Faculty of Engineering of the University of Porto

Computer Networks

SERIAL PORT PROJECT REPORT

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Summary

We are students of a Master's Degree in Informatics and Computing Engineering at FEUP. In Computer Networks class, we have been challenged to develop a program that uses the serial port to send data between two connected Linux machines.

We've concluded that a serial port transfer is, by today' standards, very slow compared to other forms of data transfer, at least with the protocol that was adopted. On the other hand, with our implementation of the protocol it resists errors caused by interference or interrupted connection.

Introduction

The objective was to create software that sends information between two Linux machines using the serial port, using a Stop-and-Wait ARQ mechanism and a specific protocol. This report will explain the architecture and its modules; the code structure by showing the code flow as well as listing the most important data structures and functions; the protocols used in both the link layer and application layer.

Architecture

The program consists of two decupled primary modules: application layer and link layer. On the other hand, the link layer module depends on a set of secondary modules: alarm, serial port and utilities.

The link layer is a set of functions that create an API. It's responsible for developing a protocol that allows it to open/close the serial port connection, read/write data from/to the serial port buffer and recover from errors and interruptions.

The application layer is a generic program that uses the link layer API to send data through a serial port. Its purpose is to read a file's data and call the link layer functions to open/close the serial port and read/write the data. It's responsible for adopting an application-specific protocol, so that both sender and receiver work in sync.

