Anbar Journal Of Engineering Science©
ISSN:1997-9428

Study of WMAN Physical Layer under Fading Channels

Hatem Fahad Frayyeh*
Electrical Department, College of Engineering
University of Anbar, Iraq

ABSTRACT

WMAN (wireless metropolitan area network) technology is based on the IEEE 802.16 air interface standard suite, which provides the wireless technology for fixed and nomadic data access. WMAN employs orthogonal frequency division multiplexing (OFDM), and supports adaptive modulation and coding depending on the channel conditions. The objective of this paper is to study the performance of the IEEE 802.16d WMAN physical layer under Nakagami model as a Multi-path and frequency-selective fading channel beside the additive white Gaussian noise (AWGN) and Doppler. Finally, we compared it with the Rayleigh fading model. The transmission bit rate, Probability of Error (P_e) and estimated SNR have been compared under single/multi path propagation conditions.

KEYWORDS: IEEE 802.16d, WMAN, OFDM, Frequency-selective, Rice, Nakagami, Rayleigh, Fading.

. Introduction

IEEE 802.16 standard is a promising wireless technology that has several desirable characteristics that make it a viable alternative to form wireless backhaul networks. First, it supports very high data rates which enable it to carry a large amount of traffic – a basic requirement for the next generation backhaul network. Second, it allows communication over large distances of the order of several miles both in Line-of-sight and Non-line-of-sight modes. Third, its wireless nature reduces the deployment and maintenance cost especially in providing wireless access in rural areas [1].

In any wireless communication channel there can be more than one path in which the signal can travel between the transmitter and receiver antennas. The presence of multiple paths may be due to atmospheric reflection or refraction, or reflections from buildings and other objects. Multipath and/or fading may occur in all radio communication systems. Several statistical models are available for describing the fading envelope of the received signal, among these the Rayleigh model agrees very well with experimental data for multipath propagation where no line of sight (NLOS) path exists between the transmitter and receiver antennas

Corresponding Author Email: hatemfahd57@gmail.com

This applies to macro-cellular radio mobile systems as well as to tropospheric and ionospheric communication. Other models include the Nakagami, which applies to LOS paths of microcellular urban and suburban land mobile and pico-cellular indoor as well as to the dominant LOS path of satellite radio links. But on the other hand, the most versatile statistical model is that of the Nakagami-m which can model a variety of fading environments, where it closely approximates the Nakagami-n models. It also gives the best fit to mobile multi-path propagation [2].

The Rayleigh fading model is known to be a reasonable assumption for the fading encountered in many wireless communications systems.

Nevertheless, many measurements campaigns show that the Nakagami-*m* distribution provides a much better fitting for the fading channel distribution. In fact, since the Nakagami-*m* distribution has one more free parameter, it allows for more flexibility. It moreover contains both the Rayleigh distribution $(m = 1)$ and the uniform distribution on the unit circle $(m \to \infty)$ as special (extreme) cases [3, 4].

Nakagami environment was considered in some studies in analyzing various wireless systems, such as [5] and [4]. Singh [6] analyzed the BER and the spectral efficiency of the 802.16e WiMAX per modulation scheme. Hussein [7] studied the performance of the physical layer of the IEEE802.11a WLAN under the Nakagami-Rice channel models as multipath fading channels. In this paper, we consider Nakagami and Rayleigh channel models as multipath channel models, and test and compare the performances of the IEEE 802.16d WMAN PHY layer under these channels, taking into account the adaptive rating according to the estimated SNR at the receiver

2. Multi-path Fading Channel

A defining characteristic of wireless communication channels is the variation of the channel strength over time and over frequency, which is usually termed as “fading”. The fading effect is usually divided into two types, namely large-scale fading, mainly due to path loss as a function of distance and shadowing by large objects such as mountains and tall buildings, and small-scale fading, due to the constructive and destructive combination of randomly scattered, reflected, diffracted, and delayed multiple path signals [8].

