# Computer Networks
# **Data Link Protocol**

Ana Aguiar
DEEC, FEUP
Fall/Winter Semester 2020-21

Thanks to Prof. José Ruela and Prof. Manuel Ricardo for developing this assignment

# Overview

- Goals
  - Implement a data communication protocol
  - Test protocol with data transfer application

- Competences
  - Understand principles of data communication, layering, interfaces, functionality separation, state machines
  - Compiling and debugging a distributed application in Linux environment
  - Developing a distributed application in a team environment
  - Basic Linux commands, gdb, make

# Organisation

- Development Environment
  - PCs with Linux (in the lab)
  - Programming language: C
  - Serial ports: RS-232 (asynchronous communication)

- Groups
  - Groups of 2 students

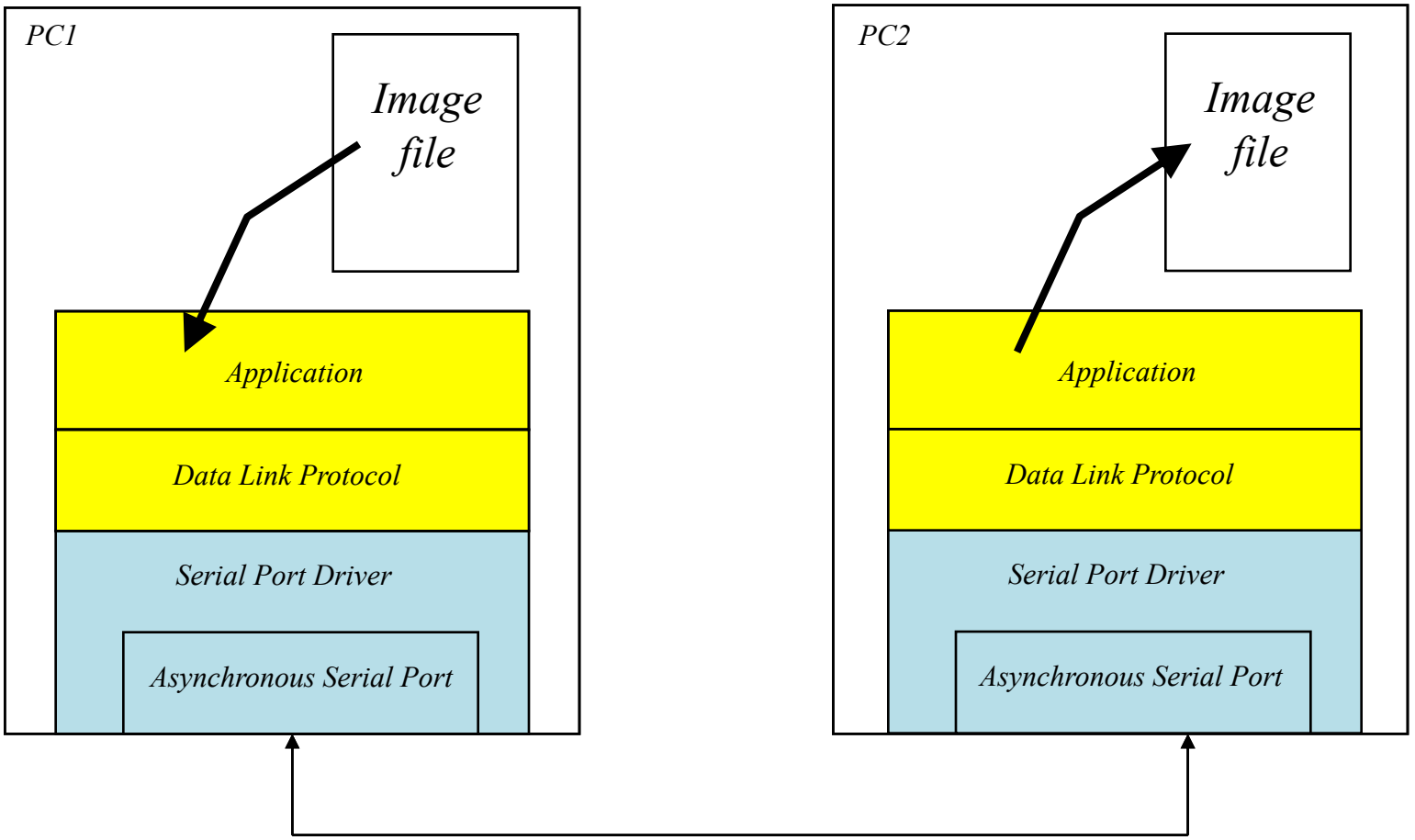
# Evaluation

- Implementation of the data link protocol
  - Frame synchronisation, error detection, ARQ, ...
- Testing with ready made application protocol
- Code organisation
  - Modularity and layering, Data link protocol API
- Demonstration

# Valorisation Elements

- User parameter selection
  - Baud rate, maximum size of I frames data field size (without stuffing), maximum number of retransmissions (default = 3), time-out interval
- Random error generation in data frames
  - Suggestion: for each correctly received I frame, simulate at the receiver the occurence of errors in header and data field according to pre-defined and independent probabilities, and proceed as if they were real errors
- REJ implementation
- File transmission statistics
  - Error recovery – for example, close the connection (DISC), re-establish it (SET) and restart the process
  - Event log (errors)
  - Number of retransmitted/ received I frames, number of time-outs, number of sent/ received REJ