Code Structure

Code Flow

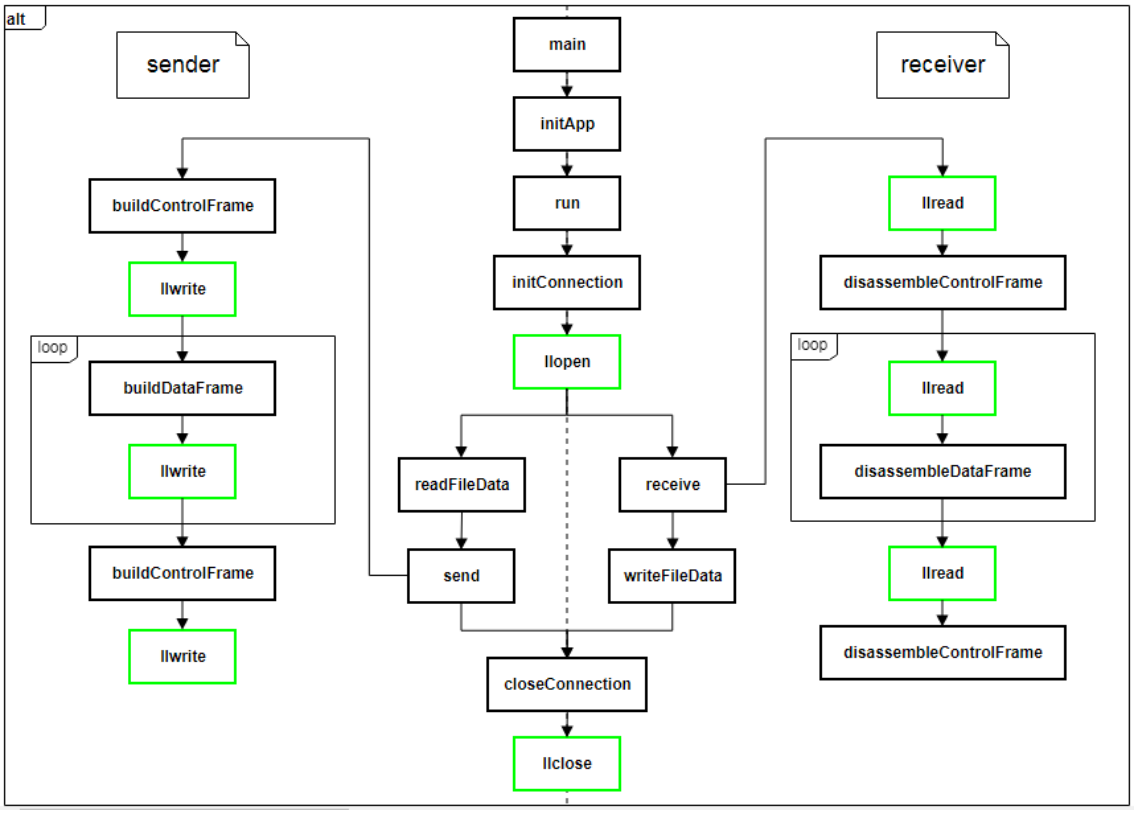


Figure 1 - Application layer code flow

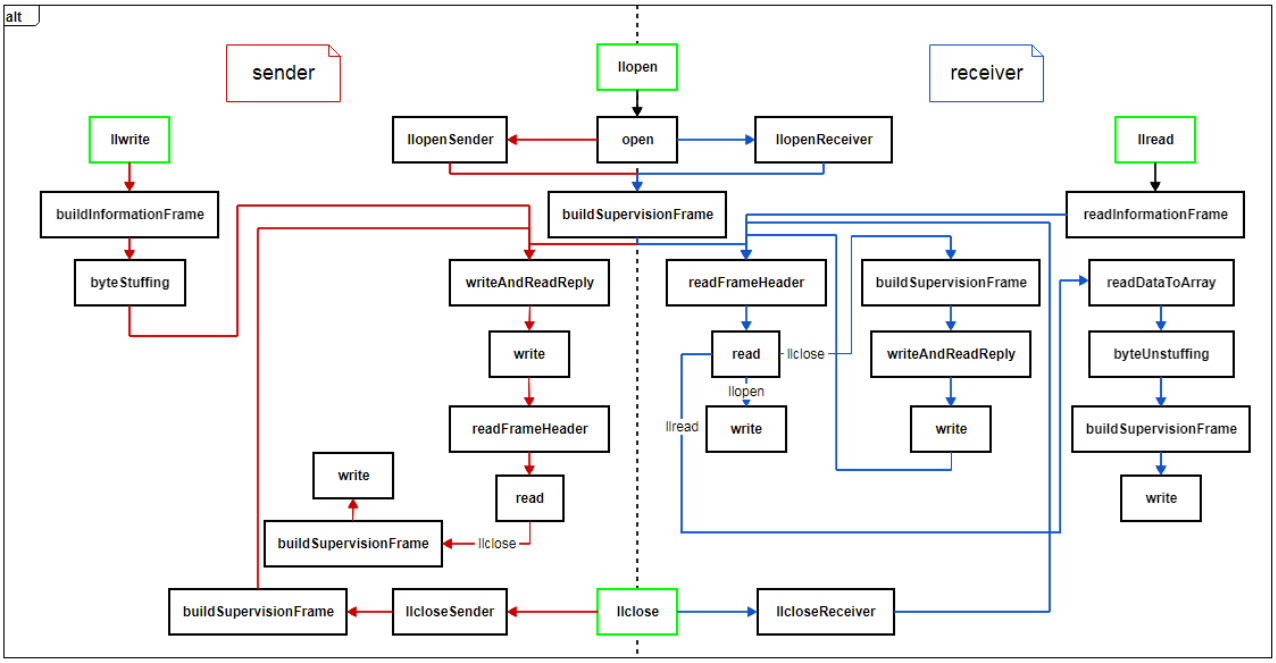


Figure 2 - Link layer code flow

Primary Data Structures

```
typedef struct {
  int sp_fd;
  int mode;
  char* port;

  char* file_path;
  unsigned char* file_data;
  unsigned long long file_size;
  unsigned long long bytes_processed;

  unsigned long long bytes_per_data_packet;
} ApplicationLayer;

typedef struct {
  unsigned char* frame;
  char* file_name;
  unsigned int frame_size;
  unsigned long long file_size;
} ControlFrame;

typedef struct {
  unsigned char* frame;
  unsigned char* data;
  unsigned int frame_size;
} DataFrame;
```

The application layer has three important data structures. 'ApplicationLayer' holds data regarding the serial port connection, mode of operation and information about the file. 'ControlFrame' and 'DataFrame' holds important fields from a control/data frame as well as the complete frame itself.

```
typedef struct {
  char* port;
  int baud_rate;
  unsigned int sequence_number;
  unsigned int timeout;
  unsigned int number_transmissions;
  char* frame;
} LinkLayer;

typedef struct {
  unsigned char address;
  unsigned char control;
} FrameHeader;
```

The link layer has two important data structures. 'LinkLayer' holds some serial port settings, protocol helping variables and the current frame. 'FrameHeader' holds the fields from a frame's header that are needed for post processing in other functions.