2.1 Rayleigh Fading

For small-scale fading, Rayleigh fading is probably one of the most frequently used models. It provides a good fit for multipath fading channels with no direct line-of-sight (LOS) path. The channel fading amplitude α is distributed according to [7]

$$p(\alpha) = 2\alpha/\Omega \ \exp[-\alpha^2/\Omega] \ , \quad \alpha \geq 0 \qquad (1)$$

where $\Omega = \mathrm{E}\{\alpha^2\}$ is the mean value.

2.2 Rician Fading

In contrast to Rayleigh fading, Rician fading is often used to model propagation paths consisting of one strong direct LOS component and many random weaker components. The channel fading amplitude distribution can be expressed as [8]

$$p(r) = \frac{2(1+n^2)e^{-n^2}r}{\Omega} \exp\left(-\frac{(1+n^2)r^2}{\Omega}\right) I_0 \left(2nr\sqrt{\frac{1+n^2}{\Omega}}\right) , \quad r \geq 0 \qquad (2)$$

where n is the fading parameter, which ranges from 0 to ∞, and is related to the Rician K factor by $K = n^2$ which corresponding to the ratio of the power of the LOS component to the average power of the scattered component. $I_0(\cdot)$ is the Bessel function of the first kind.

2.3 Nakagami-m Fading

Nakagami-m fading is a more general fading distribution, which encompasses Rayleigh distribution as a special case, and can approximate well the Rician distribution. The channel fading amplitude distribution is given by [9]

$$\mathrm{p}(r) = \frac{2m^m r^{2m-1}}{\Omega^m \Gamma(m)} \exp\left[-\frac{r^2}{\Omega}\right] , \quad r \geq 0 \qquad (3)$$

where m is the fading parameter, which ranges from 1/2 to ∞. When m = 1, Nakagami-m distribution reduces to Rayleigh distribution. Moreover, the Rician distribution can be approximated by Nakagami-m distribution via a one-to-one mapping between the m parameter and the K parameter as follows [10]:

$$m = \frac{(1+K)^2}{1+2K} \quad , \quad K \geq 0 \qquad (4)$$

Or

$$K = \frac{\sqrt{m^2-m}}{m-\sqrt{m^2-m}} \quad , \quad m \geq 1 \qquad (5)$$

The Nakagami-m distribution is a general, but approximate solution to the random phase problem [9]. The exact solution to this problem involves the knowledge of the distribution and the correlations of all of the partial waves composing the total signal and becomes infeasible due to its complexity [3]. This has been circumvented by Nakagami [9] who, through empirical methods based on field measurements followed by a curve-fitting process, obtained the approximate distribution.

3. IEEE 802.16d WMAN

The IEEE 802.16 standard approved in 2001 specifies the air interface and medium-access-control (MAC) protocol for WMAN [11]**.** The idea there is to provide broadband wireless access to buildings through external antennas communicating with radio base stations (BSs). The wireless MAN thus offers an alternative to fiber optic link, cable modem, and digital subscriber loop. Using the new standard, home and business users can be connected via radio links directly to telecommunication networks and Internet.

3.1 IEEE 802.16d Physical Layer (PHY) Design

One of the PHY layers that are defined by the IEEE 802.16d (also called 802.16-2004) is the Wireless MAN OFDM, which can be used with the MAC layer to develop a broadband wireless system. Wireless MAN OFDM is a 256-point FFT-based OFDM PHY layer for point-to-multipoint operations in non-LOS conditions at frequencies between 2GHz and 11GHz. This PHY layer has been accepted by WiMAX for fixed operations and is often referred to as *fixed WiMAX* [12].

3.2 OFDM

The orthogonal frequency division multiplexing (OFDM) transmission scheme has gained in popularity due to its many advantages. These advantages include its ability to mitigate the effects of multipath and frequency-selectivity. Parallel OFDM transmission in an allocated frequency band is accomplished by subdividing the available bandwidth into numerous narrow sub-bands. Spectra of the individual sub-channels overlap which allows the bandwidth to be used more efficiently. The withstanding propagation channel impairments that degrade the performance of OFDM include attenuation, additive noise, multipath effects, and Doppler spreading. These impairments cause severe degradation in error rates. Consequently, channel state information is required for the OFDM receiver to perform coherent detection [5].

