

1708165

by Adam Bedner

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Executive Summary

The main focus of this assignment is research into different topic of digital communication. The main topics researched are Digital communication systems, their discrete components and its functions. Some interesting topics like data encryption will also be briefly looked into. Error checking and systems such as PDH and SDH that are used in digital telephony will also be looked into.

The executive summary should cover all the sections of the report and give a complete overview

1. Digital Communication System

A digital communication system is a system that is designed to transmit data from one device to another in a digital form. An example of such system is DAB radio, Satellite TV, stationary and mobile phones.

Below (Fig. 1) is shown a model of a digital communication system. It being a model, is a simplification of a real-life scenario but it does have all the essential components.

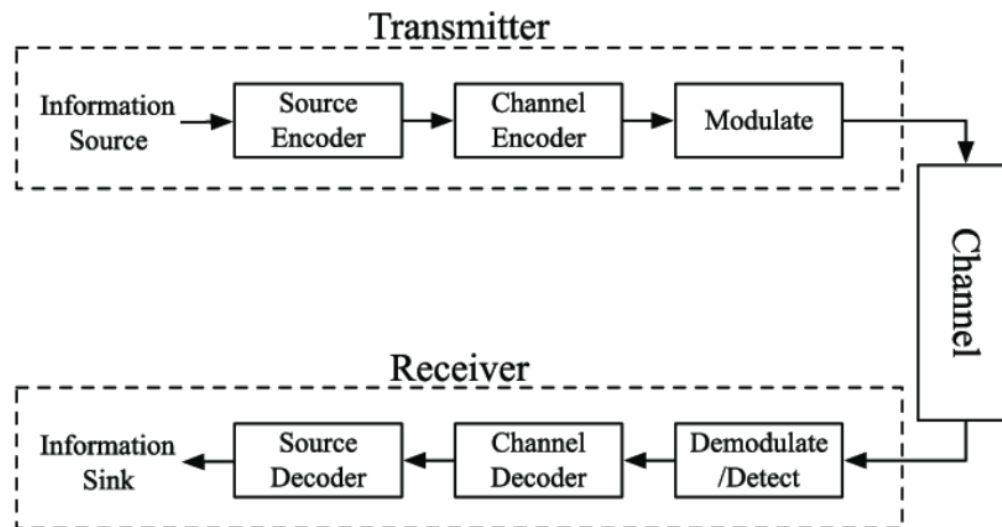


Fig. 1 Model of a digital communication system (Wesolowski, 2002)

The three considerably basic components of any digital transmission system are a transmitter, which codes and transmits the data; a channel, through which the data is sent; receiver which receives, checks and decodes the data.

Transmitter

It is the part of the system that codes and transmits the data that is inputted. The input data can be either analogue or digital, but it will have to be converted to digital if it is an analogue input. The digital stream is usually coded and compressed as it is preferable for the data to occupy as little space as possible. The transmitted code can also contain additional data that will be used to check the data at the receiver's end for any corruption in the data. Therefore, the transmitter can be split into four main parts: Input (source of data), Source Encoder (Conversion, encryption and compression of data), Channel Encoder (Addition of error checking bits) and modulator (Modulation of the bit stream before transmission). (Wesolowski, 2002)

Input

If the Input data is an analogue signal, such as from a telephone's microphone, it first must be converted and coded into a digital signal with the use of ADCs. Although, if the data is of a digital source (ex. Keyboard), the ADC would not be necessary.

Source Coder

That is the part of the system that converts the input signal/data into a stream of data to be transmitted. It converts the analogue signals into digital data with the use of ADCs. Older systems use PAM and PCM to code the signal; in digital telephony the PCM usually is nonlinear so there is data saved by greatly decreasing the dynamic range of the input signal (Quiet and loud sounds are made to have the same loudness/volume). The source encoder can also encrypt the data using encryption key and logarithms (ex. end-to-end encryption) to ensure the security and privacy of the transmitted data.

Data Encryption (End-to-End Encryption)

End-To-End Encryption (E2EE) is a technique that has been developed to provide security to transmitted data. It is based on unique encryption keys with a specially designed coding algorithm (similar to such of the Enigma Devices). E2EE ensures that the data being transmitted can be deciphered only by the sender or the receiver, but not by any third party (known as middleman attack). This type of encryption has been implemented into some telephone lines; such phones are known as *secure phones* or *secure lines*. Such devices were developed and introduced because, even after switching from analogue to digital telephony, the connections were not fully encrypted and it was possible to tap into the lines and listen to other people's conversations, although it was not as simple as tapping into an analogue communication line. (Moldal & Jorgensen, 2003)

Channel Encoder

It is usually responsible for coding the message and adding additional bits that will be used upon receiving the data on the other end to check the data for any errors in the data. Such solutions are used due to the possible interference (noise) with the modulated transmitted data. This helps to ensure that the data arrives at the other end of the transmission intact.

