Modulation Techniques in ISM Band

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***Abstract*— Now-a-days enormous volume of information is communicated using radio communications systems through radio frequencies(ISM Band). Both analog radio communications systems and digital or data radio communications system are used. However one of the essential aspects of any radio communications transmission system is modulation, or the way in which the information is overlaid on the radio carrier. In order that a steady radio signal or "radio carrier" can carry information it must be changed or modulated in one way so that the information can be conveyed from one place to another. There are very many ways in which a radio carrier can be modulated to carry a signal, each having its own advantages and disadvantages.**

This document describes the process of modulation and its need in ISM Band. It also explains the different types of modulation techniques used in ISM Band which include Frequency Hopping Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS) & Orthogonal Frequency Division Multiplexing (OFDM).This document gives a brief outline about Spread Spectrum and its use in ISM Band.

Keywords*— *ISM BAND, FHSS, DSSS, OFDM

I. INTRODUCTION

The November 1997 approved 802.11 Standard defines the protocol and compatible interconnection of data communication equipment via radio or infrared air interface in a local area network. The radio application of the PHY specifies the use of either Frequency-Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS) modulation. For frequency-hopping radios the IEEE stipulates a minimum requirement of 1Mbit/s data rate using two-level Gaussian frequency shift keying (2GFSK) modulation. An optional rate of 2Mbit/s is supported using four-level Gaussian FSK (4GFSK) modulation. For direct sequence systems two modulation formats and data rates are supported, a basic access rate of 1Mbit/s and an enhanced access rate of 2Mbit/s. Both data rates utilize phase shift keying modulation with differential binary phase shift keying (DBPSK) used for the 1Mbit/s basic access rate and differential quadrature phase shift keying (DQPSK) used for the improved access rate. These two techniques, FHSS and DSSS, establish the currently approved standard for IEEE 802.11. Orthogonal Frequency Division Multiplexing (OFDM) was not covered by the CFR and would have required licensing.802.11a, employing OFDM, was created to work in the 5GHz Unlicensed National Information Infrastructure (UNII). In May, 2001 CFR, Part 15 was modified to allow alternative "digital modulation techniques" .This resulted in 802.11g which employs OFDM in the 2.4 GHz range. Orthogonal Frequency Division Multiplexing (OFDM) operates in both the 5 GHz and 2.4 GHz range with a data rate of between 6 and 54 Mbps. The modulation scheme can be BPSK, QPSK or QAM depending upon the speed of transmission. [1]

II. ISM BAND & ITS USES

A. *Introduction to ISM Band*

Due to its practically global availability, the 2.4 GHz Industry Scientific and Medical(ISM) unlicensed band constitutes a popular frequency band suitable to low cost radio solutions such as the ones proposed for WPANs and WLANs. The distribution of the spectrum among various wireless devices can operate in the same environment. [2]

The ISM (industrial, scientific and medical) radio bands were initially reserved internationally for the use of RF energy for industrial, scientific and medical drives other than communications. Examples of applications in these bands include radio-frequency process heating, microwave ovens, and medical diathermy machines. The ISM bands are defined by the ITU-R in 5.138, 5.150, and 5.280 of the Radio Regulations. Distinct countries' use of the bands designated in these sections may differ due to variations in national radio regulations. Since communication devices using the ISM bands must bear any interference from ISM equipment, unlicensed operations are typically permitted to use these bands, since unlicensed operation typically needs to be tolerant of interference from other devices anyway. The ISM bands share provisions with unlicensed and licensed operations; however, due to the high likelihood of harmful interference, licensed use of the bands is typically low. In the United States of America, uses of the ISM bands are governed by Part 18 of the FCC rules, while Part 15 contains the rules for unlicensed communication devices, even those that share ISM frequencies. In Europe, ETSI tries to govern.