OFDM is based on the idea of dividing a given high-bit-rate data stream into several parallel lower bit-rate streams and modulating each stream on separate subcarriers, the subcarriers are selected such that they are all orthogonal to one another over the symbol duration [6], as shown in **Fig. 1**. Multicarrier modulation schemes minimize inter-symbol interference (ISI) by making the symbol time large enough so that the channel-induced delays. The sub-channel spectra overlap each other but the sub-carriers are still orthogonal in the receiver and can therefore be separated by a Fourier transformation [13].

The OFDM transmission technique can efficiently deal with multi-path propagation effects. The time duration of an OFDM symbol is composed of the useful symbol time T_b and the cyclic prefix (CP) time T_g. The cyclic prefix is a duplication of the tail part of the useful symbol and placed in the beginning of the symbol. With proper duration T_g, it may efficiently mitigate the effect of multipath. From frequency domain viewpoint, an OFDM symbol is made up from a series of subcarriers as shown in**Fig. 2**.

3.3 Channel Rate Selection Scheme

WMAN supports Adaptive Modulation and Coding (AMC) mechanism to achieve efficient bandwidth utilization. We introduce AMC design for time-vary wireless channel [14] similar to the traditional model. The objective of AMC is to maximize the channel data rate by adjusting transmission mode to the channel variation while maintaining a prescribed packet error rate (PER, P_o).

IEEE 802.16 provides seven physical modes with various modulations and coding rate operating based on OFDM technology. BPSK, QPSK, 16QAM and 64QAM modulations with convolution coding in different rates provide capabilities of communicating at different channel data rate, as shown in **Table 1**.

To model the physical channel, we suppose that the channel is frequency flat and remains invariant per frame. Therefore, channel quality can be expressed by the received Signal to Noise Ratio (SNR) and, the general Nakagami-m model can be applied to this channel. To model a slow Nakagami fading channel, a Finite State Markov Channel (FSMC) with z+1 states is assumed. The received SNR(γ) at the receiver is partitioned into the finite number of non-overlapping consecutive intervals. Let $\gamma_0 < \gamma_1 < \cdots < \gamma_{z+1}$ be the thresholds of the received SNR for different states. The channel is said to be in the state n if $\gamma_n < \gamma < \gamma_{n+1}$ where n = 0,1 , ... z. To avoid deep channel fades, no data are sent when $\gamma_0 < \gamma < \gamma_1$ (mode 0). Suppose seven transmission modes introduced in IEEE802.16 are corresponding to the states of a FSMC (with 8 states). It means that when the channel is in the state n, mode n will be used and packets will be transmitted with the channel data rate associated with that mode. [15]

Now, to find out the thresholds and the state transition matrix of the FSMC, first, average packet error rate is computed. Since there is no exact closed-form expression for the Packet Error Rate (PER) in coded modulations. In this study, without loss of generality, the upper bounds of PER equations [16] are utilized and for simplicity approximated with the following formula [14]:

$$\mathrm{PER}_n(\gamma) = \begin{cases} 1 & \text{if } 0 < \gamma < \gamma_{th} \\ a_n e^{-\gamma g_n} & \text{if } \gamma \geq \gamma_{th} \end{cases} \quad (6)$$

where, n is mode index, a_n, g_n and γ_{th} are constant parameters which are determined through the fitting algorithm. Average PER in mode n, $\overline{\mathrm{PER}_n}$, is found to be [14]:

$$\overline{\mathrm{PER}_n} = \frac{1}{\Pr(n)} \frac{a_n}{\Gamma(m)} \left(\frac{m}{\bar{\gamma}}\right)^m \frac{\Gamma[m, (m\sqrt{\gamma} + \mathrm{g}_n) \cdot \gamma_n] - \Gamma[m, (m\sqrt{\gamma} + \mathrm{g}_n)}{(m\sqrt{\gamma} + \mathrm{g}_n)^m} \quad (7)$$

$$= 1,2, \ldots, K$$

$$\Pr(n) = \frac{\Gamma[m, \gamma_n m\sqrt{\gamma}] - \Gamma[m, \gamma_{n+1} m\sqrt{\gamma}]}{\Gamma(m)} \quad (8$$

where, $\bar{\gamma}$ represents average received SNR, m denotes the Nakagami fading parameter (Rayleigh channel $m = 1$). $\Pr(n)$ denotes probability of chosen mode n, $\Gamma[m, x]$ is the complementary incomplete Gamma function and $\Gamma(m)$ is Gamma function.