Modulator

Part of the system responsible to modulate an analogue carrier signal with the digital stream signal. This can be done using amplitude modulation (AM), frequency modulation (FM), phase modulation (PM) or combination of all three. Each of those techniques has its own advantages and disadvantages, and most of them were first developed for transmission of analogue radio through air. With the development of the digital communication those were combined and used together to increase maximum kb/s transfer, that being through air, wires or fibreoptic. Examples of such advancements are QPSK or 16-QAM. Those are known as modulation schemes.

QPSK (Quadrature Phase Shift Keying)

Any modulation scheme has a specific spectral efficiency, which defines the number of bits that the carrier is able to carry at a specific carrier frequency (bit/Hz). A simple binary modulated signal, if being AM, FM or PM, can carry 1bit/Hz. To overcome that limitation, the different modulation techniques (AM, FM, PM) were combined. An example is QPSK, which combines frequency and phase modulation. It modulates the frequency to two different states and modulates the carrier's phase into four stages (0° , 90° , 180° , 270°) as it is represented on Fig. 2. QPSK can carry twice the information in comparison to simple binary modulation, 2bit/Hz. (Maxim Integrated, 2002)

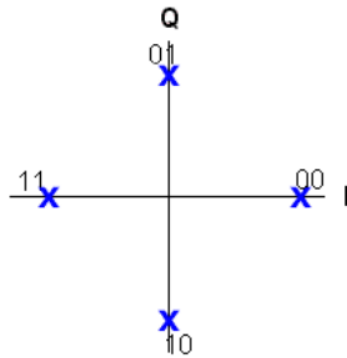


Fig. 2 QPSK constellation

16-QAM

Another advancement is the 16-QAM which uses frequency and amplitude modulation to modulate the carrier. It is called **16-QAM** because the modulation has 16 possible (Fig. 3) states and therefore can transmit 4 bits of data simultaneously, giving it a spectral efficiency of 4bit/Hz. (Davies, 1997)

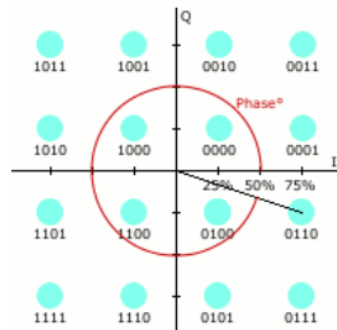


Fig. 3 16-QAM constellation, pointing at bit 0110

Channel

The channel is the medium that the information is transported by. That is an important part of the digital communication as it is the main source of noise in the system. The signal in different mediums is affected by external noise sources to a different extent. For example, signal sent via radio frequencies will be more susceptible to noise interference than sending the same signal over a wired connection and this will be more susceptible to noise than a shielded wired connection. Another important part of the transportation medium is the voltage drop, this is especially significant in wired connections due to the in-line resistance of the wires. The voltage drop can also be caused by the inevitable series inductance and parallel capacitance of the cables. That can be very limiting when working with high frequencies (MHz and GHz Regions). Appendix A. shows a comparison between the parameter of different transportation mediums. (Abernathy, et al., 1996)

Receiver

The receiver is the part of the system that receives the encoded/encrypted and modulated data. It's purpose is to detect the data that is directed to this specific device, receive the message, reverse the modulation (demodulate), decipher the code and pass it for further processing, for example conversion back to the analogue domain. Therefore, the receiver will need some basic parts: Detector/demodulator, channel decoder, source decoder and DAC (for analogue conversion) (Fig. 1).

Detector/receiver

It is the part of the circuit that is responsible for detecting, receiving and usually amplifying the signal. As the signal is sent using a modulated analogue carrier, some filtering or ADC might be present in this part of the system. (Green, 2000)

The detector will also detect which signal is directed for it in systems such as a TDM (time-division multiplex). As name indicates, is a solution where multiple signals are transmitted over the same carrier; those are multiplexed and assigned to each receiver based on time.

Channel decoder

This part checks the bit stream of data for any errors with the given additional error-checking bits. This is further explained in the section Error detection/correction (Pg. 10).

