# Performance Degradation due to Phase Jitter in IEEE 802.16 Downlink Signals

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**Abstract**: A multilevel modulation with selectable constellations is adopted in the downlink subframe modulation of the IEEE 802.16 standard to increase the total throughput. One of the decision factors of the modulation is the location of SS(Subscriber Station). Also, for the 802.16, low phase noise of local oscillator is needed due to high operating frequency and severe loss in the propagation channel. We investigate the BER of downlink subframe with the phase jitter under the standard's specified LOS(line of sight) and multipath environment with randomly generated SS locations. Simulation results show BER performance degradation for the modulation corresponding to selected constellations and additionally required SNR to achieve $10^{-3}$ BER under various phase jitter.

## 1. Introduction

IEEE 802.16 working group standardized the air interface of the LAN(Local Area Network)/MAN( Metropolitan Area Network) for the Broadband wireless access (BWA) system [1]. RF propagation over frequencies 10-66GHz experiences free space loss and severe rain attenuation. Absorption by terrain and manmade structure is also severe. Under this channel environment, several techniques are considered for 802.16 to overcome severe loss and to increase the throughput.

The 802.16 selects a specific constellation of a multilevel modulation to generate a kind of modulation such as QPSK, 16QAM and 64QAM, as a result, the usage of channel(spectral efficiency) is improved. Higher layer offers mechanism to optimize the selection of constellation and coding rates to satisfy QoS (BER) requirements for each subscriber. The switching mechanism for multilevel modulation with selectable constellation depends on the various parameters, such as channel SNR, mobility of SS, information to be transmitted and etc. In this paper, we use the channel SNR to switch the multilevel modulation. The minimum SS receiver performance specified in the 802.16 expresses the minimum receiver SNR to achieve target BER. Using this performance, we can calculate the switching location boundary of randomly generated SSs.

To implement a cost-effective and concise modems for 802.16, we need to evaluate various effects of non-ideal components of corresponding systems, among which oscillators are of main concern. A perfect oscillator will operate at one discrete frequency but any corrupting noise will spread this frequency, resulting in high power levels at near frequencies. The phase noise of oscillator with high operating frequency range is one of the main factors that degrades the system performance. From the spectral shape of phase noise which is obtained by using the real sample of frequency output, we can evaluate the degraded performance of 802.16, as a function of approximated phase noise variance representing the phase jitter.

This paper is organized as follows: In Section 2, we present an overview of IEEE 802.16 and its downlink structure. The basic environment of simulation is described. In Section 3, the system model for simulation is described. The oscillator phase jitter is considered without PLL. Then, we present the simulation results in next section. Performance is simulated with various phase jitter values to suggest minimum phase noise level for operability. Also the additionally required SNR is presented under 3 channel propagation models with phase noise. Finally, we conclude this paper in Section 5.

## 2. IEEE 802.16 Overview

### 2.1 Basic of 802.16

IEEE standard 802.16 specifies the air interface of a fixed(stationary) point-to-multipoint broadband wireless access system providing multiple services in a wireless LAN/MAN. 802.16 is for physical and medium access control layer with operating frequency of 10-66GHz, generally known as local multipoint distribution service (LMDS), characterized by very high data rates and quite short range due to rain and foliage attenuation. Because this standard is the part of 802 standards family the coexistence with other parts is emphasized [2]. Several techniques are used to increase the throughput, which are the multilevel modulation with constellation switching, highly directional antennas and LOS environment.

### 2.2 Propagation Condition

The operating frequency band of 10-66GHz has much more free space loss than that of the conventional communication systems. This is because free space loss increases quadratically with frequency.The major source of fading comes from the rain. The amount of fading is dependent on the regional rain rate which is conditioned by operating frequency and cell radius. Also, there are two forms of interference, co-channel interference and out-of-channel interference. The co-channel interference is interferer's spectral sidelobes or transmitter's output noise within the receiver filter's passband. It cannot be removed at the receiver whereas the out-of-channel interference can be removed by passband filter. The link

Table 1. Propagation models for IEEE802.16

| Propagation Model | Tap Number | Tap Delay | Tap Amplitude |
|---|---|---|---|
| *Type0* | 1 | 0 | 1.0 |
| *Type1* | 1 | 0 | 0.995 |
|  | 2 | 400/B | $0.0995exp(-j0.75)$ |
| *Type2* | 1 | 0 | $0.286exp(-j0.75)$ |
|  | 2 | 400/B | 0.953 |
|  | 3 | 800/B | -0.095 |

margin for rain loss, interference and other additionally introduced factors are considered in the minimum SS receiver performance which will be explained later.