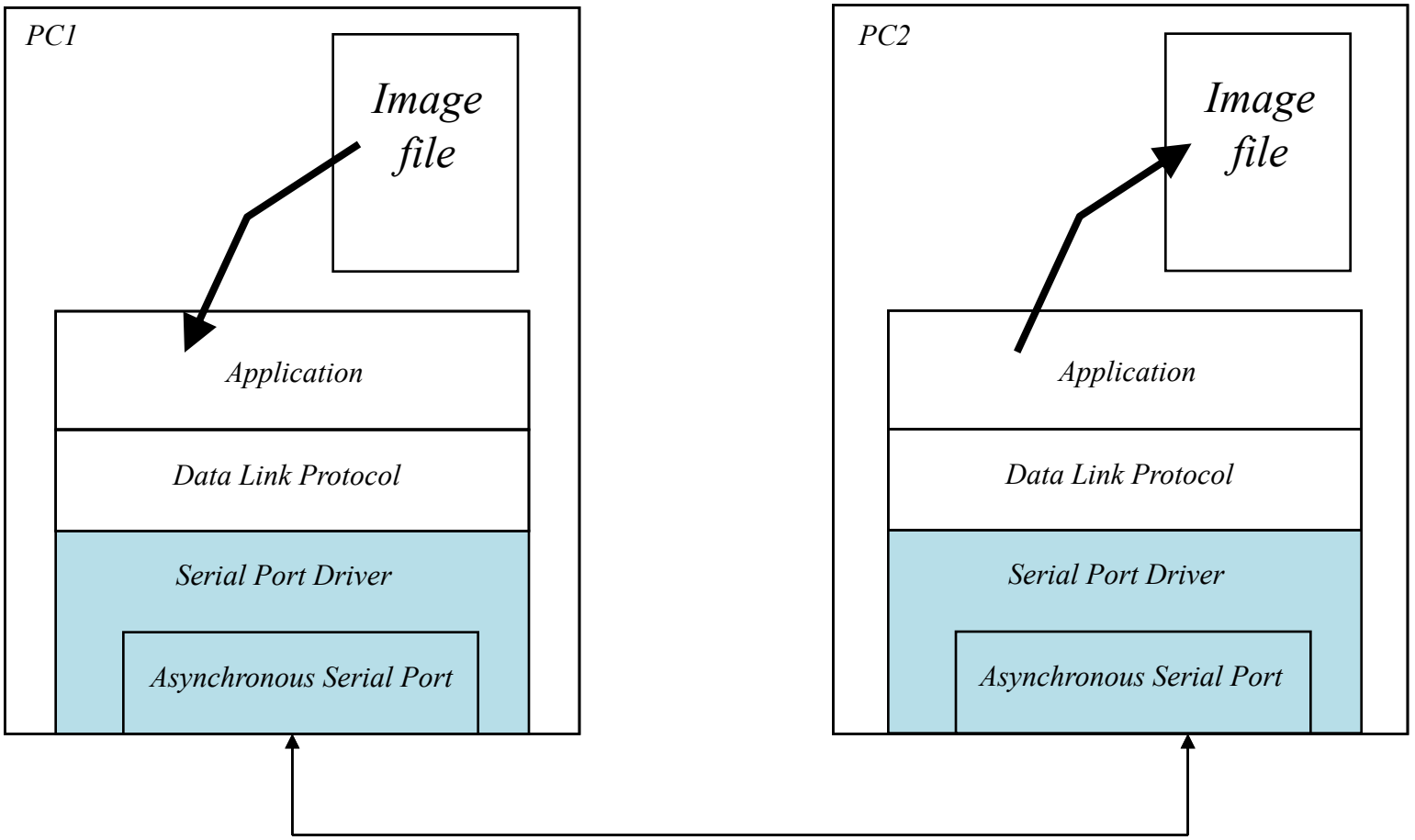
# Communication System Overview



# Data Link Protocols–Typical Functionality

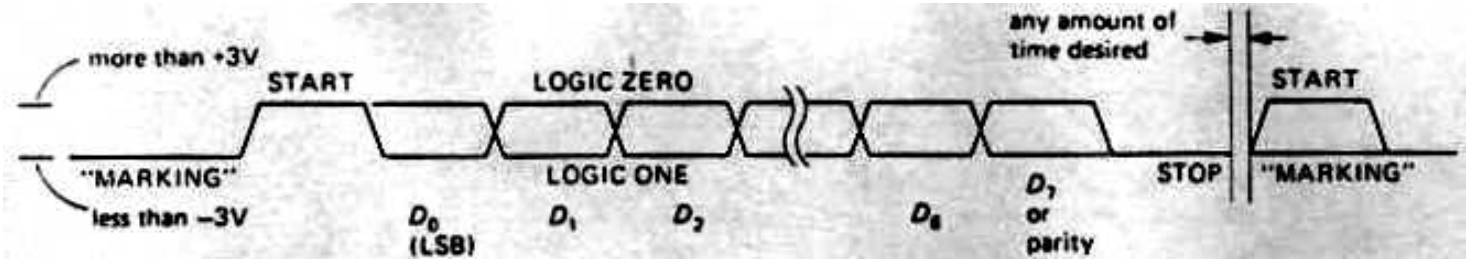
- Goal
  - Provide reliable communication between two systems connected by a communication medium – in this case, the serial cable
  - Service provided to applications using the communication medium
- Typical Functionality
  - Frame synchronisation – data organised in frames
    - Characters/ flags to delimit start and end of frame
    - Data size may be implicit or indicated in the frame header
  - Connection establishment and termination
  - Error control (e.g.: Stop-and-Wait, Go-back-N, Selective Repeat)
    - Acknowledgements after reception of a correct and ordered frame
    - Timers (time-out) – transmitter decides on retransmission
    - Negative acknowledgement (out of sequence frames) – receiver requests retransmission
    - Retransmissions may originate duplicates, which should be detected and eliminated
    - Sequence numbers
  - Flow control

# Serial Port


PC1
Image file
Application
Data Link Protocol
Serial Port Driver
Asynchronous Serial Port
PC2
Image file
Application
Data Link Protocol
Serial Port Driver
Asynchronous Serial Port

# Synchronous Serial Transmission

- Each character is delimited by
  - Start bit
  - Stop bit (typically 1 or 2)
- Each character consists of 8 bits (D0 – D7)
- Parity
  - Even – even number of 1s
  - Odd – uneven number of 1s
  - Inhibited (bit D7 used for data) – option adopted in this assignment
- Transmission rate: 300 to 115200 bit/s



# RS-232 Signals

- Physical payer protocol between computer or terminal (DTE) and modem (DCE)
  - DTE (Data Terminal Equipment)
  - DCE (Data Circuit-Terminating Equipment)

**TABLE 10.4. RS-232 SIGNALS**

| Name | Pin number 25-pin | Pin number 9-pin | Direction (DTE↔DCE) | Function (as seen by DTE) | |
|---|---|---|---|---|---|
| TD | 2 | 3 | → | transmitted data | } data pair |
| RD | 3 | 2 | ← | received data | |
| RTS | 4 | 7 | → | request to send (= DTE ready) | } handshake pair |
| CTS | 5 | 8 | ← | clear to send (= DCE ready) | |
| DTR | 20 | 4 | → | data terminal ready | } handshake pair |
| DSR | 6 | 6 | ← | data set ready | |
| DCD | 8 | 1 | ← | data carrier detect | } enable DTE input |
| RI | 22 | 9 | ← | ring indicator | |
| FG | 1 | – | | frame ground (= chassis) | |
| SG | 7 | 5 | | signal ground | |