Source decoder

This part deciphers the transmitted data. this part of the system will be doing the opposite of the source encoder. Therefore, if the file was compressed in any way, it will now be decompressed. If the file is encrypted (example: E2EE), this part will have the required algorithms to decode the message if the correct private key is provided (deciphering key). (Moldal & Jorgensen, 2003)

DAC

Its only job is to convert digital signal into an analogue one. There is many different DACs and the choice usually has to be a compromise between quality, speed and cost.

2. Error detection/correction

As explained in the previous section “channels” (pg. 8), the data sent through any medium is susceptible to noise. In order to ensure that the signal received matches the signal sent, there are some techniques to make sure that the signal was not corrupted.

Parity-check Codes

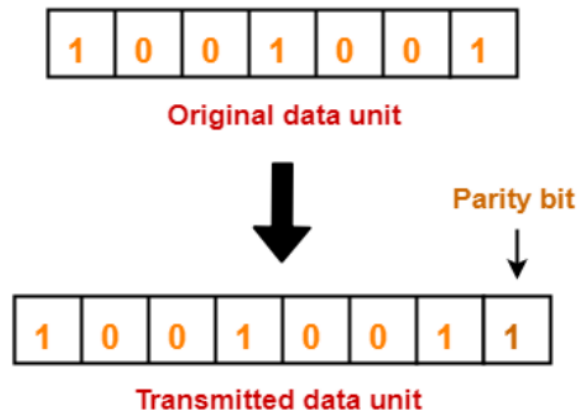


Fig. 4 example of a parity bit being added to a stream of data

In a single, one-dimensional, parity-check code an extra bit is added to each data unit (ex. 8-bit BYTE) and the extra bit is called parity bit. The extra bit is added to make the total amount of 1s in the data unit (including the parity bit) even (Fig. 4). Then the amount of 1s is checked when the data is received and if the amount of 1s is even, it is considered that the data stream is correct. The data stream is rejected if the number of 1s is odd. Therefore, only an odd amount of errors can be detected, as if there is an even amount of errors (Fig. 5), the amount of 1s in the data unit will remain even. (Grami, 2016)

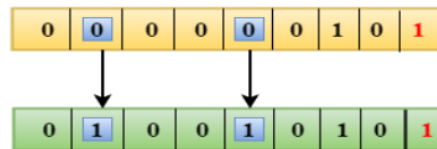


Fig. 5 example of two errors in data stream that can pass undetected

That can be improved by a two-dimensional parity check. For that, the data is organised in rows and columns. The same technique as for one-dimensional check is used to check the data, although now both, the rows and columns are checked for parity. The bit that is at the cross section of the column's and row's parity check bit is the global parity check for the whole block of data (Fig. 6). That limits greatly the amount of errors that can 'escape' detection. Only some patterns with 4 or more errors can pass undetected as it is shown in Appendix B.. (Grami, 2016)

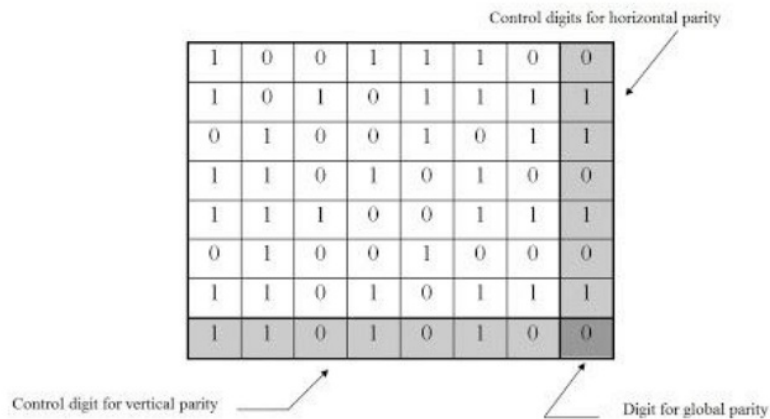


Fig. 6 two-dimensional parity check block

Checksum

With the Checksum technique, the data is usually divided in 16-bit words. Then, on the sender's side, the data chunk is added together (with the checksum initially set to 0), the result of the sum is complemented and send with the data. Therefore, if the data stream has no errors, the sum on the receiver's end (including the checksum word) will be 0 (Fig. 7). If the sum on receiver's end is not equal to 0, the data received is corrupted and rejected. No errors will be detected if the value of one word increases the same amount as another word decreases. (Grami, 2016)

