

1708159

by Jonathon Williams

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1 Executive Summary

Digital communication techniques are heavily relied upon in today's world for effective and efficient communication. This report focuses on understanding the principles of a modern communication system by critically analysing the essential components of a digital communication system, evaluating some of the more commonly used methods of detecting and correcting errors that can occur during the transmission of the signals and the development of the UK telephone network into a modern digital system using first Pleisio-synchronous Digital Hierarchy and then Synchronous Digital Hierarchy systems.

Through research, it is evident that the basic essential components forming a digital communication system comprise an information source, input transducer, transmitter, communication channel, receiver and output transducer. The report describes what each basic component is for to enable the information source to be converted into an electrical signal which can then be transported over great distances by wire such as fibre optics or through non-wireless channels eg via air. The signal is subsequently captured by a receiver which reconstructs the signal and then goes to an output transducer that converts the electrical signal created by the input transducer back into its original form at its destination.

During the transmission of this data from source to destination, errors can be introduced into the communication channel due to environmental interference and physical defects. Error detection techniques detects these errors and error correction is a combination of detection and correction of the errors.

Although there are numerous error coding techniques utilised to detect/correct single bit or multiple bit errors, this report concentrates on Parity Bit, the Cyclic Redundancy Check (CRC) and Carrier Sensed Multiple Access (CSMA) and evaluates all 3 techniques. It was established through the research, that the main advantages of parity bit are its simplicity and ease of use for detection of single errors and is inexpensive. However, it unsuitable for multiple (burst) errors. CRC provides a simple method for detection of burst errors which can occur during digital transmission, particularly over noisy communication channels and storage but is not suitable for protecting against intentional alteration of data. CSMA is a network access method used to control access to the network on a shared transmission medium. There are 3 different types of CSMA protocols described in the report, with the chosen protocol being dependent upon the transmission medium. CSMA/CD is used for wired networks, CSMA/CA is used in wireless networks and CSMA/CR is used in controller networks. However, although CSMA is fairly simple to implement, it can't eliminate the collision permanently.

Pleisio-synchronous Digital Hierarchy (PDH) and Synchronous Digital Hierarchy (SDH) are both associated with multiplex technology used in telecommunication systems. PDH was the first type of digital telecommunications network technology developed in the 1960's using a 64k bit/s data rate which was determined using the Nyquist sampling theorem. However, as PDH had different multiplexing hierarchies, it was difficult to integrate interconnecting networks and was not suitable to meet the growing internet requirements for transmitting signals. Consequently, this was superseded by SDH in the late 1980's. SDH was developed to allow for extended capabilities, including improved performance, optical interface as standard and bandwidth on demand. The report then compares the SDH frame composition and data rates from STM-1 to STM-64 which is based on multiples of 155.52Mbit/s. STM-1 (Synchronous Transport Module-1), is the basic unit at 155.52Mbit/s, with higher levels increasing by a factor of 4 each time to form its hierarchy.

2 Research into Digital Communication Systems & Techniques

Communication systems traditionally used analogue signals for long distance communication. However, due to these distances, the signal incurred many losses such as distortion and interference. To overcome this, signals are now digitised whereby analogue signals are sent via communication channels using different techniques. This makes transmission effective and efficient, with communication being clearer and more accurate incurring minimal or even no losses. This report discusses the essential components of a digital communication system, evaluates methods for error checking and correction, and discusses the development of the UK telephone network into a modern digital system using Pleisio-synchronous Digital Hierarchy and Synchronous Digital Hierarchy systems.

2.1 The Essential Components of a Digital Communication System

The basic components forming a digital communication system comprise of an information source, input transducer, transmitter, communication channel, receiver, output transducer and destination (Shaik, ND). Figure 1 shows a block diagram representing these basic elements.