B. *Use of ISM Band*

The 2.4 GHz ISM band allows for primary and secondary uses. Secondary uses are unlicensed but must follow rules defined in the Federal Communications Commission Title 47 of the Code for Federal Regulations Part 15 [COM] relating to total radiated power and the use of the spread spectrum modulation schemes. Interference among the various uses is not talked as long as the rules are followed. Thus, the major down side of the unlicensed ISM band is that frequencies must be shared and potential interference tolerated. While the spread spectrum and power rules are fairly effective in dealing with multiple users in the band, provided the radios are physically separated, the same is not true for close proximity radios. Multiple users, including self-interference of multiple users of the same application, have the effect of raising the noise floor in the band resulting in a degradation of performance. The impression of interference may be even more severe, when radios of diverse applications use the same band while positioned in close vicinity. Thus, the interference problem is considered by a time and frequency overlap. [2]

For many people, the most frequently encountered ISM device is the home microwave oven operating at 2.45 GHz. However, in current years these bands have also been shared with license-free error-tolerant communications applications such as wireless sensor networks in the 915 MHz and 2.450 GHz bands, as well as wireless LANs and cordless phones in the 915 MHz, 2.450 GHz, and 5.800 GHz bands. Since unlicensed devices already are required to be tolerant of ISM emissions in these bands, unlicensed low power uses are generally able to operate in these bands without causing problems for ISM users; ISM equipment does not necessarily include a radio receiver in the ISM band (a microwave oven does not have a receiver).

In the United States, according to 47 CFR Part 15.5, low power communication devices must accept interference from licensed users of that frequency band, and the Part 15 device must not cause interference to licensed users. Note that the 915 MHz band should not be used in countries outside Region 2, except those that specifically allow it, such as Australia and Israel, especially those that use the GSM-900 band for cellphones. The ISM bands are also widely used for Radio-frequency identification (RFID) applications with the most commonly used band being the 13.56 MHz band used by systems compliant with ISO/IEC 14443 including those used by biometric passports and contactless smart cards.

In Europe, the use of the ISM band is covered by Short Range Device regulations issued by European Commission, based on technical recommendations by CEPT and standards by ETSI. In most of Europe, LPD433 band is allowed for license-free voice communication in addition to PMR446.

- Wireless LAN devices use wavebands as follows:
- Bluetooth 2450 MHz band
- HIPERLAN 5800 MHz band
- IEEE 802.11/Wi-Fi 2450 MHz and 5800 MHz bands
- IEEE 802.15.4, ZigBee and other personal area networks may use the 915 MHz and 2450 MHz ISM bands since of frequency sharing between different allocations.

Wireless LANs and cordless phones can also use frequency bands other than the bands shared with ISM, but such uses require approval on a country by country basis. DECT phones use allocated spectrum outside the ISM bands that differs in Europe and North America. Ultra-wideband LANs require more spectrum than the ISM bands can provide, so the relevant standards such as IEEE 802.15.4a are designed to make use of spectrum outside the ISM bands. Despite the fact that these additional bands are outside the official ITU-R ISM bands, since they are used for the same types of low power personal communications, these additional frequency bands are sometimes incorrectly referred to as ISM bands as well.

III. NEED FOR MODULATION IN ISM BAND

Heinrich Hertz (1857 to 1894) built on the discoveries of Maxwell by proving that electromagnetic waves travel at the speed of light and that electricity can be carried on these waves. How they relate to wireless local-area networks (WLANs). Here is the tie-in: In standard LANs, data is broadcasted over wires such as an Ethernet cable, in the form of electrical signals. The discovery that Hertz made opens the airways to transfer the same data, as electrical signals, without wires. Therefore, the simple answer to the relationship between WLANs and the other discoveries previously mentioned is that a WLAN is a LAN that does not need cables to transfer data between devices, and this technology exists since of the research and discoveries that Herschel, Maxwell, Ampere, and Hertz made. This is accomplished by way of Radio Frequencies (RF).With RF, the objective is to send as much data as far as possible and as fast as possible. The problem is the plentiful influences on radio frequencies such as interference that need to be either overcome or dealt with. To attain bandwidth from RF signals, you need to send data as electrical signals using some type of emission method. One such emission method is known as Spread Spectrum. In 1986, the FCC agreed to allow the use of spread spectrum in the commercial market using what is known as the industry, scientific, and medical (ISM) frequency bands. To place data on the RF signals, you use a modulation technique. Modulation is the addition of data to a carrier signal. To send music, news, or speech over the airwaves, you use frequency modulation (FM) or amplitude modulation (AM).Listening to the radio, is using this technology. [3]