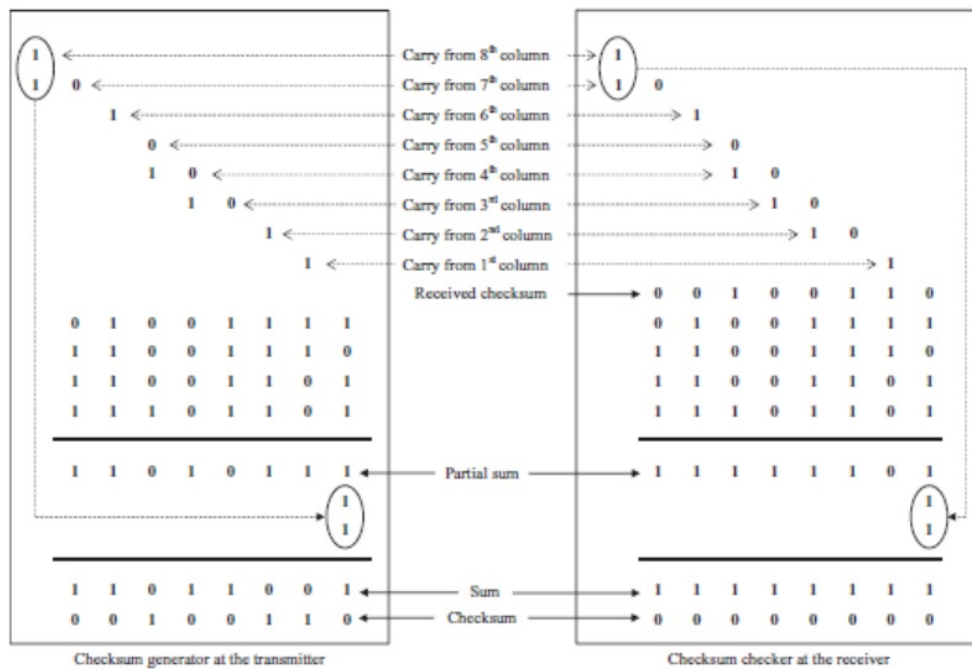


Fig. 7 Example of a checksum

CRC (Cyclic Redundancy Check) Error Detection

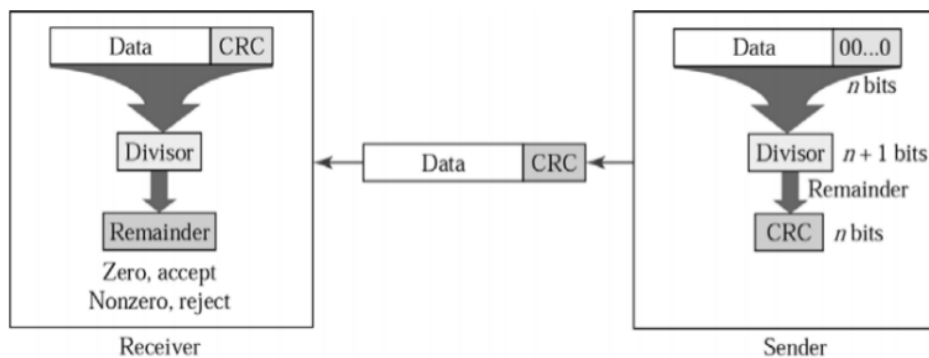


Fig. 8 example of CRC error detection

The CRC error check is quite simple, it uses division to check the transmitted data. It is based on modulo-2 division, in which, the addition is done using XOR gates (ex. $1+1=0$). The CRC part of data of n-bit length is pre-set to "0" before the division. Then the data is divided by a generated divisor and the remainder is added at the end of the data stream before transmission (Fig. 8). This way, when the data is divided by the same divisor upon arrival on the receiving end, the division is supposed to have no remainder (remainder=0). If there is any remainder, that means that the data is corrupted. Appendix C. shows an example of such division using polynomials. (Sai Pavan, et al., 2019)

3. PDH (Plesiochronous Digital Hierarchy)

Plesiochronous (from Greek: *plēsiōs*=near; *chronos*=time) means that the individual signals before multiplexing are almost but not completely synchronized. That means that the different data fed into the PDH multiplexer can run at a very slightly different rate. That is compensated by running the incoming data through buffers. In European standard, it is four, 2.048Mbit/s, streams that are fed into the multiplexer's buffer and come out as a 2.112Mbit/s stream with 'stuffed' bits (gaps, not containing data). (Wesolowski, 2002)

