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A COMPREHENSIVE EXPLORATION OF MODULATION TECHNIQUES AND ENABLING TECHNOLOGIES IN COMMUNICATION SYSTEMS: FROM ANALOG TO DIGITAL CARRIERS.

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Keywords: modulation, communication systems, modulation techniques, subcarriers, constellation points, analog carriers, digital carriers, 3G, 4G, 5G, WiFi 5, WiFi 6.

Abstract

The rapid advancement of communication technology has led to the obsolescence of certain systems, emphasizing the need for a comprehensive understanding of modulation techniques and their underlying enabling technology in communication systems. This article aims to provide a concise yet thorough exploration of modulation, focusing on modulation techniques, subcarriers, and constellation points. The conceptual framework aims to identify fundamental concepts in communication systems and explain them in relation to modulation. Additionally, it examines various types of communication systems, including analog and digital carriers, and their respective subdivisions.

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

The modulation techniques covered include AM, FM, PM, ASK, FSK, PSK, and QAM. Furthermore, the article shed light on the enabling technology in telephony and internet connectivity, specifically in 3G, 4G, 5G, WiFi 5, and WiFi 6. It then concludes that as communication technology continues to evolve, staying updated with modulation techniques and enabling technologies will be essential for optimizing communication systems and ensuring reliable and high-quality information transmission.

INTRODUCTION

Modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a separate signal called the modulation signal that typically contains information to be transmitted. Communication technology refers to all equipment and programs that are used to process and communicate information. The trend of communication technology recently is advancing very quickly such that some others are becoming outdated. This article will shed more light on the essence of having a very concise, yet thorough understanding of modulation underlying the enabling technology of communication systems in very trickish details, with a particular emphasis on modulation techniques, their subcarriers and respective constellation points. The conceptual framework was written with the objective of identifying basic concepts in communication systems, and explaining them in relation to modulation.

The section on types of communication system x-rayed the different types of communication systems based on respective criteria, and eventually buttressing the analogue-carrier and digital-carrier classification, and mentioning their respective sub-divisions. The modulating techniques were the next, as the basic types are the AM, FM, PM, ASK, FSK, PSK and QAM. Then the enabling technology in telephoning and internet connectivity and their respective modulation techniques were briefly explained in the 3G, 4G, 5G, WiFi 5 and WiFi 6. The closing remarks were given in the conclusion, and the recommendations marked the end of the review.

Statement of Problem

The rapid advancement of communication technology has led to the obsolescence of certain systems, highlighting the need for a comprehensive understanding of

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

modulation techniques and their underlying enabling technology in communication systems, hence this study.

Objectives

The objectives of this study are to provide a comprehensive understanding of modulation techniques, their underlying enabling technology in communication systems, explore modulation techniques, subcarriers, and constellation points in communication systems, to shed light on the enabling technology in telephony and internet connectivity, and to examine different types of communication systems based on respective criteria, including analog and digital carriers, and their subdivisions.

CONCEPTUAL FRAMEWORK

Telecommunication refers to the method of communication in journalism, broadcasting, events, sports and so on, which involves communication in agreeable signs and language between one station or the other, or between one party or the other, or among individuals. Communication system involves the transmitting of signals from one station and receiving of same signal from another station through the use of modulation techniques and multicomplexing techniques. These techniques do help to compress the signals as much best possible in order to increase the tone, frequency, transmission, reception, as well as the efficiency of the waves so generated. The signal so generated from a source, will be transformed through the help of a transducer to electronic signal, which will be processed by a processor into a form that is easily accepted by a transmitter (Schwartz et al., 1996).

The transmitter will generate electromagnetic waves that will travel in space or medium within a range of bandwidth, with specific wavelength, so generating specific frequency definition in the transmission. The idea of modulation is compressing the signal while travelling in the form of a wave such that the transmission will be given high definition. A receiver transforms the waves into readable form as electronic signal in another transducer. This other transducer transforms the electronic signal into a signal familiar to the human ear (Schwartz et al., 1996). Communication system involves the analysis and synthesis of signals, sent from one or many sources to receivers at the other end through a mechanism. This mechanism is called modulation technique.

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

INTERNATIONAL JOURNAL – NSAR
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In the crossing of signal in media, there are many disturbances like attenuation, noise, distortion and so on, hence the urgency of modulation as a mechanism in order to alleviate disturbance and facilitate transmission. In a communication system, the transferring of information is called communication. The transmitter is used to send the information signal through a travelling medium to a station where a receiver receives the signal. The transducer is a device that help to transform the signal from one form of energy to the other; for instance, from the original message signal to electronic signal, whereas a processor conditions the signal into a form that is easily transmitted by a transmitter, or into a form that is easily received by the receiver (Rappaport, 1996).

