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The Modeling of MEMO Technology and Power Management for IEEE 802.11n: Software Simulation

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Abstract

The application of Wireless Local Area Networks (WLANs) has increased noticeably over recent years and they have been deployed in various locations such as homes, schools, airports, and many other venues. The rationale behind this increased use is the freedom that wireless communications provide and the decreasing costs of the underlying technology. However, with the increased deployment of wireless networks, many additional technical issues have arisen. One of the most important issues is throughput or speed. The main goal of this paper was to investigate and evaluate the next generation of wireless local area network standard, IEEE 802.11n, and compare it with the existing standards IEEE 802.11a, b, and g. The investigation was done to demonstrate the new techniques that have been used to achieve high system performance and reliability compared with legacy standards, and how this new technique plays a key role in the next WLAN generation. To achieve this aim, Maltlab simulation has been used to simulate the system and to obtain numerical evaluations such as bit error rate plots.

The IEEE 802.11n standard utilizes MIMO (Multiple Input Multiple Output) technology, which increases the data rate since multiple streams of data can be sent and received simultaneously. Moreover, many different modulation techniques can be used to implement the IEEE 802.11n standard, such as binary phase shift keying (BPSK), Quadrature phase-shift keying (QPSK),16- Quadrature amplitude modulation (16-QAM), and 64-Quadrature amplitude modulation (64-QAM).

Keywords: IEEE802.11n, wireless network modeling, software Simulation, MIMO Technology, wireless power management

Introduction

Rationale and Background

The growing acceptance and utilization of Wireless Technology has seen its use expand beyond PC-PC communication into other consumer products and applications. The benefits of wireless LANs include convenience, mobility, productivity, deployment, expandability, and cost have driven the industry to extend the technology beyond the Personal Computer and into consumer electronics applications like Internet telephony, music streaming, gaming, and even photo viewing and in-home video transmission. Yet, the growing numbers of WLAN users and the increasing number of applications that take advantage of WLAN, mean that existing Wi-Fi networks are becoming increasingly strained. However, a solution to this increasing Wi-Fi demand may shortly be available.

The industry has agreed on the components that will make up IEEE 802.11n promises both higher data rates and increased reliability. However, wireless LAN technology has its share of downfalls. It may not be desirable for several reasons such as security, reliability, range, and speed.

Some of the greatest benefits of the new IEEE 802.11n standard over previous generations are the improvements made in data transmission rates, network coverage, backward compatibility, and reduced latency. IEEE 802.11n has significantly increased the throughput from 11 or 54Mbps based upon IEEE 802.11a/b/g standards, to more than 400Mbps. However, with multiple antennas, the energy consumption is greater than the previous standards. Therefore it will be necessary to use energy reduction methods to deploy the next-generation Wi-Fi associated with mobile devices, which are already widely used and are still expected to show a marked increase in utilization.

The motivation for this investigation was to introduce how the benefits of the IEEE 802.11n standard are achieved by using simulations.

The purpose of this paper is to measure the effect of MIMO technology and the power management for IEEE802.11n in term of system performance.

Literature Review

The IEEE 802.11 Family

Introduced by the IEEE in 1997, IEEE 802.11 standard was the first WLAN standard accepted by multiple vendors as a true industry standard [1].The IEEE802.11 standards provide the rules that manufacturers of communication products should follow when developing products to ensure that they are compatible with other WiFi devices that use the same standard. The standard itself provides information on physical (PHY) and medium access control (MAC) specifications, these would include allowed carrier frequencies or medium access protocol for data transmission. A throughput of 1-2 Mbps (1 Mbps= 1*10^6 bits / second) was first specified in the IEEE 802.11 standards to be transmitted via infrared signals or transmission was via radio signal using the Industrial Scientific Medical (ISM) frequency of 2.4 GHz. Two different physical layer methods were supported by IEEE 802.11: (1) Direct Sequence Spread Spectrum DSSS and (2) Frequency Hopping Spread Spectrum (FHSS). However, these two methods meant that equipment was often incompatible if they used different physical platforms. At the same time, IEEE 802.11 generated collision problems as well as generating signals that would reflect due to surfaces such as walls [2]. Due to these problems, the IEEE introduced a series of modified IEEE 802.11 standards to address the problems associated with the original standard. All the subsequent WLAN standards allowed for multiple transmission options. This meant that the network could drop to lower, easier to maintain data rates as there were changes in communication performance due to environmental interference. In optimal situations the IEEE 802.11a and IEEE 802.11b could support data rates up to 54 Mbps and 11 Mbps respectively [1] [3].