Similar to [14], it is assumed that the average PER is the same and equals to a prescribed target packet error in all modes ($\overline{\mathrm{PER}_n} = P_e$). Therefore, the received SNR thresholds can be calculated with the assumption $\gamma_{n+1} = \infty$, $\gamma_0 = 0$ and above equation through a simple searching algorithm. Finally, using the determined thresholds, the BS can easily find out channel mode once receives SNR. [14, 17] give more details about the computing of thresholds and state transition matrix of the FSMC from.

For each transmission step, several bits are coded on each subcarrier. When clear line of sight exists between sender and receiver over very short distances, 64-QAM (quadrature amplitude modulation) is used, which codes six bits on a single subcarrier. Under harsher conditions, less demanding modulation schemes like 16-QAM, QPSK and BPSK are used, which code fewer bits on a subcarrier per transmission step. **Fig. 3** illustrates the different modulation schemes and the signal-to-interference-plus-noise ratio (SINR) required for each.

Different combinations of modulation and FEC result in different block sizes and code rates, IEEE802.16-2004 WirelessMAN-OFDM PHY defines seven combinations (modes) of mandatory channel coding per modulation, which are listed in **Table 1**. For later reference convenience, they are numbered as Mode 1 to Mode 7. When the modulation is done, modulated data are multiplexed by OFDM [11].

Table 1 Data rates for the different configurations mandatory modulation / coding modes [11].

Mode Index	Modulation	Block size (bytes) Uncoded	Coded	RS code	CC code rate
1	BPSK	12	24	(12,12,0)	1/2
2	QPSK	24	48	(32,24,4)	2/3
3	QPSK	36	48	(40,36,2)	5/6
4	16-QAM	48	96	(64,48,8)	2/3
5	16-QAM	72	96	(80,72,4)	5/6
6	64-QAM	96	144	(108,96,6)	3/4
7	64-QAM	108	144	(120,108,6)	5/6

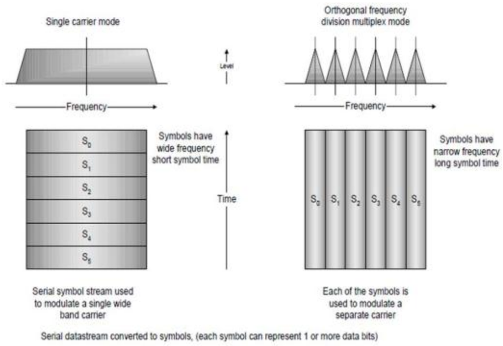

Figure. 1 (A) Single carrier and OFDM

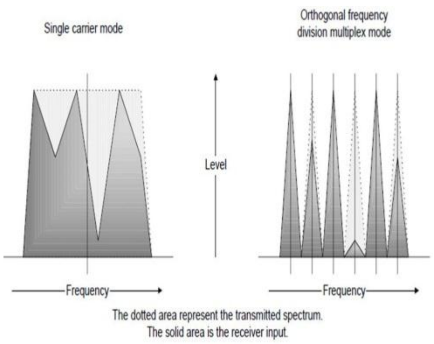

Figure. 1 (B) Single carrier and OFDM received signals

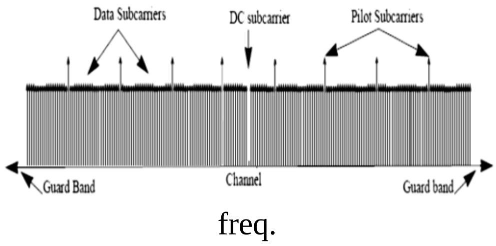

Figure. 2. OFDM symbol Frequency domain structure [18].

