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Review of Communication System Modelling for Supervisory Control and Data Acquisition (SCADA) Network

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Abstract— Communication remains a vital backbone of computer network such as Industrial Control System (ICS), Municipal Area Network (MAN), Wide Area Network (WAN), Supervisory Control and Data Acquisition (SCADA) Systems, isolated inter-company networks and the general worldwide network – the internet. We examine the evolution of communication system model from the forties to the present day. It is observed that while the model evolves, the fundamental role of communication system remains the same which is primarily that of getting the information across (transmits) from the source (sender) to the destination (receiver) with high fidelity. Communication types, transmission media and formal modeling of signal behavior as proposed by Fourier [1] are also considered. The components of the earlier model is compared with the current model and it is found out that variation arises mainly from the inclusion of binary interface that simplifies the process of digitization of source information.

Index Terms: Binary-Interface, Communication, Information, Model, Network, Transmission-Media, Signal.

1 Introduction

SIMPLIFIED model of a communication system comprises the information source from where the information is produced, the information sink that receives the information from the source and the medium through which the information is passed. Formats of the information that is exchanged between two or more entities (Computers, routers, persons, etc) may be any or combination of text, voice, image and video. The goal of a communication system is to transmit the information from the source to the receiver (sink) as faithfully as possible, that is, without or with minimal errors [2]. Lehman, Leighton and Meyer [3], in their book titled, "Mathematics for Computer Science", emphasized the same point remarking that: "Whatever architecture is chosen, the goal of a communication network is to get data from *inputs* to *outputs"*.

This age long problem was highlighted by Shannon [4] in his paper titled "A Mathematical Theory of Communication". This is developed further in section 2 where we summarise the essential components of Shannon's communication model. In the subsequent subsections, communication system with layers and interface, transmission media (guided and unguided media) are discussed. Following this is a peep into the electromagnetic spectrum in telecommunication. The work is rounded up by delving into formal theory of communication. The substance of this section is presentation of Fourier analytical model of the signal behavior; computation of channel capacity and entropy as proposed by Shannon [4].

2 Methodology

The research area of the first author is on SCADA System. Since communication system is vital to its effective implementation, the need for deeper exploration of communication system characteristics is obvious. Hence, related online and hard-copied journals are studied with a view to having better insight into the development in communication system. Other sources of information include books and search engines. The outcome of the exercise is described below.

2.1 Model of Communication System

Fig. 1 was the 1948 model of Communication system proposed by Shannon [4] in his paper titled "Mathematical Theory of Communication". It consists of 5 parts:

1 **Information Source**: This produces the message or series of messages that are communicated to the destination (the receiving terminal). Five types of messages are identified viz.: (a) letters arranged in sequence as in teletype system's telegraph. (b) a single function of time f(t) as in telephony or radio; (c) a function of variables such as time as in black and white television i.e. a function f(x, y, t) i.e. two space quantity and time with light intensity

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represented by (x, y); (d) Two or more functions of time - f(t), g(t) ,h(t) as in the case of a system serving several channels in multiplex. (e) multiple functions of several variables such as in colour television where the messages comprises three functions f(x,y,t), g(x, y, t), H(x, y, t) in a three dimensional continuum.

2 **Transmitter**: It acts on the message to produce a signal that is appropriate for transmission over the channel. Changing pressure of sound into electrical current is all that is needed in telephony operation while in telegraphy, there are encoding operation that produces ordered series of dashes, dots and spaces on the channel corresponding to the message. Different speech functions are sampled, quantized, compressed and encoded.

3 **Channel**: is the medium for transmitting the signal from the transmitter to the receiver. This may be wires, a beam of light, a coaxial cable, a band of radio frequencies, etc.

4 **Receiver**: it performs the reverse of all the operations done by the transmitter, reassembling the message sent.

5 **Destination**: This is the person or thing that is message's target.