IEEE 802.11n

The IEEE802.11n specification is different from its predecessors by providing for a variety of optional modes and configurations that will determine different maximum raw data rates. This enables the standard to provide baseline performance parameters for all IEEE802.11n devices. At the same time, the standard allows manufacturers to enhance or tune capabilities to accommodate different applications and marketing requirements. When every possible option is enabled, the IEEE802.11n device could offer raw data rates up to 600 Mbps. However, WLAN hardware need not support every option to be compliant with the standard. Thus the majority of WLAN hardware using the standard are expected to support raw data rates up to 300 Mbps [4] [5].

The modulation scheme for the standard is Multiple Input Multiple Output-OFDM (MIMO-OFDM). Multiple Input Multiple Output is a generic term for systems that use multiple transmit and multiple receive antennas. The data rate of IEEE802.11n is proposed to reach a theoretical 600 Mbps, which is noted to be more than 54 times faster than IEEE. Table (1) below shows the differences among the primary IEEE 802.11 specifications in terms of data rate, modulation scheme utilized, and channel width [6] [7].

Table 1 IEEE 802.11a,b,g,n Specifications [8]

	802.11a	**802.11b**	**802.11g**	**802.11n**
Maximum Data Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps
Modulation	OFDM	DSSS or CCK	DSSS or CCK or OFDM	DSSS or CCK or OFDM
RF Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5GHz
No of Spatial Streams	1	1	1	1,2,3 or 4
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation (QAM) is a digital modulation technique that maps binary information to complex signals to communicate efficiently over a physical channel. A set of bits will define a complex signal, called a QAM symbol, which is to be sent by the transmitter. There are different forms of this modulation defined by M-QAM, where M is usually a power of 2. The case of

16 QAM will suffice to explain the technique. Since M=16 in this case, and $16=2^4$, 4 binary bits will map to 1 16-QAM symbol [9].

Figure 2 shows a block diagram of a QAM transmitter and receiver, which is not exactly as implemented in the IEEE 802.11n standard, but it shows how the binary data can be mapped to complex signals

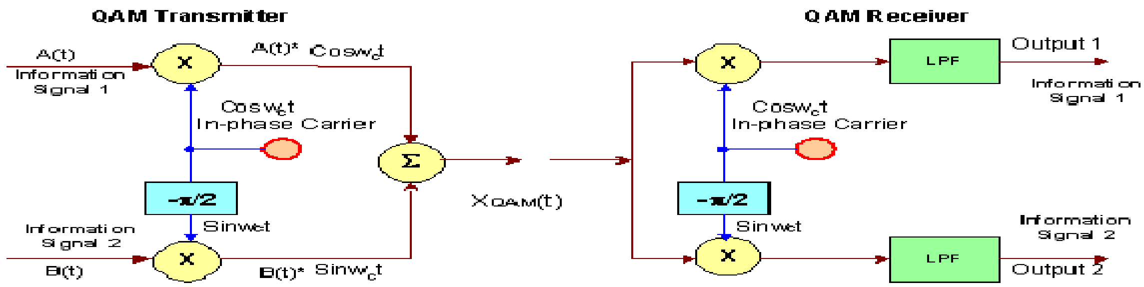

Figure 1 QAM Transmitter and Receiver [10]

The encoding of the binary data with Gray's encoding is important because adjacent symbols in the constellation only differ by inverting 1 bit. This helps to minimize bit errors in the detection process.

The amount of separation between symbols is inversely proportional to the probability of incorrect detection. That is to say the further the symbols, in a Euclidean distance sense, the more likely the receiver can interpret them correctly. For higher-order QAM systems, the transmitter can send more bits per symbol, 256 QAM sends 8 bits per symbol for example. Nevertheless, if the expected energy of the signal is constant, then a 256 QAM system will encounter more detection errors than a 16 QAM system for a given signal-to-noise ratio (SNR) [10], [11].

Orthogonal frequency division multiplexing (OFDM)

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier transmission technique that has been recently recognized as an excellent method for high speed bi-directional wireless data communication. Its history dates back to the 1960s, but it has recently become popular because economical integrated circuits that can perform the high speed digital operations necessary have become available. OFDM effectively squeezes multiple modulated carriers tightly together, reducing the required bandwidth but keeping the modulated signals orthogonal so they do not interfere with each other. Today, the technology is used in such systems as asymmetric digital subscriber line (ADSL) as well as wireless systems such as IEEE 802.11a/g (Wi-Fi) and IEEE 802.16 (**W**orldwide Interoperability for Microwave Access -WiMAX). It is also used for wireless digital audio and video broadcasting [12].

