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Principles of Digital Communication

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1 Contents

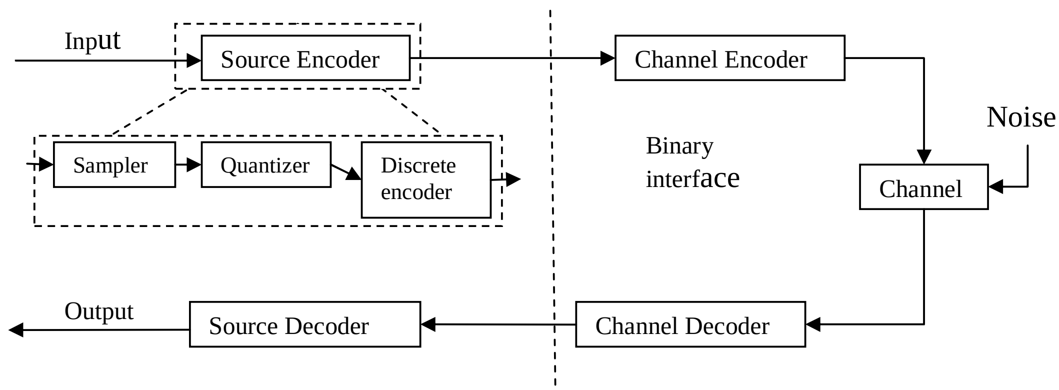
4 Principles of Digital Communications

4.1 Introduction

The purpose of this chapter is to explain the concepts that are widely referred to in the later chapters of Wi-Fi, WiMAX and Long-Term Evolution (LTE).

Wireless spectrum is a finite resource. The only way to increase data throughput is to find ways to use spectrum more effectively – This is called Spectral Efficiency.

4.2 Binary Interface



Source [401], Separation of source and channel coding

For the purposes of this report we are particularly interested in what happens to the right hand side vertical dotted line in the figure above, the Binary Interface.

As far as Wi-Fi, WiMAX and LTE are concerned, the "channels" are wireless and the objective is that whatever is sent to the channel encoder is what comes out of the channel decoder. To add to this challenge, with each progressing year we want to improve the spectral efficiency and send data ever faster.

To use the "channel", data needs to be converted into a form that is appropriate for the channel – i.e. we have to modulate our digital data onto an analogue carrier for the channel. What we are particularly interested in is how we can efficiently transmit as much data as possible.

4.3 Modulation techniques

4.3.1 Introduction

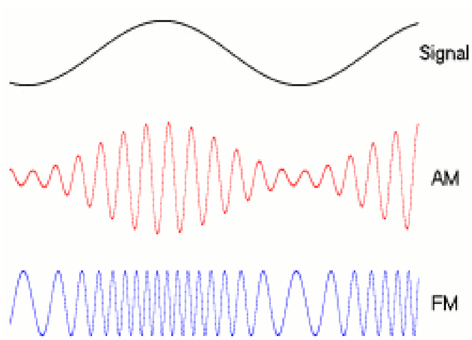
Modulation is the process of varying the high frequency carrier wave that is appropriate for the channel in such a way that it transports our binary data.

4.3.2 Amplitude Modulation (AM)

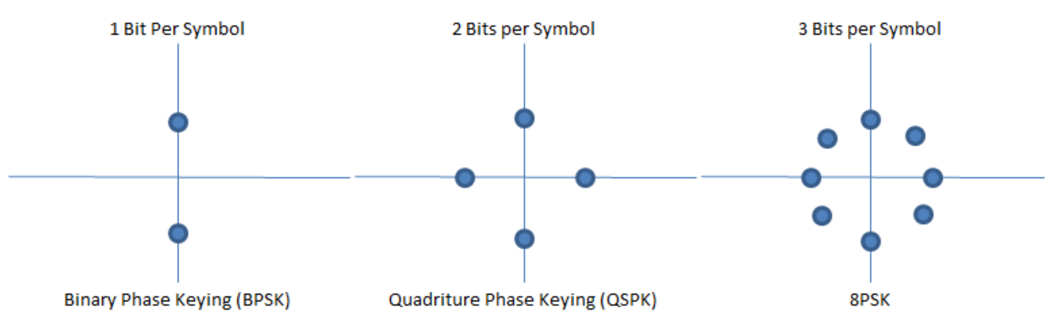
Amplitude Modulation varies the amplitude depending on whether a “1” or “0” is being sent.