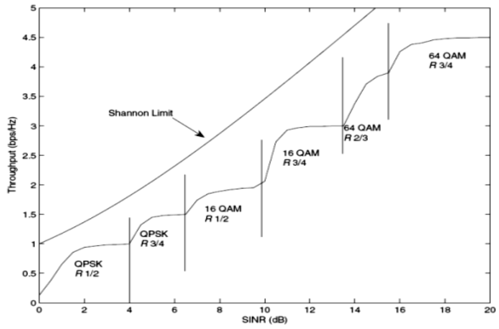

Figure. 3 Illustration of adaptive rating: throughput versus SINR [19].

4. Simulation Parameters

The current model, which supports all data rates, is used to simulate the PHY layer performance via adaptive modulation and coding over the multipath fading channels. The communication system in the simulation performs these tasks:

1. Forward Error Correction (FEC), consisting of a Reed-Solomon (RS) outer code concatenated with a rate-compatible inner convolutional code (CC).
2. Data interleaving is used to improve the capabilities of FEC algorithms.
3. Bit randomization is used to minimize the possibility of long sequences of one's or zero's [18].
4. Modulation, using one of the BPSK, QPSK, 16-QAM or 64-QAM constellations specified.
5. Orthogonal Frequency Division Multiplexed (OFDM) transmission using 256 sub-carriers: (192 for data,

8 for pilots and 56 are guard band subcarriers), 256-point FFTs, and a Cyclic prefix factor (G) of 1/8.

6. A single OFDM symbol length preamble that is used as the burst preamble.
7. A choice of non-fading, flat-fading or dispersive multipath fading channel for the model.
8. OFDM receiver that includes channel estimation using the inserted preambles.
9. Hard-decision demodulation followed by deinterleaving, Viterbi decoding, and Reed-Solomon decoding.
10. Low SNR thresholds for rate control (in dB): [4, 10, 12, 19, 22, and 28].

The procedures are depicted in **Fig. 4**.

5. Simulation Results

We have applied Nakagami and Rayleigh channel models beside the AWGN as described in **Table 3** to the physical layer model of the WMAN system model. Due to the multipath phenomenon, the arriving signals to the receiver through different paths are either constructively or destructively added to each other, which results in variation in the SNR with time as noticed by the receiver. As a result, in each of the studied multipath cases, the data bit rates were variable per OFDM frame according to the instantaneous hannel SNR. For the best omparison, the length of the information data used to be transmitted at each run is set to be 600000bits. It is clear through **figs** (**5a** and **5b)** that the average modulation index and the corresponding modulation scheme (and hence the information transfer rates) are increased according to the basic channel SNR for all the types. For the flat-fading channel AWGN+Doppler), **Fig. 5a** shows that at lower values of the SNR, all the types have the same behavior against the small SNR. But as the SNR value is increased it will be easy to see the

differences, the Rayleigh channel is the lowest modulation scheme among the other types, and Rician channel type is getting better for larger values of K. the K=25 curve is almost considered as No-Fading, as the LOS component is the strongest one. The larger SNR is also results in larger ModIndex in frequency-selective fading channels as in **Fig. 5b**, it also shows that at each SNR the modulation scheme is apparently smaller than the no-fading case, this occurs due to the mentioned rapidly changing SNR. As in the flat-fading, the higher K value of Rican model results in better performance, and the Rayleigh still the worst. As a result of the SNR values getting worse, the adaptive modulation controller of the physical layer each time adjusts the operation to the next more robust modulation scheme. So, **figs (5a** and **5b)** can be translated in terms of number of OFDM frames required to transmit all the 600000 information bits at each indicated SNR, these numbers are listed in the Table (4a and 4b). It is clear that the number per certain channel type is get smaller as SNR increased due to switching to the higher ModIndex as shown in (**Table 1**). For both Flat and Frequency-selective