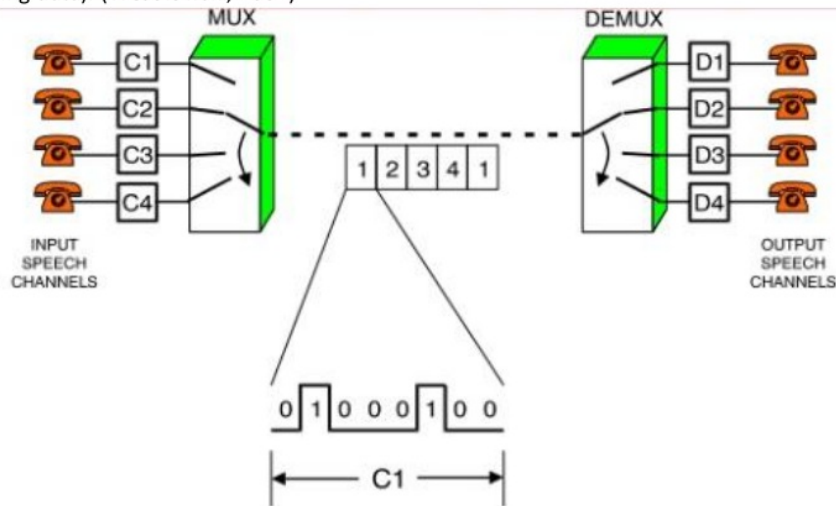


Fig. 9 Example of a TDM frame with 4 individual voice channels

PDH was developed for early digital telecommunications. Each of the 2.048Mbit/s channels mentioned above were composed by TDM (Time-Division Multiplexing) frames. Each of those TDM frames contained 24 (American T1 standard) or 30 (European E1 Standard) individual voice channels. Each of the individual voice channels has a bit rate of 64kbit/s. That is defined by how the voice is sampled with PCM techniques. As a standard, the voice is sampled at 8kHz with a resolution of 8-bit (hence 64kbit/s). According to Nyquist theorem the maximum sampled frequency can be around half the sampling frequency, 4kHz. That became a standard as the standard human voice frequency range, up to 4kHz. (Valdar, 2006)

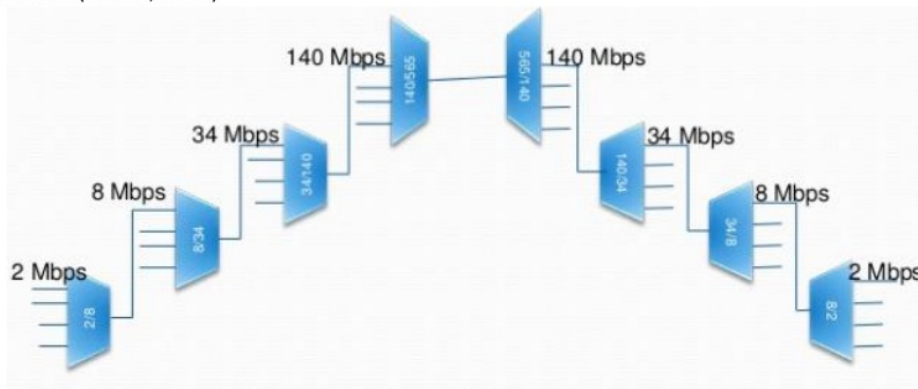


Fig. 10 Simple example of PDH hierarchy

Now, when transporting data, it is ideal to transport as much of it as possible. Hence why the individual TDM Frames are multiplexed in groups of 4, once multiplexed, it was called a higher order bit stream; those groups of four can be multiplexed in groups of four again (Fig. 10) multiplying the data rate by 4 every stage.

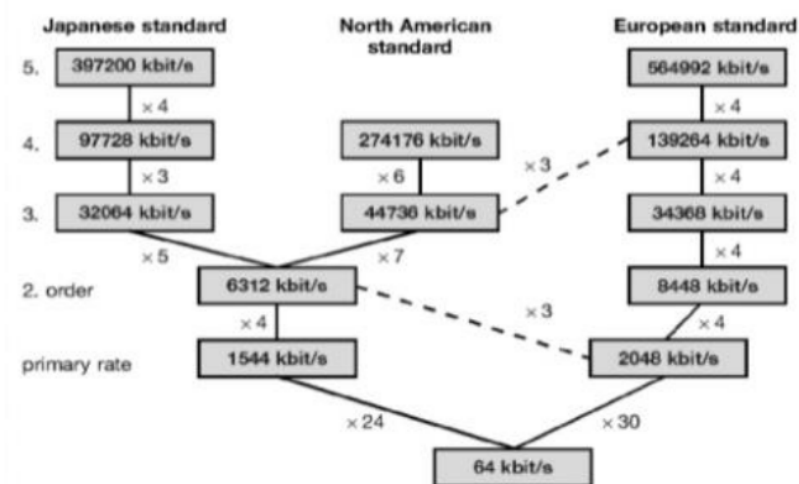


Fig. 11 Real-life example of PDH hierarchy with different standards in different parts of the world

