thus, the system represented below will be simulated through the set of primitives of the two services.

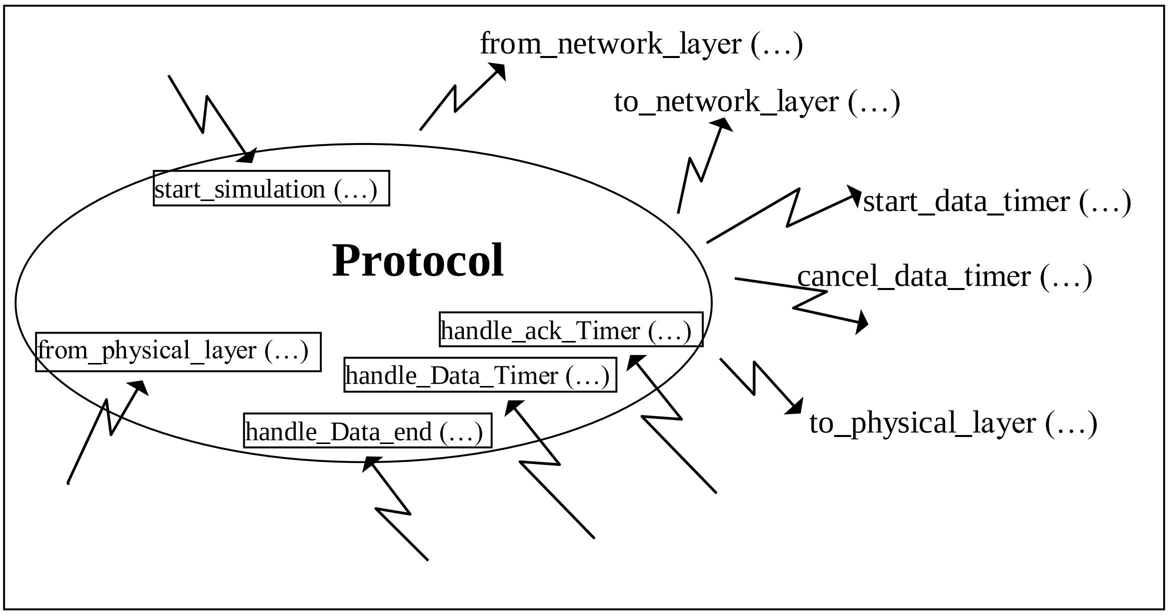


The proposed approach was inspired in the simulator described in sections 3.3 and 3.4 of the recommended book (Computer Networks 5th edition), although it makes the simulation a bit closer to reality (e.g. it considers the transmission time of data frames). The data-link layer protocol will react to events and can invoke commands.

The Data Link layer begins with the event that is served by the method `start_simulation()`. To receive packets (strings) from the Network layer, the data-link layer uses the method `from_network_layer()` and sends packets (strings) to the Network layer invoking the method `to_network_layer()`. The data must be delivered in the same order they were received, recovering from channel errors at the Physical layer.

The protocol can send frames to the Physical layer using `to_physical_layer()` and it can receive frames from the Physical layer in its method `from_physical_layer()`, invoked by the Physical layer protocol.

Finally, you can use a set of support features to manage timers. Using the methods `set_timer` and `cancel_timer`, you can set or cancel a timer identified by a number greater than or equal to zero (called *key*). When the time expires, the method `handle_timer()` is called. The figure below illustrates what was just described. Students should implement the balloon called "Protocol".



2.1. FRAMES TYPES

The protocol can send or receive two kinds of frames: DATA or ACK.

Data frames (DATA)

The data frames have the following fields:

- Sequence number (`seq`)
- Acknowledgment (`ack`)
- Information (`info`)

The frames are numbered with a `seq` number between 0 and a maximum number specified in a window (`sim.get_max_sequence()`). The `ack` field contains the sequence number of the last data frame received.