It is based on frequency division multiplexing (FDM), which is a technology that uses multiple frequencies to simultaneously transmit multiple signals in parallel. Each signal has its own frequency range (subcarrier) which is then modulated by data. Each sub-carrier is separated by a guard band to ensure that they do not overlap. These sub-carriers are then demodulated at the receiver by using filters to separate the bands [13].

Figure 2 FDM spectrum source [13]

Multi-Input-Multi-Output MIMO

Multiple-input and multiple-output, or MIMO, is the use of multiple antennas at both at the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna (SA). MIMO technology has attracted attention in wireless communications since it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per Hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is a current theme of international wireless research. A key feature of MIMO systems is the ability to turn multipath propagation, traditionally a pitfall of wireless transmission, into a benefit for the user. MIMO effectively takes advantage of random fading and when available, multipath delay spread for multiplying transfer rates [15], [16]

IEEE 802.11n with MIMO

As I have mentioned before the basic idea of MIMO system is that the same information can be transmitted from multiple transmit antennas and received at multiple receive antennas simultaneously. Since the fading for each link between a pair of transmit and receive antennas can be usually considered to be independent, the probability that the information is detected accurately is increased

The IEEE 802.11n relies on MIMO technology to improve performance. The use of multiple antennas at the transmitter and receiver proves useful in signal detection, increases throughput, and takes advantage of spatial dimensions. With N antennas, the transfer rate can be increased N times theoretically. Traditional Single Input Single Output (SISO) systems are designed to transmit signals, given the conditions of the channel. These systems combat multi-pathing by using cyclic extensions, or propend irrelevant data to a symbol, such that ISI doesn't degrade the relevant data. They also use equalizers to increase the reliability of transmission by applying gains to the signal where it was most corrupted. However, these techniques are utilised to minimise the degrading effects on a signal due to the channel, rather than considering the channel conditions and optimizing the transmission technique [16].

Spatial Division Multiplexing (SDM)

Spatial division multiplexing (SDM) techniques increases the total throughput by transmitting independent information streams through multiple transmit antennas. Another definition of spatial multiplexing is that is proprietary transmission technology developed by Stanford University and Iospan Wireless in California exploiting multiple antennas at both the transmitter and the receiver to dramatically increase the bit rate in a wireless radio link with no additional power or bandwidth consumption. Under certain conditions, SDM offers linear increase in spectrum efficiency with the number of antennas [17].

From figure 10, and In LOS situations, the performance of SDM is controlled by amount of physical spacing between the antennas on transmit and on receive and the distance R between the transmitter and the receiver. In multipath environments, the scattering radius around both the transmitter and the receiver become the key drivers along with the range R. The scatterers behave as virtual antennas and the performance becomes independent of the actual antenna spacing (as long as a separation of a half wavelength approximately is maintained). When scatterers are assumed to be disposed in rings around the transmitter and the receiver then the maximum performance for N number of antennas (channel rank is full) is found to be related to the following condition: transmitter*receiver/R>= wavelength/N, where DT and DR this time refer to the scattering radius on transmitter ands on receiver side. They also denote the spacing of hypothetical antennas spanning the entire scattering diameter at the transmitter and the receiver sites [17].

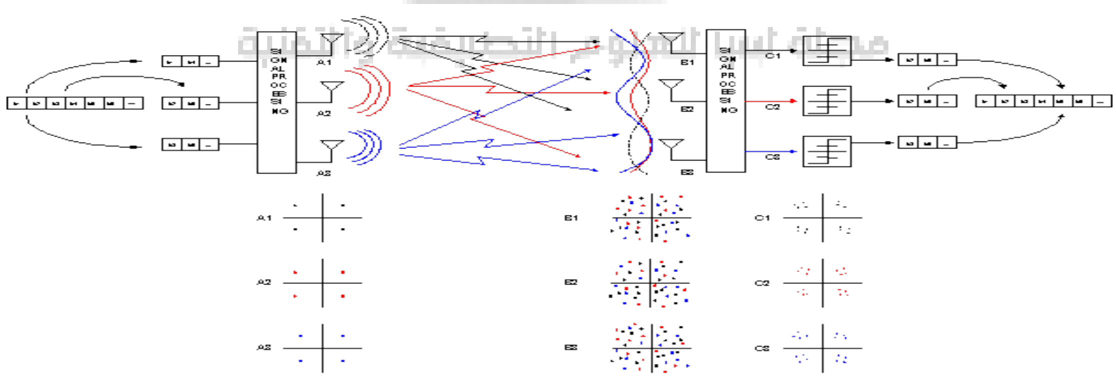

Figure 3 MIMO Spatial Division Multiplexed System [17]

So SDM allows the system to efficiently increase the throughput almost linearly with the number of transmit and receive antennas. The IEEE 802.11n standard supports systems with up to 4 transmit and 4 receive antennas to allow for dramatic gains in throughput. Besides using diversity for more robust transmission and SDM for drastically increasing throughput, MIMO systems can use a technique called Space Time Block Coding (STBC).

