LINK QUALITY ESTIMATION OF INDOOR WLANs USING SNR, EVM AND BER PERFORMANCE MATRICS

ISSN: 2141 – 3290
www.wojast.com

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ABSTRACT

Signal-to-noise ratio represents one of the widely accepted figures of merit employed in the evaluation of link quality. In recent works, this metric has been related to other performance metrics such as the error vector magnitude and the bit error rate. This paper examines the relationship between system metrics in both ideal and amplified environments. The amplified environment uses the additive white Gaussian noise and asserts that noise measurements may not be relevant. Both systems were evaluated using extensive computer simulation and relationships between the various performance matrics established. Results obtained prove that amplified environments are better. The results are useful for selecting the best performance matric, and for the estimation of the overall system reliability.

INTRODUCTION

In wireless communication systems, complex digital modulation schemes are used for meeting stringent spectral and Signal-to-Noise Ratio (SNR) requirements. In such systems, the overall quality of signal transmission and reception are determined by various base-band and Radio Frequency (RF) system specifications. Among these, Bit Error Rate (BER) and Error Vector Magnitude (EVM) are the two primary specifications that determine the performance of wireless systems in terms of transmitted and received symbols corresponding to a given digital modulation scheme. While BER is useful as a conceptual figure of merit, it suffers from a number of practical drawbacks that compromise its value as a standard test in manufacturing or maintenance. For measurements and testing devices, EVM is a viable alternative test method when looking for a figure of merit in non-regenerative transmission links. It offers insight information on the various transmitter imperfections, including carrier leakages, non-linearity, Local Oscillator (LO), phase noise and frequency error.

Relating SNR to other performance metrics such as EVM and BER is an important research option as well. These relations are quite useful since they allow for the reuse of already available SNR measurements to infer more information regarding the communication system. High dynamic range receiver and demodulator are required to detect the base-band symbols necessary for computing waveform quality metrics. The non-linear behaviour of RF and microwave amplifiers results in in-band (or co-channel) distortion which is manifested as SNR degradation and ultimately affects the bit error rate. Characterizing in-band distortion and its relationship to the system metrics require the identification of correlated and uncorrelated components of the output spectrum. The correlated output consists of an amplified version of the input waveform with gain compression/expansion and represents the useful part of the output that leads to correct detection of received data. On the other hand, the uncorrelated output adds to the system interference in a similar way to that of the additive white Gaussian noise (AWGN). Therefore, the correlated and uncorrelated non-linear output components contribute differently to the degradation of system's SNR, EVM and ultimately BER.

The prediction of system performance parameters is usually difficult in an amplified environment. Given this complexity, coupled with lack of direct measurements, collection of field data seems to be the closest alternative. Wave signals are frequently troubled by various communication related defects such as multi-path fading, noise, obstacles, etc. These could frustrate the efforts of network operators in their bid to offer effective quality of service to her increasing customers. This major challenge therefore calls for the adoption of useful measures that involves the development of performance and predictive models, capable of analyzing the random corruption of transmitted signal by considering the additive white Gaussian noise (AWGN). This paper therefore models the relationship between SNR, EVM and BER in indoor WLAN environments. To ensure accurate prediction, the required parameters are estimated using field data. The aim is to assert if further measurement of noise is necessary in an amplified environment. In obtaining the data, a computer with a WLAN card utility software was used. The signal was transmitted via a Linksys wireless access point (WRT54G) with wireless network standard (802.11g) that has a maximum data transfer rate of 54 Mbps and an operating frequency of 2.4GHz. The equipment was used in infrastructure mode.

In modern wireless communication devices, sophisticated modulation schemes are deployed to increase capacity and provide broadband mobile data services. Higher data rates for the same occupied bandwidth place greater SNR requirements for the station transmitter. The SNR works independently with non-linear distortion, thermal noise, device noise, etc. However, in assessing these imperfections on SNR degradation, an attempt has been made to evaluate this assertion with known measured signal power and evaluate the non-linear distortion and their corresponding system metrics such as EVM and BER. In recent years, a non-linear spectral analysis technique for WLANs have been successfully deployed to ensure that digital communication systems provide high speed data services. The system metrics are estimated from the measured output power and in-band distortion power (Gharaibeh, *et al,* 2005).