Table 3 Channels used in the Simulation

Flat Rayleigh Channel	Doppler , AWGN
Selective Rayleigh Channel	Three paths , Doppler , AWGN
Nakagami Channel	$K = 0, 1, 25$; Three paths , Doppler , AWGN

fading channels, at a certain SNR value the number of required OFDM frames are largest for the Rayleigh case, while it will require less frames to send the data at higher K values, and always the ultimate is highest K Rice channel

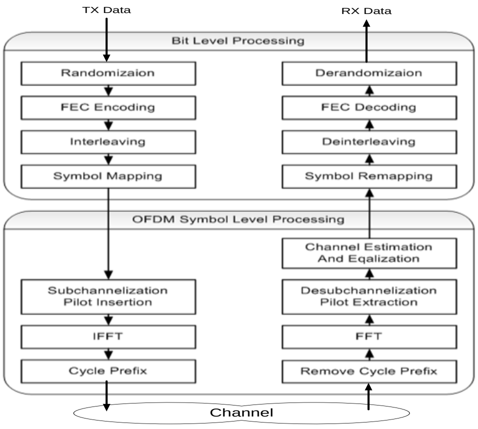

Figure. 4 IEEE 802.16 physical layer[6] .

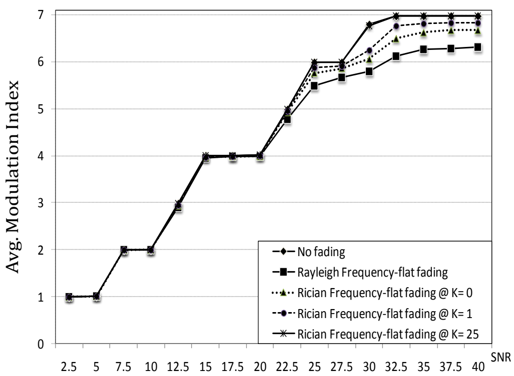

Figure. 5a Average Modindex per SNR when Flat Fading channels are used.

which almost the same of No-Fading case. Figs (**6a** and **6b)** show the probabilities of errors of the various types. The same behavior is reflected in these charts, the No-Fading at the best and the Rayleigh is the worst while the larger K value of the Rician channel results in lower Pe, the flat is much better than the frequency selective channel. The slight degradation of the Pe at some mid values of the SNR can be explained as follows: as the modulation controller noticed some improvement in the channel SNR, it orders to step forward to higher rate modulation scheme, which is less robust to the channel, the multipath phenomenon results in sudden and short decrease of the received voltage which severely affect the Pe at that modulation scheme, this will force the modulation controller to step back to the lower rate scheme which is stronger against the channel. These mid values of the SNRs are around the thresholds of the modulation schemes selection criteria.

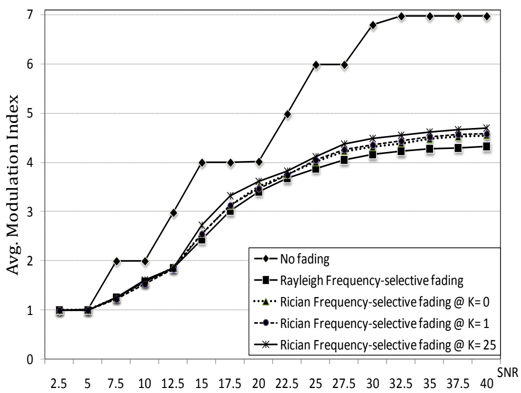

Figure. 5b Average Modindex per SNR when Frequency Selective Fading channels are used.