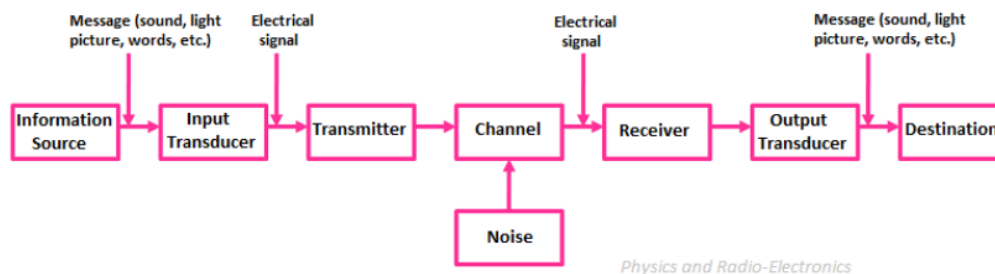


Figure 1: Basic components of a digital communication system

(Shaik, ND)

2.1.1 Information Source

This is the origins of a message or input signal and can be electric or non-electric. Examples of sources include: audio files, email messages, human voice and television pictures.

2.1.2 Input Transducers (sensors)

The input transducer or sensor, such as a microphone, captures non-electric sources e.g. sound and converts them into electrical signals so that they can be transported over greater distances.

2.1.3 Transmitter

The transmitter modifies the signal for efficient transmission once the source signal has been converted into an electric signal. For this to occur, the signal passes through an electronic circuit comprising:

- a noise filter
- Analog to digital convertor (A/D converter)
- Encoder- (source encoder compresses the data into minimum number of bits, helping in effective utilisation of the bandwidth and the channel encoder codes for error correction) (Electricalfundablog, ND)

- Modulator
- Signal Amplifier

Following signal amplification, it is ready for transmission via an antenna, where the signal is released as electromagnetic waves or electromagnetic radiation.

2.1.4 Communication Channel

This is the medium by which a signal travels from the transmitter to the receiver end and can either be wired e.g. fibre optic cables or wireless channels e.g. via air for radio frequency communication and water for sonar applications.

2.1.5 Receiver

Following transmission of the signal through the communication channel, a receiver captures and reconstructs the signal. This is achieved by passing the received signal through another circuit comprising a noise filter, A/D converter, decoder, demodulator and signal amplifier which boosts the signal which may have lost some of its energy when it was passed through the communication channel.

2.1.6 Output Transducer

This converts the electric signal initially created by the input transducer back into its original form. Examples include speakers, monitors, motors and lighting.

2.2 An Evaluation of Methods of Error Checking and Error Correction

e.g. Parity Bit, CRC checks and CSMA

As communication channels can be subject to channel noise or other impairments due to eg environmental interference, errors can be introduced during transmission from source to receiver. Error detection techniques detect these errors and error correction is a combination of detection of errors, enabling reconstruction of the original error-free data. Error coding applications include cellular telephone networks.

A study on error techniques by Deepika S S, Ashwin Kumar & Gurusiddayya H, states all error-detection and correction schemes add redundancy i.e. "some extra bits to the data called check bits or parity bits" (2016). Receivers use this to check consistency of the delivered message enabling recovery of data that has been determined as corrupted. According to Javatpoint (ND), errors can either be single-bit where only one bit of a given data unit is changed from 1 to 0 or from 0 to 1 as in Figure 2. They could also be burst errors, where two or more bits are changed from 0 to 1 or from 1 to 0 (Figure 3). Deepika et al advise codes can therefore be divided into either single or burst error detecting/correcting codes, although some codes can be used for both, with error coding schemes being either systematic or non-systematic.