Several other research works have also been carried out in the area of wireless LAN. An analysis of the IEEE standard for local and metropolitan area networks reveal an extensive procedure to measuring throughput and physical parameters. In Mahmoud, and Arslan (2009), relationship between Error Vector Magnitude and SNR conversion for non-data aided receivers system has been established. The authors propose a model that examines the relation for non-data aided receivers that have shown poor performance, especially for low SNR values or high modulation orders. They conclude that reliably estimating the SNR values from the measured EVM can reduce system complexity by eliminating the need for modules required to separately estimate the SNR.

Researches on the performance evaluation of WLANs are directed towards system optimization as well as checking the imbalances in radio frequency propagation. In Olgaard (2004), the versatility of EVM measurements for testing WLAN variable-envelop is investigated. The goal was to optimize EVM test parameters by reducing of the number of specification measurements that require time and/or expensive test equipment. Analysis shows that enhanced EVM measurements coupled with simple path measurements can produce the desired fault coverage, thus eliminating spectrum mask and noise figure test. In Acar, *et al,* 2006), techniques are described to identify and troubleshoot the impacts of amplitude, phase and group delay imbalances between I and Q channels, phase noise, spurious signals and transient effects, as well as signal compression and transmitter performance. A non-linear spectral analysis technique of WLAN has been successfully deployed to enable digital communication systems provide high speed data services. The system metrics were estimated from the measured output power and in-band distortion power (Gharaibeh, *et al,* 2005). In Mahmoud and Arslan (2009), relationship between EVM and SNR conversion for non data aided receivers system has been established. The authors propose a model that examines the relation for non data-aided receivers that have shown poor performance, especially for low SNR values or high modulation orders. They conclude that reliably estimating the SNR values from the measured EVM can reduce system complexity by eliminating the need for modules required to separately estimate the SNR. This paper establishes relationship between frequently used figures of merit (SNR, EVM and BER). The proposed models are useful for effective evaluation and prediction of the system and can be applied where data measurements of a particular performance metrics are difficult to obtain.

SYSTEM MODEL

In any communication system, the channel serves as the physical medium for sending signal between the transmitter and the receiver. One major problem associated with the channel is random corruption of the transmitted signal. The additive white Gaussian noise (AWGN) model (Fan and Zilic, 2008), is predominantly used to analyze this problem. This communication channel model applies to a broad class of physical communication channels and is diagrammatically presented in Figure 1.

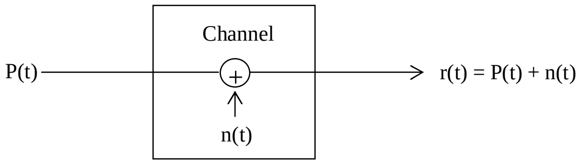


Figure 1. The AWGN channel model

In the AWGN model, the transmitted signal *P(t)* is coupled by noise *n(t)*, and is given by the model equation:

$$r(t) = P(t) + n(t) \tag{1}$$

The noise is introduced by the channel and other electronic components, including amplifier(s) at the receiver. This type of noise is most often characterized as thermal noise or statistically as Gaussian noise. Its probability density function (*pdf*) is given as:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-m_x)^2/2\sigma^2} \tag{2}$$

where m_x is the mean and σ^2 is the variance of the random variable. An important function used to characterize the Gaussian distribution is the Q-function, which represents the area under the tail of the Gaussian *pdf*. Q(x) is required to compute the probability of error in communication systems. A normalized form of Q(x), i.e., $N \sim (0,1)$ is defined in Proakis (2001) as:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{\frac{t^2}{2}} dt \tag{3}$$

In Zigangirov (2004), the inequality that describes the upper bound of equation (3) is expressed as:

$$Q(x) \le \frac{1}{2} \exp\left(-\frac{x^2}{2}\right), \quad x \ge 0 \tag{4}$$

The SNR compares the peak signal strength to noise (Shafic, *et al,* 2006). And is defined as the ratio of the average signal power to average noise power, i.e.,

$$SNR = \frac{Signal\ Power\ (SP)}{Noise\ Power\ (NP(t))} \tag{5}$$

An expression that amplifies the signal power is derived in Jeruchim, *et al,* (2000). This expression which approximates the data measurements and implicitly caters for the noise is given as:

$$SNR = \frac{34}{\left(1 + \frac{5.2 \times 10^{13}}{(102 + SP)^4}\right)^{\frac{1}{9}}} \tag{6}$$

where SP represents the signal power in dBm and the resulting SNR is in dB. In this paper, a comparative performance evaluation of the SNR expressions in equations (5) and (6) is made, and their impact on service quality revealed.

