IMPLEMENTING TV WHITE SPACE INDOORs with Orthogonal Frequency Division Multiplexing (OFDM) using different modulation schemes.

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ABSTRACT - The extent at which Indoor broadband can be enhanced using Wi-Fi in Television White Space (TVWS) is examined at the third floor of the Engineering Building, Queen Mary University of London, (QMUL). QMUL is at the latitude 51.5241^{0}N and Longitude 0.0404^{0}W, East London, United Kingdom (UK). We implemented the OFDM model of wireless communication with three types of modulation schemes. Performance metrics such as latency, Bit Error Rate (BER), throughput and signal-to-noise ratio have been analysed using TV channel 49 which is Rayleigh fading channel. OFDM utilises less bandwidth while achieving good spectral efficiency. The project also compared different modulation schemes on the Orthogonal Frequency Division Multiplexing (OFDM). We compared the binary phase-shift-keying (BPSK), Quadrature phase-shift-keying (QPSK) and 16-Quadrature Amplitude Modulation (QAM). At the end, the 16-QAM demonstrated more efficient exploitation of TVWS for indoor Wi-Fi applications with more favourable characteristics such as extended coverage and almost-homogeneous data distributions. The work estimated the average downlink and uplink capacity of an indoor TVWS network. No other work known to the authors has thought it necessary to compare the variations in the downlink and the uplink signal propagation through indoor measurements.

Keywords :- TV White Space, Signal Propagation, Downlink and Uplink, Homogeneous data distribution.

INTRODUCTION

TV White Space (TVWS) refers to TV channels that are not used by licensed services at a particular location and at a particular time. TVWS is a new wireless communication technology that provides broadband speed data links over several kilometres in license-free spectrum. Devices contact qualified geo-location database that provides channels and power transmission parameters at set number of a chosen minutes-intervals. For regulatory reasons, white space devices (WSD) that operate in the Ultra-High-Frequency TV band in the range 470MHz – 790MHz, sharing spectrum with Digital Terrestrial Television (DTT) and Public Making Special Events (PMSE) are license-exempt [7]. In the Europe and in most countries of the world, the amount of available white space lies within 470 -790MHz giving channels 21 – 60. With the application of spectrum sharing, TVWS technology renders access to new services. Demands for spectrum uses include, meeting up with the exponential rise for mobile broadband services. This has resulted to massive penetration of the new generation of wireless-user equipments like the smart phone and tablets in the population and the proliferation of bandwidth-intensive applications. Indeed wireless connectivity has never been in such great demand globally. Although this band had been assigned for television broadcast purposes, it can dynamically be used by secondary users (SU) in a particular geographic area, [1], [2], [3], [4], [6]. The success in TVWS technology has given rise to smart city applications and location-based services. The steps taken by the regulators, especially in the deployments of white space devices (WSDs), TVWS trials and development, [7], have recorded a huge success.

Achieving this can pose some technical challenges. But, one method of successful deployment of TVWS is using modulation schemes like the BPSK, QPSK and QAM modulate data sent over parallel sub-channels utilising the Orthogonal Frequency Division Modulation (OFDM) method to encode the data on multiple carrier frequencies. The OFDM has the ability to cope with severe channel conditions [8], while maintaining the data rates of a conventional scheme with the same bandwidth. Baseband signals cannot be transmitted without modulation. Information of baseband signal is transmitted in the way that parameter of high frequency carrier wave, such as amplitude or phase, is modulated by baseband signal, hence conveys the information that can be restored to original signal at the receiver. Selection of proper modulation scheme is essential to communication system design.

The OFDM modulation scheme has attracted sufficient attentions in view of its application to the digital TV signal transmission. In such an application, it is preferable to use a multi-level modulation such as 16-QAM, BPSK, QPSK and QAM to each carrier so as to increase the transmission bit rate. A digital signal transmission using an OFDM modulation scheme where the digital signals are transmitted by using a number of mutually orthogonal carriers has various advantages such as its capability to deal with multi-paths, relatively high frequency utilization efficiency, and its nearly Gaussian white noise like spectrum which causes very little interference with other communication services. For these reasons, the OFDM modulation scheme is considered to be particularly suitable.