Space Time Coding (STC)

In particular, coding over the space, time, and frequency domains provided by MIMO-OFDM will enable a much more reliable and robust transmission over the harsh wireless environment. Space-time block coding scheme can be considered the middle ground between diversity and SDM, it combines these two techniques to maximize the link performance. A space-time (ST) code is a bandwidth-efficient method that can improve the reliability of data transmission in MIMO systems. It encodes a data stream across different transmit antennas and time slots so that multiple redundant copies of the data stream can be transmitted through independent fading channels. By doing so, more reliable detection can be obtained at the receiver. As an example of STBC in MIMO applications, the IEEE 802.11n standard is still being discussed, but one prototype can offer up to 250 Mbit/second. This is over five times the (theoretical maximum) speed of the existing IEEE 802.11g hardware. STBC sends multiple versions of the symbols through spatially separated channels. For example, Alamouti's algorithm sends two symbols sequentially through one antenna, while sending conjugate, time-reversed symbols through another antenna. The matrix below represents the Alamouti's coding scheme [18]

$$C_2 = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad (1)$$

Where Si is the symbol for time interval I, while s* is the complex conjugate of the symbol s. Alamouti's code is the STBC supported by the IEEE 802.11n standard. STBC is advantageous because the receiver is much more likely to receive the signal with the repetitious transmission. Space-time codes may be split into two main types:

Space-Time Block Codes

Space-time block code is a technique used in wireless communications to transmit multiple copies of a data stream across several antennas and to exploit the various received versions of the data to improve the reliability of data transfer. The fact that transmitted data must traverse a potentially difficult environment with scattering, reflection, refraction, and so on as well as be corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than others. This redundancy results in a higher chance of being able to use one or more of the received copies of the data to correctly decode the received signal. Space-time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible [19].

An STBC is usually represented by a matrix. Each row represents a time slot and each column represents one antenna's transmissions over time:

$$\begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ . & . & .. & .. \\ S_{T1} & S_{T2} & .. & S_{Tn} \end{bmatrix} \quad (2)$$

where sij is the modulated symbol to be transmitted in time slot i from antenna j. There are to be T time slots and n transmit antennas as well as n receive antennas.

The code rate of an STBC measures how many symbols per time slot it transmits on average over the course of one block. If a block encodes k symbols, the code rate is

$$r = \frac{k}{T} \quad (3)$$

Only one standard STBC can achieve full rate r = 1, Alamouti_scode.

Encoding: Alamouti's code

Alamouti invented the simplest of all the STBCs in 1998, although he did not coin the term" space-time block code" himself. It was designed for a two-transmit antenna system

And has the coding matrix:

$$C = \begin{bmatrix} S1 & S2 \\ -S_2^{\ *} & S_1^{\ *} \end{bmatrix} \quad (4)$$

Where * denotes complexconjugate

It is readily apparent that this is a rate-1 code. It takes two time-slots to transmit two symbols. Using the optimal decoding scheme discussed below, the bit-error rate (BER) of this STBC is equivalent to 2n-branch maximal ratio combining (MRC). This is a result of the perfect orthogonality between the symbols after receiving processing. There are two copies of each symbol transmitted and n copies received

One particularly attractive feature of orthogonal STBCs is that maximum likelihood decoding can be achieved at the receiver with only linear processing. To consider a decoding method, a model of the wireless communications system is needed.

At time t, the signal r_t^j t received at antenna j is

$$r_t^j = \sum_{i=1}^{n} \alpha_{ij} s_t^i + n_t^j \quad (5)$$

Where α_{ij} is the path gain from transmit antenna i to receive antenna j and n_t^j is a sample of AWGN.

The maximum-likelihood detection rule [10] is to form the decision variables

$$R_i = \sum_{t=1}^{n} \sum_{j=1}^{n} r_t^j {}_{\alpha\varepsilon t(i)_j} \delta_t(i) \quad (6)$$

Where $\delta_t(i)$ is the sign of si in the kth row of the coding matrix, Єk(p) = q denotes that sp is the (k, q) element of the coding matrix, for i = 1, 2, ..., n and then decide on constellation symbol si that satisfies.

$$\text{si} = \text{argmin}_{s\in A} |Ri - s|2 + (-1 + \sum_{k,l} |\alpha_{kl}|^2)|S|^2 \quad (7)$$

Where A is the constellation alphabet this is a simple, linear decoding scheme that provides maximal diversity.