PDH has worked in telecommunication for a while, but with the technological advancement, there was much more than just voice being sent through the telephone lines. That was putting strain on the PDH system showing its limitations. Some of those limitations were:

- ❖ Lack of global standard and difficulties interfacing two hierarchies.
- ❖ Inability of identifying individual channels in the higher bit orders.
- ❖ Higher bit streams were difficult to achieve, and thus difficulties meeting the demand (Abernathy, et al., 1996)

4. SDH (Synchronous Digital Hierarchy)

SDH is an ITU-T standard for high capacity networks. It was developed to substitute the existing PDH network. It was developed to improve the network and allow it to meet the demand. As the name clearly indicates, unlike PDH, all parts of this system run synchronously. Big advantages of SDH over PDH, between other, are: (Grami, 2016)

- ❖ Simpler multiplexing, where individual channels can be identified from the higher SDH Levels
- ❖ Backwards compatibility with PDH
- ❖ Capability of carrying ATM and Ethernet

The SDH data transport, similarly as PDH, as multiple stages, the data rates of those stages are multiples of 15.52Mbit/s. Table below shows few of the different SDH levels.

SDH Levels	Bit rates (Mbit/s)
STM-1	155.520
STM-4	622.080
STM-16	2488.320
STM-64	9953.28

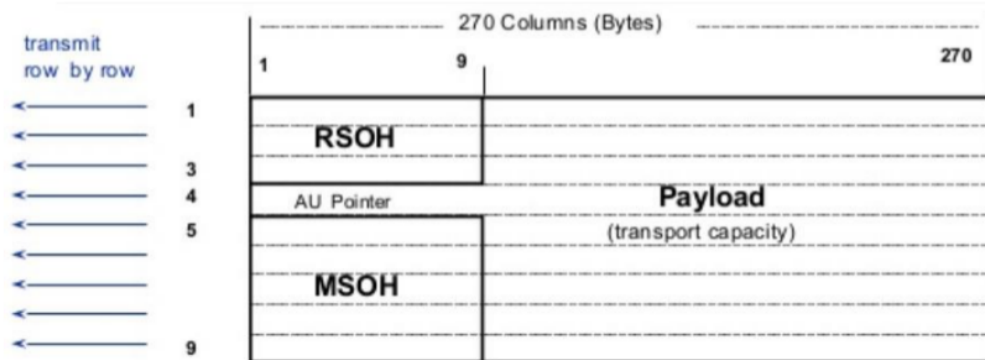


Fig. 12 SDH Frame structure (STM-1)

Each SDH frame is composed by a matrix of 9 rows with 270 bytes in each row (Fig. 12). The data is transmitted from left to right and top to bottom. The first 9 bytes in each row are used by the SDH systems itself and the 261 remaining are used for the transport of data. The first 9 bytes of each row are separated in three sections:

RSOH: Regenerator section overhead

MSOH: Multiplex Section overhead

Payload: Data transmitted

(Valdar, 2006)

A1	A1	A1	A2	A2	A2	J0	X	X	RSOH
B1			E1			F1	X	X	
D1			D2			D3			
AU POINTER									MSOH
B2	B2	B2	K1			K2			
D4			D5			D6			
D7			D8			D9			
D10			D11			D12			
S1					M1	E2	X	X	

Fig. 13 Overhead byte arrangement

The assignment of the individual bytes in the overheads (RSOH & MSOH) are shown above on and each byte type is explained in the table below.

A1, A2	Frame alignment
B1, B2	Error monitoring
D1- D3	Data Communication channel for RSON
D4- D12	Data Communication channel for MSON
E1, E2	Order wire channel
F1	Maintenance
J0	STM Identifier
K1, K2	Automatic protection switching
S1	Synchronisation status
M1	TXMN error acknowledgement

The different elements of the SDH are:

- ❖ Container (C)
- ❖ Virtual Container (VC)
- ❖ Tributary Unit (TU)
- ❖ Tributary Unit Group (TUG)
- ❖ Administrative Unit (AU)
- ❖ Administrative Unit Group (AUG)
- ❖ Synchronous Transport Module- N (STM-N) (Fig. 12)

Those elements are stages of multiplexing that the data of the individual container undergoes before becoming a STM-N frame such as the one shown on Fig. 12. An example of SDH Multiplexing structure is shown below on Fig. 14. (Wesolowski, 2002)