Primary Functions

```
ReplyStatus readFrameHeader(int sp_fd, FrameHeader *expected_frame_header, int is_data);
```

This function is capable of reading any frame's header using the state machine defined in the link layer protocol. It reads byte by byte using the 'read' function and while applying the state machine logic, determines if the header is what's expected (OK), duplicate message (DUPLICATED), rejection message (REJECTED) or timeout (ERROR), returning the respective enum. To avoid blocking, in the while loop that covers almost the entire function there's a condition that breaks the loop if the alarm flag is set by the alarm handler.

```
int writeAndReadReply(int sp_fd, unsigned char *frame_to_write, unsigned long frame_size,
unsigned char expected_control_field, int caller);
```

This function writes any frame to the serial port buffer and waits for a reply. After writing 'frame_to_write' with the 'write' function the alarm is set for the alarm timeout and the program calls 'readFrameHeader'. If it succeeds to read it before the alarm timeout, the alarm is cancelled and the return value of it is checked. If it's OK or DUPLICATED, the function ends with success (returns 0). If it's REJECTED or ERROR, the frame is retransmitted, with the last one incrementing the amount of tries it took to send it. If this amount surpasses the predefined maximum of tries, the loop breaks and the function ends with error (returns -1).

Protocols

The implementation in our software of the following protocols allows for total layer independency, meaning they have no knowledge of each other's protocol.

Link Layer Protocol

The program can send and read Information, Supervision and Unnumbered acknowledge frames. We'll define Supervision and Unnumbered Acknowledge as Headers, as they are very similar to Information frame headers.

A Header consists of ADDRESS FIELD, CONTROL FIELD and BCC1.

ADDRESS FIELD is used to identify who is sending the frame and the type of the frame.

CONTROL FIELD is used to identify the sequence number of the frame on Information frames. On Control frames it is used to identify the type of control byte being sent which can be SET, DISC, UA, RR or REJ.

SET - establish the connection.

DISC - close the connection.

UA - unnumbered acknowledge.

RR - receiver ready: positive acknowledge.

REJ - reject: negative acknowledge.

BCC1 is the parity byte, calculated as the XOR between ADDRESS and CONTROL BYTE.

An Information frame consists of a Header, DATA and BCC2.

DATA is the data to be transmitted.

BCC2 is the parity byte, calculated as the XOR between all DATA bytes.

All the frames are delimited on both ends by a **FLAG** byte.

To ensure transparency when sending Information frames, byte stuffing is done on all DATA and BCC2 bytes thus avoiding a byte being interpreted as a FLAG or as the ESCAPE character used on the process. For the same reason, when reading Information frames, DATA and BCC2 bytes are unstuffed before checking BCC2 correctness. Each frame is protected from errors, which can be detected in BCC1 and BCC2 (if they're information frames). If the control fields fail to match the expected ones, a REJ frame will be sent by the receiver. The sender, in this situation and if a timeout occurs will retransfer

the last frame. On the last situation, there are a predefined maximum of tries that once surpassed will cause the sender to “give up”.

To read **Headers** a state machine is used to make sure that the **Sender** sent a valid frame.