The data frames have a non-null transmission time, so its transmission is carried out in two phases:

1) It starts sending the frame using the method `to_physical_layer`;

2) It is received an event `handle_Data_end`, stating that ended the sending of the data frame.

Other frames can not be sent between the beginning of the sending of a data frame and the reception of the end event. Using the method método `is_sending_data()` you can check if a data frame is being transmitted.

Acknowledgment frames (ACK)

The acknowledgement frames (ACK) are generated after the reception of data frames, indicating the sequence number of the last data frame successfully received. The ACK frame is considered instantaneous, being sent on a single method invocation to `to_physical_layer`. The ACK frame contains a single field:

- Acknowledgment (`ack`)

As it is more efficient to send this information via data frames (for piggybacking), an auxiliary timer was set (*ack_timer*) that can be used to wait for a data frame, only sending ACK after this time. Thus, after receiving a data frame you should:

1) Start the ACK timer using the method `start_ack_timer()`;
2a) If a data frame to transmit arrives, the timer can be canceled using the method `cancel_ack_timer()`;
2b) If the timer expires, the event `handle_ack_Timer` is generated, which should send the ACK frame.

2.2. DATA LINK LAYER PROTOCOLS

In sections 3.3 and 3.4, the recommended book describes the four basic types of data link layer protocols that will be implemented in this work. This section briefly reproduces the fundamental aspects of each, but we recommend a careful reading of the book for proper completion of the work.

Utopian protocol

The Utopian protocol is described in section 3.3.1 of the book, corresponding to realize the transmission of frames sequentially without any error recovery mechanism. The receiver is limited to receive the frames and send them to the network level.

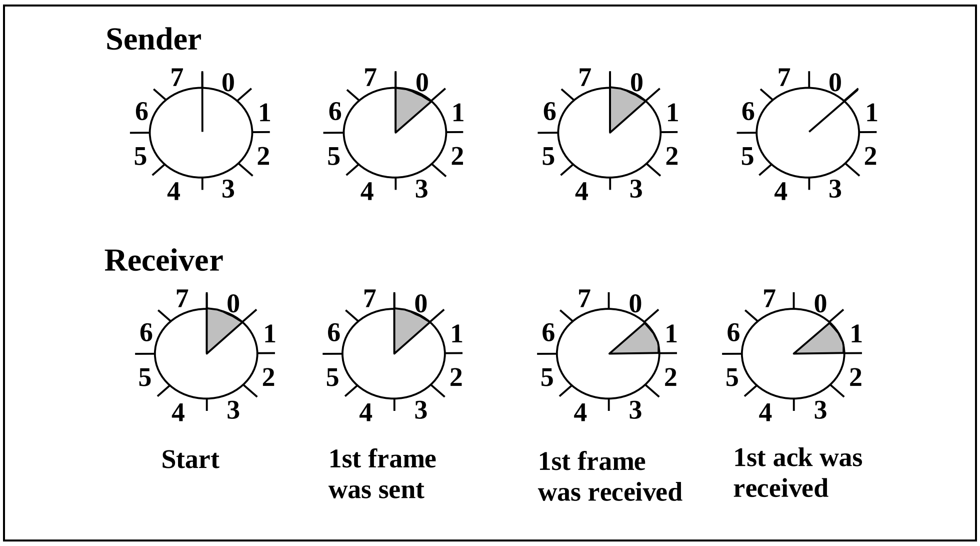
It is provided the complete code of a sender and of a receiver of this protocol with the work assignment.

Stop & wait Simplex protocol

The Stop & Wait simplex protocol is described in sections 3.3.2 and 3.3.3 of the book and corresponds to the sequential sending of the frames using error recovery mechanisms. The sender sets a timer each time it sends a data frame. If it expires, he retransmits the frame. Whan an ACK confirms the frame, the timer is cancelled and the next frame is sent.

Stop & Wait (duplex) protocol

The Stop & Wait protocol is described in section 3.4.1 of the book and corresponds to a sliding window protocol with unitary transmitting and receiving windows. The sender holds the next sequence number transmitted and the receiver the next expected sequence number, in accordance with the diagram to the right.