Methodology and the Simulation Results

Research plan

The strategy selected should be based on the goals and objectives of the study. Therefore, to answer the research question of this study the initial approach to investigating the performance of the next generation of WLAN IEEE 802.11n was to model the transmitter and receiver that communicated over a user-defined channel using the main components of the IEEE 802.11n. Matlab 7.0.1 was used to model the proposed physical layer of the IEEE 802.11n standard. Using high-level language and an interactive environment MATLAB enables the user to perform computationally intensive tasks at a rate that is faster than with other programming languages such as C, C++. MATLAB integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation

The investigation was based on two parts

- Modeling IEEE 802.11n physical layer.
- Modeling the power consumption scheme of the standard.

Modeling IEEE 802.11n physical layer

To obtain a fully simulated model of the IEEE 802.11n physical layer, the simulation program has been divided into three programs. First, the simulation program will model different modulation schemes, which are used in IEEE 802.11n, such as BPSK, QPSK, 16-QAM, and 64-QAM to explain the probability of detection error among different modulation schemes. Secondly, the program will simulate two different antenna systems, which are SISO and MIMO, to point out the differences in performance, in terms of baud rate, between these antenna structures and the variation of channel capacity in different antenna numbers for a particular bandwidth. To achieve a fully implemented IEEE 802.11n model, the main simulation program will gather different modulation schemes, and space-time coding schemes and transmit the data through different numbers of antennas. The simulation will show how a selected modulation scheme with a particular number of antennas will significantly affect the system performance in terms of signal-to-noise ratio and the probability of errors. At the same time how the Space Time Block Coding can guarantee greater reliability and more robust transmission over the harsh wireless environment will be shown.

It should be noted that several Matlab programs were used from the Matlab file exchange website to help build the various Models.

Figure 4 shows the constellation diagram of QPSK with White Gaussian Noise AWGN channel.

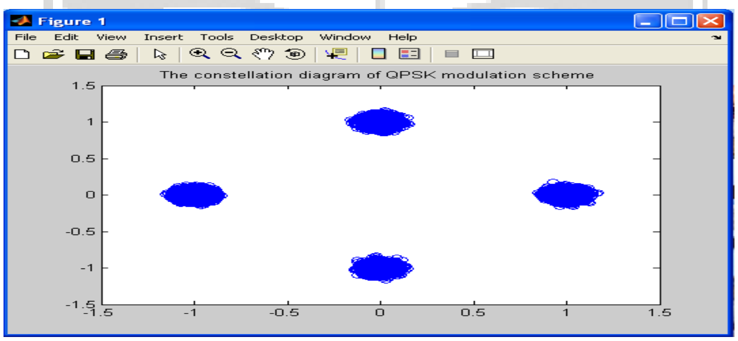

Figure 4 constellation diagram of QPSK with AWGN

Simulate the Quadrature Amplitude Modulation (QAM)

With white Gaussian noise AWGN. 64QAM in after AWGN channel. The general form of an M-ary QAM signal can be defined as

$$s_i(t) = \sqrt{\frac{2E_{\min}}{T_s}} a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{\min}}{T_s}} b_i \sin(2\pi f_c t), \quad (8)$$

Where E_{min} is the energy of the signal with the lowest amplitude, and a_i and b_i are a pair of independent integers chosen according to the location of the particular signal point

For a rectangular constellation, a Gaussian channel, and matched filter reception, the probability of bit error is expressed by

$$Pb = \frac{2(1-L^{-1})}{\log_2 L} Q\left[\sqrt{\left(\frac{3\log_2 L}{L^2-1}\right)\frac{2E_b}{N_o}}\right] \quad (9)$$

Figure 5 illustrates the constellation diagrams of the 16 QAM with white Gaussian noise AWGN channel.

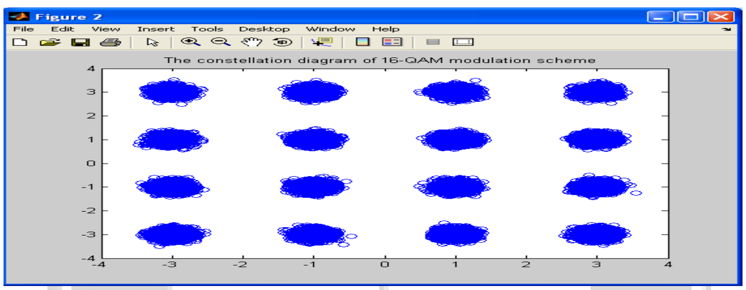

Figure 5 constellation diagram of 16 QAM with AWGN

The constellation diagram of 64-QAM White Gaussian Noise (AWGN), channel is shown in figure 6.