A. *Advantages of Digital Modulation*

- Noise in the system does not have the same detrimental effect (damage) on the received signal.
- It is thinkable to encode messages in special ways so that the receiving system can able to detect an error.
- Digital modulation and demodulation circuitry may be easier to implement for certain types of modulation.
- Digital signals are easier to combine together so that they can then be modulated as a group using multiplexing process.

B. *Disadvantages of Digital Modulation*

- It has the disadvantage of cost and requirement of more bandwidth.

IV. TYPES OF MODULATION TECHNIQUES

A. *Frequency Hopping Spread Spectrum (FHSS)*

Carrier changes frequency (HOPS) according to a pseudorandom Sequence. Pseudorandom sequence is a list of frequencies. The carrier hops through this list of frequencies. The carrier then repeats this pattern.

During Dwell Time the carrier remains at a certain frequency. During Hop Time the carrier hops to the next frequency. The Dwell time per frequency is around 100 ms (The FCC specifies a dwell time of 400 ms per carrier frequency in any 30 second time period). Longer dwell time = greater throughput. Shorter dwell time = less throughput

Hop Time is measured in microseconds (us) and is generally around 200-300 us.The data is spread over 83 MHz in the 2.4 GHz ISM band. This signal is resilient nonetheless not resistant to narrow band interference.The original 802.11 FHSS standard supports 1 and 2 Mbps data rate. FHSS uses the 2.402 – 2.480 GHz frequency range in the ISM band. It splits the band into 79 non-overlapping channels with each channel 1 MHz wide.

FHSS hops between channels at a minimum rate of 2.5 times per second. Each hop must cover at least 6 MHz. [4] FHSS uses Gaussian Frequency shift keying (GFSK) for its modulation. However FHSS has few disadvantages also. They are as following:

- Not as firm as a wired LAN or the newer WLAN Standards.
- Lower throughput due to interference.
- FHSS is subject to interference from other frequencies in the ISM band since it hops across the entire frequency spectrum.
- Adjacent FHSS access points can harmonize their hopping sequence to rise the number of co-located systems, however, it is excessively expensive.

B. *Direct Spread Spectrum (DSSS)*

DSSS spreads the signal by adding redundant bits to the signal prior to transmission which spreads the signal across 22 Mhz [5].

The procedure of adding redundant information to the signal is called Processing Gain. The redundant information bits are called Pseudorandom Numbers (PN). DSSS works by uniting information bits (data signal) with higher data rate bit sequence (pseudorandom number (PN)).

The PN is also called a Chipping Code (eg. the Barker chipping code)The bits resulting from merging the information bits with the chipping code are called chips - the result- which is then transmitted. The higher processing gain (more chips) rises the signal's resistance to interference by spreading it through a greater number of frequencies.

IEEE has set their minimum processing gain to 11. The number of chips in the chipping code associates to the signal spreading ratio. Doubling the chipping speed doubles the signal spread and the required bandwidth.

The Spreader employs an encoding scheme (Barker or Complementary Code Keying (CCK).The spread signal is then modulated by a carrier employing either Differential Binary Phase Shift Keying (DBPSK), or Differential Quadrature Phase Shift Keying (DQPSK). The Correlator contraries this procedure in order to recover the original data [5].

The Figure below shows how the spreading of signal takes place. [6][8]

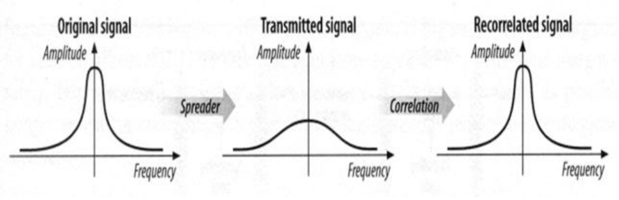

Figure 1. Spreading of DSSS Signal

Fourteen channels are identified, however, the FCC stipulates only 11 channels for non-licensed (ISM band) use in the US. Each channels is a contiguous band of frequencies 22 Mhz wide with each channel separated by 5 MHz.