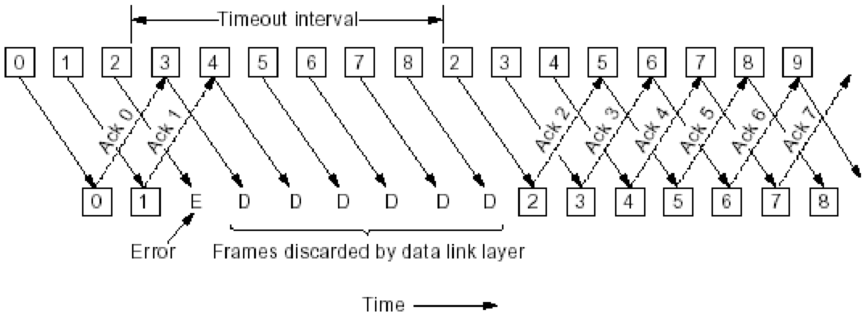


In practice, this protocol combines the sender and receiver of the stop&wait simplex protocol, and is able to send and receive data concurrently. The main difference is that data frame confirmation may be done using the ACK field of the data frame. Using an ACK timer, you can postpone the sending of the ACK frame, cancelling it if a data frame is sent before the timer expires.

Go-Back-N protocol

The Go-Back-N protocol is described in section 3.4.2 of the book. It corresponds to a sliding window protocol with a unitary receiving window, which uses pipelining to improve performance when the bandwidth * delay product is high.

In this case, the sender will need an array to maintain the transmit buffers, and may transmit up to `sim.get_send_window()` frames without receiving acknowledgments (i.e. transmission window). When an error occurs, it has to retransmit all data frames from the one that has not been confirmed, as shown in the figure below.



The management of timers is somewhat more complex in this protocol. In this work **you should use a single timer for all data frames**. The timer would be reset each time it is confirmed a new data frame.

Selective Repeat protocol

The Selective Repeat protocol is described in section 3.4.3 of the book, although the Negative ACK (NACK) frames will not be used in this work. It corresponds to a sliding window protocol with arbitrary sending and receiving windows, which uses pipelining to improve performance when the bandwidth * delay product is high.

The big difference compared to the protocol above is that out of order data frames in the receiving window are received and stored in a buffer. However, the data is sent to the network layer orderly. As before, you should use a single data timer.

2.3. SIMULATION SCENARIO

In this work, a network with variable delay time and a constant average frame loss rate is simulated. Two programs are used:

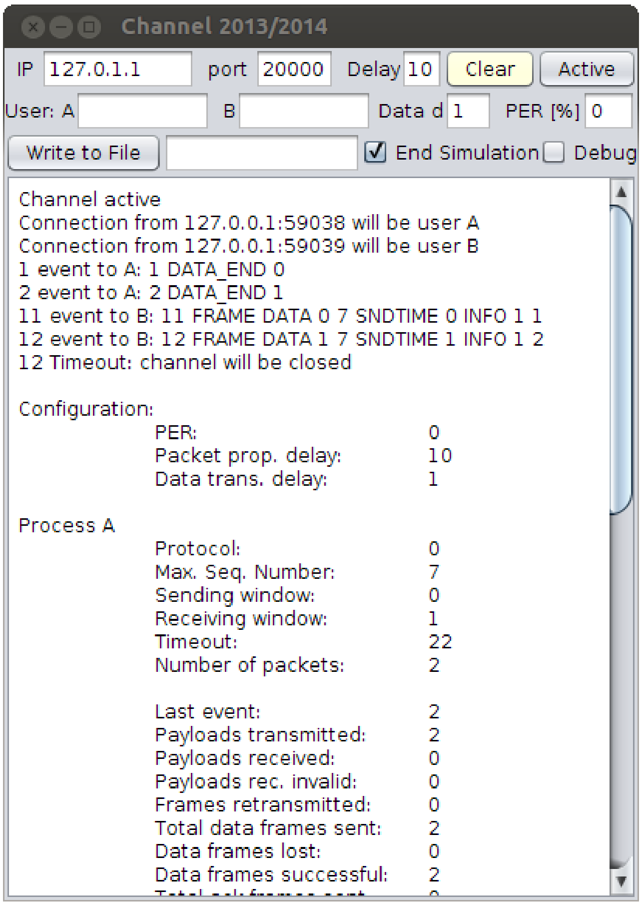
- *Protocol* – implements the data link layer protocol and emulates the network level, controlling the sending and receiving of data packets numbered sequentially. The data link layer part will be made by students;
- *Channel* – connects two instances of *Protocol*, emulating the propagation time and missing frames with a certain probability of loss.