The bandwidth describes the range of distance through which the signal is traveling; the signal could go through attenuation which is reducing in strength, or amplification which is increasing in the strength of the signal. Signal from original message has low amplitude and frequency, and so should be compressed into high frequency in order to facilitate transmission. This can be done by superimposing the original message on high frequency. This method of superimposing the message on high frequency is called MODULATION. Modulation is therefore the amplification of signal into high frequency. There are known modulations like phase modulation (PM), frequency modulation (FM) and amplitude modulation (AM) (Rappaport, 1996).

Types of Communication Systems

In the time line, down to the recent time, communication systems had witnessed remarkable evolution, from the simplest transmission scheme seen as physical infrastructure to the latest Hi-Tech transmission observed in sophisticated technology. The line communication system for instance, is a line infrastructure that transmits information in the form of a data, and so called a power line. The radio wave as another example is also transmitted from physical infrastructure. This means that there is a physical link in the form of hardwire for the transmission. The baseband Communication System uses very low frequency or near zero frequency for transmission, while transmission on very high frequency is called carrier wave communication system (Madhow, 2014).

The line communication system can tolerate long distances, carrier communication cannot tolerate long distances, except it is compressed by superimposing the transmission on high frequency. Carrier wave communication system is therefore transmission with modulation. The transmission of audio,

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

video and pictures through analogue signal explains the analogue communication system, unlike the digital communication system where information is sent via digital signal discreetly between two points. The transmission via digital signal usually gives the advantage of high definition over the transmission via analogue signal. The internet for instance, is a transmission through digital signal. In the description of communication system, pairing of concepts become common, such as line/carrier communication system or analogue/digital communication system (Yi et al., 2017).

On the wireless/wired paired-type of description for Communication System, the wireless described the waves within the range of radio and electromagnetic waves, usually found in ground wave, sky wave, space wave and satellite communication. The wired transmission involves passing the signals through wires like the optical fiber, twisted wire, coaxial wire and parallel wire for wired communication. There is a spectrum of the electromagnetic waves, which consists of different types of waves at different frequencies for the wireless transmission. The principle on which the wired Communication do work upon relies on the total internal reflection principle. The range of frequencies at which signals of the electromagnetic waves are transmitted through the wireless communications is called bandwidth (Otun, 2021).

Generally, there are three types of modulation; known in the early times when radio transmission was very common, which are the Amplitude Modulation (AM), Frequency Modulation (FM) and the Phase Modulation (PM). The AM transmission involves superimposing of high frequency on carrier waves, at the same time keeping the frequency constant, and where the FM transmission eliminates much noise as an advantage over the AM, the FM transmission involves varied frequency when modulated with carrier wave. In PM transmission, it is the phase that is varied when modulated with carrier wave, such that the phase-change (or phase-shift) is dependent on the frequency of the carrier wave, and by this being immuned to noise to a greater level than AM and FM transmission (Otun, 2021).

In the transmission of these waves, the transmitter plays the role of rearrangement of signals in the form that is easily transmitted or received, and the antennae radiate the electromagnetic waves or receive them at the receiving station. The channel is the physical medium as wire, cable, or even the space medium through which the wave is transmitted. The noise mentioned above is one in the trio of the impairments that happen during transmission; the other two are attenuation and distortion. Noise as a disturbance in transmission, can be caused

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

from external noise as a result of interference of other transmission, or it could be caused from internal noise, resulting from faulty conductor, electron disturbance, exposed cable or wire, and others. Attenuation is when the signal reduces in strength after transmission over a long distance, and distortion happens when the frequency and the bandwidth of the signal are different from the frequency and the bandwidth of the initial signal from the transmitter (Otung, 2021).

On the basis of transferring information from one party to the other, there are other recognized and defined types of communication systems. Optical Communication System involves the sending of light signal, radio communication system involves the sending of radio signal from the transmitter to the receiver at another end, and both the transmitter and the receiver having antennae. In duplex communication system, communications happen in both ways between the two parties simultaneously and at the same time (e.g. telephone). In half-duplex, the communication from one end stops for the communication to takes place at other end, and both do not take place at the same time (e.g. walkie talkies). In tactical communication system, communication varies with the environment and situation. In a nutshell, the transmission could be simplex as a point-to-point communication system from one transmitter to a receiver (e.g. telephony), or multiplex which is a broadcast communication system from one transmitter to several thousand receivers (e.g. radio and television) (Yi et al., 2021).