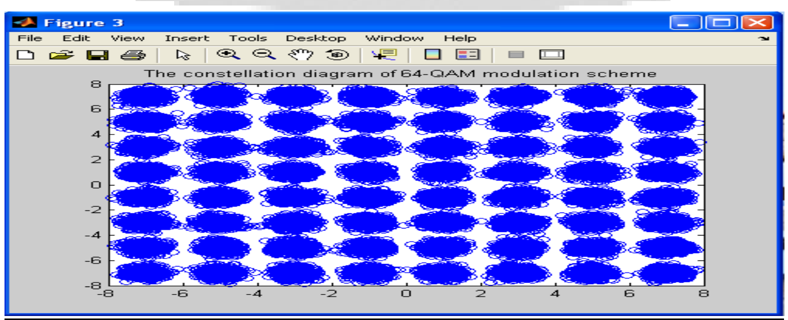

Figure 6 constellation diagram of 16 QAM with **white Gaussian noise** AWGN

To clarify the trade-off between different modulation schemes performance obtained from the figures 1, 2, and 3, it is clear that PSK system and a QAM. PSK would be transmitting symbols with the lowest probability of detection error. 16-QAM would be transmitting more symbols, but with a higher probability of detection error, and 64-QAM would have the highest probability of detection error but with the largest transmitting symbols. Consequently the greater the amount of data transmitted the more detection error will be obtained.

Modeling the channel capacity and SISO and MIMO antenna structure

MIMO exploits the use of multiple signals transmitted into the wireless medium and multiple signals received from the wireless medium to improve wireless performance [20]. For an 'N' number antenna system carrying equal power N-parallel independent data streams, the Shannon's channel capacity equation can be written as

$$C = BW \times N \times \log_2(1 + Eb/N0), \quad (10)$$

Where BW is bandwidth, E_b/N_0 is signal to noise ratio.

From this equation, by increasing BW or the number of antennas N, the channel capacity can be increased proportionally.

Figure 7 shows the variation of channel capacity C with the SNR $Eb/N0$ and the number of antennas N.

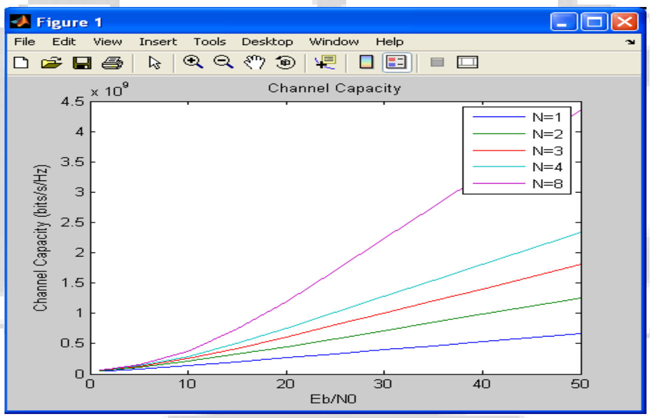

Figure 7 Channel Capacity of MIMO System: BW=40MHZ

Shannon's channel capacity equation is the maximum channel capacity. However, in practice, this capacity is impossible to achieve due to the limited code rates and other factors.

The equation used to calculate data rate can be written as.

$$R = BW \times N \times S_e \quad (11)$$

Where S_e is a spectral efficiency. For a 64 QAM modulation with SNR_s of around 25dB, the spectral efficiency is $\log_2(64) = 6_{bps}$/HZ. When BW = 40MHZ and for a 2×2 MIMO, the maximum channel capacity using Shannon's capacity equation is approximately 580Mbps. With additional error-code redundancy, preambles, and training pilots, the achievable data rate is around 70% of the total rate or 400Mbps.

Figures (8-a) and (8-b) illustrate ideal data rates according to question (8) for different modulation schemes with BW = 40MHZ and different number of antennas.

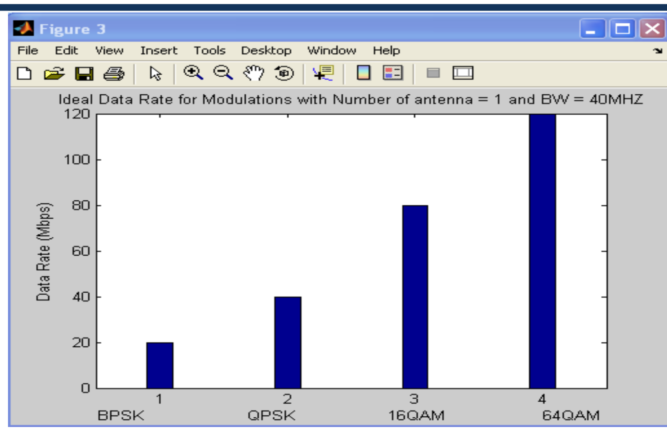

Figure 8-a Ideal Data Rate for Modulations with N=1 and BW = 40MHZ

Note that about double the data rate can be achieved in case of doubling the number of antennas. However, this cannot be achieved in practice.