The desire to utilise the potentials and deploy TVWS gave rise to this project. Some of the results under our performance tests under different modulation and coding schemes resulted in improved broadband in indoor areas using TVWS technology. For instance, a link was established at the antenna laboratory, located 108m, four

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floors from the base station. At this location, Wi-Fi had previously failed to provide internet connectivity. Again we were able to establish that, at short distances, propagation of signals is not terribly attenuated. Even at the busy third floor, there was no serious signal attenuation, showing excellent device performance result. The body of this paper is arranged in the following way, section II is the literature review, section III is the measurement set-up of the utilized WSDs, section IV presents the measurement results and analysis while section V concludes with forecast for the future.

II LITERATURE REVIEW

Many studies have been done on indoor signal propagation characteristics through field measurements based on UHF bands. There has been performance testing and assessment of appropriate scenarios for TVWS deployments in [1] where it has been observed that in the UK, TVWS has most performance potential in below rooftop receivers and indoor/underground deployments. The design for efficient method for the calculation of maximum allowable equivalent isotropic radiated power in TVWS was carried out in [2]. The strength of TVWS for the indoor through link performance test and achievable TVWS availability through the Ofcom approach was considered in [7] while [9] showed that TVWS signals can penetrate up to two floors above and below the base station whereas Wi-Fi signals experience significant path loss even through a single floor. In [10], line-of-sight blockages by office walls and corners have significant effect on the Wi-Fi link throughput whereas the transmitter/receiver orientation is found to have no significant effect. These authors presented a quantitative analysis of the performance of a network of office buildings that influence propagation between the transmitter and the receiver located in the same floor. The belief of [11] is that Downlink communication from access point to mobile stations share the radio channel with Uplink communication from mobile stations to the access points. In [12], the transmitted signal autocorrelation is embedded in the received signal correlation and makes it different from the channel correlation.
According to [13], OFDM results in an improved downlink multimedia services requires high data rates communications, but this condition is significantly limited by inter-symbol interference (ISI) due to the existence of the multiple paths. Multicarrier modulation techniques, including OFDM modulation are considered as the most promising technique to combat this problem, OFDM technique is a multi-carrier transmission technique which is being recognized as an excellent method for high speed bi-directional wireless data communication.

Nevertheless, none of all these presented works compared the characteristics of TVWS and Wi-Fi bands in the very short distance indoor environment. Presentations of [1], [7] and [10] measured the achievable TVWS indoors and penetration values, but, they paid no attention to what happened to the Downlink and Uplink characteristics of the signals with varying modulation the way this paper analysed and presented. It is therefore crucial for a field measurement of this kind so that it is possible to predict the efficacy of TVWS in indoor environment that was traditionally served by Wi-Fi.

A. Overview of the utilized White Space Devices.

A client with 4cm UHF-omni-directional antenna, one base station with its client and a 1.96m directional antenna, provided by the Carlson Wireless Technologies were used to analyse the performances. The test set up CPE is in operating mode of Orthogonal Frequency Division Multiplexing at the TVWS frequency of UHF 470 MHz to 790 MHz, modulation schemes of 16-QAM, QPSK and BPSK and a band width of 8MHz. Data transmission rates are in the broadband range over varied distances. Power spectrum measurements explored the propagation of signals over UHF frequencies and discerned how they correlate to throughput speeds measured by Internet-based broadband speed tests. For the tested shortest distance, there is an average SNR 25.9 dB for the down link and 28.6 dB for the uplink. The Data rate at this point is 16.60 Mbps for the down link and 1.05 Mbps for the uplink with latency of 5ms. The longest distance is the Antenna Laboratory, 108m from the base station, with an average SNR 24 dB down link and 22.66 dB for uplink, data rate of 1.25 Mbps downlink and 0.80 Mbps uplink at the latency of 9ms. Based on the achieved results, it is concluded that for such short distance indoor measurements, barriers like the walls had little effect on the signal strength at proper placement of CPE antenna.