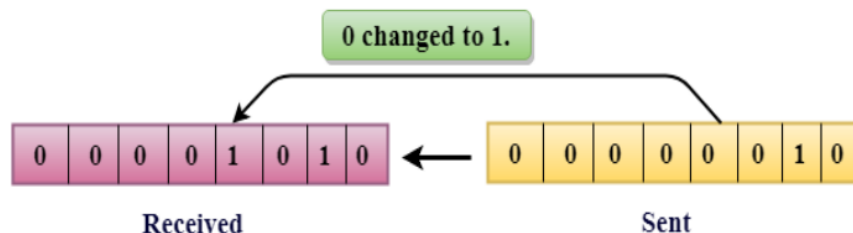
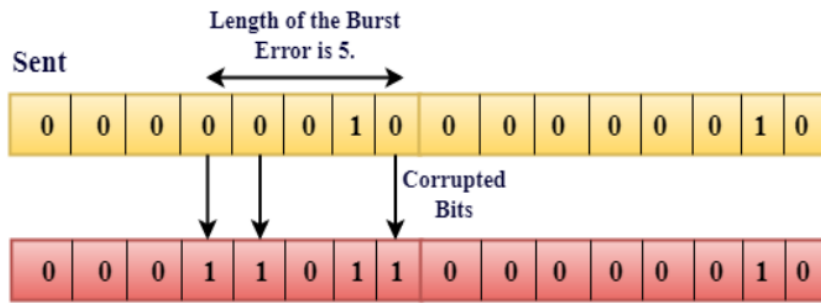


Figure 2: Single bit error example



Received

Figure 3: example demonstrating burst error

(Javatpoint, ND)

2.2.1 Parity Bit Checks

This is a common technique for error detecting. Single parity bit checking is simple and inexpensive to detect the errors. In this technique, a redundant bit (also known as a parity bit) is added at the end of the data unit so that the number of 1s becomes even, making the total number of transmitted bits, 9. If the number of 1s bits is odd, then parity bit 1 is attached and if the number of 1s bits is even, then parity bit 0 is attached at the end of the data unit. The parity bit is subsequently calculated from the received data at the receiving end and compared with the received parity bit. This method generates the total number of 1s even, so it is called even-parity checking. Figure 4 shows a block diagram representing this process. (Javatpoint, ND)

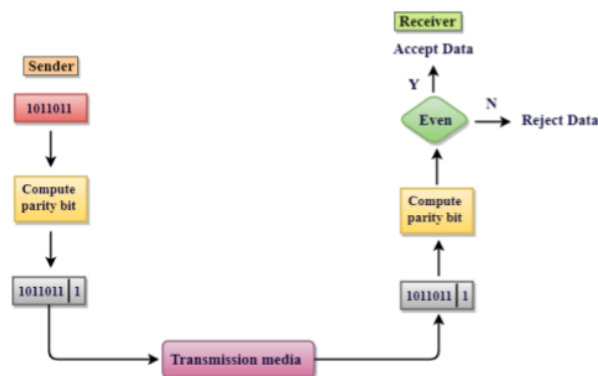


Figure 4: Block diagram showing single parity bit checking

(Javatpoint, ND)

Although this is a simple technique, it can only detect single-bit errors which are rare and if two bits are interchanged, then it cannot detect the errors as shown in Figure 5.

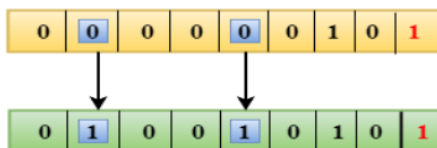


Figure 5: Representation of drawback of single parity bit checking

(Javatpoint, ND)

Performance can be improved using two-dimensional (2D) parity check which arranges the data in table form as shown in Figure 6. However, if two bits in one data unit are corrupted and two bits exactly the same position in another data unit are also corrupted, then 2D parity checker will not be able to detect the error.



Figure 6: 2D Parity Checking

(Javatpoint, ND)

2.2.2 Cyclical Redundancy Check (CRC)

According to Deepika et al (2016), CRC uses the principle of division to check errors where the m-bit binary sequence being transmitted, is divided by a generating polynomial and a remainder of order c-bit is obtained. At the receiver end, the received binary coded sequence is divided by the generating polynomial used at the sender's end. If zero as the remainder is obtained, the received sequence has no error and the data is accepted. If not, it shows error was introduced during transmission process and the receiver then requests for retransmission of the coded sequence as shown in Figure 7.