4.3.3 Frequency Modulation (FM)

Frequency Modulation uses varying frequencies in relation to the information being sent. Below is a diagram showing AM and FM.

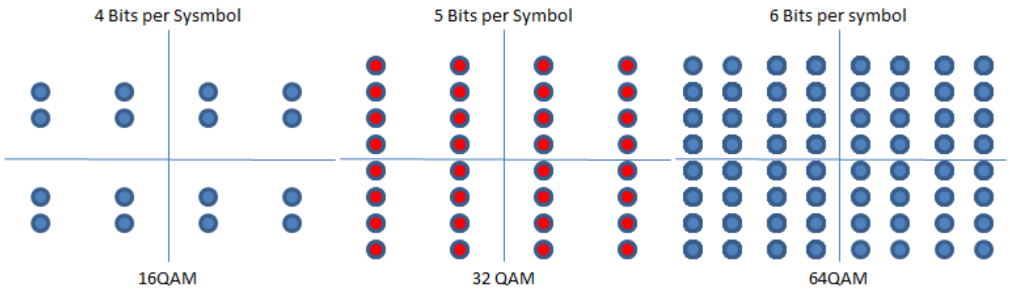


4.3.4 Phase Modulation



In phase modulation, the carrier phase is altered. In BPSK, it is modified by +/- 180 to represent a zero or one. The aim of a Communications Engineer is to transfer data as efficiently as possible. In QPSK, 00,01,10,11 are represented by modifying the carrier by +0, +90, +180, +270. In 8PSK 000,001,010,011,100,101,110,111is represented by carrier shifts of +0, +45, +90,+135,+180, +225, +270,+315. The more granular the angle shift, the more data that can be sent per symbol. However, the channel decoder finds it more difficult to discriminate especially when there is noise on the channel.

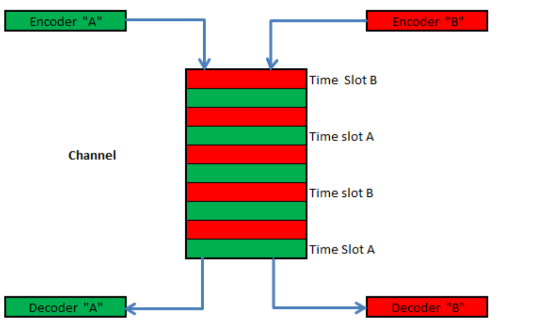
4.3.5 QAM



In QAM, two physical properties of the wave are varied, amplitude and phase. It can be considered as a mixture of amplitude and phase modulation. The goal is to achieve ever higher spectral efficiency. 16QAM delivers 4 bits per symbol, 64QAM delivers 6 bits per symbol and 256QAM would deliver 8 bits per symbol.

4.4 Multiplexing

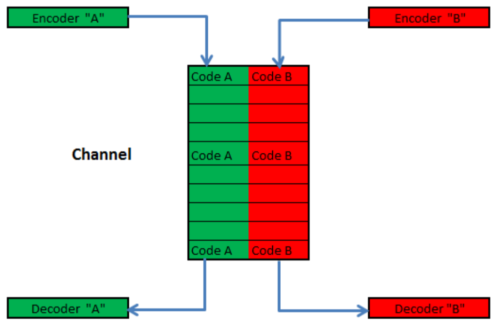
4.4.1 Time Division Multiplexing



Time Division Multiplexing

In time division multiplexing, the capacity of the channel is higher than what has been allocated to encoder A or B. Each encoder is allocated a time slot in which to transmit. The decoders only accept information in their respective time slots.

4.4.2 Code Division Multiplexing

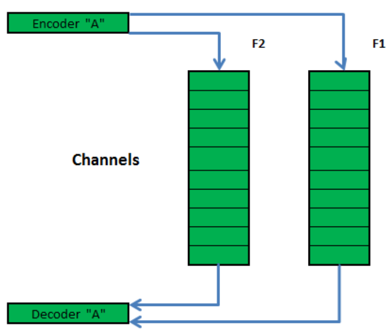


Code Division Multiplexing

In code division multiplexing, the channel again is larger than the service that has been allocated to either encoder A or B. Each encoder encodes its messages with a code. The receiving decoders only decode the messages that they have the key for. They treat the other messages as noise and discard them.

4.4.3 Spatial Multiplexing

4.4.4 Frequency Division Multiplexing



Frequency Division Multiplexing

In frequency and spatial multiplexing, the allocation of bandwidth to the encoder is more than can be handled by one channel. In frequency multiplexing, additional channels are added at different frequencies i.e. F1 and F2. The encoder splits its data between the two channels and the decoder reassembles the data at the other end.

