Comparison analysis between IEEE 802.11a/b/g/n

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Abstract— 802.11 refers to a family of specifications developed by the IEEE for wireless LAN technology. IEEE accepted the specification for 802.11 in 1997. Wireless Local Area Network (WLAN) has become popular in the home due to ease of installation, and the increasing popularity of laptop computers. WLAN is based on IEEE 802.11 standard and is also known as Wireless Fidelity (WiFi) [1]. The task groups within the 802.11 working group have produced few extensions to the original specifications. The products of these extensions are named after the task group and the original specification for example, 802.11b is an extension developed by the task group b. The most popular extensions of 802.11 specifications are 802.11b, 802.11a, 802.11g and 802.11n. This article represents the major differences between various 802.11 standards, their operation, interoperability, and deployment constraints.

Index Terms— Wi-Fi technology, IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE802.11n, CCK, DSSS, OFDM, & MATLAB.

1 INTRODUCTION

The 802.11 standard specifies wireless LANs that provide up to 2 Mbps of transmission speed and operate in the 2.4–GHz Industrial, Scientific, and Medical (ISM) band using either frequency–hopping spread spectrum (FHSS) or direct–sequence spread spectrum (DSSS). The IEEE approved this standard in 1997. The standard defines a physical layer (PHY), a medium access control (MAC) layer, the security primitives, and the basic operation modes [2].

The 802.11 Working Group realized that the initial standard that was passed in 1997 would not be sufficient to attract implementers. Therefore, the working group established various task groups with the responsibilities to develop different extensions to the 802.11 standard. The idea behind having different task groups is to develop standards for different types of usage scenarios that still conform to a basic set of operating rules and are still interoperable to a certain extent. The most promising standards at this time include 802.11b, 802.11a, 802.11g, and 802.11n.

IEEE 802.11b is an extension to 802.11 that operates at speeds up to 11 Mbps transmission (with a fallback to 5.5, 2, and 1 Mbps) in the 2.4–GHz band and uses only DSSS. IEEE 802.11b is also known as 802.11 high rate or wireless fidelity (Wi–Fi) [3].

The 802.11a standard was approved in December 1999, right around the same time as 802.11b was approved. 802.11a is an extension to 802.11, which operates at speeds of up to 54–Mbps transmission rate (with a fallback to 48, 36, 24, 18, 12, and 6 Mbps) in the more recently allocated 5–GHz Unlicensed National Information Infrastructure (UNII) band. 802.11a uses an Orthogonal Frequency Division Multiplexing (OFDM) encoding scheme as its spread spectrum technology.

The 802.11g standard operates in the 2.4–GHz band and provides speeds up to 54 Mbps (with a fallback to 48, 36, 24, 18, 11, 5.5, 2, and 1 Mbps). The 802.11g differs from 802.11b because it can optionally use OFDM (802.11g draft mandates that OFDM be used for speeds above 20 Mbps).

The IEEE 802.11n channel models are designed for indoor wireless local area networks for bandwidths of up to 100 MHz, at frequencies of 2 and 5 GHz. Table-1 shows the basic difference between the parameter of different extensions of WLAN 802.11.

TABLE-1
Basic difference between the parameter of 802.11a /b/g/n

Parameters	802.11a	802.11b	802.11g	802.11n
CWmin	16	31	32	15
CWmax	1024	1024	1024	1024
Slot time	9 µs	20 µs	20 µs	9 µs
SIFS	16 µs	10 µs	10 µs	16 µs
DIFS	34 µs	50 µs	50 µs	34 µs
Propagation Delay	1 µs	1 µs	1 µs	1 µs
Basic Rate	1000 Bytes	1000 Bytes	1000 Bytes	1000 Bytes
MAC Header	28 Bytes	28 Bytes	28 Bytes	28 Bytes
RTS Packet	44 Bytes	44 Bytes	44 Bytes	44 Bytes
CTS Packet	38 Bytes	38 Bytes	38 Bytes	38 Bytes
ACK Packet	38 Bytes	38 Bytes	38 Bytes	38 Bytes
PHY Header	24 Bytes	24 Bytes	24 Bytes	24 Bytes