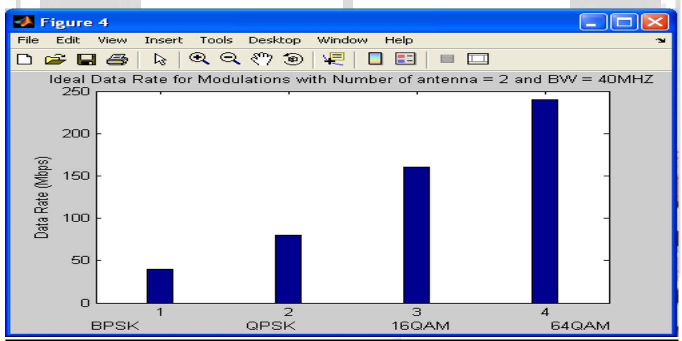

Figure 8-b Ideal Data Rate for Modulations with N=2 and BW = 40MHZ

Having simulated the first two stages, the next section will explain the simulation results of the proposed IEEE 802.11n MIMO using a space-time coding code scheme to obtain a fully implemented IEEE 802.11n physical layer. This simulation aims to outline how using different antenna systems and different modulation schemes can affect the performance of the model. First, the program will simulate the performance of the SISO antenna structure with different modulation schemes then the performance of the MIMO antenna system with the same modulation schemes used as in the SISO simulation will be demonstrated.

simulation of the performance of IEEE 802.11n SISO Model

The bit error probability P_b vs. E_b/N_0 for different modulation schemes is shown in Figure 9 With $P_b = 10^{-3}$, the E_b/N_0 are about 9dB, 9.7dB, 16dB, and 19dB for BPSK, QPSK, 16QAM and 64QAM respectively. From this figure, we know that when the battery power is low, the mobile device can change the modulation scheme from a higher data rate to a lower data rate. Thus the device can decrease the SNR to save power while maintaining the same probability of bit error.

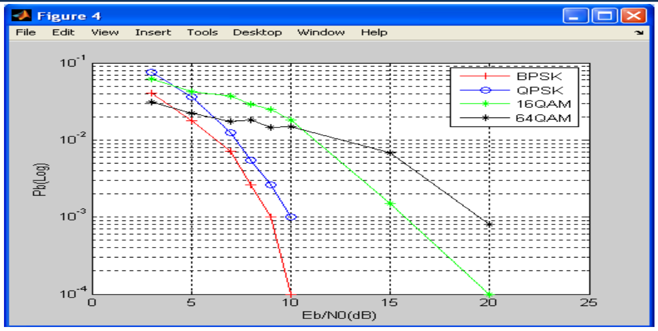

Figure 9 Bit Error Prob. vs. *Eb/N0* for IEEE 802.11n SISO model

Simulation of the performance of IEEE 802.11n MIMO Model

The simulation result of bit error probability (P_b) vs. SNR (E_b/N_0) for the MIMO system is shown in Figure 10

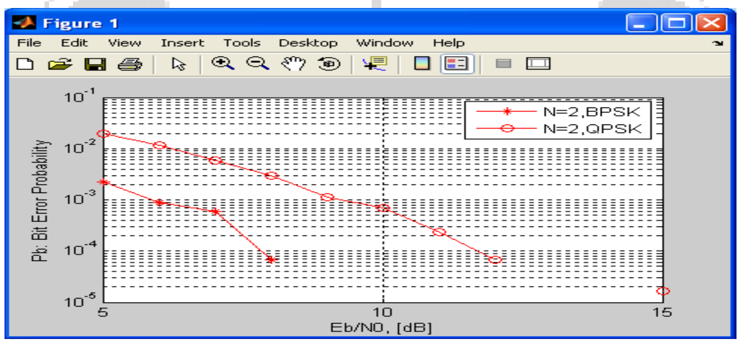

Figure 10 Bit Error Prob. vs. *Eb/N0* for IEEE 802.11n MIMO model

According to the results illustrated in figures (6) and (7), with $P_b = 10^{-3}$, which can be considered a reasonable value of the probability of bit error in wireless systems, the E_b/N_0 are about 6dB and 9.5dB for BPSK and QPSK respectively for antenna number N = 2; the E_b/N_0 are about 11dB and 15dB for BPSK and QPSK respectively for antenna number N = 1 with the same probability of bit error. We can see that the performance of a 2-antenna MIMO is better than the one with a 1-antenna MIMO system. Both the performances of BPSK and QPSK with 2 antennas are much better than the performances of BPSK and QPSK with 1 antenna. The performance of BPSK is always much better than QPSK. However, inaccurate results for both 16-QAM and 64-QAM were obtained in the case of 2 antenna MIMO and the expected problem may be caused by the space-time coding scheme, which was not working probably with these modulation schemes.