B. The base station and client.

With the base station fixed at room 358 of the Engineering building at the Queen Mary University of London (QMUL), Mile End campus, the radio is connected to the Ethernet. The radio frequency transmit is set to 23dBm while signals are transmitted from a directional sector antenna with a gain of 11dBi and whose feeder cable is 1dBi loss with therefore a 33dBm EIRP. Figure 1 shows (a) client and 4cm antenna connected and (b) base station 1.96m antenna.

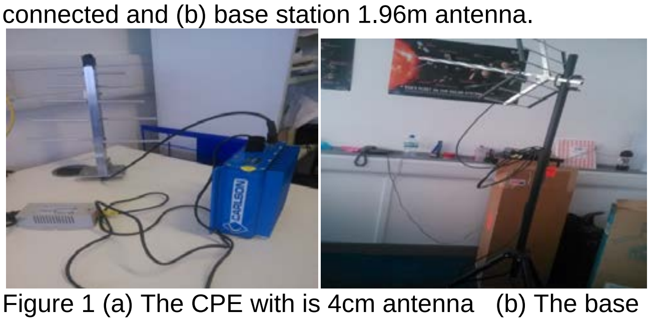

Figure 1 (a) The CPE with is 4cm antenna (b) The base station 1.96m antenna.

EXPERIMENTAL SETUP

The experimental set up includes measurement instruments

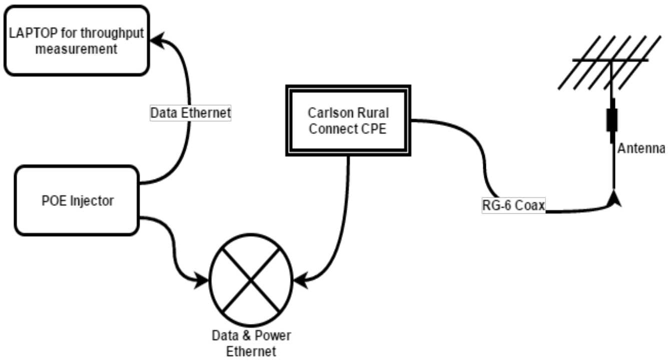

Fig. 2 Experiment setup

The block diagram in figure 2 shows the block diagram of the experimental set up of our measurement campaign. The Carlson Wireless Base station acts as a master WSD. It accesses the broadcast for itself and for the CPEs in order to make initial connection at low modulation mode. CPEs are slave units and have no configuration of its own, so the base station sends a request for it.

III Presentation of locations

Measurements were at twelve locations, though only six selected locations were eventually analysed. The Base Station (BS) is fixed at room 358, third floor of the Engineering Building. The floor and the room are used by the Antenna research group. Location 1 (room 355) is the link 1 which is 12.7m diagonally away from the base station and separated by two walls and a corridor. Location 2 is the link 2, the approaching Corridor, named corridor 1, 16.3m, north of the BS with a separation of two walls. Location 3 forms the link 3 at inside of room 351, 13.2m away from the BS with a separation of three walls and two double wooden doors. Location 4 is the link 4, inside room 356, directly next room to the BS location and only separated by a wall with a distance of 7.7m from the base station. Location 5 is the link 5, positioned at Southern corridor, named corridor 2, 13.2m away with two-wall separation. Location 6 is the link 6, inside the same room as the BS but with the radio antenna facing the opposite direction and 7.8m away from the base station. The summary of the measurement campaign outcome is shown in table 1 using the RSSI as the parameter for signal strength.

TABLE 1 : Summarizes the Receiver Signal Strength Indicator (RSSI) behaviour with position, modulation type, Error correction, Signal-to-Noise Ratio (SNR) and distances from the BS.