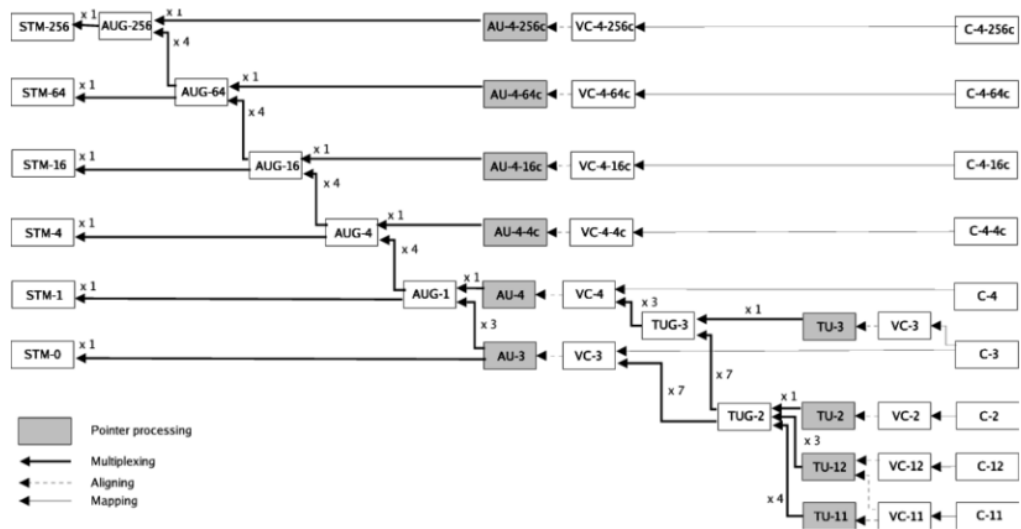


Fig. 14 SDH multiplexing structure

5. Conclusions and recommendations

This report has presented the evidences of in-depth research of the basics of Digital Communication systems.

It has shown the different essential parts of the digital communication system, also presenting some additional research in the area of digital communication. For example, a brief look into the concepts of encryption or data encryption and modulation schemes.

It has also provided sound understanding of the error detection techniques with the strength and limitations of each of the techniques.

The extensive research into PDH and SDH has proven the superiority of SDH, although PDH is still used in some cases in conjunction with SDH which is backwards compatible with it.

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Appendix A.

Theoretical Bit Rate Limits of Popular ITS Communication Mediums

Medium	Bandwidth (BW) (typical, range)	SNR (dB) (typical, range)	Theoretical Bit Rate Limit (using typicals)	Theoretical Limit Bits per Hz of Bandwidth	Typical Bit Rates in Practice	Comment
TWP only, Wire	400 kHz, 5 kHz - 500 kHz	35, 15-30 dB	116 kbps	11.6 bits / Hz	Up to 1.544 Mbps for 12,000 ft. using HDSL, higher possible	Bandwidth decreases as length increases
TWP/digitized public network, modem over wire	3.5, 2.4-3 7 kHz	15, 15-40 dB 20 dB 35 dB	17.6 kbps 23.3 kbps 40.7 kbps	5.0 bits/Hz 6.7 bits/Hz 11.6 bits/Hz	1.2 - 28.8 kbps	Codecs restrict bandwidth to less than 4 kHz
Coax, wire	6 MHz	10 dB, 10-25 dB	7.2 Mbps	1.2 bits/Hz	6 Mbps	Bandwidth rapidly decreases as length increases
SMFO, fiber	10, 10-200 GHz	Greater than 40 dB	132 Gbps	13.3 bits/Hz	to 10 Gbps	Bandwidth slowly decreases as length increases
Microwave Radio, wireless	10, 5-1000 MHz	15 10-25 dB 20 dB	50 Mbps 830 Mbps	5 bits/Hz 8.3 bits/Hz	SONET OC-3 155 Mbps	Limited by noise, multipath, and signal strength
Cellular Radio, wireless	25 kHz	10 dB	25 kbps	1 bits/Hz	19.2 kbps	Limited by noise, multipath, and signal strength

(Abernathy, et al., 1996)

Appendix B.

0	1	0	0	1	0	0
0	1	0	1	0	1	1
1	0	0	1	0	1	1
1	1	1	0	1	1	1
0	0	1	0	0	1	0
0	1	0	0	0	0	1

No errors

0	1	0	0	1	0	0
0	1	0	1	0	1	1
1	0	0	1	0	1	1
1	0	1	0	1	1	1
0	0	1	0	0	1	0
0	1	0	0	0	0	1

One error
(detected)

0	1	0	0	1	0	0
0	1	0	0	0	1	1
1	0	0	1	0	1	1
1	0	1	0	1	1	1
0	0	1	0	0	1	0
0	1	0	0	0	0	1

Two errors
(detected)