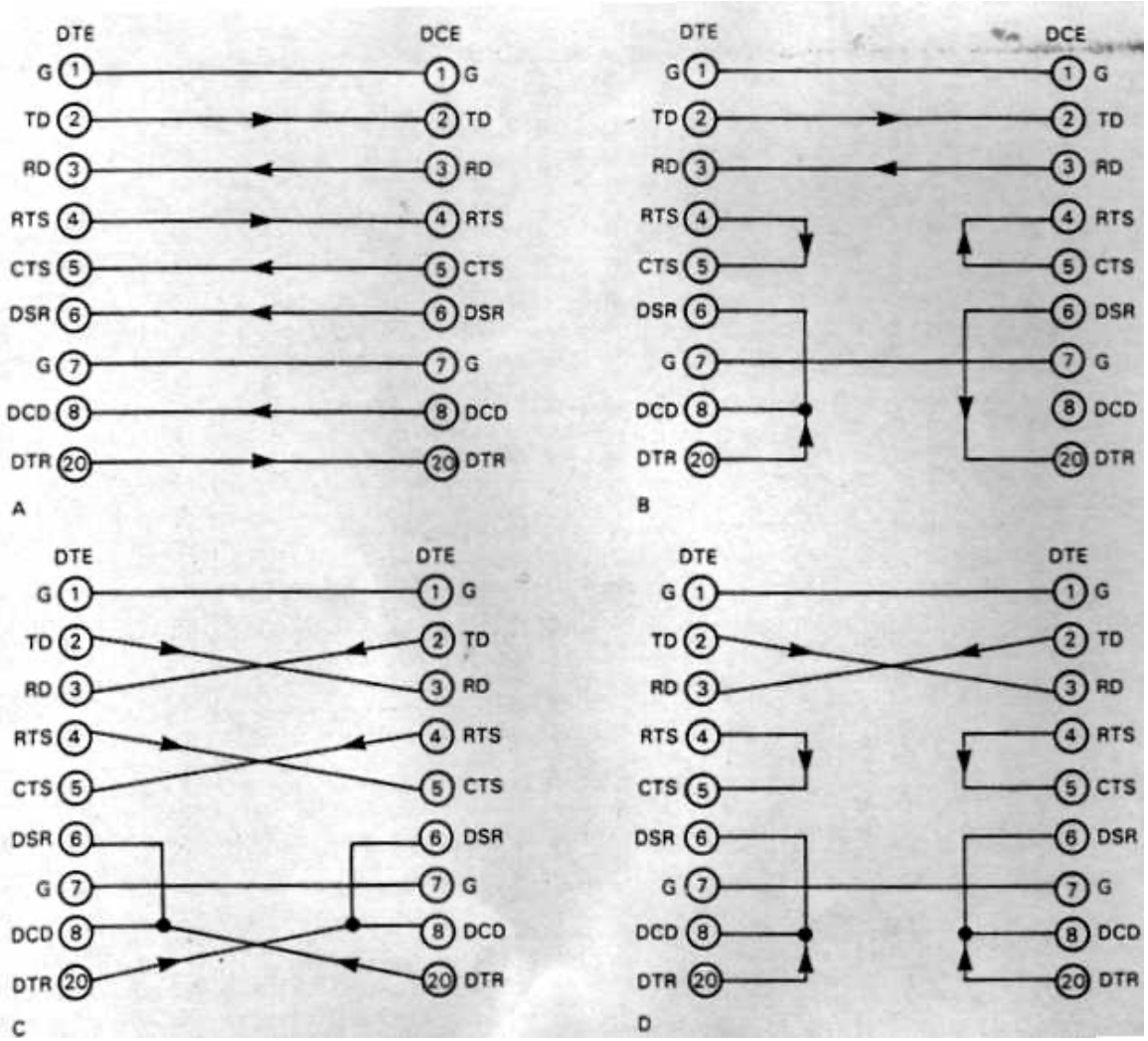
# RS-232 Signals

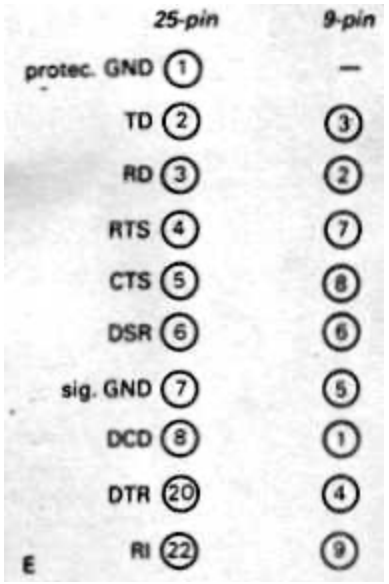
- **Active signal**
  - Control signal (> + 3 V)
  - Data signal (< - 3 V)
- **DTR (Data Terminal Ready) –** Computer on
- **DSR (Data Set Ready) –** Modem on
- **DCD (Data Carrier Detected) –** Modem detects carrier on phone line
- **RI (Ring Indicator) –** Modem detects ringing
- **RTS (Request to Send) –** Computer ready to communicate
- **CTS (Clear To Send) –** Modem ready to send
- **TD (Transmit data) –** Data transmission
- **RD (Receive data) –** Data reception

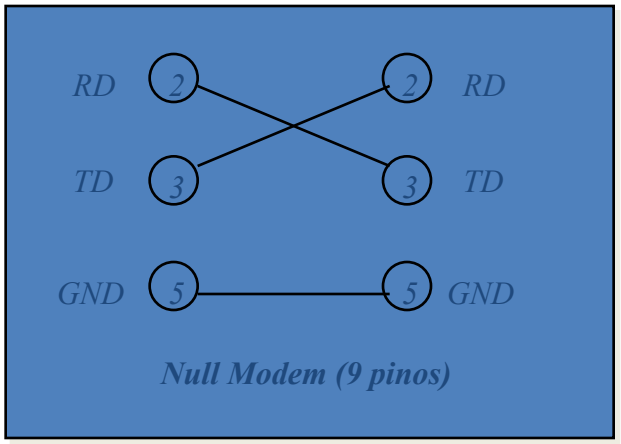
DB9

DB25

# Equipment Connections



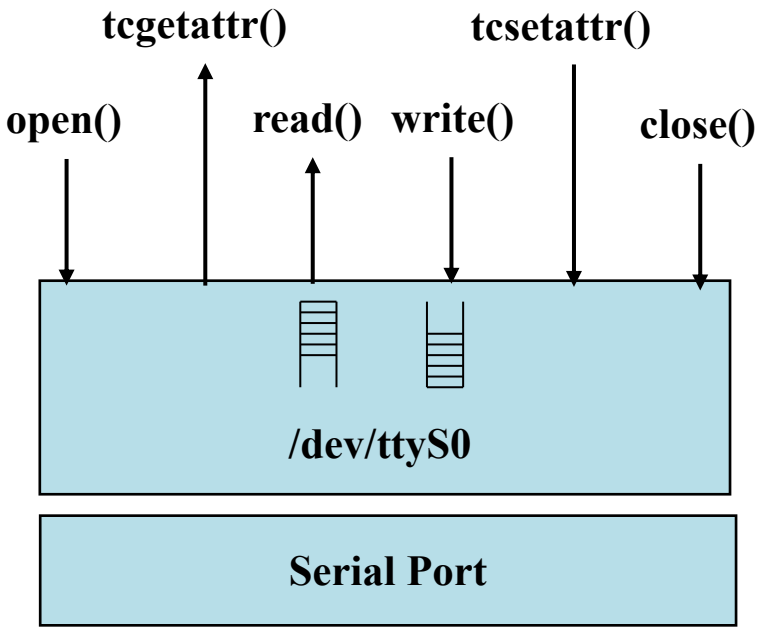



# Unix Drivers

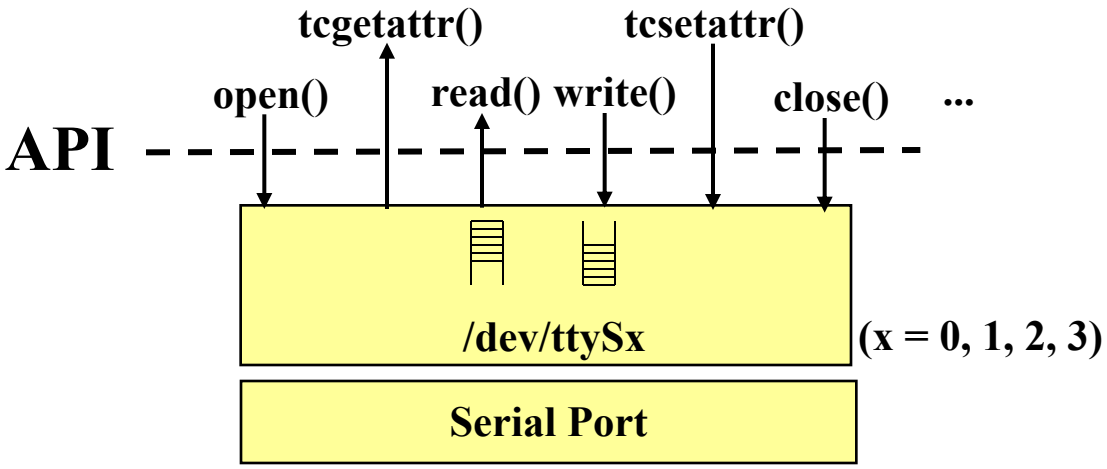
- Software that manages a hardware controler
  - Low level routines with previleged access
  - Reside in memory (part of the kernel)
  - Have associated hardware interrupts
- Access method
  - Mapped into Unix file system (/dev/hda1, /dev/ttyS0)
  - Interface similar to files (open, close, read, write)
- Driver types
  - Character
    - Read and write carried out on multiples of a character
    - Direct access (data is not stored in buffers)
  - Block
    - Read/ write as multiples of a block of octets
    - Data stored in random access buffer
  - Network
    - Read and write variable size data packets
    - Socket interface

# Serial Port Driver – API



# Serial Port Driver API

API – *Application Programming Interface*




## Some API Functions

int **open** (DEVICE, O_RDWR); /* returns a file descriptot */
int **read** (int fileDescriptor, char * buffer, int numChars); /* returns nr characters read */
int **write** (int fileDescriptor, char * buffer, int numChars); /* returns nr characters written */
int **close** (int fileDescriptor);

int **tcgetattr** (int descritorFicheiro, struct termios *termios_p);
int **tcflush** (int descritorFicheiro, int selectorFila); /*TCIFLUSH, TCOFLUSH ou TCIOFLUSH*/
int **tcsetattr** (int descritorFicheiro, int modo, struct termios *termios_p);