Number of LEDs (RSSI)	Location	Approximate SNR (dB)		Modulation type		Error Correction (convolution rate)		Distance From BS
		ownlink	Uplink	Downlink	Uplink	Downlink	Uplink	
3	**RM 355 LC1**	**22.7**	**28.7**	**16QAM**	**16QAM**	**¾**	**none**	**12.7m**
3	**Corr1 LC2**	**22.5**	**27.6**	**QPSK**	**16QAM**	**¾**	**½**	**16.3m**
3	**RM 351 LC3**	**13.5**	**23.9**	**BPSK 2**	**16QAM**	**½**	**¾**	**13.2m**
4	RM 356 LC4	29.6	26.6	16QAM	16QAM	None	None	**7.7m**
3	Corr2 Loc 5	29.4	26.7	BPSK2	BPSK2	½	½	**13.2m**
4	RM 358 LC6	25.0	28.1	16QAM	16QAM	½	¾	**7.8m**
3	Electron Lab Lc7	24.7	28.1	QPSK	16QAM	¾	½	**62.25m**
1	Antenna lab Lc8	0.0	8.2	BPSK2	BPSK2	½	1/2	**234 steps or 108m**

IV Measurement Results and Performance Analysis of OFDM

OFDM performance analysis presented in this section is based on computer simulations. The basic scenario of our simulation is represented by the OFDM transmission system performing through multipath fading and AWGN transmission channel. The mapping of OFDM system uses different type of modulation schemes. We note here that in OFDM, all queuing data in buffer are uniformly allocated on small sub- carriers while it efficiently squeezes multiple carriers. This makes OFDM unique. The world standard bodies such as IEEE and ETSI have selected the OFDM as their physical layer techniques for the next generation of wireless systems [13]. The growing demand for modulated carriers now squeezes together thereby reducing the required bandwidth but keeps the modulated signals orthogonal so that they do not interfere with each other. An efficient OFDM technique shows favourable properties such as robustness to channel fading and inter symbol interference (ISI) and is more immune to noise. OFDM system is capable of mitigating a frequency selective fading channel to a set of parallel flat fading.

With the modulation schemes like the 16-QAM, BPSK and QPSK with modulation rates of ½ and ¾., we chose to have adaptive modulation selection mode. In the Carlson wireless setup, performance of each link depends on two factors, the available signal-to-Noise Ratio and the modulation mode.

As illustrated below, OFDM simulation block diagrams have layouts with binary bit, CRC Generator, and Convolution encoders. The convolution interleave with the different modulations, and frequency hopping while AWGN channel is connected to the receiver and the transmitter parts. It is connected with receiver by the smart antenna then there is the frequency de-hopping while the modulations will demodulate. There will be convolution de-interleaved, decoder and finally the errors are checked.

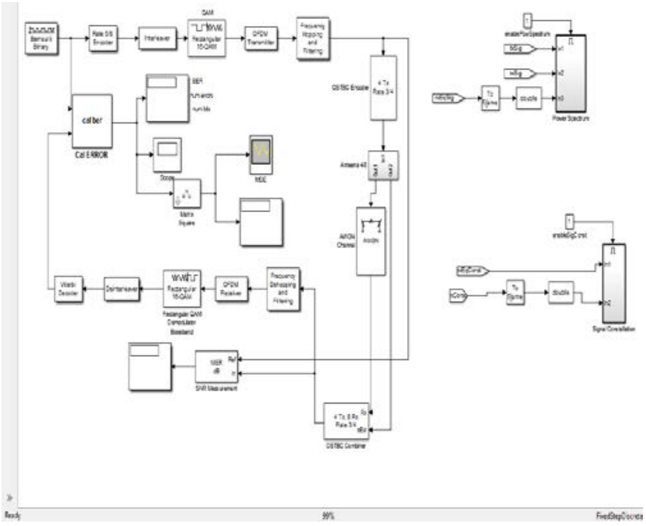

Figure 3 Simulation block of OFDM System using 16-QAM modulation.