After booting, the *channel* accepts two TCP connections from two *Protocol* programs, starting a new simulation. The channel implements a discrete event scheduler, receiving the commands generated by the protocols and generating the events related to the physical level and the timers shown previously, ordered according to the simulation time. The simulation time is measured in units of virtual time, called *tics*.

Both the *protocol* and the *channel* provided with the statement write briefly (or exhaustively, in *debug* mode) the events and commands that are generated, and the contents of the queue with events waiting to be fired.

3. Program Development

3.1. Channel Application



The *channel* application is provided fully implemented. It consists of a Java application with the GUI shown on the right. Pressing the button "*Active*", the channel starts a *ServerSocket* on the IP and port shown, getting ready to receive connections from *protocols*, to be designated respectively the *protocol* (*User*) A and B.

The application allows you to perform various configurations of the simulation scenario:

- "*Delay*" – propagation time of frames in the channel;
- "*Data d*" – duration of a data frame (time between sending the frame and the event *Data_end*);
- "*PER [%]*" – average *Packet Error Rate* in the channel, which can affect all frames transmitted with equal probability;
- "*End Simulation*" – controls whether the channel automatically terminates a simulation when it does not receive events for a second, or if the decision is left to the user by pressing the "*Active*" button;
- "*Write to File*" – controls whether messages written to the screen are echoed to a file.

At the end of the simulation, it is a written report with the value of the various settings used in the channel and protocols, and several measures of system performance for protocols A and B. The measures are:

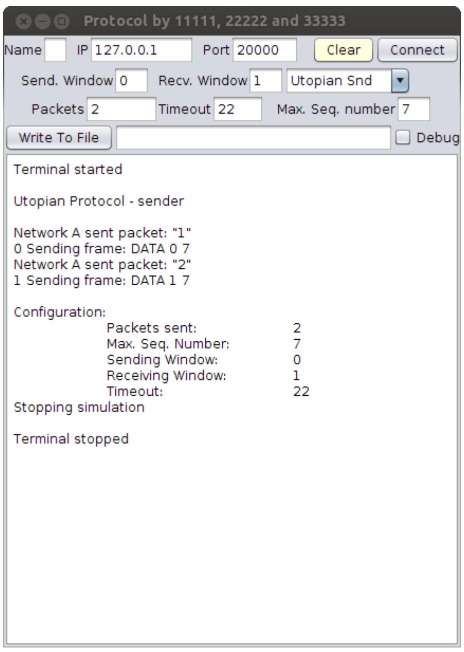
- *Last event* – time of the last event that the *protocol* received / originated, returning the total delay that occurred to send and receive all the data;
- *Payloads transmitted* – number of packets transmitted by the network level;
- *Payloads received* – number of packets received by the network level;
- *Payloads rec. invalid* – number of packets received out of order by the network level;
- *Frames retransmitted* – number of retransmitted data frames (<u>the programmer should explicitly update this counter</u>);
- *Total data frames sent* – total number of data frames sent;
- *Data frames lost* – number of data frames lost due to channel errors;
- *Data frames successful* – number of data frames received successfully;
- *Total ack frames sent* – total number of ACK frames sent;
- *Ack frames lost* – number of ACK frames lost due to channel errors;
- *Ack frames successful* – number of ACK frames received successfully;
- *Timeouts* – number of Timeout events received;
- *Ack timeouts* – number of ACK_Timeout events received.

