ICWMC/MAAZE: Wireless Communications: The March Towards Absolute Zero Editorial

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At the outset, everyone must be surprised at the strange title of this session: "march towards absolute zero". Rest assured, we are not going towards zero degrees Kelvin (or minus 273 degrees Celsius), rather we need to approach zero decibels (dB) signal-to-noise ratio (SNR) per bit (or E_b/N_0), with an arbitrarily low bit-error-rate (BER) when communicating over wireless channels. While it is well known that for additive white Gaussian noise (AWGN) channels (or distortionless channels) the minimum E_b/N_0 for error-free communication is -1.6 dB, it is not known that the same is true for wireless channels as well. Surprisingly, the SNR per bit has not been used as a performance measure in the context of wireless communications. Therefore, we begin this session with an open question: *What is the operating SNR per bit of the present day mobile phones*? Since there is no answer to this question in the open literature, instead of doing the customary "literature survey" to know the state-of-the-art on the subject of the fifth generation wireless communication systems or simply 5G[1] (which is supposed to arrive by the year 2020), we shall directly proceed to state our contributions. However, before we state our contributions, it may be prudent to know what this fuss is all about.

The science (call it art if you like) of communication involves conveying information from a source to the destination. The information can be voice, video or data. This information is converted to an electrical signal by a transmitter which is sent over a wireless channel to the receiver, which converts the electrical signal back to voice, video or data and delivers it to the destination. The transmitter, receiver and the wireless medium together constitute a communication system. The main objectives of a communication system are to:

1) maximize the bit-rate (the rate at which the information is transmitted) – this is the main aim of 5G, which hopes to achieve peak data rates of 1 gigabits per second for each user, with the help of a large number of transmit and receive antennas (also known as massive multiple input multiple output (MIMO)),
2) minimize the BER,
3) minimize the transmission bandwidth,
4) minimize the transmit power.

Note that items (1) and (3) are conflicting requirements.

Typically, many transmitters and receivers exchange information over the same wireless medium or the channel[2]. Therefore, each of the receivers must have a mechanism to extract the desired information from the combined signal. This concept is known as multiple access (MA). Clearly, the interference from undesired transmitters (multiple access interference or MAI) has to be minimized. The various multiple access techniques are time division (TDMA), frequency division (FDMA), code division (CDMA) and interleave division (IDMA).

It is also possible for the information source and destination to transmit and receive information simultaneously. In other words, information travels in both directions simultaneously. This is known as full duplex communication. The common example is frequency division duplex (FDD). On the other hand, in half duplex communication, information can travel in only one direction at a time, e.g. walkie-talkie, where one has to push a button to speak or time division duplex (TDD).

Communication channels can be classified as:

1) time-invariant e.g. telephone lines, Ethernet
2) time-variant e.g. wireless channels.

Communication channels can also be classified as:

1) distortionless or frequency flat, that is, the channel impulse response is a Dirac-delta function
2) introduces distortion or frequency selective, that is, the channel impulse response is not a Dirac-delta function. A distorting channel introduces intersymbol interference (ISI).

The transmitted signal travels through the channel and reaches the receiver. The received signal is the convolution of the transmit signal and the channel impulse response. There may be additional impairments in the received signal, like carrier frequency offset (CFO) and noise. Note that the carrier is just the sinusoidal modulating signal. The carrier frequency offset

[1]Actually the literature associated even with a very recent topic like 5G is quite vast. This is probably because in the early days, papers used to be published by people who made inventions or discoveries, hence they had a few papers in their lifetime. These days, everyone is expected to publish several papers in one year. This is a typical example of "Too many cooks spoil the broth".