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2 Discussion about various extensions

2.1 802.11b Limitations

802.11b is haunted by the possibility of interference in the 2.4–GHz frequency band in which it operates. However, the 2.4–GHz frequency is already crowded and will soon be more so. An even greater threat to 802.11b stability is just around the corner. Blue–tooth, the short–range wireless networking standard, which also operates in the 2.4–GHz range, is slated to coexist with wireless LANs. Bluetooth is not bothered a bit by 802.11b signals, but not vice versa. Depending on the proximity and number of devices, Bluetooth can have a negative impact on the performance of an 802.11b connection due to electromagnetic interference caused by the Bluetooth devices. Fig -1 shows the bit error rate versus Es/N0 at different data rate for 802.11b extension. The bit error rates for different data rate are shown in table-2.

2.1.1 802.11b interoperability and compatibility with 802.11

802.11b devices are backward compatible with 802.11 implementations, which use the DSSS as their spectrum technology. Therefore, 802.11b devices operate at lower speeds when they are connected to an 802.11 network. 802.11b devices are not compatible with the HomeRF devices because HomeRF uses the FHSS standard.

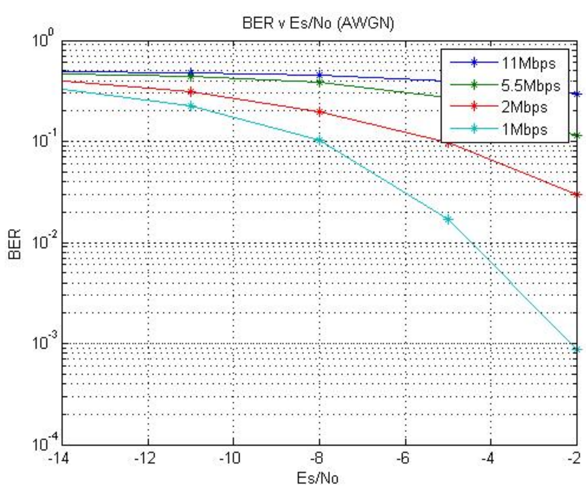

Fig. 1 BER rate for IEEE 802.11b on different data rate using AWGN channel

2.1.2 Direct–Sequence Spread Spectrum (DSSS)

In DSSS the information-bearing signal is multiplied directly by a high chip rate spreading code. **T**he transmission signal is spread over an allowed band [4]. The data is transmitted by first modulating a binary string called spreading code. A random binary string is used to modulate the transmitted signal. This random string is called the spreading code. The transmitter and the receiver must be synchronized with the same spreading code. Recovery is faster in DSSS systems because of the ability to spread the signal over a wider band.

TABLE -2
BER rate for IEEE 802.11b

E_s/N_0	BER@ (1Mbps)	BER@ (2Mbps)	BER@ (5.5Mbps)	BER@ (10Mbps)
-14	.3312	.3913	.4705	.4868
-11	.2222	.3074	.4380	.4722
-8	.1022	.1980	.3814	.4480
-5	.0168	.0974	.2711	.3930
-2	.0009	.0300	.1142	.2946

2.1.3 Frequency–Hopping Spread Spectrum (FHSS)

The carrier frequency at which the information bearing signal is transmitted is rapidly changed according to the spreading code. The transmitter then hops between the sub channels sending out short bursts of data for a given time. In order for FHSS to work correctly, both communicating ends must be synchronized otherwise they lose the data. FHSS is more resistant to interference because of its hopping nature.

2.2 IEEE 802.11a

802.11a is an extension to 802.11, which operates at speeds of up to 54–Mbps transmission rate (with a fallback to 48, 36, 24, 18, 12, and 6 Mbps) in the more recently allocated 5–GHz Unlicensed National Information Infrastructure (UNII) band. 802.11a uses an Orthogonal Frequency Division Multiplexing (OFDM) encoding scheme as its spread spectrum technology.