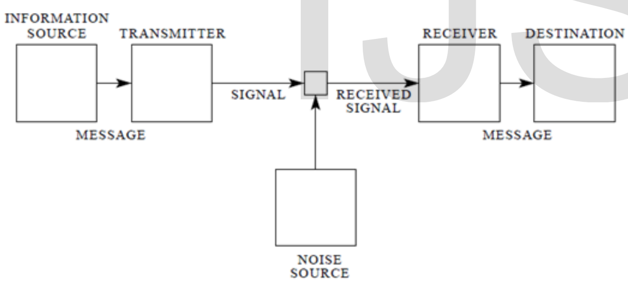

Fig. 1: Communication System Model
Source: Shannon [4]

2.2 Shannon Communication System Model – Modified

Gallager [5] presented a modified fashion of Shannon's 1948 model of communication system. Essentially, the difference between the 1948 model of computer system and the model of fig. 2 is in the transmitter which is replaced with Source encoder and channel encoder and the receiver which is replaced with channel decoder and source decoder. These additions are discussed as follows:

Source Encoder – It performs the function of converting the information input that can be any or combination of voice, image, text and video into series of "1s" and "0s" called binary sequence. The significance of the conversion of source information into binary sequence is demonstrated by the binary interface in fig. 3.

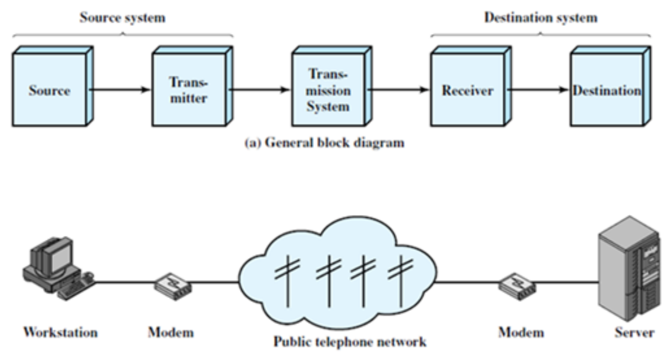

Fig. 2: Simplified Communication Model
Source: Stallings [6]

Channel Encoder: Often called a modulator. It processes the binary sequence for transmission over the channel.

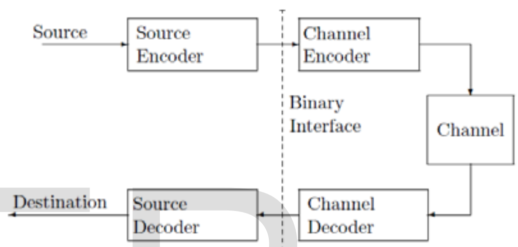

Fig. 3: Shannon Communication System Model – Modified
Source: Gallager [5]

The channel decoder (demodulator) and the Source decoder perform the inverse of what the source encoder and channel encoder have done, reconstructing the source information. Gallager [5] advanced four main reasons why binary interface are now part of communication systems – why the standard now is digital communication systems. These reasons are:

1. Low cost, miniaturization and reliability of digital
2. Simplification of understanding and implementation resulting when the source and the channel has standard binary interface.
3. Networking is simplified when there is a standardized binary interface between the source and channel as the activity is reduced to transmitting of binary sequences through the network.
4. Shannon [4]'s source/channel separation theorem that "if a source can be transmitted over a channel in any way at all, it can be transmitted using a binary interface between source and channel.

2.3 Standardized interfaces and layering

Modelling of communication system with standard interfaces and layers as in fig. 4 enables the equipment or users on one side of the interface to concentrate on specific layers of interest without bothering about what happens in the others.

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Layering idea in a communication system is to support the breaking communication functions into a set of separate layers. Each layer consists of an input module at the source end of a communication system and output module at the other end. The input module at layer i processes the information received from layer i+1 and sends the processed information on to layer i-1. The peer output module at layer i works in the opposite direction, processing the received information from layer i-1 and sending it on to layer i.

Fig. 5 is an example using the information flow in a TCP/IP Protocol suite.