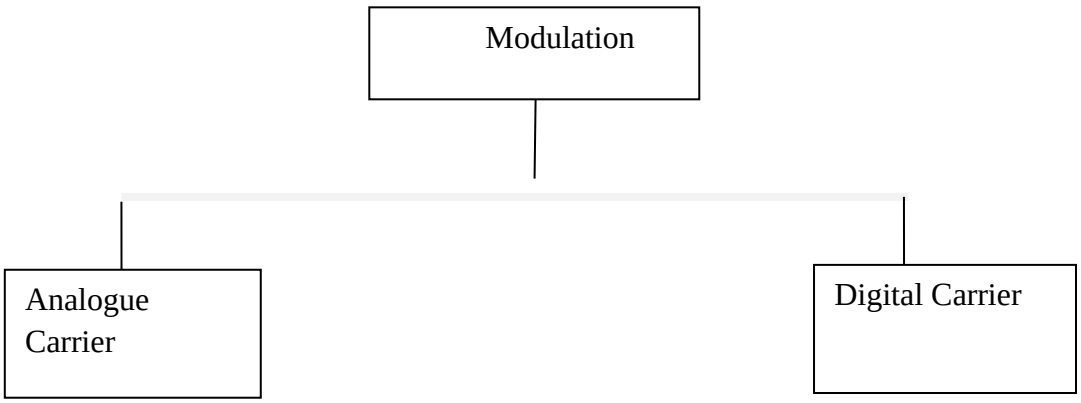
MODULATION TECHNIQUES

The best entry point to introduce the modulation techniques is to remind of AM, FM and PM modulations that they are analogue modulations. When these analogue modulations are initiated into digital forms, the modulation techniques are established. AM becomes Amplitude Shift Keying (ASK) when digitalized, FM becomes Frequency Shift Keying (FSK) when digitalized and PM becomes Phase Shift Keying (PSK) when digitalized. AM, FM and PM are analogue modulations; ASK, FSK and PSK are digital modulations. These digital modulations are the modulation techniques because techniques have been applied to transform the respective analogue modulations to their corresponding digital modulations (Peng et al., 2021).

The necessity of modulation is attached to efficient transmission over a long distance, to combine frequencies from baseband onto carrier wave and a suitable way to transmit low-frequency electromagnetic wave from antennae.

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

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In the analogue carrier classification, when analogue signals are modulated with the analogue carrier, the AM, FM, and the PM are produced. Modulating the digital signals on the analogue carrier will produce the ASK, FSK, PSK and the QAM. The modulating of analogue signal on the digital carrier will produce the pulse signals such as Pulse Amplitude Modulation (PAM), Pulse Width Modulation (PWM), Pulse Frequency Modulation (PFM) and Pulse Position Modulation (PPM); however, when the digital signal is modulated with digital carrier, Pulse Coding Modulation (PCM), Delta Modulation (DM) and Pulse Density Modulation (PDM) are produced. Pulse modulation scheme is aimed at transmitting at two-level signal called pulse wave, whereas On-Off Keying (OOK), a common form of ASK do help to transmit Morse Code at radio frequencies to produce Continuous Wave (CW). (Dobre et al., 2007).

Modulation Techniques in Transmission Schemes

3G

QPSK (Quadrature Phase Shift Keying) is the modulation principle used in the 3G mobile wireless telecommunication system. It allows signal to carry twice as much information that an ordinary Phase Shift Keying (PSK) can carry. The signal is combined with Radio Frequency (RF) carrier (Olusanya and Ogunseye, 2014).

4G

The 4G LTE combines the Quadrature Phase Shift Keying (QPSK) to the Quadrature Amplitude Modulation (QAM) to permit higher order of QAM, wider bandwidth and state-of-the-art antennae called MIMO to allow the LTE (i.e., the emerging LONG TERM EVOLUTION technology) a higher rate of data transfer. On the

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

Multicomplexing order, Orthogonal Frequency Division Multicomplexing (OFDM) is the general transmission scheme, whereby the whole of the bandwidth of 20 MHz is divided into 15 kHz subcarriers, and a digital modulation technique is applied to each subcarrier (Wang et al., 2017).