# Serial Port Driver API

- termios data structure – enables configuring and saving all serial port parameters

```
struct termios {
   tcflag_t  c_iflag;    /*flags de configuração da recepção*/
   tcflag_t  c_oflag;    /*flags de configuração da transmissão*/
   tcflag_t  c_cflag;    /*flags de controlo*/
   tcflag_t  c_lflag;    /*flags de configuração local*/
   cc_t      c_line;     /*não usado */
   cc_t      c_cc[NCCS]  /*caracteres de controlo; NCCS = 19*/
};
```

# Serial Port Driver API

- Exemplo:

```
#define BAUDRATE B38400
struct termios newtio;

/* CS8:     8n1 (8 bits, sem bit de paridade,1 stopbit)*/
/* CLOCAL:  ligação local, sem modem*/
/* CREAD:   activa a recepção de caracteres*/
newtio.c_cflag = BAUDRATE | CS8 | CLOCAL | CREAD;

/* IGNPAR:  Ignora erros de paridade*/
/* ICRNL:   Converte CR para NL*/
newtio.c_iflag = IGNPAR | ICRNL;

newtio.c_oflag = 0; /*Saída não processada*/

/* ICANON:  activa modo de entrada canónico, desactiva o eco e não envia
            sinais ao programa*/
newtio.c_lflag = ICANON;
```

# Serial Port Reception Types

- Canonic
  - read() returns only full lines (ended by ASCII LF, EOF, EOL)
  - Used for terminals
- Non-canonic
  - read() returns up to a maximum number of characters
  - Enables configuration of maximum number of characters
  - Adequate for reading groups of characters
- Asynchronous
  - read() returns immediately and sends a signal to the application on return
  - Requires the use of a signal handler

# Code Examples

## Canonic Reception

```
main() {

int fd,c, res;
struct termios oldtio,newtio;
char buf[255];

fd = open(/dev/ttyS1,O_RDONLY|O_NOCTTY);
tcgetattr(fd,&oldtio);

bzero(&newtio, sizeof(newtio));
newtio.c_cflag = B38400|CS8|CLOCAL|CREAD;
newtio.c_iflag = IGNPAR|ICRNL;
newtio.c_oflag = 0;
newtio.c_lflag = ICANON;
tcflush(fd, TCIFLUSH);
tcsetattr(fd,TCSANOW,&newtio);

res = read(fd,buf,255);

tcsetattr(fd,TCSANOW,&oldtio);
close(fd);
}
```

## Non-canonic Reception

```
main() {

int fd,c, res;
struct termios oldtio,newtio;
char buf[255];

fd = open(argv[1], O_RDWR | O_NOCTTY );
tcgetattr(fd,&oldtio);

bzero(&newtio, sizeof(newtio));
newtio.c_cflag = B38400 | CS8 | CLOCAL | CREAD;
newtio.c_iflag = IGNPAR;
newtio.c_oflag = 0;
newtio.c_lflag = 0;
newtio.c_cc[VTIME] = 0; /* temporizador entre
                           caracteres*/
newtio.c_cc[VMIN] = 5;  /* bloqueia até ler 5
                           caracteres */
tcflush(fd, TCIFLUSH);
tcsetattr(fd,TCSANOW,&newtio);

res = read(fd,buf,255); /*pelo menos 5 caracteres*/

tcsetattr(fd,TCSANOW,&oldtio);
close(fd);
}
```

# Code Examples

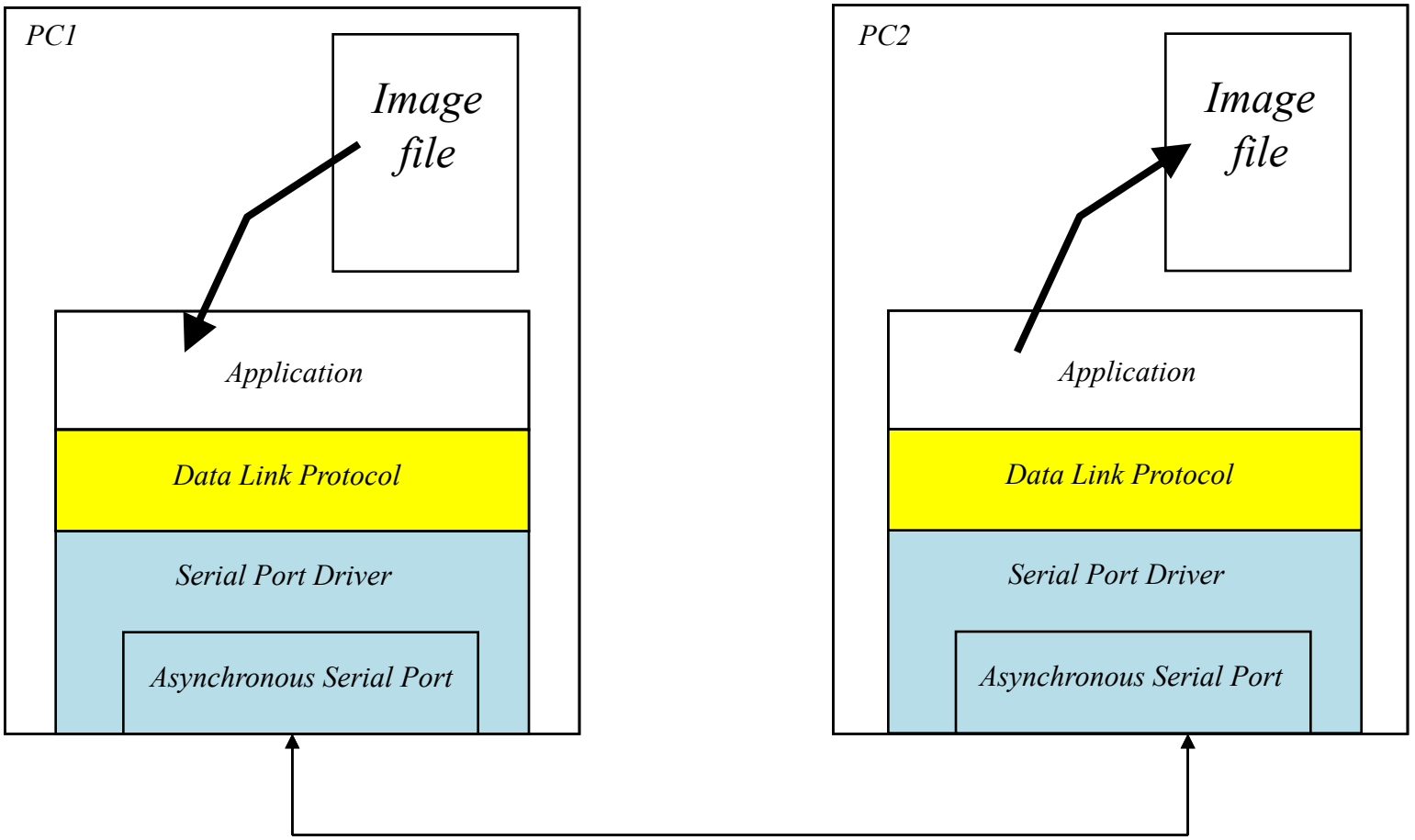
## Asynchronous Reception

```
void signal_handler_IO (int status);   /*definição
signal handler */
main() {
   /*…declaração de variáveis e abertura do dispositivo
série...*/
    saio.sa_handler = signal_handler_IO;
    saio.sa_flags = 0;
    saio.sa_restorer = NULL;    /*obsoleto*/
    sigaction(SIGIO,&saio,NULL);
    fcntl(fd, F_SETOWN, getpid());
    fcntl(fd, F_SETFL, FASYNC);
   /*… configuração da porta através da estrutura
termios ...*/
  while (loop) {
      write(1, ".", 1);usleep(100000);
      /* após o sinal SIGIO, wait_flag = FALSE, existem
dados na entrada para o read */
      if (wait_flag==FALSE) {
        read(fd,buf,255); wait_flag = TRUE; /*aguardar
novos dados*/
      }
    }
    /* … configurar a porta com os valores iniciais e
fechar ...*/
}
void signal_handler_IO (int status) { wait_flag =
FALSE; }
```