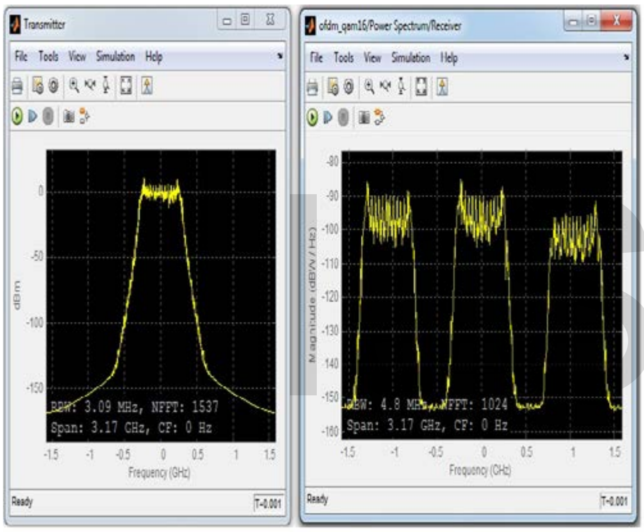

Fig.4 OFDM Transmitted & Receiver Signal using 16-QAM Modulation.

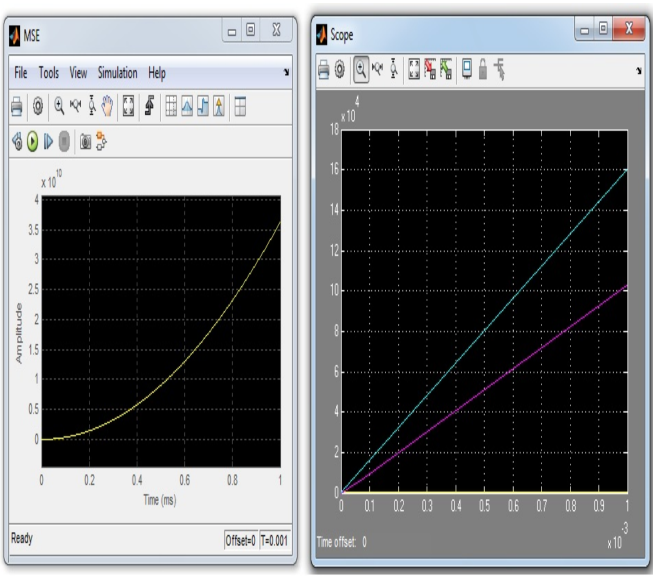

Figure 5 OFDM Mean Square Error (MSE) left & Total Bits (Blue), number of error (Magenta) and Bit error rate (yellow) in right side using 16-QAM Modulation.