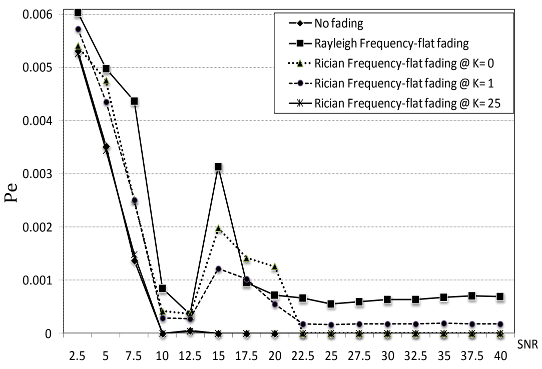

Figure. 6a Average Pe per SNR when

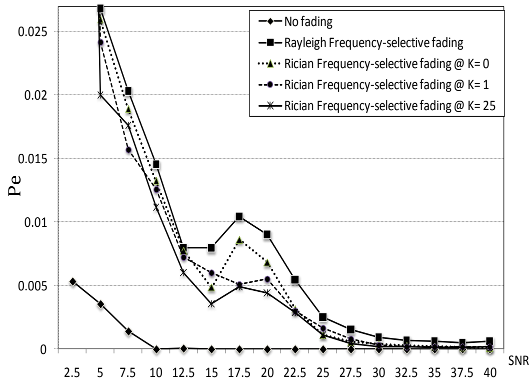

Figure. 6b Average Pe per SNR when Frequency Selective Fading channels are used.

Table 2 the parameters used in the simulation

Name	*Value*
Doppler Frequency	$f_d = 200\text{Hz}$
Channel SNR	2.5dB to 40dB at step of 2.5dB
Channel Path Gains	$[0, -5, -10]$ dB
Channel Path Delays	$[0, 0.4, 0.9]$ μs

Table 4 Number of OFDM frames needed to transmit 600000bits over different channel types and at the indicated SNR

a. Flat Fading Channels

SNR	Rayleigh + AWGN	Rician + AWGN			AWGN Only
		K= 0	K= 1	K= 25	
2.5	6819	6819	6819	6819	6819
5.0	6746	6737	6741	6750	6750
7.5	3271	3271	3266	3262	3262
10.0	3267	3264	3263	3262	3262
12.5	2216	2196	2181	2159	2160
15.0	1613	1609	1607	1598	1598
17.5	1604	1605	1603	1598	1598
20.0	1599	1599	1595	1584	1583
22.5	1140	1087	1071	1059	1059
25.0	906	840	813	793	793
27.5	860	820	808	793	793
30.0	840	797	773	722	719
32.5	803	754	727	705	705
35.0	788	742	723	705	705
37.5	785	738	722	705	705
40.0	783	737	721	705	705

b. Frequency Selective Channel

SNR	Rayleigh + AWGN	Rician + AWGN			AWGN Only
		K= 0	K= 1	K= 25	
2.5	6819	6819	6819	6819	6819
5.0	6819	6819	6819	6819	6750
7.5	5375	5411	5475	5384	3262
10.0	4192	4235	4326	4119	3262
12.5	3554	3514	3574	3527	2160
15.0	2668	2547	2545	2370	1598
17.5	2134	2065	2055	1935	1598
20.0	1882	1826	1846	1776	1583
22.5	1741	1707	1710	1670	1059
25.0	1620	1542	1509	1480	793
27.5	1511	1414	1382	1325	793
30.0	1444	1363	1337	1269	719
32.5	1401	1322	1291	1237	705
35.0	1376	1278	1253	1208	705
37.5	1364	1257	1231	1184	705
40.0	1351	1246	1225	1172	705

6. Conclusions

In this paper, we considered the channel models: Nakagami and Rayleigh as the multipath channel beside the AWGN. We also studied the behavior of the system model of the IEEE 802.16d physical layer under these channels. The performance of the WMAN as measured through its throughputs can be derived from the channel SNR manners. The channel SNR as viewed by the receiver tends to be less fluctuation as the LOS component of the Nakagami channel becomes larger. And hence the overall system performance gets better. The frequency selective Rayleigh channel has the worst performance due to the absence of a dominant component of the received multipath signals. As a result, the data rate and Pe for the case of the larger K values of Nakagami channel are superior (which the case of only AWGN). And as K value become smaller, they will approach the case of Rayleigh, which is apparently the worst.

References:

[1] Bhatnagar, S.; Ganguly, S.; Izmailov, R.; "Design of IEEE 802.16-based Multi-hop Wireless Backhaul Networks", Conference: AccessNets'06, Greece, 2006.