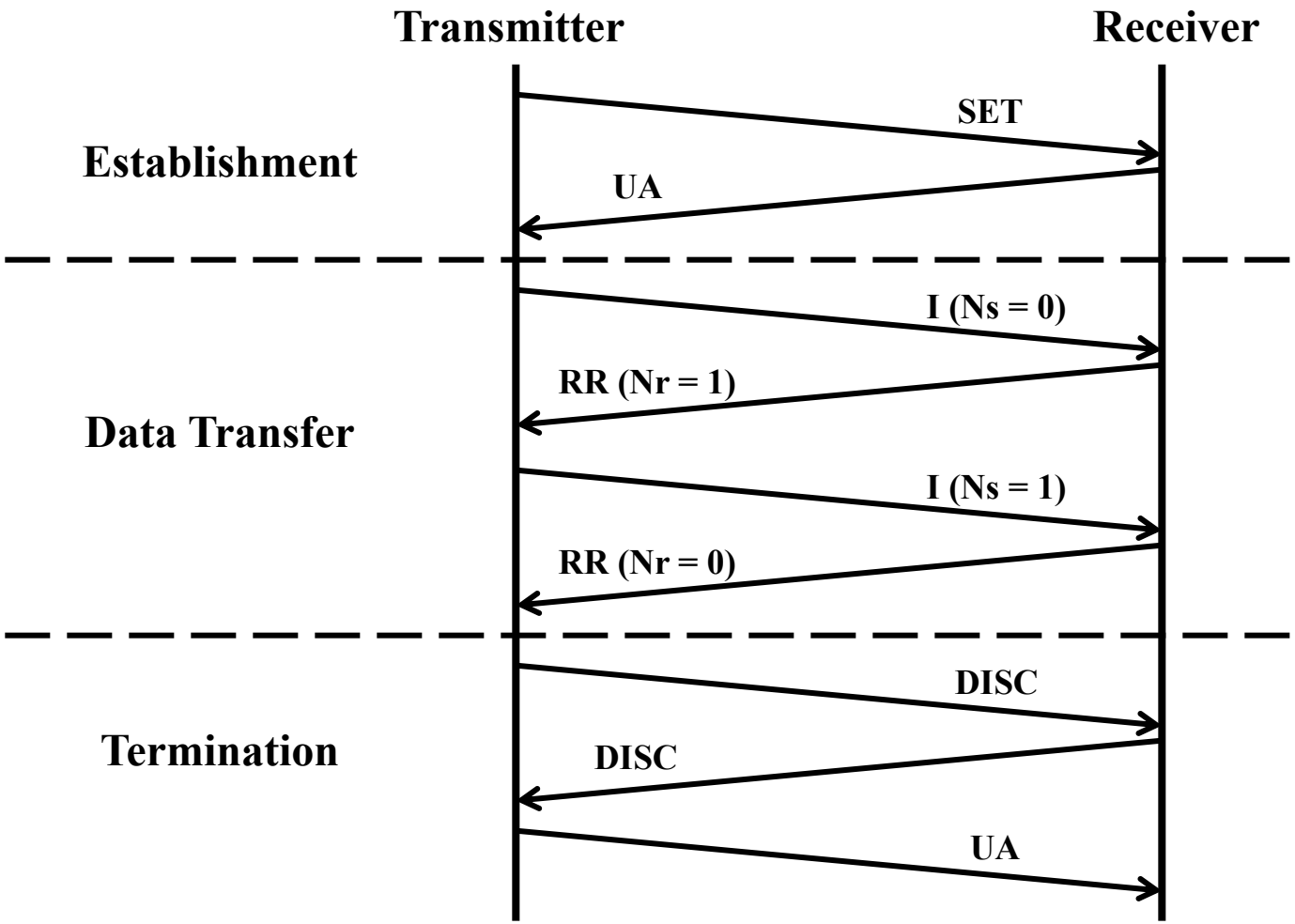
## Multiple Reception

```
main(){
int fd1, fd2;  /*input sources 1 and 2*/
fd_set readfs; /*file descriptor set */
int maxfd, loop = 1; int    loop=TRUE;
     /* open_input_source opens a device, sets the
port correctly, and returns a file descriptor */
     fd1 = open_input_source("/dev/ttyS1");   /*
COM2 */
     fd2 = open_input_source("/dev/ttyS2");   /*
COM3 */
     maxfd = MAX (fd1, fd2)+1;  /*max bit entry
(fd) to test*/
     while (loop) {     /* loop for input */
       FD_SET(fd1, &readfs);  /* set testing for
source 1 */
       FD_SET(fd2, &readfs);  /* set testing for
source 2 */
       /* block until input becomes available */
       select(maxfd, &readfs, NULL, NULL, NULL);
       if (FD_ISSET(fd1))        /* input from
source 1 available */
         handle_input_from_source1();
       if (FD_ISSET(fd2))        /* input from
source 2 available */
         handle_input_from_source2();
     }
  }
```

# Data Link Protocol

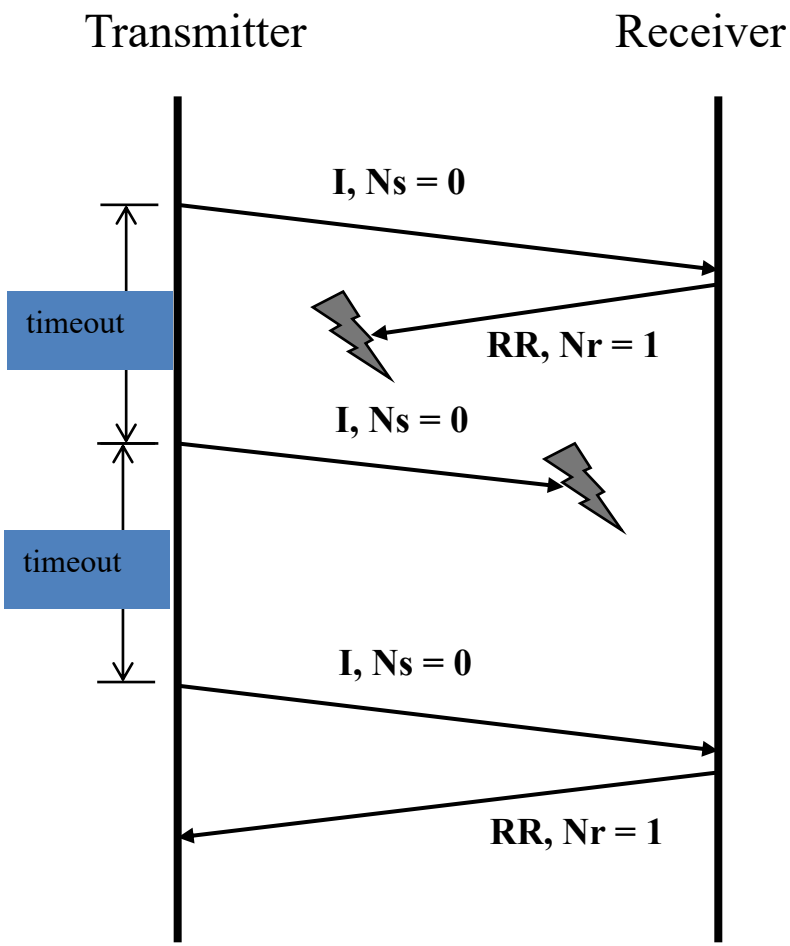


# Data Link Protocol Phases



# Data Transfer – Retransmissions

- Acknowledgement/ Error Control
  - *Stop-and-Wait*
- Timer
  - Set after an I, SET or DISC frame
  - De-activated after a valid acknowledgement
  - If exceeded (*time-out*), forces retransmission
- I frame retransmissions
  - After *time-out*, due to loss of frame or acknowledgement
    - Configurable maximum number of retrials
  - After negative acknowledgement (REJ)
- Frame protection
  - Generation and verification of the protection fields (BCC)