For Example:

Channel 1 = 2.401 – 2.423 (2.412 plus/minus 11 Mhz).

Channel 2 = 2.406 – 2.429 (2.417 plus/minus 11 Mhz).

Only Channels 1, 6 and 11 do not overlap

A spectrum Mask signifies the maximum power output for the channel at various frequencies. From the center channel frequency, 11 MHz and 22 MHZ the signal must be attenuated 30 dB. From the center channel frequency, outside 22 MHZ, the signal is attenuated 50 Db [7].

The Center DSSS frequencies of each channel are only 5 Mhz apart but each is 22 Mhz wide consequently adjacent channels will overlap.

DSSS systems with overlapping channels in the same physical space would cause interference between systems. Co-located DSSS systems should have frequencies which are at least 5 channels apart, e.g., Channels 1 and 6, Channels 2 and 7, etc.

Channels 1, 6 and 11 are the only theoretically non-overlapping channels.

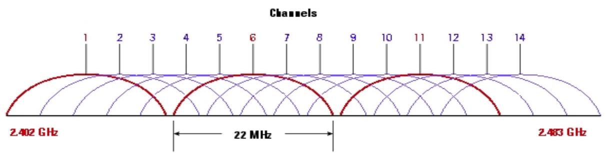

Figure 2. Frequency Assignment

The simple data rate for the DS system is 1 Mbits/s encoded with differential binary phase shift keying (DBPSK). Likewise, a 2 Mbits/s rate is provided using differential quadrature phase shift keying (DQPSK) at the similar chip rate. Higher rates of 5.5 and 11 Mbits/s are also accessible using techniques merging quadrature phase shift keying and complementary code keying (CCK) ; all of these systems use 22 MHz channel. [8]

C. *Orthogonal Frequency-Division Multiplexing (OFDM)*

In response to Ethernet networks that were adopting 100 Mb/s throughput another modulation technique had to be found to growth the speed beyond 11 Mb/s. The point was not only to intensification the speed, but also to find even improved techniques to match the wireless-specific experiments presented by multipath and interference. Orthogonal frequency-division multiplexing (OFDM) was previously in use in some other radio transmissions and was offering a good alternative to DSSS for wireless networks.

Instead of directing one large 22-MHz wave, OFDM divides the carrier into 52 subcarriers (or tones), 312.5 kHz apart. Forty-eight of them are used to carry data, while the four others are used to control the statement, which adds to the toughness of the whole. To these 52 subcarriers,12 others are added to be used as guards on the side (to distinguish one main carrier from the other next to it) and in the middle to mark the center of the carrier. The great benefit of this system is that if there are 48 channels carrying data, each of them can transmit slower than a CCK channel and the group of 48 will still attain a higher throughput. For example, if each subcarrier sends at 1 Mb/s, the total speed achieved will be 48Mb/s. The consequence is that not only is OFDM faster but, as each channel transmits slower (that is to say bearing less density of symbols per millisecond), it develops more resistant to multipath. Since there are many channels, some of them can be affected by interferences but the other scan still offer normal communications. The control channels allow the receiver to sense which channels are unusable and provide feedback to the sender [9].

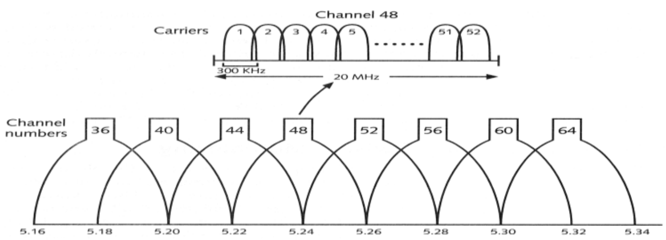

Figure 3. OFDM

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