2.2.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM technique distributes the data to be transmitted into smaller pieces, which are simultaneously transmitted over multiple frequency channels that are spaced apart. This spacing provides

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the orthogonality that prevents the demodulators from seeing frequencies other than their own. When transmitting data using OFDM [5], the data is first divided into frames and a mathematical algorithm known as Fast Fourier Transformation (FFT) is applied to the frame, then OFDM parameters (for example, timing) are added. An Inverse Fast Fourier Transformation (IFFT) is then applied on each frame. The resulting frames are then transmitted over the designated frequencies. A receiver performs the inverse operations to get the transmitted data by performing FFT on the frames. The benefits of OFDM are high spectral efficiency, resiliency to RF interference, and lower multipath distortion.

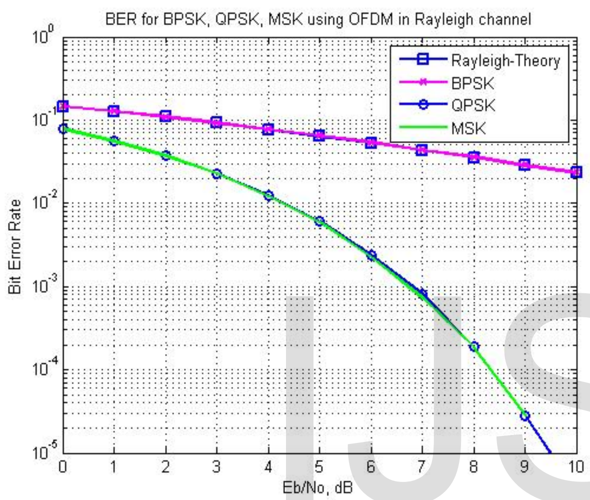

Fig. 2 BER rate for different modulation using Rayleigh channel for 802.11a

Fig -2 shows the bit error rate versus Eb/N0 comparison between different modulation techniques using Rayleigh channel for 802.11a extension. The bit error rate for different modulation techniques are shown in table-3.

2.3 802.11g

IEEE 802.11 adopted the 802.11g standard in late 2001. The 802.11g [6] standard is still under development. The 802.11g standard operates in the 2.4–GHz band and provides speeds up to 54 Mbps (with a fallback to 48, 36, 24, 18, 11, 5.5, 2, and 1 Mbps). The 802.11g differs from 802.11b because it can optionally use OFDM [7]. The most important enhancement offered by 802.11g is its higher speed. The ability to operate up to 54 Mbps provides 802.11g a higher edge over other 802.11 compliant devices that operate in the 2.4–GHz band. The support of OFDM is another enhancement that 802.11g maintains over the basic 802.11 standard.Fig.3 shows the BER/SNR plot for IEEE 802.11g and table-4 shows values of SNR for different values of BER.

TABLE -3
BER rate for different modulation using Rayleigh channel for 802.11a

E_b/N_o(dB)	Rayleigh theory	BPSK	QPSK	MSK
0	0.1464	0.1445	0.0788	0.0788
1	0.1267	0.1275	0.0561	0.0562
2	0.1085	0.1088	0.0374	0.0374
3	0.0919	0.0913	0.0229	0.0227
4	0.0771	0.0768	0.0127	0.0124
5	0.0642	0.0642	0.0060	0.0059
6	0.0530	0.0524	0.0024	0.0023
7	0.0435	0.0437	0.0008	0.0008
8	0.0355	0.0356	0.0002	0.0002
9	0.0288	0.0292	0.0000	0.0000
9.5	0.0233	0.0232	0.0000	0.0000