# Data Link Protocol – Specification

- Frame delimitation is obtained by a special 8 bit sequence (FLAG)
  - Transparency must be guaranteed through bit stuffing
- Transparent data transmission, i.e. independent of the code used for transmission
- Transmission organised into 3 types of frames – Information (I), Supervision (S) e Unnumbered (U)
  - Frames have a header with common format
  - Only I frames have a field for data communication that carries application data without interpreting it – **layer independence / transparency**
- Frames are protected by an error correction code
  - In S and U frames, there is simple frame protection, since they do not carry data
  - In I frames, there is double independent protection for header and data fields, enabling the use of the header even if there are errors in the data field
- Stop and Wait error control, unit window and modulo 2 numbering

# Specification Frame Reception

- I, S or U frames with a wrong header are ignored without action
- The data field of an I frame is protected by an own BCC
  - Even parity on each bit of the data and BCC
- I frames received without errors on the header and data field are accepted
  - If it is a new frame, the data field is passed to the application and the frame is confirmed with RR
  - If it is a duplicate, the data field is discarded, but the frame is confirmed with RR anyway
- I frames without detected errors on the header but with errors detected on the data field: data field is discarded, but control field can be used to trigger an action
  - If it is a new frame, a retransmission request can be issued with a REJ request, triggering a faster retransmission that waiting for a timeout
  - If it is a duplicate, the frame should be confirmed with RR
- I, SET e DISC frames are protected by a timer
  - If a time-out occurs, transmission should be repeated a maximum number of times, e.g. 3, which should be configurable

# Frames – Header Delimitation

- All frames are delimited by flags (**01111110**)
- A frame may be initialised with one or more flags, and this must be taken into consideration by the reception mechanism
- I, SET e DISC frames are designated Commands and UA, RR and REJ frames Replies
- All frames have a header with a common format
  - A (Address field)
    - **00000011** (0x03) in Commands sent by the Transmitter and Answers sent by the Receiver
    - **00000001** (0x01) in Commands sent by the Receiver and Answers sent by the Transmitter
  - C (Control fiels) – Defines the type of frame and carries the sequence numbers N(s) in I frames and N(r) in S frames (RR, REJ)
  - BCC (Block Check Character) – Provides error control based on an octet that guarantees that there is an even pair of 1's (even parity) for each bit position, considering all octets protected by the BCC (header or data) and the BCC (before stuffing)

Please check concrete values for addresses and control fields in the portuguese description, as these may be outdated.

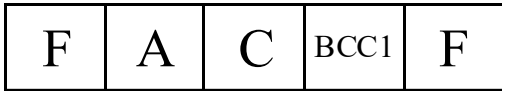
# Specification – Frame Formats

## – Information Frames


(before *stuffing* and after *destuffing*)

**F** **Flag**
**A** **Address field**
**C** **Control field** **0 0 0 0 0 0 S 0** **S = N(s)**
**$D_1$ ... $D_N$** **Data field (contains data generated by the application)**
**$BCC_{1,2}$** **Independent protection fields (1 – header, 2 – data)**

## – Supervision and Unnumbered Frames




**F** **Flag**
**A** **Address field**
**C** **Control field**

| | | |
|---|---|---|
| **SET (set up)** | **0 0 0 00011** | |
| **DISC (disconnect)** | **0 0 0 01011** | |
| **UA (unnumbered acknowledgment)** | **0 0 0 00111** | |
| **RR (receiver ready / positive ACK)** | **0 0 R 00001** | |
| **REJ (reject / negative ACK)** | **0 0 R 00101** | **R = N(r)** |

**$BCC_1$** **Protection field (header)**

# Transparency – Why?

- This work uses asynchronous communication
  - This technique is characterised by the transmission of characters (short sequence of bits, whose number can be configured) delimited by a Start and a Stop bit
- Some protocols use characters (words) of a code (e.g. ASCII) to delimit and identify the frame fields and support protocol mechanisms
- For transparent communication, i.e. communication independent of the code used for transmission, it is necessary to use escape mechanisms
  - To identify the occurence of delimiting characters in the data and replace them so that they can be correctly interpreted at the receiver

# Transparency – Why?

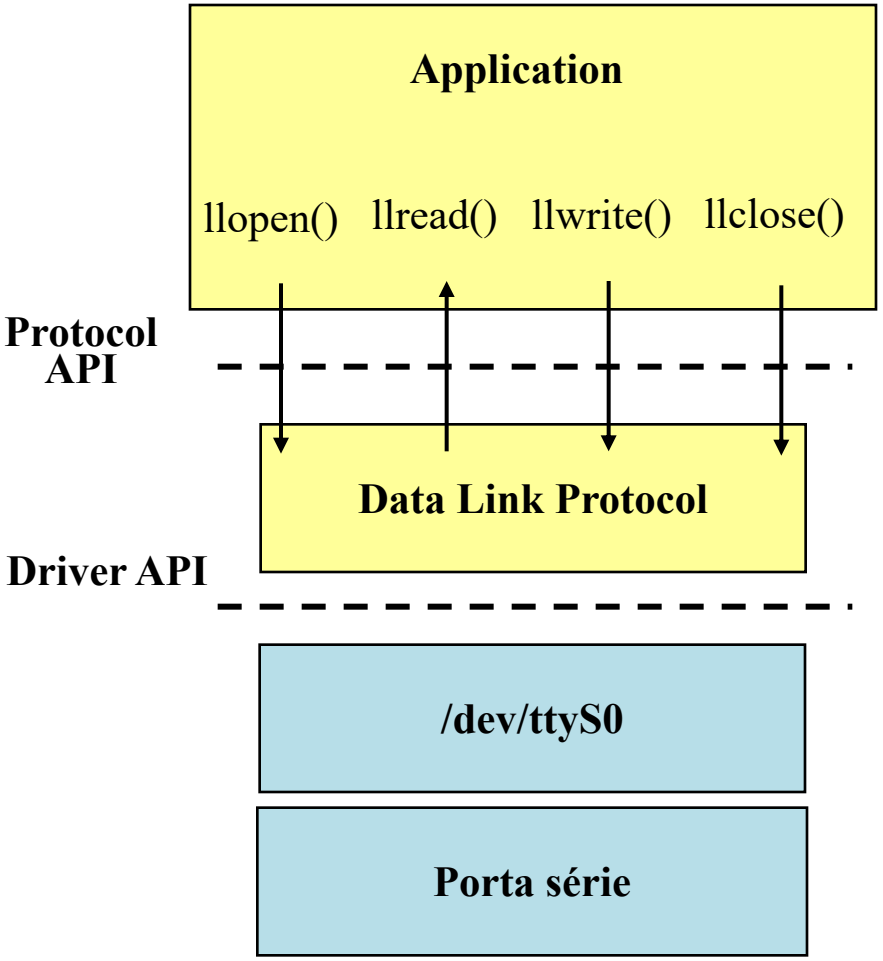
- The protocol to be implemented here is not based on any code, so the transmited/ received characters should be interpreted as plain octets (bytes), where any of the 256 possible combinations can occur
- To avoid that a character inside a frame is wrongfuly recognised as a delimiting flag, you need to use a mechanism that provides transparency
  - You shall use a mechanism called bit stuffing, used in common link protocols like PPP or HDLC
  - Your protocol shall use the escape byte **01111101** (**0x7d**)