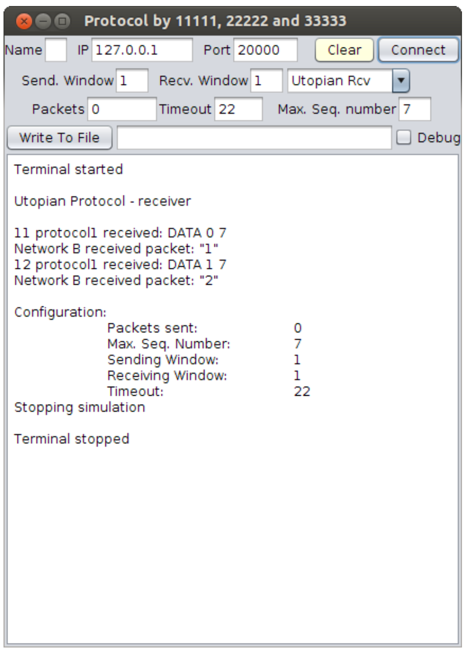
The performance of the developed protocols will be measured using these metrics, highlighting the delay and the ratio of the total number of packets transmitted per data packet. It is suggested that the performance of the protocols is tested for: i) a scenario without error and with adjusted timeout (PER = 0 and Timeout = 22 tics), ii) scenario with errors and adjusted timeout (PER = 50% and Timeout = 22 tics), and iii) scenario with errors and a long timeout (PER = 50% and Timeout = 44 tics).

You can run the *channel* from the terminal with the command: `java -jar Channel.jar`

3.2. Protocol Application

The work consists solely in implementing the data link layer protocols. Everything else is supplied fully implemented. The two figures below represent the *protocol* nodes A and B with protocol messages generated according to channel figure previously shown.





The graphical interface allows you to define which channel is connected, selecting the IP and port. The simulation starts when you press the "*Connect*" button and the channel generates a start event simulation.

Through the graphical interface, you can set:

- *Packets* – the number of packets that will be sent during the simulation;
- *Max. Seq. number*– the maximum sequence number (generaly given by 2^n-1);
- *Send Window* – the sending window size;
- *Recv Window* – the receiving window size (it is always 1 in this work);
- *Timeout* – time waiting for an acknowledgment before resending a data frame.

There is also a combo box that allows you to choose the data link layer protocol: *Utopian Snd*; *Utopian Rcv*; *Simplex Snd*; *Simplex Rcv*; *Stop & Wait*; *Go-Back-N*; and *Selec. Repeat*. The objective is to develop the code for the last four protocols.

The given program consists of three packages, each having the following classes:

- Package `terminal`:
  - *Terminal,java* (completed) – Main class with graphical interface that manages the timing of various objects used;
  - *Connection.java* (completed) – Thread that habndles the TCP connection to the channel;
  - *NetworkLayer.java* (completed) – Class that implements the network layer interface;
- Package `simulator`:
  - *Frame.java* (completed) – Class that saves and serialises frames;
  - *Event.java* (completed) – Class that saves and serialises events;
  - *Log.java* (completed) – Interface that defines the *Log* function;
- Package `protocol`:
  - *Simulator.java* (completed) – Interface that defines all the commands that can be used to implemente a daat link layer protocol;
  - *Callbacks.java* (completed) – Interface that defines all the methods that must be implemented while performing a data link layer protocol;
  - *Base_Protocol.java* (completed) – Support class that defines a set of methods that handle sequence numbers, a data timer simplified interface, and a default implementation for all methods of interface *callbacks*. All protocolo classes inherit this set of functions;
  - *Utopian_snd.java* (completed) – Implementation of the sender of the Utopian data link layer protocol;
  - *Utopian_rcv.java* (completed) – Implementation of the receiver of the Utopian data link layer protocol;
  - *Simplex_snd.java* (<u>**to be completed**</u>) – Implementation of the sender of the simplex Stop & Wait protocol;
  - *Simplex_rcv.java* (<u>**to be completed**</u>) – Implementation of the receiver of the simplex Stop & Wait protocol;
  - *StopWait.java* (<u>**to be completed**</u>) – Implementation of the Stop & Wait protocol;
  - *GoBackN.java* (<u>**to be completed**</u>) – Implementation of the Go-Back-N protocol;
  - *SelectiveRepeat.java* (<u>**to be completed**</u>) – Implementation of the Selective Repeat protocol.