### 2.3 Downlink Subframe Structure

In the physical layer for 802.16, in order to allow for flexible spectrum usage, both TDD and frequency division duplex(FDD) configurations are supported. Here, we consider the TDD operation which has downlink subframe structure of time division multiplexed(TDM) and uplink subframe structure of time division multiple access(TDMA). The number of symbols in each frame depends on the symbol rate. For 20 MBaud which is used as a simulation parameter, the standard recommends 20,000 symbols within a frame.

In the downlink subframe, at least 75 symbols of QPSK preamble and the multilevel modulated symbols coexist. Preambles are based upon constant amplitude zero auto-correlation (CAZAC) sequences and used for synchronization and equalization. In this paper, we don't consider CAZAC sequences since no synchronization and equalization effects are considered. The modulation constellation can be selected per subscriber based on the quality of the RF channel. If link conditions permit, then a more complex modulation scheme can be utilized to maximizing air link throughput while still allowing reliable data transfer, i.e., target BER.

### 2.4 Minimum SS Receiver Performance

For 802.16, the main source for fading is rain. Also, other things should be considered for the SS receiver performance, such as adjacent channel interference, noise level, required BER. With all environmental parameters, the standard presents the minimum SS receiver performance. 802.16 specifies the BER performance threshold as $-94 + 10log(B)$, $-87 + 10log(B)$ and $-79+10log(B)$ for QPSK, 16QAM and 64QAM, respectively. These values are measured uncoded dBm and for $BER = 10^{-3}$. B is a carrier symbol rate in Mbaud. This minimum SS receiver performance is used for the simulation to assign the randomly generated SSs to adequate modulation scheme using following equation.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}[watt] \tag{1}$$

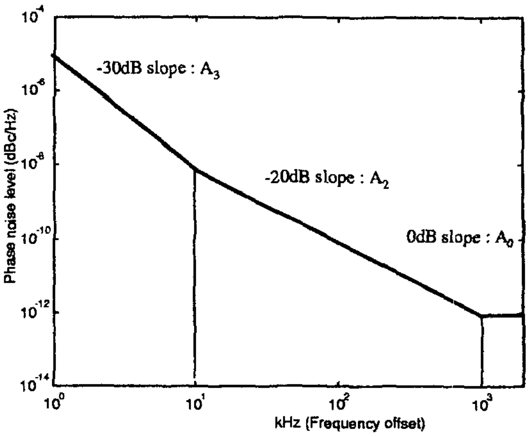

Figure 1. The spectral shape of phase noise of local oscillator

Eq.(1) shows the received signal power where $P_t$ is the transmitted power, $G_t$ is the transmitter antenna gain, $G_r$ is the receiver antenna gain, $\lambda$ is the wavelength, $d$ is the distance between transmitter and receiver and $L$ is the system loss.

## 3. System Model

### 3.1 Signal Model

The received complex signal $r(t)$ can be represented as

$$r(t) = \sum_m a_m g(t - mT) + n(t) \tag{2}$$

where $a_m$ is in the m-th complex data set of QPSK, 16QAM and 64QAM signals. $g(t)$ is the square-root raised cosine filter, $T$ is a symbol duration and $n(t)$ is the complex AWGN with real and imaginary parts each having power spectral density $P/(2Es/No)$. In the square-root raised cosine filter, the excess bandwidth factor $\alpha$ shall be 0.25 as recommended in the standard. In the time domain, we limited the length of root-raised cosine filter as 6T. $r(t)$ is multiplied by $\theta(t)$ which is a zero-mean random process with a variance $\sigma^2$. When there is no PLL for local oscillator, this phase noise can be modelled as Gaussian process. The $T$ sampled output of $r(t)$, $z(kT)$ is

$$z(kT) = \int_{-\infty}^{\infty} r(\tau)e^{j\theta(\tau)}g(\tau - kT)d\tau \tag{3}$$

and

$$z(kT) = a_k e^{j\theta} + N_k \tag{4}$$

where $E\{|N_k|^2\} = No/E_s$.

### 3.2 Propagation Model

Within the 802.16 structure, LOS radio propagation conditions between BS and SS are required to achieve high quality and availability of service. Also, the SSs need highly directional antennas, which minimize the number of multipaths and interferences from unexpected sources. The intersymbol interference may

Table 2. Simulation Parameters

| parameter | value |
|---|---|
| target BER | $10^{-3}$ |
| $P_t$ | 126mW |
| $G_t$ | 18dBi |
| $G_t$ | 14dBi |
| RF frequency | 40GHz |
| system loss, L | 1 |
| noise figure | 6dB |
| thermal noise psd | -138dBW/MHz |
| minimum SS receiver performance | -80(QPSK), -74(16QAM), -66(64QAM) dBm |
| spectral shaping | $\alpha$ =0.25 |
| number of SSs | 100 |
| downlink subframe size | 20000 symbols |
| simulation | 100 times |