# Transparency – Byte Stuffing

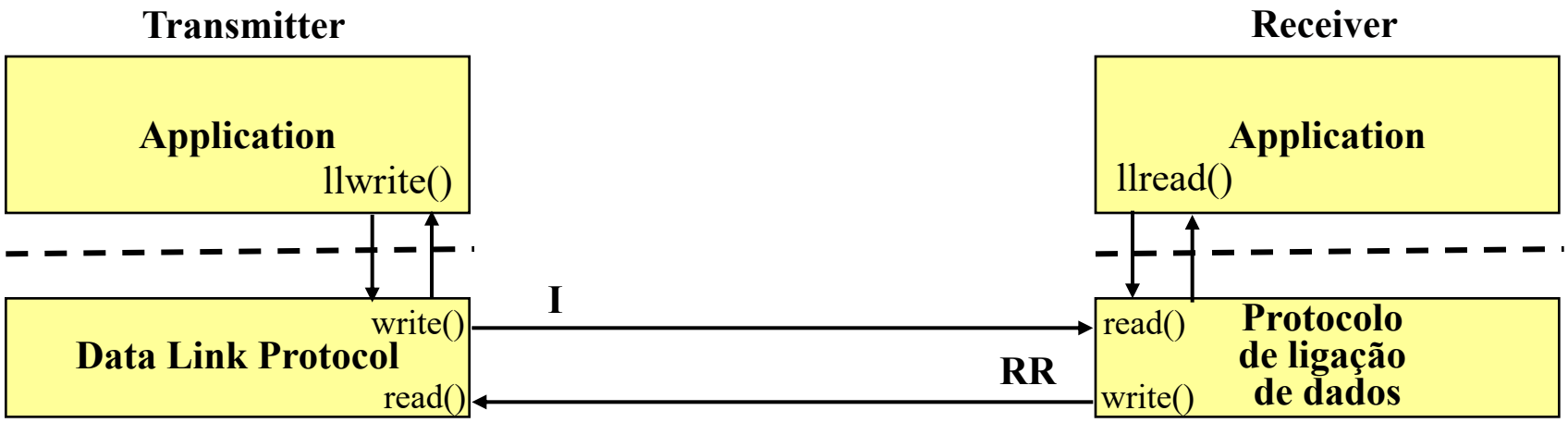
- If the octet 01111110 (0x7e), the pattern corresponding to a flag, occurs inside a frame the octet is replaced by the sequence 0x7d 0x5e (escape octet followed by the result of the exclusive or of the replaced octet with octet 0x20)
- If the octet 01111101 (0x7d), the escape octet pattern, occurs inside a frame the octet is replaced by the sequence 0x7d 0x5d (escape octet followed by the result of the exclusive or of the replaced octet with octet 0x20)
- The generation of BCC considers only the original octets (before stuffing), even if any octet must be replaced by the escape sequence
- The BCC verification is performed on the original octets, i.e. after the inverse operation (destuffing) in case there had been any substitution of the special octets by the escape sequence

# Protocol APInterface

- Implement the protocol API in a .h file to be included by the applications
- The application should only use the functions in that file

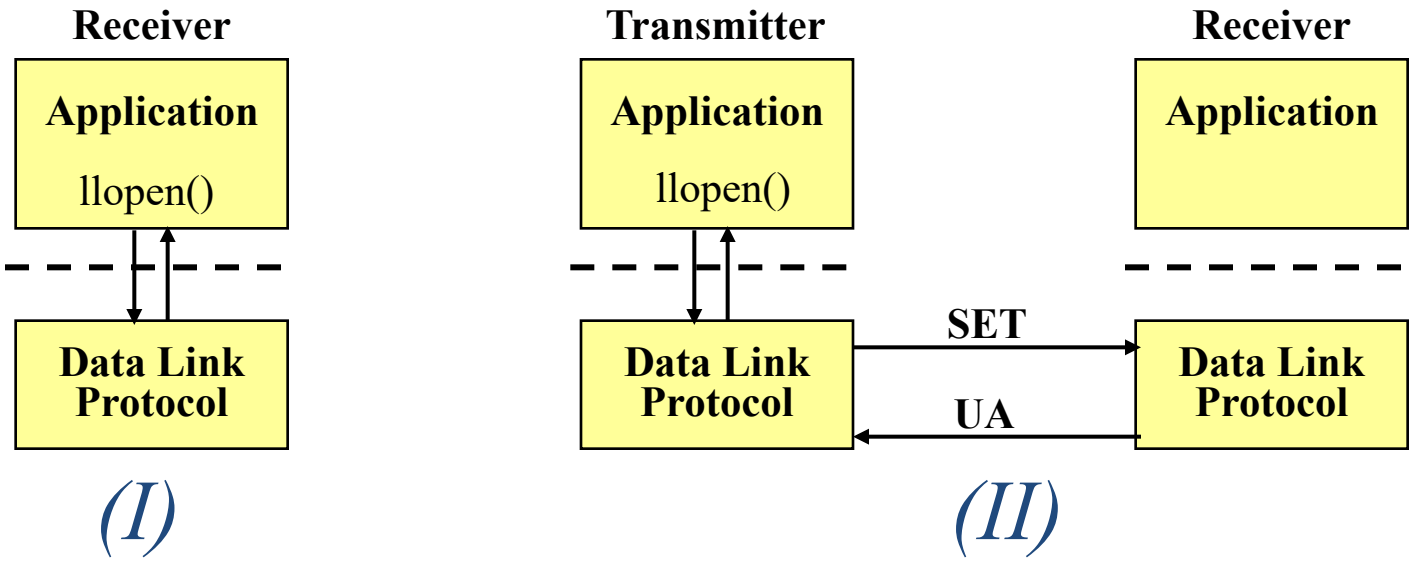


# Protocol API: read / write



# Protocol API – open

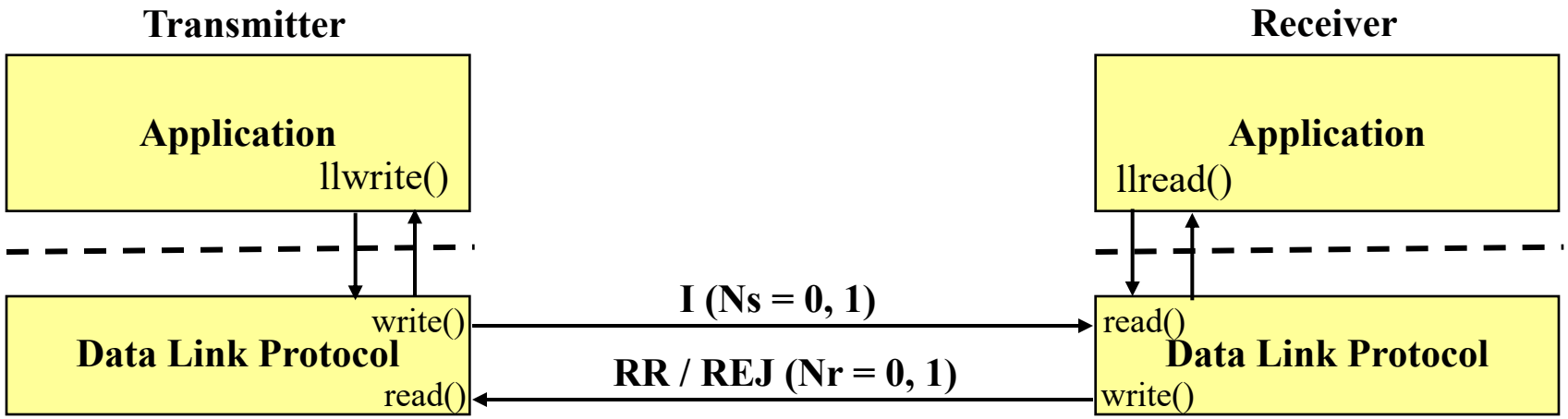
- int llopen(int porta, TRANSMITTER | RECEIVER)
  - arguments
    - port: COM1, COM2, ...
    - flag: TRANSMITTER / RECEIVER
  - return value
    - Data connection id
    - Negative value in case of failure/ error



# Protocol API – read / write

- int llwrite(int fd, char * buffer, int length)
  - argumentsfd: data link identifier
    - buffer: array of characters to transmit
    - length: length of the character array
  - Return value
    - Number of written characters
    - Negative value in case of failure/ error