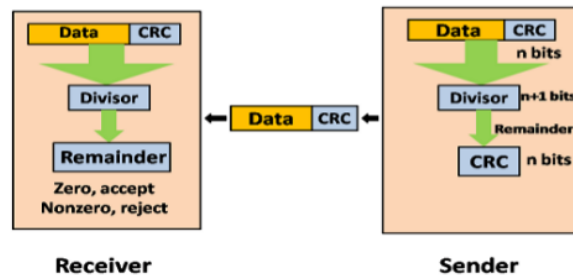


Figure 7: CRC technique

(Javatpoint, ND)

CRC is commonly used in digital networks and storage devices to detect accidental changes to raw data. It is simple to implement and good at detecting common errors caused by noise in transmission and for the detection of burst errors during digital data transmission. However, its mechanism is easy to crack and is not suitable for protecting against intentional alteration of data. Overflow of data can also occur in CRC. (Sai Pavan, et al., 2019)

2.2.3 Carrier Sensed Multiple Access (CSMA)

Dinesh Thakur states "CSMA is a network access method used on shared network topologies such as Ethernet to control access to the network. Devices attached to the network cable listen (carrier sense) before transmitting. If the channel is in use, devices wait before transmitting" (ND). Several devices

can connect to and share the same network which all have equal access to use the network when it is clear. There are three different type of CSMA methods used depending on the transmission medium: CSMA/CD (collision detection), CSMA/CA (collision avoidance) and CSMA/CR (collision resolution) with 3 different types of CSMA- see Figure 8.

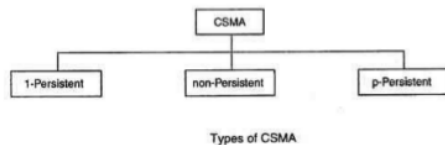


Figure 8: 3 types of CSMA

(Thakur, ND)

The CSMA/CD protocol uses carrier-sensing to defer transmissions until no other stations are transmitting thereby dealing with transmissions after a collision has occurred and works well for wired networks. However, CSMA/CA acts to prevent collisions before they happen and utilised in wireless networks. CSMA/CR identifies a collision by additional sensing after data transmission starts and is used in controller area networks, mainly used in cars and machines. CSMA is fairly simple to implement and is a functional scheme that works. However, it can't eliminate the collision permanently.

2.3 The Origins of the UK Telephone Network in Pleisio-synchronous Digital Hierarchy (PDH) and how the 64kbit/s Data Rate was Determined

Up until the 1950's, analogue transmission lines made up nearly all telephone systems. However, they used expensive modulators, demodulators and filters. A Technology UK article (ND) stated that this led to the development of 'digitisation of an analogue voice channel into a 64kbit/s using Pulse Code Modulation (PCM)'. This made it possible to use time division multiplexing (TDM) to multiplex a number of lower speed voice channels onto a single synchronous trunk line known as an E carrier, transforming the telecommunication sector. Accordingly, PDH multiplexing and transmission was developed in the 1960's and was the first type of digital telecommunications network technology, making it easy to transfer huge data over digital transport equipment such as optical fibre. (Coombs & Coombs, 1998)

In PDH, the data rate which is controlled by a clock in the equipment generating the data is not the same throughout the transmission network. Hence, different data streams can run at similar but slightly different rates, making multiplexing and de-multiplexing very complex. According to Professor Keith Ward (2006) the hierarchy in PDH is '*constructed stage by stage from the 30 channels at 64 kbit/s making up the 2 Mbit/s primary bit stream to 8 Mbit/s, 34 Mbit/s, 140 Mbit/s, and 565 Mbit/s*'. Figure 9 shows the working requirements of PDH.