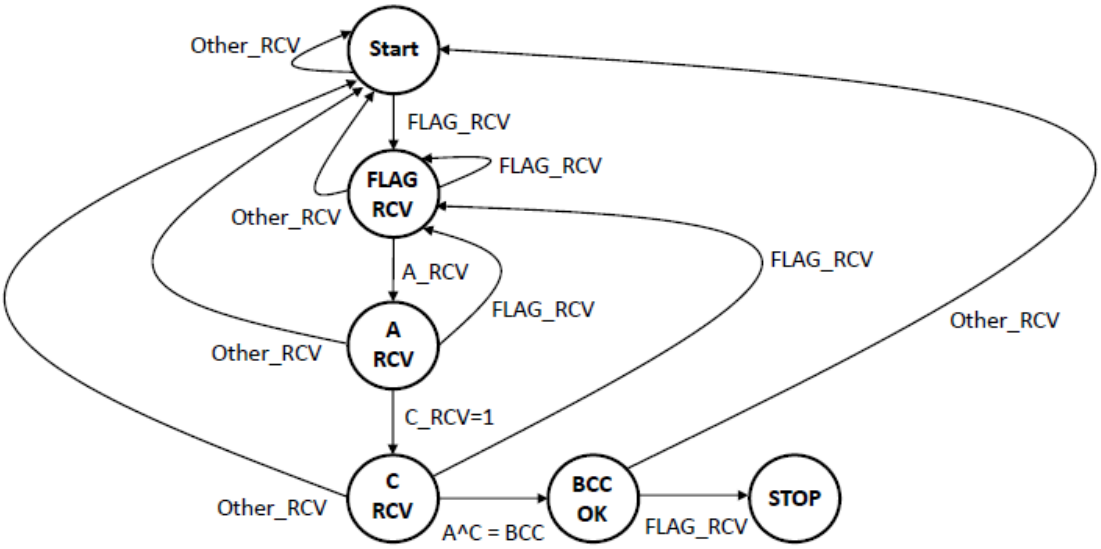


Figure 3 - State machine used to read a frame header

The implementation of this protocol can be best seen in following functions:

- buildSupervisionFrame
- buildInformationFrame
- byteStuffing / byteUnstuffing
- writeAndReadReply
- readFrameHeader

Application Layer Protocol

The protocol defines two types of packets: control and data. Control packets mark the start and end of transmitting data from a file as well as relevant information about said file, such as its size and name. Data packets, on the other hand, contain fragments of data from the file.

They both have a Control (**C**) field. Its possible values are: 1 – data, 2 – start, 3 – end.

Additionally, the data packets have the following byte structure:

N – 'Sequence number' mod 255.

L2 and **L1** – Size of the data. Size = 256 * L2 + L1.

Data – A fragment of data from the file.

Likewise, the control packets follow a TLV structure with 2 parameters:

T – Parameter index (0 – file size, 1 – file name).

L – Length of the V field

V – Parameter value

The implementation of this protocol can be best seen in following functions:

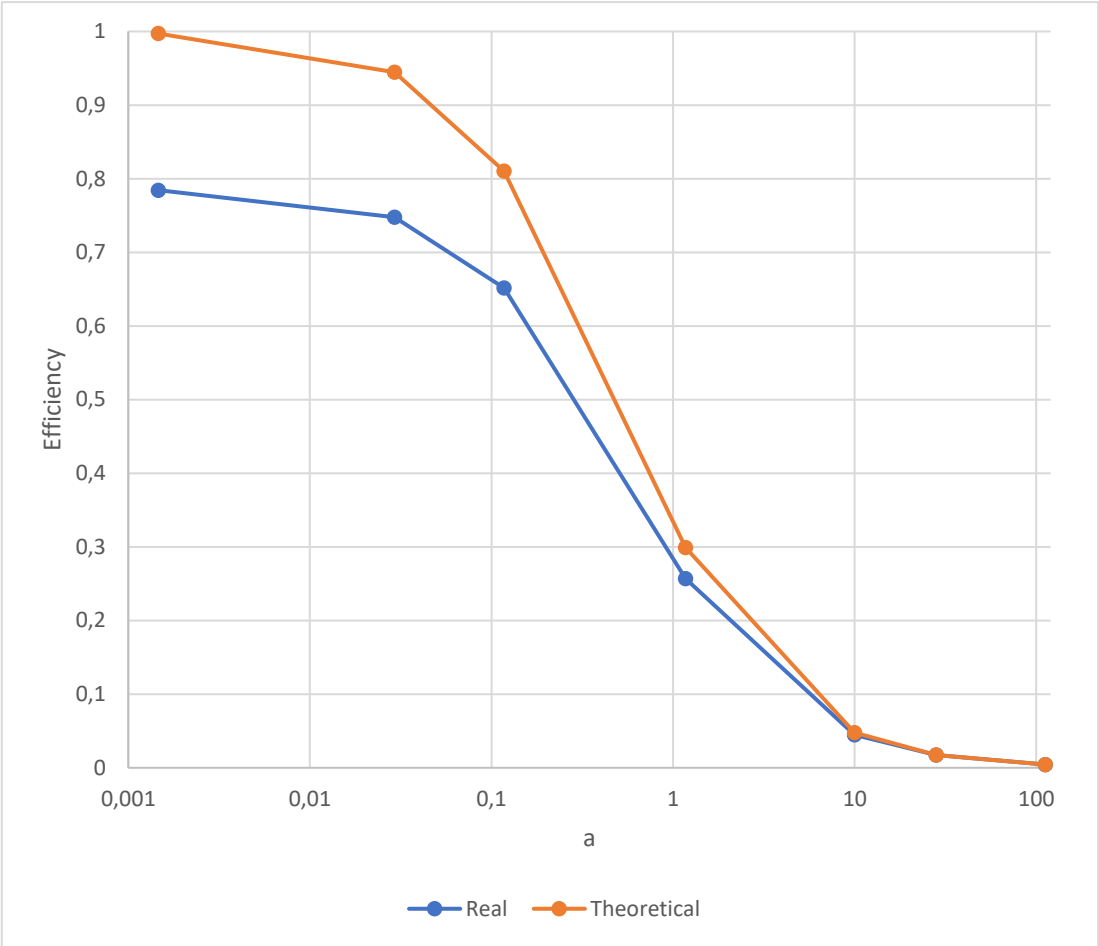
- buildControlFrame / disassembleControlFrame
- buildDataFrame / disassembleDataFrame

Validation

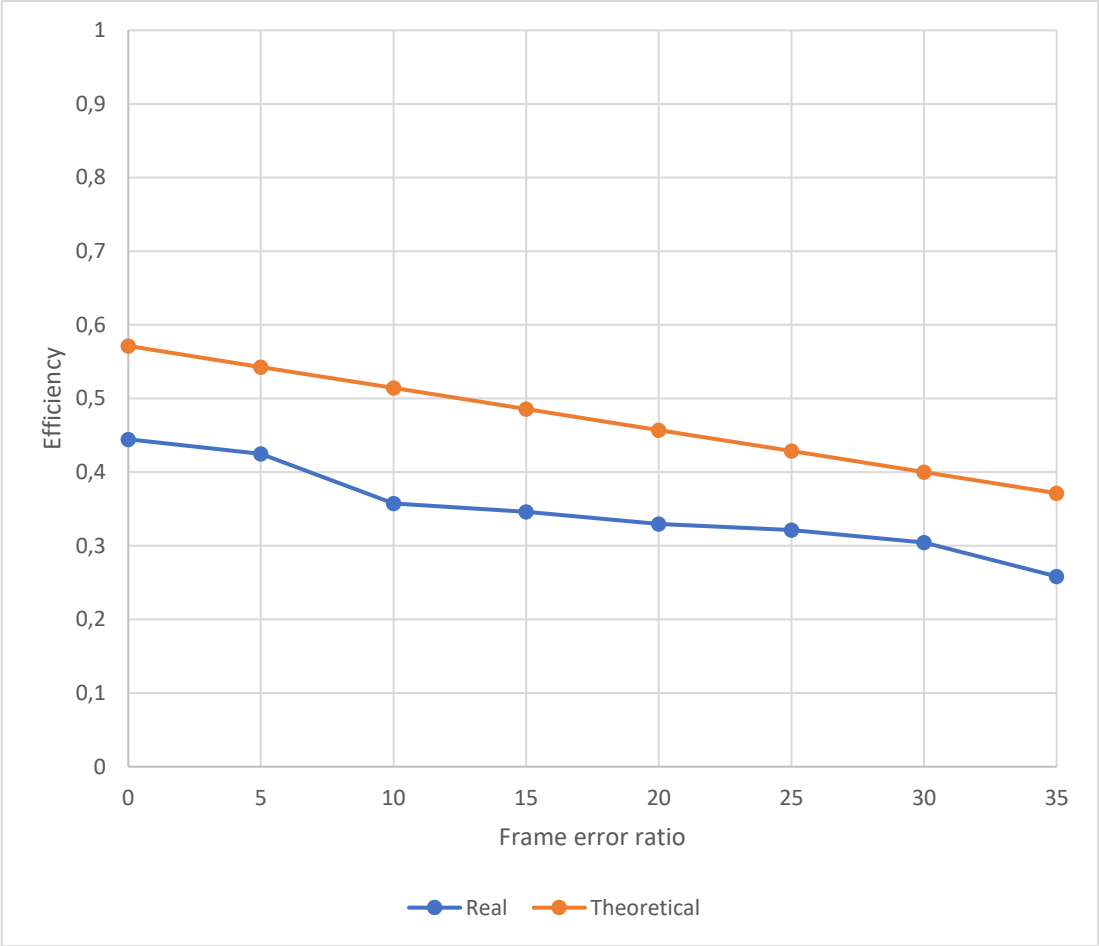
During the development of this software we've tested it along the way, making sure everything worked as expected. As requested, we've interrupted the connection multiple times while there was an active transference as well as causing interference (short circuits). The first tests whether the alarm module of the protocol works properly. The second tests whether the parity byte(s) error checks are working as well as the rejection and retransmission.