- int llread(int fd, char * buffer)
  - Arguments
    - fd: data link identifier
    - buffer: received character array
  - Return value
    - Array length (nurmber of characters read)
    - Negative value in case of failure/ error



# Protocol API

- Example data structures
  - Application

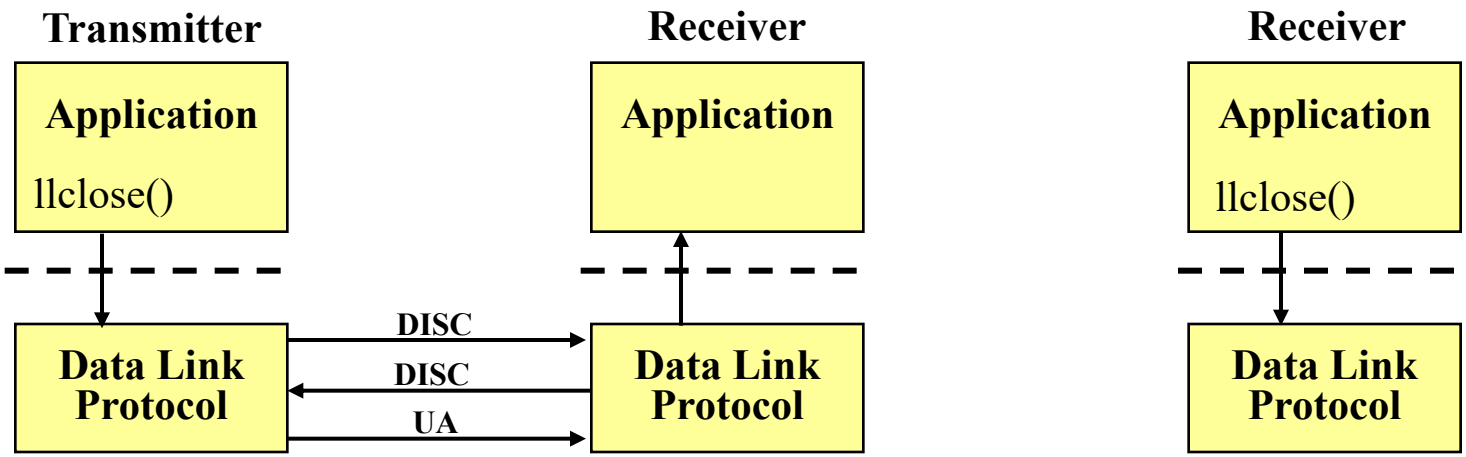
```
struct applicationLayer {
  int fileDescriptor; /*Descritor correspondente à porta série*/
  int status;         /*TRANSMITTER | RECEIVER*/
  }
```

  - Protocol

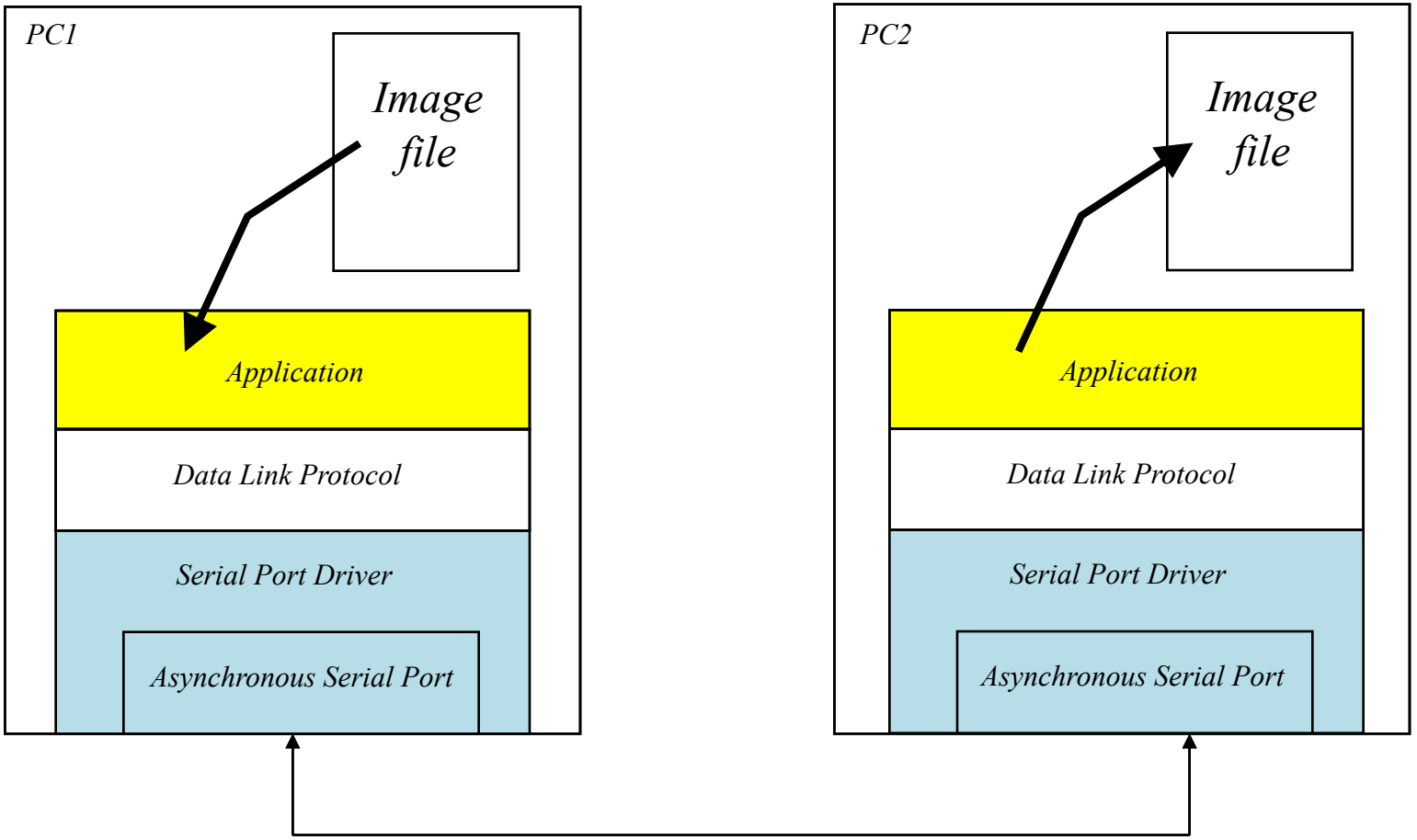
```
struct linkLayer {
  char port[20];              /*Dispositivo /dev/ttySx, x = 0, 1*/
  int baudRate;               /*Velocidade de transmissão*/
  unsigned int sequenceNumber;    /*Número de sequência da trama:
  0, 1*/
  unsigned int timeout;           /*Valor do temporizador: 1 s*/
  unsigned int numTransmissions; /*Número de tentativas em caso de
                                   falha*/
  char frame[MAX_SIZE];           /*Trama*/
}
```

# Protocol API – close

- int llclose(int fd)
  - arguments
    - fd: data link identifier
  - Return value
    - Positive value in case of failure/ error
    - Negative value in case of failure/ error



# Application



# Application

- You will be given the source code of an application that uses the defined link layer protocol interface
- You shal include the .h file and compile the application code, and run tests to verify protocol operation
- You shall not change the source code of the application

# Layer Independence

- Layered architectures are based on layer Independence to achieve modularity
- This has following implications in this assignment
  - The data link layer does no processing on the headers of the packets to be carried by I frames – this information is considered inaccessible to the data link protocol
    - At the the data link level there is no distinction between application control and data packets, nor is the numbering taken into account
  - The application does not know details of the data link protocol, only how to access its service
    - The application protocol does not know the frame structure or the delimitation mechanism, the existence of stuffing, the frame protection mechanism, eventual retransmissions, etc
    - All these functions are implemented exclusively at the data link layer
  - In particular, the I frame numbering and the application data packet numbering should be completely independent and unrelated