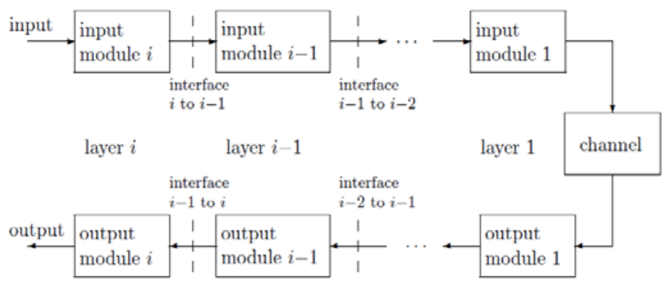

Fig. 4: Communication System with Layer and Interface-Source: Gallager [5]

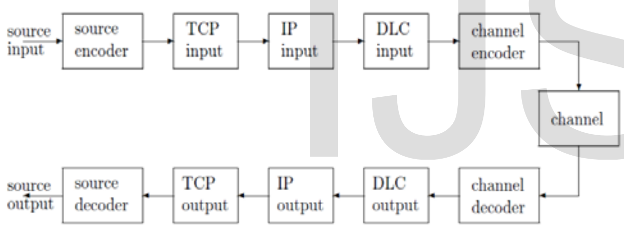

Fig. 5: Simplified TCP/IP Protocol Suite as an Example of Layering
Source: Gallager[5]

The Transport Control Protocol (TCP) which features in a pair of Source/Destination is among other things responsible for end-to-end recovery from error and for controlling the rate if data flow during network congestion by slowing the source down. Next is the IP (Internet Protocol) module identified with every network node. It collaborates with the former in the function of reducing congestion. Followed is a DLC (data link control) module associated with each channel; this accomplishes rate matching and error recovery on the channel. The physical layer in a network comprises the encoder, decoder and the channel.

2.4 Transmission Media

Transmission medium plays significant role in the process of exchanging information from source to destination. In computer networks, the medium transports bits from one entity to another. The transmission media are also the sources of errors known in communication systems. Prasad [3] in his book titled "Principles of Digital Communication Systems and Computer Networks" classified the common impairment due to communication media into three: attenuation distortion, delay distortion and noise. Noise is further split into thermal, inter-modulation, impulse and cross talk. Media can be wired (guided) or wireless (unguided). Each medium has its specific characteristics in terms of bandwidth, cost, delay, maintenance and installation ease. Highlight of the essential characteristic of some popular transmission media follows.

1. Guided Media (Wired)

a. Twisted Pair

It is made up of two copper wires insulated from each other. It is twisted as revealed from the name in order to reduce radiation from the wires as the radiation effect reduces since waves from from each twisted wire cancel out.

Twisted pair of wires is able to transmit both analog and digital information with bandwidth varying according to the wire's thickness and the travelled distance. Twisted wires are widely used as they perform satisfactorily when used for transportation of information. Their low cost is an equal advantage. They are popular in telephony network and the signal level which decreases with distance can be boosted with repeaters [2], [7].

b. Coaxial Cable

A coaxial cable has a hard copper wire as the core and it is surrounded by an insulated which is enclosed in a woven braided mesh of cylindrical conductor. This outer conductor has a cover sheath made up of plastic to protect it from mechanical pull. It is used widely in LANS, telephony networks/trunks for long distance communication, cable television distribution, etc.

It has high bandwidth and good immunity to to noise. The band width which is in the range of a few GHz depends on the cable length and quality.

c. Power Lines

Power Lines refers to the high voltage electricity wires that are deployed for the transmission of electricity from the power station to long distance. For this purpose, it conveys electricity generated at frequency of 50Hz as in Nigeria, Africa or Europe and 60 Hz as in North America from generation source to the consumption end.