0	1	0	0	1	0	0
0	0	0	0	0	1	1
1	0	0	1	0	1	1
1	0	1	0	1	1	1
0	0	1	0	0	1	0
0	1	0	0	0	0	1

Three errors
(detected)

0	1	0	0	1	0	0
0	0	0	0	0	1	1
1	0	0	1	0	1	1
1	0	1	1	1	1	1
0	0	1	0	0	1	0
0	1	0	0	0	0	1

Four errors
(undetected)

0	0	0	0	1	0	0
0	1	1	1	0	1	1
1	0	0	0	0	1	1
1	1	1	0	0	1	1
0	0	1	0	0	1	0
0	1	0	0	0	0	1

Four errors
(detected)

Appendix C.

Generator (divisor) polynomial: $g(x) = x^3 + x + 1$

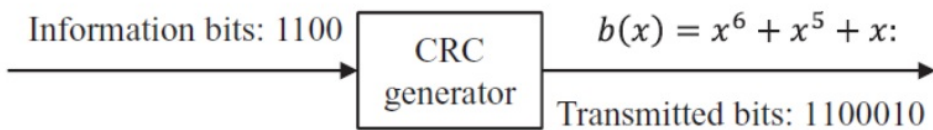
Information polynomial: $i(x) = x^3 + x^2$

Dividend polynomial: $p(x) = x^3 i(x) = x^6 + x^5$

$$\begin{array}{r}
 x^3 + x + 1 \overline{) \begin{array}{l} x^3 + x^2 + x \\ x^6 + x^5 \\ x^6 + x^4 + x^3 \\ x^5 + x^4 + x^3 \\ x^5 + x^3 + x^2 \\ x^4 + x^2 \\ x^4 + x^2 + x \\ x \end{array}}
 \end{array}$$

Remainder polynomial: $r(x) = x$

Transmitted polynomial: $b(x) = p(x) + r(x) = x^6 + x^5 + x$



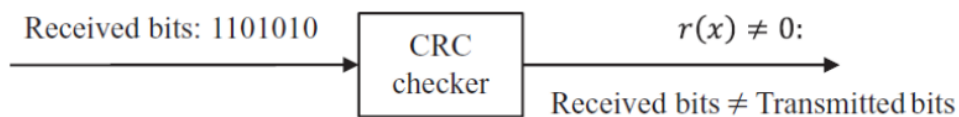
Appendix C. cont

Generator (divisor) polynomial: $g(x) = x^3 + x + 1$

Received (dividend) polynomial: $b'(x) = x^6 + x^5 + x^3 + x$

$$\begin{array}{r}
 x^3 + x^2 + x + 1 \\
 x^3 + x + 1 \overline{) x^6 + x^5 + x^3 + x} \\
 \underline{x^6 + x^4 + x^3} \\
 x^5 + x^4 + x \\
 \underline{x^5 + x^3 + x^2} \\
 x^4 + x^3 + x^2 + x \\
 \underline{x^4 + x^2 + x} \\
 x^3 \\
 \underline{x^3 + x + 1} \\
 x + 1
 \end{array}$$

Remainder polynomial: $r(x) = x + 1$



FINAL GRADE

GENERAL COMMENTS

Instructor

76/100

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Text Comment. The executive summary should cover all the sections of the report and give a complete overview

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GRADING FORM: CSG-RUBIC

ADAM BEDNER

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RESEARCH-INFORMED LITERATURE



There was evidence of extensive further reading and research from credible and reliable sources. Your interpretation and understanding of the additional research was very good and demonstrated a deep underlying appreciation of the subject. Your references were consistently applied and appropriate to the task and your reference list was of an appropriate length for this assignment

16/20

KNOWLEDGE AND UNDERSTANDING

The knowledge and understanding of the subject



demonstrated by this assignment was generally very good. There were few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was demonstrated to a high degree. You have demonstrated a competent critical understanding of the main concepts and expanded your knowledge beyond that contained in the course notes.

32/40

ANALYSIS



Your analysis of the task was generally satisfactory, both in class and as shown in this assignment, however it did tend more towards descriptive rather than analytical. You have demonstrated some analytical skills and your approach to the task was logical. You wrote a short conclusion that demonstrated some skills in analysing quantitative and qualitative data, however this was generally basic in nature. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory and provide a detailed critical analysis of this.

19/30

PRACTICAL APPLICATION AND DEP.



N/A

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your

9/10

written report was exceptionally well structured and written in a highly coherent and logical way. The report was presented in a professional manner using appropriate language and formatting, good diagrams in appropriate places, good sentence/paragraph structure and clear calculations.