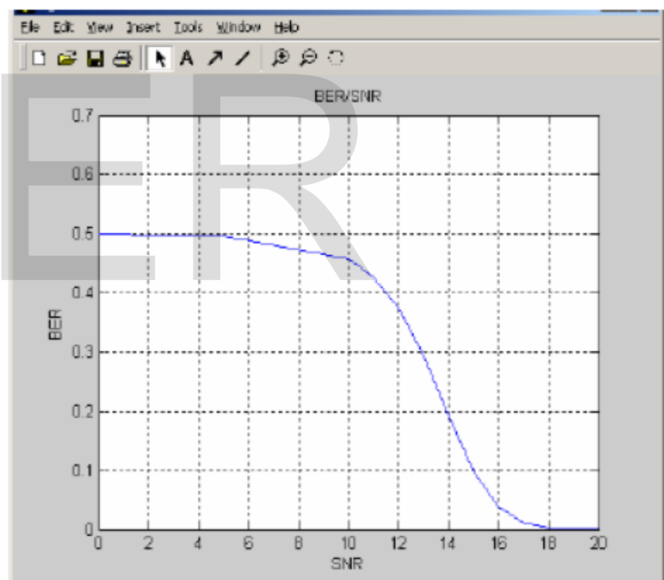

Fig. 3 BER rate for 802.11g using OQPSK modulation

2.3.1 802.11g Applications

The 802.11g devices are not available yet. However, electrical industry analysts predict that when 802.11g becomes available, it would be the only choice that users would consider, as it provides the direct upgrade path and interoperability with the 802.11b standard devices.

2.3.2 802.11g Limitations

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Though 802.11g devices would provide higher speed than the currently available 802.11b devices, it still suffers the interference issue with other devices operating in the same RF band; primarily the Bluetooth devices.

TABLE -4
SNR/BER using OQPSK modulation for IEEE 802.11g

SNR	BER
0	0.50
2	0.50
4	0.48
6	0.47
8	0.46
10	0.45
12	0.37
14	0.22
16	0.04
18	0.01

2.4 IEEE 802.11n

The IEEE 802.11n amendment is the latest addition under development for the IEEE 802.11 standard providing a marked increase in throughput (from 20 Mbps to around 200 Mbps, in practice) as well as range of reception (through reducing signal fading) over the IEEE 802.11a/g standards currently in use. Multiple antennas, or MIMO (Multiple-Input, Multiple-Output), is the key innovation used to obtain these benefits. The current draft for the IEEE 802.11n amendment supports the use of MIMO features such as spatial-division multiplexing (SDM) [8], space-time block coding (STBC) and transmitter beam forming. In addition, there are provisions for the use of advanced coding with LDPC (low-density parity check codes), as well as a 40 MHz bandwidth mode (known as channel bonding). The above features allow the IEEE 802.11n amendment to specify data rates up to 600 Mbps, a more than ten-fold increase over the maximum data rate with the 11a/g standards.