By superimposing communication frequency on this line it can serve simultaneously for both electricity and information conveyor. Besides the use of high voltage electricity lines for long distance communication, the present trend is to use electrical wires at home for both power and signal medium, especially conveying of signal from outside antenna to serve the home television [7].

d. Fiber Optics

Transmission of light through fiber is founded on the fact that light waves can be reflected with glass core and guide to the fiber end with little loss along the way. This principle is on the condition that transmission angle of the light waves is controlled to prevent light refraction instead of reflection. Fiber optics are usually deployed in high speed LANs, high speed internet access and as network backbones for long transmission. The main key components of fiber optics are light source, transmission medium and detector.

2. Unguided Media (Wireless)

a. Radio Transmission

The advantage of using free space as communication medium is that receiver can be mobile or fixed. It is unguided as electromagnetic waves travels freely in all direction (omnidirectional). Radio frequency (RF) waves can be generated easily, can travel long distances and can penetrate physical structure such as buildings with ease. It is hence deployed for both outdoors and indoors communication. Its frequency range is from 30 MHz to 1 GHz (Fig. 6).

Radio is extensively used for broadcasting as program transmitted by a central station can be received by a several number of receivers spread over a large geographical area, especially when the transmission is on specific frequency. A number of mathematical models have been developed to conceptualise the complex radio wave propagation. Each band of radio frequency spectrum is being applied for diverse purpose. Some of the problems emanating from the special characteristics of radio wave are path loss which varies with distance and frequency of propagation, irrespective of obstacles along its path; fading which results from reduction in signal strength due to obstacles on the propagation path and rain attenuation caused by heavy down pour.

b. Microwave Transmission

The frequency range of microwave is from 1 GHz to 40 GHz. (Fig. 6). Above 100 MHZ, the waves travel in nearly straight lines, hence microwaves travel in straight line and is focused narrowly. Microwaves are directional necessitating proper alignment of both transmitter and receiver. Repeaters are used to extend the distance covered by microwaves. The tower height impacts inversely on the distance covered. At lower frequencies microwaves will not pass through building unlike radio waves.

Microwave communication is used widely for long distance telephone communication, television signal distribution, mobile phones and other purposes. One advantage of microwave communication over optic fiber is that it does not require right-of-way to lay cables. A major setback of microwave as a medium is its multipath fading that occurs when some of the directional waves transmitted are refracted, off the atmospheric layer, delayed and arrive out of phase with others, there by cancelling the signal [7].

c. **Infrared Transmission**: Infrared waves operate from 0.3 THz to 20 THz (just below visible light) (Fig. 6). It uses transmitters/receivers that modulate the non coherent infra red light. The transceivers have to be within the line of sight of each other. Infra red does not penetrate solid object like walls as it localizes communication. Remote controls used for stereo and television use infra red communication. Hence, it is secure against eavesdropping. It cannot be used outside the building as it interferes with sun rays infra red waves. As there is no contention for it, license is not necessary before its use [8].

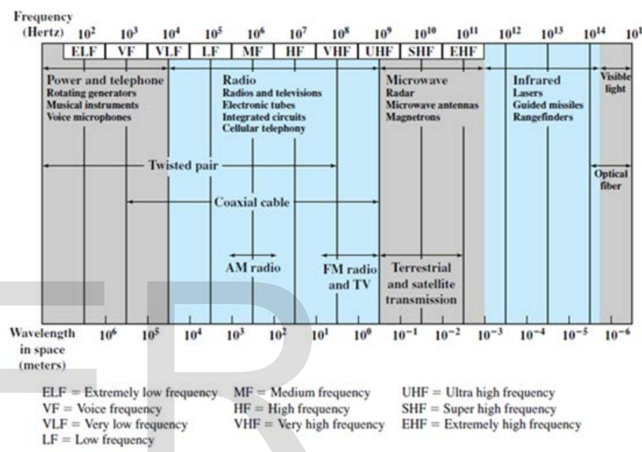

Fig. 6: Electromagnetic Spectrum
Source: Stallings [6]

2.5. Communication Types

Prasad [2] identified 6 different means of communication on the basis of requirement as follows:

Point-to-point communication: Here communication is between two end points.