5G

The 5G is the fifth generation of the mobile network, after 1G, 2G, 3G and 4G. It is meant to connect to everyone, and everything, including objects, devices and machines. The speed is extremely very high in Gbps, carrying very large information within split of seconds, having low latency, and very efficient. Comparing the 5G to the other generations of mobile network, the 1G had the analogue voice in the 1980s, the 2G had the digital voice in the 1990s, the 3G added to the mobile data in the 2000s, the 4G introduced the mobile broadbands in the 2010s, and most recently, the 5G is meant to touch everyone and everything digitally, in order to prepare the next generation for a digitalized world (Ke-Lin and Swamy, 2010).

Orthogonal Frequency Division Multicomplexing (OFDM) is the efficient modulation technique in 5G that combines the Quadrature Amplitude Modulation (QAM) and the Frequency Amplitude Modulation (FAD) as subcarriers to increase the capacity for data carriage and transfer at extremely very high rate (Banelli et al., 2014).

WiFi 5

Wi-Fi 5 is the fifth generation of the wireless networking protocol and is also known by its Institute of Electrical and Electronics Engineers (IEEE) standard name of 802.11ac. It was introduced in 2014 and brought several improvements over Wi-Fi 4 or 802.11n, including support for data rates that exceed one gigabit.

It is the wireless transmission that operate within the band of 5 GHz, and this is to ensure that it is less prone to the interference of the many transmissions that takes place within the 2.4 GHz band. It makes use of multi-user MIMO (superior antennae) technology and efficient signal modulation. In WiFi 5, the Orthogonal Frequency Division-Multiple Access (OFDMA) is the modulation technique, and the subcarriers are Phase Shifting Keying (PSK) and the Quadrature Amplitude Modulation (QAM) in their various constellation points. The constellation points are QPSK and BPSK in the PSK order; and in the QAM order there are the 16 QAM to 1024 QAM. These modulation standards are radio linked by the algorithm Fast

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

Fourier Transforms (FFT) to internet connectivity in any suitable connecting device (Yu et al., 2014).

WiFi 6

Wi-Fi 6 or 802.11ax is the sixth generation of Wi-Fi and a direct successor to Wi-Fi 5. Introduced in 2020, it builds upon Wi-Fi 5 by enhancing its total throughput to better deal with the increasing number of wireless devices in homes and corporate offices, including IoT products like smart home gear.

It is the most recent WiFi network protocol, it still does the work of internet connectivity, only that it has been more upgraded than its predecessor (i.e. the WiFi 5). WiFi 6 (better known as 802.11ax) has remarkable speed and less bandwidth congestion than WiFi 5 (also known as 802.11ac). Target Wake Time is the feature that WiFi 6 allows to schedule communications with devices and routers on internet connectivity. In the WiFi 6, the modulation scheme moves from 256-QAM to 1024-QAM as subcarrier of the Orthogonal Frequency Division-Multiple Access (OFDMA) (Weller et al., 2020).

Major Difference between 5G and Previous Technologies

Each generation of wireless broadband is classified based on a set of telephone network standards that describe the technological implementation of the system. Under this classification system, 2G refers to the second generation of mobile networks based on GSM – the Global System for Mobile, an international standard for mobile phones. Radio signals used under the first generation or 1G network were analog, while 2G networks were digital. By allowing multiple users on a single channel via multiplexing, 2G networks enabled cellular phones to work with both data and voice. From a frequency perspective, 2G and 5G refer to the 2.4GHz and 5GHz (gigahertz) wireless frequencies, respectively. And the main differences between the two frequencies lie in the range (i.e., coverage) and bandwidth (i.e., speed) that the bands provide. Note that 5GHz Wi-Fi is not 5G cellular, which utilizes the rarely used radio millimeter bands in the 30GHz to 300GHz range. 5GHz Wi-Fi is a short- range home networking system that operates in the 5GHz radio band. The third generation or 3G standard uses the Universal Mobile Telecommunications System (UMTS) as its core network architecture, and the Wide Band Wireless Network to increase clarity. Strictly speaking, this particular comparison should really be couched as 5G vs 4G LTE, because a true 4G network has actually yet to operate. "Fourth Generation" or 4G is a specification laid down

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

by the International Telecommunications Union (ITU) in 2008. The performance criteria set out for this new generation were significantly higher than those for 3G – so high, in fact, that equipment manufacturers and network providers have been unable to meet them in full. Latency is another characteristic in which 5G displays a significant edge over its 4G LTE predecessor. Latency is a measure of the time it takes for information sent from a device to be usable by the receiver. Expressed in milliseconds, latency is low for 4G (typically in the tens and 20s), but 5G is set to reduce it to virtually zero, with 1 millisecond of latency required for the official standard.