Students will only modify the last five files, to implement the desired protocols, mainly using the methods defined in the interfaces `Callbacks` and `Simulator`, and inherited from the `Base_Protocol` class, described in the next section.

3.2.1. Commands

In the protocol implementation classes you can invoke on the `sim` object the following methods (which were defined in the `Simulator interface`). The purpose of each is explained below:

- Get the size of the sending window:

```
int get_send_window();
```

- Get the size of the receiving window:

```
int get_recv_window();
```

- Get the maximum sequence number:

```
int get_max_sequence();
```

- Get the timeout value:

```
long get_timeout();
```

- Get the current simulation time:

```
long get_time();
```

- Send the frame `frame` to the physical layer (i.e. to the channel):

```
void to_physical_layer(simulator.Frame frame);
```

- Start the ACK timer:

```
void start_ack_timer();
```

- Cancel the ACK timer:

```
void cancel_ack_timer();
```

- Test if the ACK timer is active:

```
boolean isactive_ack_timer();
```

- Stop the simulation:

```
void stop();
```

The `Simulator` interface also defines a set of methods to start and stop the data timer. In this work you should use only the three equivalent methods defined in class `Basic_Protocol`, presented in section 3.2.1.1, which use a single key.

- Start a timer associated to the key `key`. If it is started twice with the same key, the first timer is cancelled:

```
void start_data_timer(long delay, int key);
```

- Cancel the timer associated with the key `key`:

```
void cancel_data_timer(int key);
```

- Test if the timer associated with the key `key` is active:

```
boolean isactive_timer(int key);
```

3.2.1.1. Data timers

Class `Basic_Protocol` defines three methods (inherited by the classes that implement the protocols) that start, stop and test the data timer with the key `TIMER_KEY=1`.

```
void start_data_timer();
void cancel_data_timer();
boolean isactive_data_timer();
```

Sugestions: Use only this set of methods to control the data timer.

3.2.2. Events

Think of the event as something that causes the invocation of the *callback* methods. These methods will be implemented by the students in a *Protocol* class, and were defined in the `Callbacks` interface:

- Start of simulation:

```
void start_simulation(long time);
```

- End of transmission of the data frame with the sequence number `seq`:

```
void handle_Data_end(long time, int seq);
```

- Firing of the timer associated with the key `key` (this work uses only the key `DATA_KEY=1`):

```
void handle_Data_Timer(long time, int key);
```

- Firing of the ACK timer:

```
void handle_ack_Timer(long time);
```

- Reception of the frame `frame` from the physical layer:

```
void from_physical_layer(long time, simulator.Frame frame);
```

- End of simulation:

```
void end_simulation(long time);
```

In all events, it is received the current simulation time in `time`.

3.2.3. Network layer

Class `terminal.NetworkLayer` defines the methods to exchange packets with the network layer, and is instanciated in `net` object:

- Get a new packet from network layer (if there is no longer any more to send, returns `null`):

```
String from_network_layer();
```

- Send a new packet to the network layer (in case of error returns `false`):

```
boolean to_network_layer(String packet);
```

3.2.4. Creation and Reading of frames

The frames are objects of class `simulator.Frame (import Simulator.Frame)`. This class contains the fields as explained previously (`seq`, `ack` and `info`) plus another one called `kind`. In addition, it has static methods for creating new instances of objects, and methods for accessing various fields. The `kind` field defines the type of frames, having two valid values for a valid frame: `Frame.DATA_FRAME` and `Frame.ACK_FRAME`; and the value `Frame.UNDEFINED_FRAME` when it is not initialized.