In Spatial multiplexing, additional spatial streams are added to achieve the same effect.

In noisy or poor signal environments the same information can be sent down both channels. This improves the signal to noise ratio. The decoder can compare the messages that were sent down both channels and it has a better chance of assembling the data correctly.

4.4.5 TDD and FDD

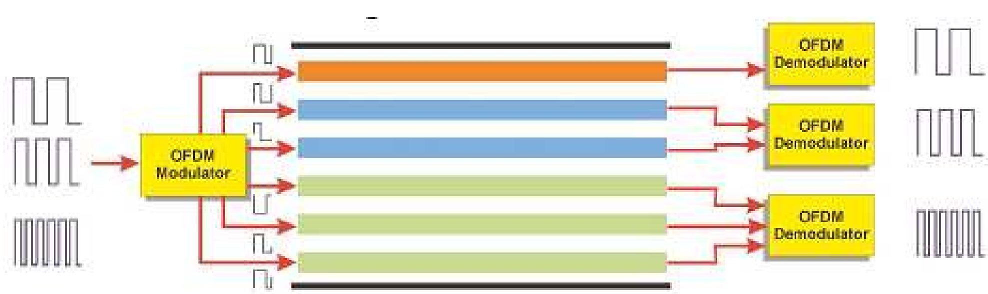
In time division duplex, the channel is divided into downlink and uplink time slots. These time slots do not have to be equal (i.e. if you expect more downlink traffic you could allocate a higher proportion of the time slots to the downlink traffic.

Frequency Division Duplex is when channel frequencies are divided between downlink and uplink traffic. Here again, the frequency bandwidth does not have to be allocated symmetrically. If more downlink traffic is expected a larger portion of the bandwidth can be allocated to it.

4.4.6 OFDM

Orthogonal Frequency Division Multiplexing is frequency division multiplexing where the total bandwidth has been divided into sub-carriers which are placed very closely together at ninety degree phase shift (hence the name orthogonal).

4.4.7 OFDMA



Source [404] OFDMA

Orthogonal Frequency Division Multiple Access is the process of dividing a radio carrier channel into several independent sub-carrier channels that are shared between simultaneous users. The OFDMA system dynamically allocates sub carrier channels or groups of sub channels to users. The data rates provided to each user depends on the number of sub carriers that are allocated to that user.

4.5 Noise and probability

4.5.1 Gaussian noise

The bane of all communication engineers is noise. Without noise, engineers could modulate at ever higher and higher QAM achieving eventually, an infinite number of bits per symbol. However with noise, it is impossible for the decoder to discriminate between minor changes in phase and amplitude.

Gaussian noise is noise which has a probability density of a normal distribution. White Gaussian noise is present at all frequencies at equal power amplitude.

4.5.2 Error Detection and Correction

The challenge of transmitting data is that the channel is subject to noise and interference so the data may get corrupted while it is being transmitted. In order to detect errors, the source encoder may transfer extra bits of data so that the decoder can use probability to work out what the correct data is. In the example below, triplets are sent.

Triplet Received	Interpreted As
000	0 (no errors)
001	0
010	0
100	0
111	1 (no errors)
110	1
101	1
011	1

Source [1] Forward Error Correction

Obviously, this is quite wasteful of bandwidth and there is no actual guarantee that 010 is 0. It only has a 67% probability that it is zero. Alternatively, the receiver can ask for the data to be retransmitted to have further confirmation of the actual values.

4.6 Conclusion

This chapter is only an introduction to the principles of Digital Communications. Its aim is to cover just enough material to make the comprehension of the subsequent chapters on Wi-Fi, WiMAX and LTE easier.

Communication engineers are always battling to achieve ever higher spectral efficiency by using higher order modulation techniques but they have to balance this with ensuring that data quality at the receiving node is high by sending extra correction data bits or at worst asking for the data to be re-transmitted at a lower order of modulation.

In the experiments carried out under “Wi-Fi, section 5.3.4 Modulation and Performance”, we demonstrate that the Wireless Access Point and the Laptop are communicating at 64QAM, with Forward Error Correction (FEC) of 5/6 and the communication channel is using one spatial stream. If the signal quality were to drop, it would reduce the order of modulation to for example, 16QAM or even to QPSK and increase the ratio of error detection bits i.e. FEC of 1/2.

4.7 References - Principles of Digital Communication

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