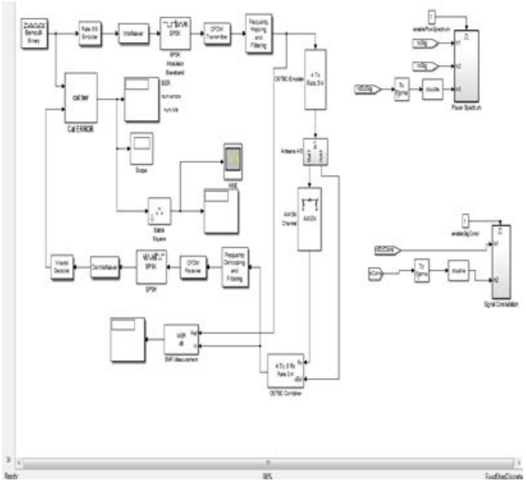

Figure 6 Simulation block of OFDM System using BPSK modulation

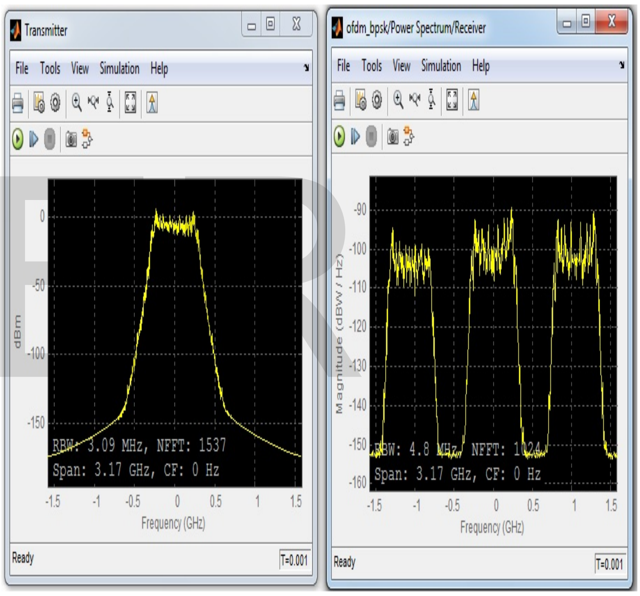

Fig.7 OFDM Transmitted & Receiver Signal using BPSK Modulation

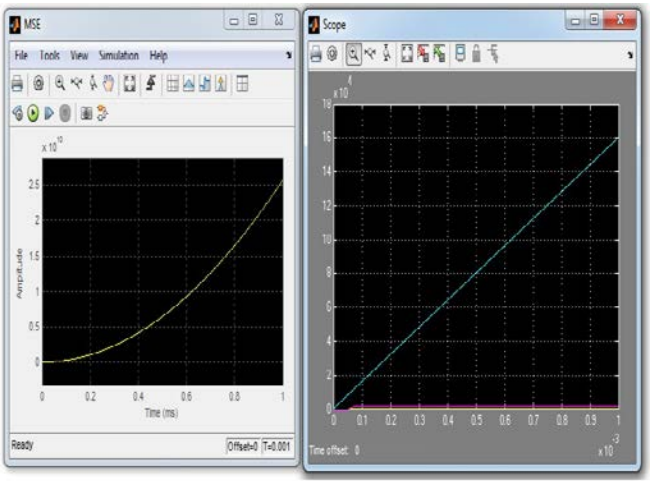

Fig.8 OFDM Mean Square Error (MSE) left & Total Bits (Blue), number of error (Magenta) and Bit error rate (yellow) in right side using BPSK Modulation