The method `kind()` can be used to get the value of `kind`.

To create a new frame of each of the two types it is possible to use the methods:

```
public static Frame new_Data_Frame(int seq, int ack, String info);
public static Frame new_Ack_Frame(int ack);
```

To access the fields you can use the methods:

```
public int seq();       // for DATA_FRAME
public String info();   // for DATA_FRAME
public int ack();       // for DATA_FRAME or ACK_FRAME
public long snd_time(); // time when it was sent
```

It is also possible to get a textual description of the contentes of a frame:

```
public String kindString();   // return the kind of the frame
public String toString();     // return the kind and the content summary
```

Two methods were defined to enable the transportation of frames through TCP sockets, which convert the contentes to and from strings (i.e. do object serialization). These functions will not be used by students, but generate the representation that is shown in the applications log.

```
public String frame_to_str();
public boolean str_to_frame(String line, Log log);
```

3.2.4.1. Sequence numbers

The `Basic_Protocol` class is inherited by all protocols. It defines a set of methods that manage the sequence numbers used in the data and ACK frames, with values between `0` and `sim.get_max_sequence()`:

- Add one unit to sequence number `n`, wrapping around following the circular order:

```
int incr_seq(int n);
```

- Add `k` units to sequence number `n`, wrapping around following the circular order:

```
int add_seq(int n, int k);
```

- Decrease one unit to sequence number `n`, wrapping around following the circular order:

```
int decr_seq(int n);
```

- Test if sequence number `b` verifies condition `a <= b < c`, considering the circular order:

```
boolean between(int a, int b, int c);
```

- Calculate the difference between two sequence numbers, considering the circular order:

```
int diff_seq(int a, int b);
```

3.2.5. Utopian Protocol

Classes *Utopic_snd* and *Utopic_rcv were* developed to serve as an example for students. They implement the utopian protocol described above.

The *Utopic_snd* class adds to the interface `Callbacks` one state variables and a method to centralize the sending of frames to the physical layer.

The state variable is used to control the sequence number used in the frames:

```
private int next_frame_to_send; // Number of the next data frame to be sent
```

The method to send frames is the following:

```
boolean send_next_data_packet() {
  String packet= net.from_network_layer();
  if (packet != null) {
    // The ACK field of the DATA frame is always the sequence number before 0,
    //   because no packets will be received!
    Frame frame = Frame.new_Data_Frame(next_frame_to_send, decr_seq(0), packet);
    sim.to_physical_layer(frame);
    next_frame_to_send= incr_seq(next_frame_to_send);
    return true;
  }
  return false;  // Failed; no more packets to send
}
```

This method is called:

- In the beginning of the simulation:

```
public void start_simulation(long time) {
  sim.Log("\nUtopian Protocol - sender\n\n");
send_next_data_packet();    // Start sending the first data frame
}
```

- When the sending of a data frame ends:

```
public void handle_Data_end(long time, int seq) {
  send_next_data_packet();    // Send the next data frame
```

```
}
```

The *Utopic_rcv* implements frame reception. It adds to the interface `Callbacks` one state variable to control the sequence number of the frames received:

```
private int frame_expected;     // Expected number for the next data frame received
```

Frames are received in method `from_physical_layer`, which does a little more than the original version of the book – it verifies if it is the expected sequence number, and advances it to the next frame.

```
public void from_physical_layer(long time, Frame frame) {
  sim.Log(time + " protocol1 received: " + frame.toString() +"\n");
  if (frame.kind() == Frame.DATA_FRAME) {      // Check the frame kind
    if (frame.seq() == frame_expected) {    // Check the sequence number
      net.to_network_layer(frame.info()); // Send the frame to the network layer
      frame_expected = incr_seq(frame_expected);
    }
  }
}
```

The remaining methods of interface `Callbacks` are not used in this protocol. They simply write that were invoked.