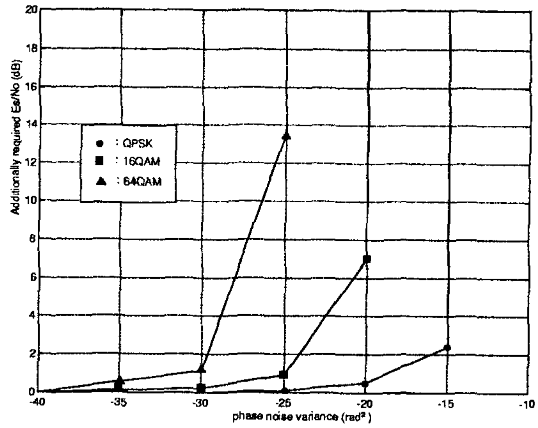

Figure 2. Additionally required Es/No to achieve $10^{-3}$ BER for type 0 propagation model

occur as a consequence of multipaths. The propagation model is described in the Table 1. B is the channel baud rate in MBaud. Type 0 is the line of sight(LOS) conditions between base station and subscriber station. This condition is achieved by the highly directional antennas of the subscriber stations. Type 1 and type 2 are multipath conditions which occur the intersymbol interference. In this paper, we consider both AWGN(LOS) and multipath conditions.

### 3.3 Phase jitter

Power-law spectral densities are often used to model the phase deviation of oscillators. In practice, the power spectral density of the phase deviation, $\theta$, can be represented by the sum of three independent noise processes as like; frequency flicker noise ($f^3$ part), white frequency noise( $f^2$ part) and white phase noise($f^0$ part) [3]. To make the phase jitter model be general, we use the model from the DAVIC standard which is similar to LMDS. Figure 1 represents the approximated power-law phase noise model specified in the DAVIC standard[4]. The solid lines with slope of -30, -20 and 0 dB/decade represent $A_3, A_2$ and $A_0$. Using these slope values, data rate and system bandwidth, we can calculate the phase noise variance as a sum of each phase noise contribution. The details are presented in [5].

## 4. Simulation Results

### 4.1 Simulation parameters

Within the downlink subframe, the data transmissions are varied by different modulation and forward error correction(FEC). We do not consider the FEC since the minimum SS receiver performance is specified with uncoded modulation. For $10^{-3}$ BER performance threshold and 20 MBaud of symbol rate, -80, -74 and -66 dBm are required for QPSK, 16QAM and 64QAM, respectively. Eq.(1) with parameters in the Table 2. results the distance, d, for transmitter and receiver. From the BS, the distance of 16,807m is for QPSK data transmission region and from 16,807m to 42,218m is for 16QAM and from 42,218m to 94,514m is for 64QAM. About 95km of radius can be easily shortened by decreasing the transmitted power, $P_t$. We verified that the average rate of each modulation type's distance is almost same regardless of $P_t$. This gives our simulation model the generality. If the number of SS is fixed as 100, the average transmission rate is easily calculated as 65.18 Mbps, assuming that the position of each SS is randomly generated with uniform distribution. Type 0 is LOS environment which is simulated with AWGN and oscillator phase jitter. Type 1 and 2 are multipath environment with intersymbol interference. With 20 MBaud ,we used tap delay $400/B$ as 20ns and $800/B$ as 40ns durations.

We simulated downlink subframe symbols of length 20000. This is recommended downlink subframe size and 75 symbols of minimum preambles. All symbols are generated with equal probability in their symbol set. Also, as specified in the standard we assumed that the Gray coding is used. To guarantee $10^{-3}$ of BER, $E_s/N_0$s of each modulation is 9.8dB for QPSK, 17.5 dB for 16QAM and 22.5dB for 64QAM. As a result, each modulation of downlink subframe keeps the BER as $10^{-3}$ regardless of modulation method when there are no phase jitter and multipath interference.

We use the variances of phase jitter $-\infty$(no phase noise), -15, -20, -25 and -30dB. For example, phase noise variance of -30dB $rad^2$ is about 1.81° of standard deviation of phase noise. Considering Gaussian randomly generated phase noise, 3 times of the standard deviation is meaningful value and about 5.43° of phase rotation of received signal occurs.