Later, we've included random error generation and random delays to simulate these physical tests as software tests. As we deliver the software, it meets all these demands.

Link Layer Protocol's Efficiency



This chart demonstrates how the link layer protocol's efficiency varies with each different $a = \frac{T_{prop}}{T_f}$ and a constant Frame Error Ratio (FER) of zero. By analysing this chart, we've concluded that the efficiency behaves with inverse proportionality given an a. Furthermore, the values calculated with our software are almost identical to the theoretical ones.



This chart demonstrates how the link layer protocol's efficiency varies with each different frame error ratio and a constant $a = 0{,}375$. By analysing this chart, we've concluded that the efficiency is linearly proportional to a given FER with a negative slope. Even though the calculated line behaves the same way as the theoretical one, their values differ by, approximately, 10%. A probable cause for this is that we're simulating a FER by generating random numbers and applying them as a probability. As we know, random number generation isn't completely random and can therefore cause this discrepancy.

Conclusion

After all the objectives being met, we can safely conclude that using the serial port with the adopted protocol is inefficient and, by today' standards, quite slow. However, it does recover from any type of errors, whether they are cause by interference or interruption of connection. Another advantage is the encapsulation of the protocol. Each layer is independent and "blind" to the other protocols.

On a learning note, we believe this project taught us a lot about networks and programming in general. It gave us the ability to go through any protocol's documentation and implement it, test it and reflect on it's efficiency.

Attachments

Attachment I - Source Code

The complete source code can be accessed at: http://tinyurl.com/RCOM-TP1-SRC.

Attachment II - Usage

Firstly, execute 'make' inside the sources directory to compile the program. Both sender and receiver are the same application, though they receive different command line arguments. To launch the application, type the name of the executable (i.e. './app'). Then, you should type the port (e.g. /dev/ttyS0) and the mode on which the program should operate (i.e. 'receiver' or 'sender').

The sender program will also need to receive as a command line argument the path of the file to send (e.g. 'banana.gif'). Optionally, you can specify the amount of file data in bytes to send per packet (e.g. '1024').

Example of usage:

- './app /dev/ttyS0 receiver'
- './app /dev/ttyS0 sender banana.gif 1024'