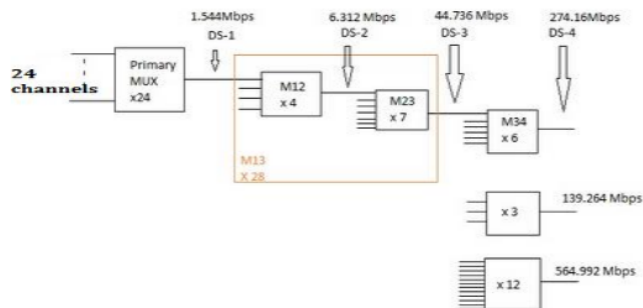


Figure 9: Working requirements of PDH

(Fiber Optical Networking, 2015)

An article on 'voice digitization and voice/data integration' recognises that the digitisation standard in the public switched telephone network uses a sampling rate of 8 KHz, derived at by application of the Nyquist sampling theorem. Each quantized sample is encoded as an 8-bit word ($8 = \log_2 256$), resulting in a bit rate of $8 \times 8 = 64$ Kbit/s, hence this is how the 64kbit/s data rate was determined. (Penn Engineering, ND)

However, due to PDH having different multiplexing hierarchies, it is difficult to integrate interconnecting networks together as every manufacture has its own standards. In addition, RF Wireless World (2012) article acknowledges, "PDH was not scalable to support high capacity bandwidth" and therefore was not suitable to meet the growing internet requirements for transmitting signals. Consequently, PDH was superseded by SDH in the late 1980's. However, PDH is still popular as the equipment is small enough for use in street cabinets, is good for point to point connections and is cost effective. (Carritech Telecommunications, 2018)

2.4 The Development of Synchronous Digital Hierarchy (SDH) Systems as used in The UK Telephone Network

SDH is a European standard used for high-speed data transmission of telecommunication and digital signals at much higher rates, although it has been designed to work with PDH. It uses standardised technology where the digital multiplexer's inputs or data stream are of the same rate and derived from a common clock, therefore allowing exact timings. Consequently, SDH allows data streams with low bit rates to be combined into high rate data streams. As acknowledged by Fibre Optical Networking (2015), SDH is able to transport large quantities of digital signals over the same optical fibre, using lasers or consistent light being emitted from LEDs, without synchronization problems, providing a simple and flexible network infrastructure. Although SDH has many advantages over PDH, the utilisation rate of SDH bandwidth is relatively low, therefore resulting in the reduction of data frames utilised to transmit signals. Furthermore, due to the type of software it has adopted (OAM) as the monitoring and maintenance instrument, it is lacking in network security. Nevertheless, the benefits far outweigh the disadvantages.

2.5 A comparison of SDH Frame Composition and Data Rates

SDH transport hierarchy is based on multiples of 155.52 Mbit/s. The basic unit of SDH is STM-1 (Synchronous Transport Module-1), which is 155.52 Mbit/s. Higher levels increase by a factor of 4 each time to form its hierarchy. Consequently, STM-4 is 622.08 Mbit/s, STM-16 is 2488.32 Mbit/s and STM-64 is 9953 Mbit/s. (Gupta, 2013). As each rate is an exact multiple of the lower rate, it is synchronous-see Figure10.