Modeling the power management scheme of the standard

Because mobile devices with Wi-Fi interfaces are becoming more and more popular, IEEE 802.11n is a Wi-Fi new proposed generation standard in which energy reduction might have to be considered. In addition to modeling this new generation standard, it was also desirable to model a power management scheme for this standard to attempt to solve or manage the power problems in the Physical Layer. With the original standard, a Proposed Energy Reduction Scheme was performed to show what the key effects in power consumption in wireless devices are, what the proposed solutions to optimize power consumption may be and to try and significantly increase the mobile device's standby time [21].

The simulation analysis of the power saving scheme was achieved by switching between modulation schemes for the SISO system, the input data was provided from the simulation program of the modulation schemes with $P_b = 10^{-3}$. Figure (4.8) shows the power needed for different modulation schemes; we can see that when switching the modulation scheme from 64QAM to QPSK, the device can save about 50% of the power with about 67% of the data rate. Therefore, with the same required P_b, BPSK or QPSK has less SNR or E_b/N_0 than 16QAM or 64QAM. That means energy is saved with BPSK or QPSK with the sacrifice of transfer rate. When battery power is low, it is necessary to switch the modulation scheme from QAM to PSK with a lower data transmission rate to conserve energy. However, it is easy to understand that shutting down some antennas can save power as well [21], [23].

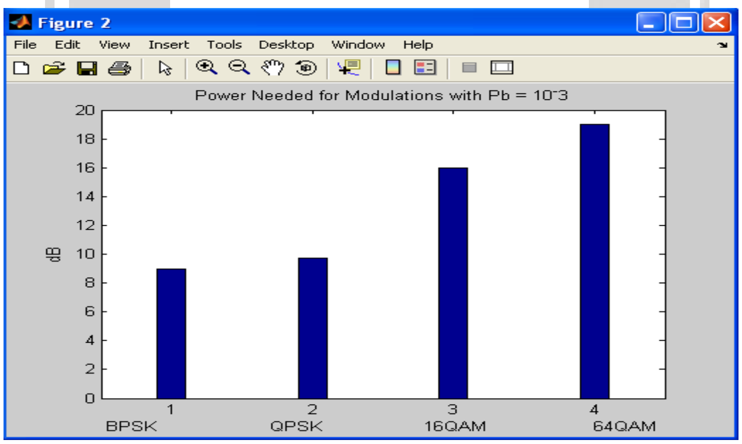

Figure 11 Power Needed for Modulations with $Pb = 10^{-3}$

It is quite reasonable to use a low power modulation scheme with a low data rate to extend battery life when this standard is used on actual mobile devices or a device based in a place where no power source can be wired into it. So when battery power is low, it is necessary to shut down some antennas and use only one antenna with about half of the transfer rate.

Conclusion

To sum up, I have deduced that IEEE 802.11n has surpassed all of its previous generations (IEEE 802.11a/b/g) in many aspects of performance. It provides a higher throughput and a wider coverage range to its users. It is also more resistant to latency and interference caused by IEEE 802.11a/b/g networks in the surrounding environment. Not only that, but the IEEE 802.11n network is also backward compatible with its previous generations. Most importantly, the IEEE 802.11n is a MIMO system. It sends and receives multiple signals at the same instant of time, which in turn increases its data rate and overall performance.

Another great aspect of this new standard is that despite its wireless nature, the IEEE 802.11n will have comparable speed to that of standard hardware. This means that even though it is exposed to many environmental interferences that could slow its throughput, it will still be capable of equal or greater speeds than that of an Ethernet cable whose data rate speed is typically about 100 Mbps. Because of this, wireless users can enjoy the best of both worlds. That is, high data speeds along with wireless connectivity.

The proposed energy reduction has come up with two main proposed solutions, which can be accomplished as. First, decrease the number of MIMO antennas, if the battery of the mobile device is used instead of AC power or battery power is low, then shut down antennas from 8 to 4 or to 2 or to 1 antenna(s) to save power. Second, switch to low energy consumption modulation schemes, such as using QPSK or BPSK instead of 6QAM or 64QAM, or 256QAM.

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