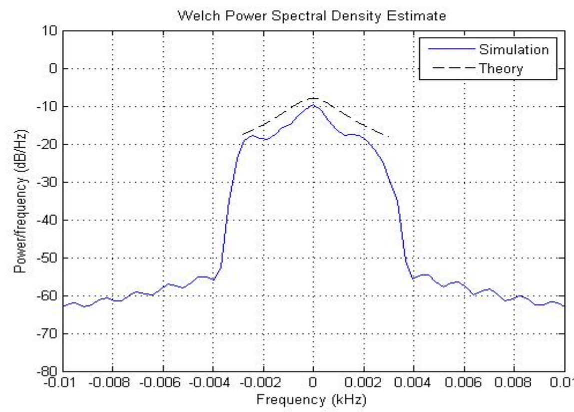

Fig.4 Welch power spectral density estimate for antenna 1 in 802.11n

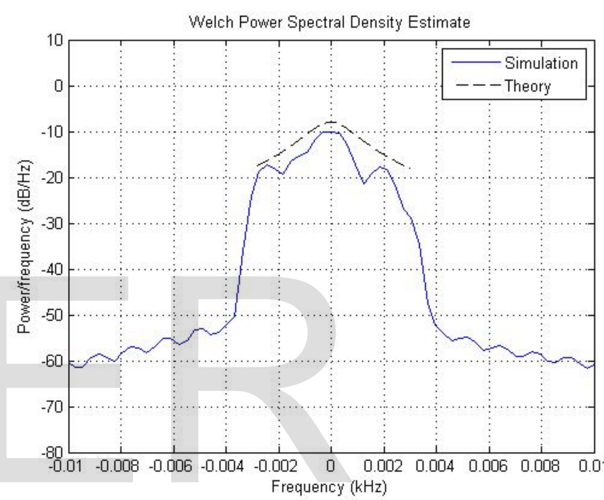

Fig.5 Welch power spectral density estimate for antenna 2 in 802.11n

TABLE- 5
Comparison between different versions of 802.11

Parameter	802.11a	802.11b	802.11g	802.11n
Operating frequencies	5 GHz U-NII band	2.4 GHz ISM band	2.4 GHz ISM band	2.4/5 GHz ISM band
Modulation techniques	OFDM	DSSS	DSSS/OFDM	OFDM & MIMO
Data rates (Mbps)	6,9,12,18,24,36, 48,54	1,2,5.5, 11	1,2,5.5,11, 6,9,12,18,24,36, 48,54	108-600
Max. range	500ft	1000ft	1000ft	2000ft

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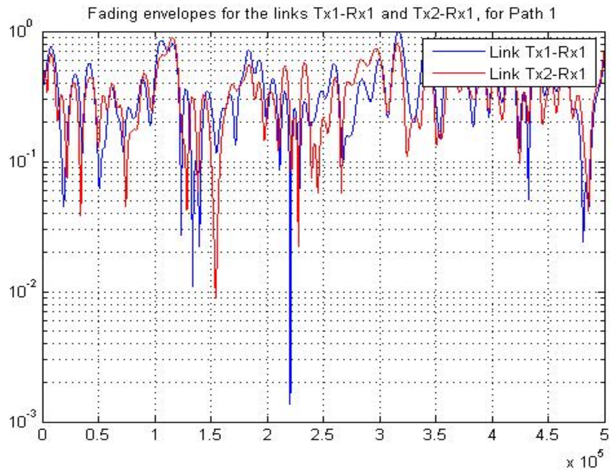