[2] Al-Hussien, A. S., "Performance Study of Nakagami-m Fading Channels with Correlated Unbalanced Branches," M.Sc. Thesis, Jordan University, 2003.

[3] Fraidenraich, G.; Leveque, O.; Cioffi, J.; "On the MIMO Channel Capacity for the Nakagami-m Channel", Global Telecommunications Conference, 2007.

[4] Saaifan, K. A. ; Al-Hussaini, E. K.; "Performance of MIMO System Through Nakagami Fading Channel with Arbitrary Fading Parameters", Wireless Pers Commun, 2009.

[5] Subotic, V.; Primak, S.; "BER Analysis of Equalized OFDM Systems in Nakagami, m < 1 Fading", Wireless Personal Communications, 2007.

[6] Singh, S. P.; "Spectral Efficiency and BER Analysis in 802.16e Standard", M.Sc. Thesis, Thapar University, 2010.

[7]Hussein, M. A.; "Performance study of IEEE 802.11a WLAN Physical Layer under Nakagami-Rice Fading Channel", Information Technology conference, the University of Technology, Baghdad, 2009.

[8]Zhong, C.; "Capacity and Performance Analysis of Advanced Multiple Antenna Communication Systems" , Ph.D. Thesis, University College London, 2010.

[9]Nakagami, M.; "The m-distribution - A General formula of intensity distribution of rapid fading", Statistical Methods in Radio Wave Propagation, 1960.

[10]Simon, M. G. and M. S. Alouini, “Digital communications over fading channels”, John Wiley & Sons, 2000.

[11]Li, J.; Häggman, S.; "Performance Improvement of IEEE 802.16-2004 System in Jamming Environment via Link Adaptation", IEEE Transactions on Magnetics, 2006.

[12]Karmakar, G., Dooley, L. S., "Mobile Multimedia Communications: Concepts, Applications, and Challenges," Information science reference, 2008.

[13]Parviz Yegani, ‘*WiMAX* Overview’, Presentation for the IETF-64 Conference, November 2005.

[14]Liu, Q.; Zhou, S.; Giannakis, G.B.; “Queuing with adaptive modulation and coding over wireless links: Cross-layer analysis and design”, IEEE Transactions Wireless Communication, 2005.

[15]R., Ghazizadeh; P., Fan; Y., Pan; “A Two-Layer Channel-Aware Scheduling Algoritlnn for IEEE 802.16 Broadband Wireless Access Systems”, Journal of Applied Sciences, Asian Network for Scientific Information, 2009.

[16]Proakis, J., "Digital Communications," 4th ed. McGraw-Hill. 2001.

[17]Liu. Q.; Wang, X.; Giannakis , G.; “A crosslayer Scheduling algorithm with QoS support in wireless networks”. IEEE Transactions Vehicular Technology, 2006.

[18]Schenk, T., "RF Imperfections in High-Rate Wireless Systems, Impact and Digital Compensation." Springer, 2008.

[19]Andrews, J. G.; Ghosh, A.; Muhamed, R., "Fundamentals of WiMAX: Understanding Broadband Wireless Networking", Pearson Education, 2007.

الخلاصة

التوصيل اللاسلكي و نقل البيانات بسرعات متغيره تعتمد على حاله الوسط الناقل. تستند WMANتوفر تقنيه
واللذي بدوره يتبنى طريقة المزج المتعامد IEEE 802.16هذه التقنيه في وسيله الاتصال اللاسلكي على نظام
) الذي يعمل بكفائة في قنوات الاتصال اللاسلكيه ذوات المسارات المتعددة. ندرس في هذا OFDMللترددات (
خلال نموذج ناكاكامي لهذه القنوات بالاضافة للضوضاء و IEEE 802.16d WMANالبحث تصرف ال
المخمنة SNRظاهرة دوبلر و مقارنة نتائجه مع استخدام نموذج ريلي. معدل نقل البيانات واحتمالية الخطأ وال
قد درست وتم مقارنتها تحت وسط ناقل منفرد وآخر متعدد

.