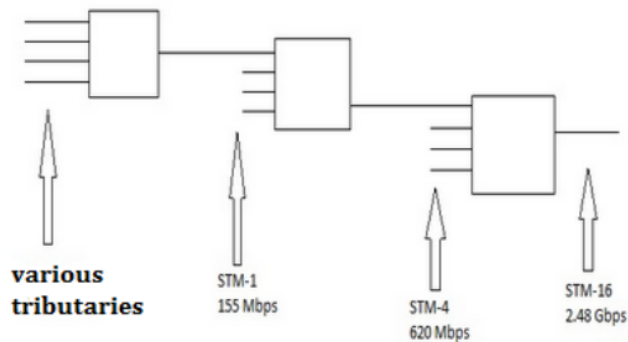


Figure 10: The working principle of SDH

(Fiber Optical Networking, 2015)

A STM-1 frame has a byte-oriented structure with 9 rows and 270 columns of bytes, equalling 2,430 bytes. Each byte corresponds to a 64 kbit/s channel (Hardy, et al., 2020). According to a Carritech telecommunications, the STM-1 frame is transmitted at 125 μ s (microseconds), resulting in 8,000 frames per second on the circuit and consists of payload blocks, overhead blocks and pointers. Carritech advises that '*the ratio of these components can vary and depends on the initial payload that needs to be transmitted*'. The STM-1 base frame (represented in Figure 11), is structured as follows

- **Length:** 270 columns of bytes with 9 rows = 2430 bytes
- **Byte:** 1-byte = 8 bit
- **Duration** (Frame repetition time): 125 μ s i.e. 8000 frame/s
- **Rate** (Frame capacity): $2430 \times 8 \times 8000 = 155.5200$ Mbit/s
- **Payload** = $2349 \text{ bytes} \times 8 \text{ bits} \times 8000 \text{ frames/sec} = 150.336$ Mbit/s
-

(Hardy, et al., 2020)

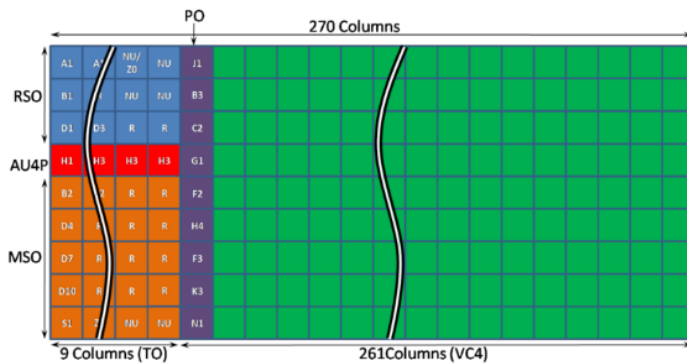


Figure 11: STM-1 base frame

(Scribd, ND)

TOH: Transport Overhead (**RSOH** + **AU4P** + **MSOH**)

- **MSOH:** Multiplex Section Overhead
- **RSOH:** Regeneration Section Overhead
- **AU4P:** AU-4 Pointers

VC4: Virtual Container-4 payload (**POH** + **VC-4 Data**)

- **POH:** Path Overhead

The section overhead (SOH) of a STM-1 signal is divided into the regenerator section overhead (RSOH) and multiplex section overhead (MSOH). These contain information from the transmission system used for signalling and measuring transmission error rates, used for a range of applications eg. monitoring transmission quality.

STM-4 has a bit rate of 622.080 Mbit/s and is designed to carry 7,680 8-bit "voice" frames every 125 micro-seconds for a total payload bit rate of 491.520 Mbit/s. Its frame consists of 36 rows each containing 270 bytes. (Hardy, et al., 2020)

STM-4 can be further multiplexed to form an STM-16 signal, with a bit rate of 2488.32Mbit/s. Table 1 lists the defined SDH frame formats, their composition, bit rates, and maximum number of 64 kbit/s telephony channels that can be carried at each rate.

Table 1: SDH Frame format, bit rates & maximum numbers of telephony channels

Frame Format	Frame Composition	Bit Rate	Maximun number of telephony channels
STM-1	1xSTM1	155.52 Mbit/s	1,920
STM-4	4xSTM1	622.080 Mbit/s	7,680
STM-16	16xSTM1	2488.32Mbit/s	30,720
STM-64	64xSTM1	9953.28 Mbit/s	122,880

(TTC Expect Excellence, ND)

3 Conclusion

A digital communication system must comprise the following essential components: an information source, input transducer, transmitter, communication channel, receiver and output transducer. Nevertheless, errors can be introduced into the communication channel during transmission from source to destination due to environmental interference and physical defects.