Fig.6 Fading envelopes for Tx1-Rx1 and Tx2-Rx1 for 802.11n

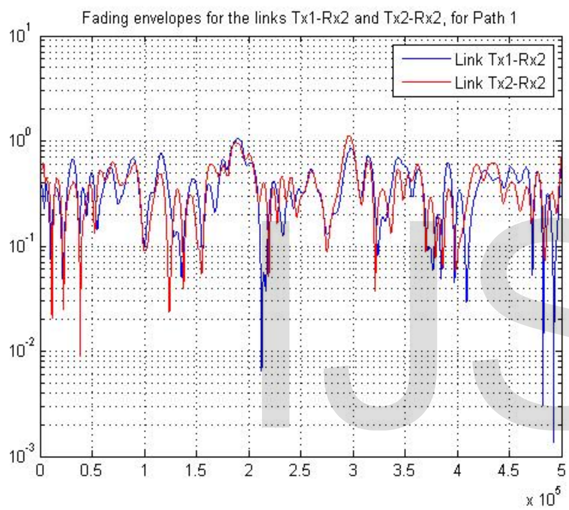

Fig.7 Fading envelopes for Tx1-Rx2 and Tx2-Rx2 for 802.11n

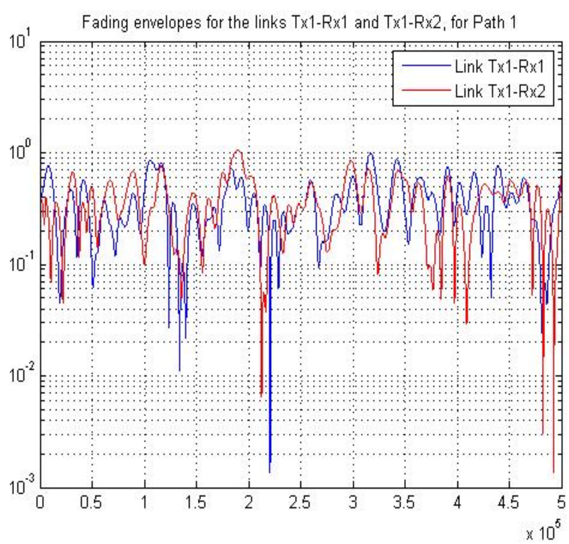

Fig.8 Fading envelopes for Tx1-Rx1 and Tx1-Rx2 for 802.11n

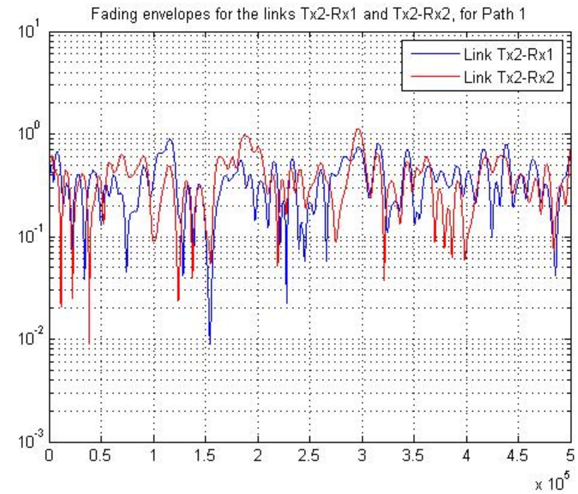

Fig.9 Fading envelopes for Tx2-Rx1 and Tx2-Rx2 for 802.11n

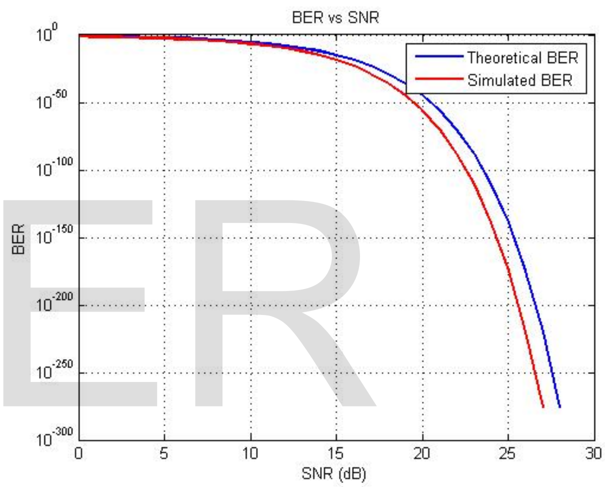

Fig. 10 BER rate for 802.11n using MIMO

2.4.1 MIMO Channel

MIMO exploits the use of multiple signals transmitted into the wireless medium and multiple signals received from the wireless medium to improve wireless performance [9]. MIMO can provide many benefits, all derived from the ability to process spatially different signals simultaneously. Two important benefits explored here are antenna diversity and spatial multiplexing. Using multiple antennas, MIMO technology offers the ability to coherently resolve information from multiple signal paths using spatially separated receive antennas.

Multipath signals are the reflected signals arriving at the receiver some time after the original or line of sight (LOS) signal has been received. Multipath is typically perceived as interference degrading a receiver's ability to recover the intelligent information. MIMO enables the opportunity to spatially resolve multipath signals, providing diversity gain that contributes to a receiver's ability to recover the intelligent information. Fig.4 to Fig.9 shows spectral power density curve and fading envelops for different pair of antennas for IEEE 802.11n and Fig.10 shows improved bit error rate by using mimo system in IEEE 802.11n.

Table -5 shows the comparison between different extensions of IEEE 802.11 by using different parameters like operating frequencies, modulation techniques, data rates, range etc.

3 Conclusion

In this paper we have analyzed the different extensions of IEEE 802.11 (802.11a, 802.11b, 802.11g, 802.11n), their performance results and compared all these technologies on the basis of their data rates, range, modulation techniques used and operating frequency band. Also we have discussed the bit error rate versus bit/symbol energy to noise ratio plots & described the BER for different modulation techniques that has been used in different extensions of 802.11.

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