3.2.6. Stop&Wait Simplex Protocol

The *Simplex_snd* and *Simplex_rcv* classes should be programmed to implement the Simplex Stop&Wait protocol, starting from the Utopian protocol code. The major changes are:

- The sender must create a timer, and start it each time it sends a data frame, retransmiting the frame if an ACK is not received;
- The receiver should send an ACK for every data frame received.

The sender sould implement the `handle_Data_Timer` method to deal with the expiration of the timer.

3.2.7. Stop&Wait Duplex Protocol

The *StopWait* class should implement the Stop&Wait duplex protocol, starting from the two classes implemented in the previous task. This protocol acts as both transmitter and receiver, gathering all the features of the two objects. Thus, the implementation involves two steps:

1) Gather in a single file the code of *Simplex_snd* and *Simplex_rcv* classes, adapting the code of `from_physical_layer` method to handle packets of the two starting classes.
2) Add an *ACK_timer* timer, so you can send the confirmation of receipt of data frames with the ack field of data frames and ACK frames.

3.2.8. Go-back-N Protocol

The *GoBackN* class must be programmed from the class *StopWait* in order to implement the Go-back-N sliding window protocol with a single timer. The changes affect only the sender part, which should support transmission windows greater than one.

Sugestions: We recommend that you declare an array of strings with the size of the number of packet identifiers (`sim.get_max_sequence()+1`) to store the packets received from the network level, allowing its retransmission. It is also recommended to add the variables necessary to store the oldest frame confirmed and the last sent.

3.2.9. Selective Repeat Protocol

The *SelectiveRepeat* class must be programmed from the class *GoBackN* to implement the selective repeat sliding window protocol with a single timer. The changes affect only the receiver part, which should support a receiving window above one.

Sugestions: We recommend that you declare an array of strings with the size of the number of packet identifiers (`sim.get_max_sequence()+1`) to store the packets received from the physical level, allowing you to store the packets received out of order and send them to the level network later neatly. Again, you may need to declare additional variables to control the reception of data.

3.3. GOALS

A sequence for the development of the work can be:

1. Programming the Simplex Protocol in `Simplex_snd` and `Simplex_rcv` classes. Start by copying the contents of `Utopic_snd` and `Utopic_rcv`, and realize what can be reused;
2. Programming the Stop & Wait duplex protocol in `StopWait` class. Start by copying the contents of `Simplex_snd` and `Simplex_rcv` classes for `StopWait` class;
3. Programming the Go-Back-N protocol with a single timer in `GoBackN` class. Start by copying the contents of `StopWait` class to `GoBackN`;
4. Programming the selective repeat protocol with a single timer in `SelectiveRepeat` class. Start by copying the contents of `GoBackN` class to `SelectiveRepeat`.

Sugestions: If a group feels very comfortable with the inheritance mechanism of Java, you can use it to reduce the number of code lines of copied (mainly in goal 4 of the work). But this is not recommended for students with little experience in Java, as is the case of most students of ST.

ALL students must try to **complete phase 2**. In the first week of the work a general introduction to the work is made and phase 1 should be finished. At the end of the second week the phase 3 you should have started phase 3. At the end of the third week you should have ended phase 3. At the end of the fourth and final week you should try to achieve the maximum number of phases, taking into account that it is preferable to do less well (running and no errors), than everything and nothing works.

STUDENT POSTURE

Each group should consider the following:

- Do not waste time with the aesthetics of input and output data;
- Program in accordance with the general principles of good coding (using indentation for comments, using variables with names conform to its functions ...) and;
- Proceed so that the work is equally distributed to the two members of the group.