Point-to-multipoint communication: This is a one source (sender) to multiple destinations (recipients) type of communication. It is also called multicast communication type.

Broadcasting: As in the point–to-multipoint, information passes from the central location to several recipients but without the need to reply (passive recipients).

Simplex communication: It is a unidirectional type of communication from sender to the receiver only.

Half-duplex communication: This is a non simultaneous bidirectional communication between two entities.

Full-duplex communication: Here both the sender and the receiver can communicate in both directions simultaneously.

2.6 Formal Framework for Data Communication

a. Modelling Signal Behaviour

Through the work of the French mathematician Fourier [1] any periodic signal from the source can be expressed as a sum of an infinite number of sines and cosines [7]:

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft) \quad (1)$$

By this representation it becomes easy to model and analyse the behavior of any signal mathematically, thus removing ambiguity and subjectivity in discussing its behavior. From the equation, g(t) is the signal of interest as a function of time t. c is a constant, an and bn denotes amplitudes of the nth harmonic of the sine and cosine, τ is the period while f=1/τ is the fundamental frequency. Decomposition of a signal into infinite series of sines and cosines is named after the mathematician and called Fourier Analysis. Given the fourier series which denotes the decomposed pieces of the original signal, the Fourier series can be reconstructed to the original signal.

C, an and bn are computed as follows:

For a_n multiply equation 1 by sine(2πkft) on both sides and integrate from 0 to T, noting that

$$\int_0^T \sin(2\pi kft)\sin(2\pi nft)\,dt = \begin{cases} 0 \text{ for } k \neq n \\ T/2 \text{ for } k = n \end{cases} \quad (2)$$

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)\,dt \quad (3)$$

Similarly, multiplying both sides of equation 1 by $\cos(2\pi kft)$ and integrate from 0 to T,

$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)\,dt \quad (4)$$

Integrating equation 1 gives:

$$c = \frac{2}{T}\int_0^T g(t)\,dt \quad (5)$$

b. Channel Capacity

Shannon [4] in his paper titled "A Mathematical Theory of Communication" derived a formula for computing the channel capacity of a transmission medium as follows:

$$C = W \log_2(1 + S/N)$$

This formula relates the channel capacity C with the bandwidth W and S/N the signal energy to noise energy ratio. Evidently from the equation, channel capacity depends on the bandwidth and the signal energy to noise energy ratio. The channel capacity is measured in bit per second (bps).

c. Entropy Computation

Entropy is a measure of the information produced. Shannon [4] derived two formulae for its computation as show:

H = log2N bits/symbol

H = - Σ P(i)log2P(i) bits/symbol

The first expression computes entropy for a case where the source produces the number of symbols, N with equal probability while the latter equation depicts a case of an equal probability of occurrence of the number of symbols produced. P(i) represents the probability that symbol i is produced.

3 Discussions

It is evident that the fundamental components of communication system as proposed by Shannon [4] are still in use this day except that addition of coding and decoding interface that caters for analogue/digital conversion.

The communication model as modified also reflects incorporation of TCP/IP protocol suite at the sending and receiving end. In common use this day for information transmission are guided media such as power lines and optical fiber and unguided media such as radio, microwave and satellite.

Apart from the Fourier analytical model that simplifies transformation of signal of any type of wave form into sinusoidal wave, the Shannon formula for computation of Channel capacity is highly informative and still very relevant today. For instance, the channel bandwidth is directly proportional to the channel capacity for a given signal to noise ratio.

4 CONCLUSION

Adequate attention should be paid to the design of efficient communication system while planning any computer network, especially a network such as SCADA System whose operation covers a wide geographical area.

The implication of applying a typical transmission media needs to be evaluated prior to choice of a specific medium for transmission as each has both benefits and cost.

Further research contributions are still required in the area of bandwidth and capacity of optical fiber which is one of the reliable and efficient transmission media.

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