Similarities between Wi-Fi 6 and Wi-Fi 5

There are a lot of similarities between both Wi-Fi generations. That said, Wi-Fi 6 brings improved versions of several Wi-Fi 5 technologies, allowing it to serve modern wireless networking needs better. Some of the most significant differences between the two Wi-Fi generations lie in their ability to connect to a large number of devices, use of wireless frequency bands, ability to transfer or receive multiple streams of data, data speed, and MIMO support. One of the highlights of Wi-Fi 6 is OFDMA technology. It's a variant of the OFDM (orthogonal frequency-division multiplexing) technology present in Wi-Fi 5. OFDMA helps Wi-Fi 6 with efficient data encoding and better use of the wireless spectrum by allowing up to 30 clients to share a channel simultaneously. Thanks to this upgrade, Wi-Fi 6 routers can better handle network congestion caused by multiple simultaneous requests from connected devices and with lower latency. In comparison, OFDM can only connect to one device per channel. Therefore, it's not as efficient at handling simultaneous requests and can't reliably serve a large number of connected devices.

Another Wi-Fi 6 feature that makes a real-world difference is the support for eight spatial streams. Compared to Wi-Fi 5's typical four and potentially (but rare) eight spatial streams, Wi-Fi 6 APs can consistently offer eight spatial streams. These streams are essentially data lanes, and more data lanes result in faster data speeds.

Speeds Comparism of Wifi 6 and Wifi5

Combined with the dual frequency band support, OFDMA and more spatial streams help Wi-Fi 6 deliver a potential maximum data rate of 9.6Gbps. On the other hand, Wi-Fi 5 topped out at 6.9Gbps. That said, neither Wi-Fi generation can

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

reach their theoretical maximum data rates in real-world usage. But you'll undoubtedly get a considerably faster data rate with Wi-Fi 6 than with Wi-Fi 5.
Additionally, the improved implementation of MU-MIMO in Wi-Fi 6 supports both uplink MU-MIMO and downlink MU-MIMO. Meaning any Wi-Fi 6 access point can both transmit to and receive data from multiple devices at the same time. As a result, Wi-Fi 6 can offer enhanced speeds and cater to multiple devices seamlessly. Wi-Fi 5, on the other hand, only supports downlink MU-MIMO.
Finally, the BSS Color feature of Wi-Fi 6 marks frames from your neighbor's router so that your router can ignore them and the interference caused by them. This makes Wi-Fi 6 routers more efficient in apartments and other settings with many wireless routers in a smaller area.

CONCLUSION

Modulation is a vital process in communication systems that involves varying the properties of a carrier signal with a separate modulation signal to transmit information. With the rapid advancement of communication technology, it is crucial to have a comprehensive understanding of modulation techniques and their underlying enabling technology. This article has explored various aspects of modulation, including modulation techniques, subcarriers, and constellation points. It discussed different types of communication systems based on criteria such as analog and digital carriers, as well as their subdivisions. It delved into modulation techniques such as AM, FM, PM, ASK, FSK, PSK, and QAM, both in their analogue and digital forms. Additionally, it provided an overview of the enabling technology in telephony and internet connectivity, specifically in 3G, 4G, 5G, WiFi 5, and WiFi 6.
Understanding modulation techniques is crucial for efficient transmission over long distances and improving signal quality in the presence of noise, attenuation, and distortion. The modulation process allows signals to be compressed, transmitted, and received with higher fidelity and efficiency. Different modulation techniques have been developed to suit specific communication needs and technologies.
As communication technology continues to evolve, staying updated with modulation techniques and enabling technologies will be essential for optimizing communication systems and ensuring reliable and high-quality information transmission.

RECOMMENDATIONS

1. Public lectures are needed to enlighten about the understanding of mechanism behind communication system.

EDITOR-IN-CHIEF
Prof. E. Mclenna [Australia]

2. The basic signals of transmission should be investigated upon to examine the health impacts on short-term and long-term bases.
3. General acceptability of the 5G should be necessitated by massive public awareness.
4. Modulation techniques and communication systems involve a wide range of disciplines, including engineering, telecommunications, computer science, and more. There is need to encourage interdisciplinary collaboration among experts from different fields to foster innovation and lead to breakthroughs in modulation techniques.

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EDITOR-IN-CHIEF
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