### 4.2 BER with Phase Jitter

**Type 0 Propagation Model**: Type 0 is the LOS environment, i.e., there are no multipath signal components. Here, we consider the AWGN and phase jitter. Table 3 shows the BER performance for type 0 propagation model and phase jitter. With no phase jitter, $10^{-3}$ BER is simulated for 3 modulation types. As $\sigma^2$

Table 3. Simulation results of BER for each modulation with various phase jitter and propagation type

| Modulation type | Propagation model | $\sigma^2 =$ - $\infty$ | $\sigma^2 =$ -30 dB | $\sigma^2 =$ -25 dB | $\sigma^2 =$ -20 dB | $\sigma^2 =$ -15 dB |
|---|---|---|---|---|---|---|
| *QPSK* | 0 | 1.01 | 1.05 | 1.17 | 1.70 | 4.47 |
|  | 1 | 0.80 | 0.82 | 0.93 | 1.39 | 4.00 |
|  | 2 | 40.60 | 41.20 | 42.30 | 45.60 | 55.26 |
| *16QAM* | 0 | 1.03 | 1.26 | 2.05 | 6.23 | 24.46 |
|  | 1 | 2.70 | 3.20 | 4.60 | 10.10 | 28.80 |
|  | 2 | 123.90 | 124.00 | 125.10 | 126.90 | 132.50 |
| *64QAM* | 0 | 1.03 | 2.30 | 6.77 | 24.46 | 54.45 |
|  | 1 | 10.90 | 13.73 | 19.42 | 34.71 | 62.40 |
|  | 2 | 139.90 | 140.20 | 140.20 | 141.10 | 142.70 |

(BER : $\times 10^{-3}$)

increases the BER is degraded from the BER of $10^{-3}$. For the same phase jitter variance, the amount of BER degradation is large for higher modulation method. Figure 2 shows additionally required SNR to achieve $10^{-3}$ BER under the phase noise. For more than -15dB of variance for QPSK, no matter how much the additional SNR is increased the BER cannot achieve $10^{-3}$. This is same for 16QAM with -20dB and 64QAM with -25dB. Due to the large phase rotation of signal, increased SNR which strengthens the signal energy only cannot recover the degraded BER performance.

**Type 1 Propagation Model**: Type 1 is multipath environment with 1 tap of delay. $0.995s(t)$ is received from the LOS and $0.0995e^{-j0.75}s(t-20ns)$ from the multipath. Table 3 shows the BER performance for type 1 propagation model and various phase jitters. Comparing to type 0, the BER degradation of QPSK symbols is not significant for various phase jitter. But for 64QAM, the BER degradation shows different behavior. The BER of 64QAM degrades from about $10^{-2}$. For $\sigma^2 = -25dB$, about a order of $10^{-1}$ BER difference occurs for both QPSK and 64QAM. This means that the higher order modulations are much more vulnerable to intersymbol interference as expected.

For QPSK modulation, the BER is below $10^{-3}$ for no phase jitter, -30 and -25dB phase jitter. This is caused from the phase component of $exp(-j0.75)$ as shown in the Table 1. About -43 degree of signal phase rotation is added to no delay component of signal, as a result, total signal energy is strengthened. This affects the only QPSK different from other modulation types due to the nature of constellation. To verify the generality, we simulated with uniformly random phase instead of -0.75. The results show that the average BER is degraded with increasing phase jitter. For example, BERs of QPSK modulation are 1.5, 1.9, 2.0, 2.3 and 5.6 $\times 10^{-3}$ for phase noise variance of $-\infty$, -30, -25, -20 and -15, respectively.

**Type 2 Propagation Model**: Type 2 is multipath environment with 2 taps of delay. $0.286e^{-j0.75}s(t)$ is received from the LOS, $0.953s(t)$ from the multipath with 20ns delay and $-0.095s(t)$ with 40ns delay. As shown in the Table 1, LOS component is very small, which will result in severe BER degradation. Table 3 shows the the BER performance for type 2 propagation model and phase jitter. The BER performance is already severely degraded and almost not affected by the phase jitter variance.

## 5. Conclusion

In this paper, we presented simulated BER of 3 propagation models specified in the IEEE 802.16 TDD downlink subframe. The constellation of multilevel modulation is switched by using the SS's location boundary generated from the minimum SS performance which contains link margins for various kinds of losses. In the type 0 propagation model, BER is moderately degraded by increasing the variance of phase jitter. Also, additionally required SNR to compensate the phase jitter is presented. For the type 1 model, the BER of 64QAM degrades from about $10^{-2}$ meaning that the severe degradation is already started. In type 2 propagation model, almost regardless of phase noise variance, BER is fixed to about $42 \times 10^{-3}$, 0.125 and 0.140 for QPSK, 16QAM and 64QAM, respectively. This results from that the dominant signal energy is received from 2nd tap delay component.

### References

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[3] IEEE Standard Definition of Physical Quantities for Fundamental and Time Metrology (IEEE Std. 1139)

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[5] Youngsun Kim, Jong-In Song and Kiseon Kim, "BER Degradation Due to the Phase Noise Spectral Shape in LMDS Systems," ITC-CSCC 2000, pp. 113-116, 2000