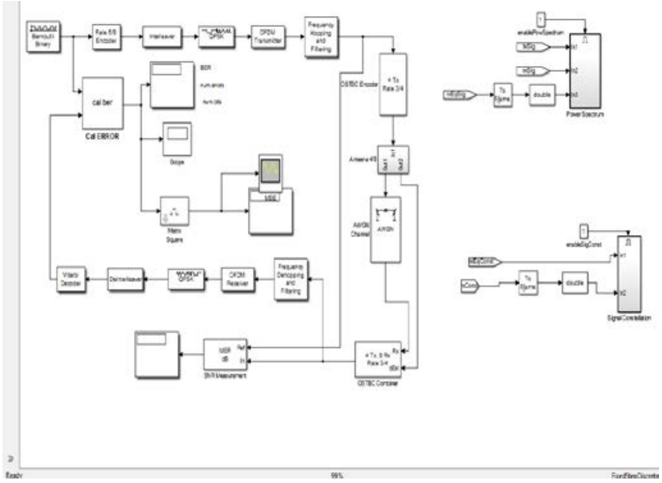

Fig.9 Simulation block of OFDM System using QPSK modulation

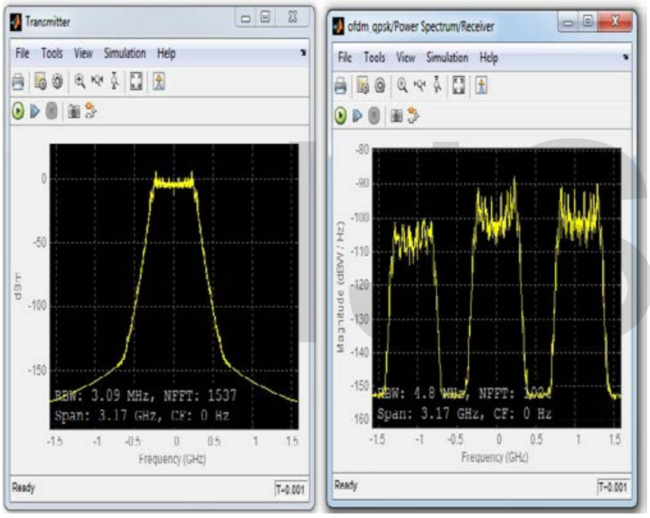

Fig. 10 OFDM Transmitted & Receiver Signal using QPSK Modulation

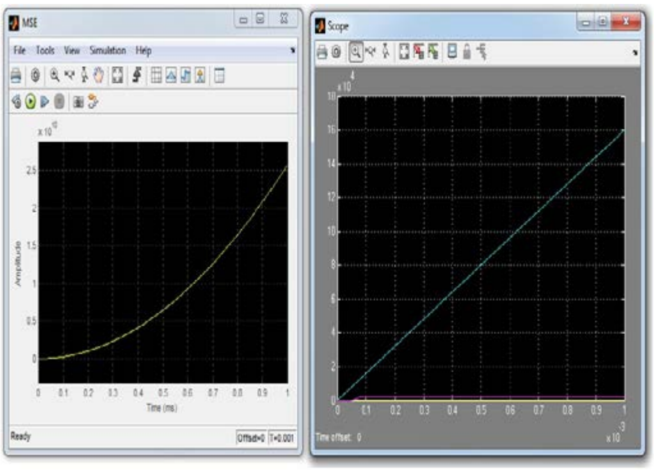

Fig. 11 OFDM Mean Square Error (MSE) left & Total Bits (Blue), number of error (Magenta) and Bit error rate (yellow) in right side using QPSK

The graphs are drawn from the minimum signal strengths for each modulation mode shown on the devices specification tab. Those numbers are somewhat hypothetical, based on the system design and some early testing. They are, however, fairly accurate.

The actual SNRs are higher, based on the lower noise floors using modulation spreading techniques for BPSK 1/2, BPSK3/4, and BPSK8 spreading modes.

The following graphs illustrate the summary of modulation and coding rates over distances. The graph gives a perfect curve making the QAM- type of modulation the best form of modulation scheme indoors.
Carefully plotting the graph of the modulation type over distances, curve below is generated. The latency at each position is also specified. The QAM family has shown more usefulness in indoor short range than the BPSK family which tend to diminish with reduced distance.

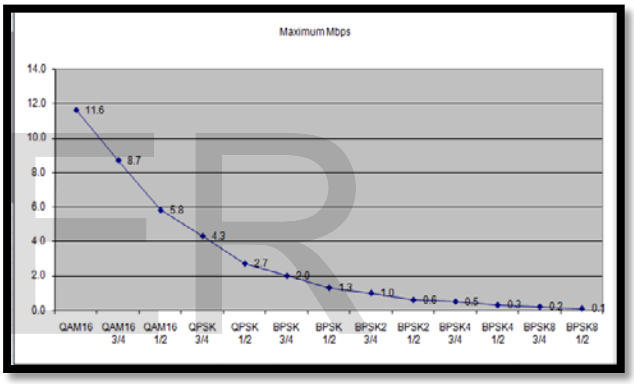

Fig. 12 – the graph of different modulation schemes, codes, distances and throughputs.

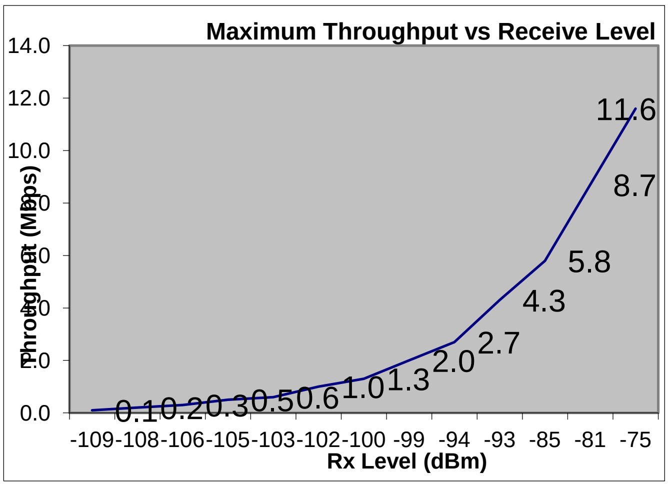

Fig. 13 graph of maximum throughput (Mbps) against RSS (dBm)

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The noise floor with an 8 MHz channel is -101 dBm. With 2x, 4x, and 8x spreading, the noise floors drops approximately to -104 dBm, -107, -110 dBm, respectively. Spreading techniques are not used with 802.22 or 802.11af systems though. Those are unique to Gen2 radios, and not very useful in real-world applications, as the system bandwidth is very low.
The radios used for Gen2 were originally designed for M2M communications, using smaller channel with spreading, allowing much lower noise floors, for M2M connection over longer distances with lower power consumption.