Error detection techniques detect these errors, whilst error correction detects and corrects them. There are numerous error coding techniques utilised to detect/correct single bit or multiple bit errors. Following analysis and evaluation of 3 of these techniques, namely; Parity Bit, the Cyclic Redundancy Check (CRC) and Carrier Sensed Multiple Access (CSMA), it can be concluded that:

- Parity bit checks are simple, inexpensive and easy to use for detection of single errors. However, it is unsuitable for detecting multiple (burst) errors.
- CRC provides a simple method for detection of burst errors which can occur during digital transmission, particularly over noisy communication channels and storage but is not suitable for protecting against intentional alteration of data.
- CSMA is a network access method used to control access to the network on a shared transmission medium. There are 3 different types of CSMA protocols depending on the transmission medium. CSMA/CD is used for wired networks, CSMA/CA is used in wireless networks and CSMA/CR is used in controller networks. However, although CSMA is fairly simple to implement, it can't eliminate the collision permanently.

Plesio-synchronous Digital Hierarchy (PDH) and Synchronous Digital Hierarchy (SDH) are both associated with multiplex technology used in telecommunication systems. PDH was the first generation of digital telecommunications network technology using a 64k bit/s data rate, which was determined using the Nyquist sampling theorem. In PDH, the data rate controlled by a clock in the equipment generating the data, is not the same throughout the transmission network, making multiplexing and de-multiplexing very complex. Consequently, as PDH had different multiplexing hierarchies, it was determined that it was difficult to integrate interconnecting networks and was not suitable to meet the growing internet requirements for transmitting signals. Nevertheless, it is still good for point to point connections and is cost effective.

PDH was subsequently superseded by SDH, allowing for high-speed data transmission of telecommunication and digital signals at much higher rates, although it has been designed to still work with PDH. SDH uses standardised technology where the digital multiplexer's inputs or data stream are of the same rate and derived from a common clock, therefore allowing exact timings. This meant that SDH had extended capabilities and improved performance. A comparison was then made of the SDH frame composition and data rates from STM-1 to STM-64 which is based on multiples of 155.52Mbit/s. It was subsequently noted that STM-1 (Synchronous Transport Module-1), is the basic unit at 155.52Mbit/s, with higher levels increasing by a factor of 4 each time to form its hierarchy. As the frame composition increases, so does the bit rate and maximum number of telephony channels.

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FINAL GRADE

GENERAL COMMENTS

Instructor

85/100

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GRADING FORM: CSG-RUBIC

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.

17/20

KNOWLEDGE AND UNDERSTANDING



The knowledge and understanding of the subject demonstrated by this assignment was generally excellent. There were very 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 highly competent critical understanding of the main concepts and expanded your knowledge well beyond that contained in the course notes.

34/40

ANALYSIS



Your analysis of the task was excellent, both in class and as shown in this assignment. You have demonstrated highly competent analytical skills and your approach to the task was highly logical. You carried out a detailed evaluation of the results and included an excellent conclusion relating your practical results to accepted theory. You have demonstrated a capacity for independent thought and your interpretation of the quantitative and qualitative data was excellent with sound judgements based on wholly valid arguments.

25/30

PRACTICAL APPLICATION AND DEP.



N/A

SKILLS FOR PROFESSIONAL PRAC.



Your application of practical skills for this task was generally exceptional. You used both the basic and advanced features of the resources appropriately when designing the circuit and you used appropriate advanced options for testing and evaluating the circuit performance. You managed to design an effective circuit that functioned well within the specification and achieved this by rarely asking for assistance thus demonstrating some advanced problem solving skills. Your results were comprehensive and allowed for a detailed conclusion to be attempted.

9/10