[2]It is assumed that the wireless medium or channel adds the signals from all the transmitters.

or the Doppler shift, in Hertz, is usually caused by the relative motion between the transmitter and the receiver. In the context of multicarrier communications, CFO introduces intercarrier interference (ICI). There is also a clock frequency offset or timing offset (TO), which is a function of the clock accuracy, since the transmitter and receiver clocks are not synchronized. The clock accuracy is usually measured in parts per million (ppm). For example, a 10 ppm clock accuracy implies that if the nominal clock frequency is 1 MHz, its actual frequency may lie anywhere in the range $[10^6 - 10, 10^6 + 10]$ Hz. This also implies that a bit or symbol may be lost or gained every $\rho = 10^6/10 = 10^5$ bits or symbols. A timing phase offset (TPO) is caused by the propagation delay, which is the time taken for the signal to propagate from the transmitter to the receiver. Due to the presence of a TPO and TO, the bit or symbol boundaries need to be estimated and tracked at the receiver.

The task of the receiver is to optimally recover the information from the received signal such that the BER is minimized. It is possible for the transmitter to compensate for the distortion introduced by a frequency selective channel, which is called precoding. It is also possible to introduce error control coding or forward error correction (FEC) in the transmitter to reduce the BER. In the case of a coherent receiver, the channel impulse response (also called the channel state information or CSI), CFO[3] and the TPO need to be accurately estimated, with the help of training or pilot signals. When the number of bits or symbols transmitted is much less than ρ, the effects of TO may be neglected, and the bit or symbol boundaries need not be tracked. In the case of noncoherent receivers, it may not be necessary to estimate the CSI and CFO. However, in some situations, the statistics of the channel impulse response may be required, like the mean and the autocovariance functions. This is known as the channel distribution information or CDI.

Now, research in telecommunications engineering usually proceeds as follows. Assuming one set of parameters are known, estimate or optimize some other parameter[4]. The parameters may be the bit-rate, BER, transmit power, transmit bandwidth, ISI, ICI, MAI, CSI, CDI, CFO, TO, TPO, FEC, training signal and so on, along with a liberal dosage of mathematics[5]. Hardly ever do authors deal with end-to-end simulation of communication systems, starting from the transmitter to the receiver, where all the relevant parameters are estimated from training signals. This is the void which this session hopes to fill. We deal exclusively with orthogonal frequency division multiplexed (OFDM) signals, which converts a frequency selective channel into a frequency flat channel, and is used in 3G/4G wireless systems.

The first paper of this session deals with a data aided timing synchronization scheme for OFDM signals. The algorithm uses multiple preambles for initial (coarse) timing estimation, and works in the time domain. A timing estimation method using one preamble is proposed, which is independent of the structure of the preamble, and works better than the other existing methods in the presence of CFO. The performance is compared in terms of probability of erasure, probability of correct estimation and mean squared error (MSE) with the existing timing synchronization methods for OFDM systems.

CFO in OFDM systems can be divided in two parts, the fractional part (FFO) and the integer part (IFO). In the second paper, four different data aided fractional frequency offset (FFO) synchronization methods for OFDM systems are proposed. The algorithms work in the time domain. An independent Rayleigh fading multipath channel in the presence of AWGN is considered. The performance is compared in terms of mean squared error (MSE) of the frequency offset estimation and computational complexity, with the existing fractional frequency offset synchronization methods.

Finally, in the third paper, the minimum average signal-to-noise ratio (SNR) per bit required for error-free transmission over a fading channel is derived, and is shown to be equal to that of the additive white Gaussian noise (AWGN) channel, which is -1.6 dB. Discrete-time algorithms are presented for timing, CFO and CSI estimation, for MIMO-OFDM systems. The algorithms can be implemented on programmable hardware and there is a large scope for parallel processing. Simulations results for a 2×2 turbo coded MIMO OFDM system indicate that a BER of 10^{-5}, is obtained at an SNR per bit of just 5.5 dB, which is a 2.5 dB improvement over the performance given in the literature.

[3]Note that the carrier phase may be absorbed into the channel impulse response.

[4]There is an old story about an exam with three questions concerning the formula $\omega = 2\pi f$. The first question was, given π and f find out ω. The second question was, given π and ω, find out f. Finally the third question was (no marks for guessing), given ω and f, find out π.

[5]Information theory is a branch of telecommunications engineering that is famous for its mathematics.