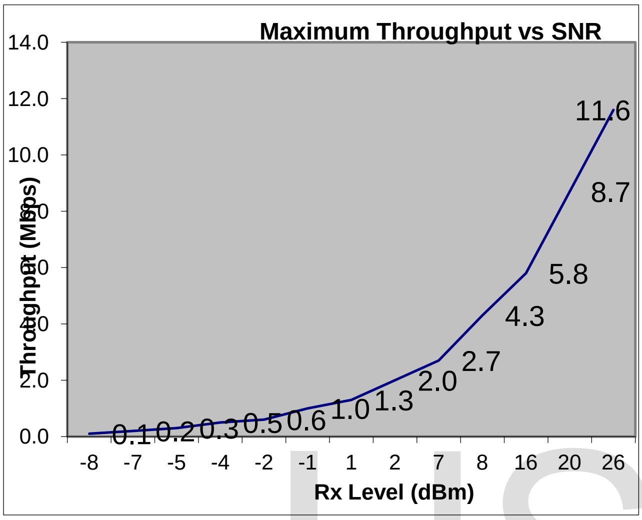

Fig. 14 graph of throughput (Mbps) against SNR (dBm)

The negative SNRs are not actual SNRs. They are what are shown in the web interface, seemingly based on a fixed noise floor.
The numbers are based on gross Ethernet throughput, not including 2nd and 3rd layer overhead and when tested TCP throughput it is up to 85-95% of the max.

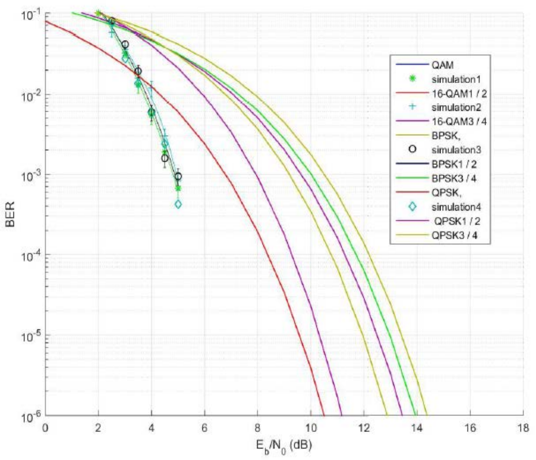

Fig. 15 - Graph of BER vs E_b/N_o for different modulation types

CONCLUSION

T research work implemented the OFDM model of Wireless Communication and a number of modulation schemes are used such as the BPSK,16-QAM, QPSK etc. The various performance parameters like BER, SNR etc are evaluated. We studied and analyzed the performances of OFDM technique under various modulation schemes. The MATLAB software was used for the implementation of this research work. It contains a wide range of functions in order to study, analyze and simulate the various kinds of communications system. This research work studies the vagaries of a Rayleigh fading channel that are most widely researched models of fading channels. The OFDM system was simulated with an attempt to single out the performance of various modulation techniques under Rayleigh Channel environment. The key inferences from this research work are that BER is the key parameter for indicating the system performance of any data link. The BER vs SNR plot for various modulation techniques shows that for higher order modulation schemes the BER increases with increasing SNR. On the other hand, the lower order modulation schemes (BPSK and QPSK) experience less BER at receiver thus lower order modulations improve the system performance in terms of BER and SNR.
Future work is in progress in Nigeria as part of developing country. This is to know if whether conditions can affect both device and signal propagation characteristics.

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