The Electromagnetic Radiation (EMR) vector magnitude (EVM) is another important performance metric for assessing the quality of communication link (Zigangirov, 2004). This figure of merit is defined as the Root-Mean-Square (RMS) value of the difference between a collection of measured symbols and ideal symbols. The EVM is linked to SNR by:

$$EVM_{RMS} = \left[\frac{1}{SNR}\right]^{\frac{1}{2}} \tag{7}$$

BER is the ratio of the number of in-correct bits to the total number of received bits. In general, the BER is a characteristic function of the following: the channel (i.e., quantity of noise), the type of waveforms used to transmit information over the channel, the transmitter power and timing filter, and the method of modulation and demodulation. The relationship between the BER and SNR is expressed as:

$$BER = Q\left(\sqrt{SNR}\right) \tag{8}$$

where Q is defined in equation (3). The relationship between BER and SNR for the quarantine phase-shift keying (QPSK) modulation using WLAN is deduced as:

$$BER \cong Q\left[\sqrt{2SNR}\left(1 - 0.5Q\left(\sqrt{2SNR}\right)\right)\right] \tag{9}$$

A relationship between EVM and BER can also be established by merging equations (7) into (8).

SIMULATION DATA

Data were collected from the field and used as input to the simulation. The data were signal power and noise power measurements collected within an indoor environment. With the WLAN utility card software, these readings were taken at different locations, but not further than 100m. The recordings were then averaged over a period of two weeks and are summarized in Tables 1 and 2, respectively.

Table 1. Average received signal power measurements (dBm)

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
-76.93	-76.96	-76.77	-75.93	-78.12	-76.98
Day 7	Day 8	Day 9	Day 10	Day 11	Day 12
-76.88	-77.08	-77.083	-76.87	-77.44	-77.116

Table 2. Average noise measurements (dB)

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
-89.95	-89.57	-89.62	-89.57	-89.20	-88.73
Day 7	Day 8	Day 9	Day 10	Day 11	Day 12
-89.43	-89.82	-88.83	-89.70	-89.85	-89.58

The MATrix LABoratory (MATLAB) was used as a simulation tool and for the transformation of the results into graphs to enhance easy interpretation.

DISCUSSION OF RESULTS

The effect of SNR on the received signal power is shown in Figures 1 and 2, for ideal and amplified environments, respectively. From these plots, we observed that the amplified environment effectively compensates for noise, as can be seen in the nature of the plots. Also, the SNR levels in Figure 2 are better than that of Figure 1. The rise in SNR is as a result of the effective inhibition of the noise which contributes to raising the amplification level.

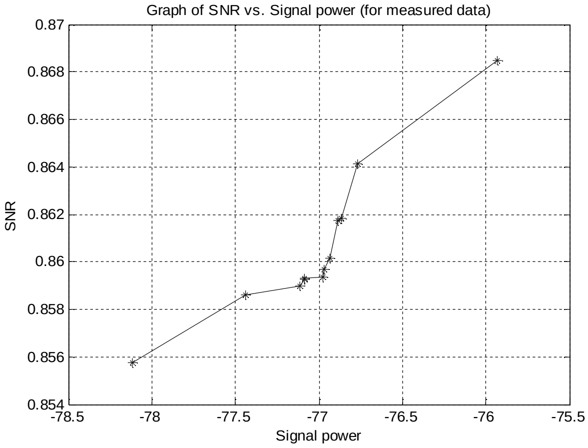


Figure 1. SNR vs. signal power for measured data

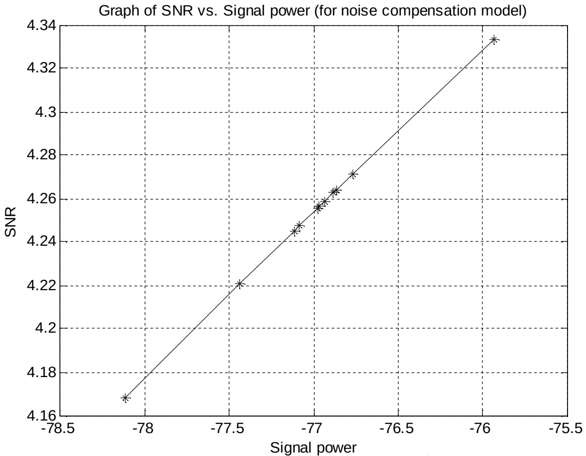
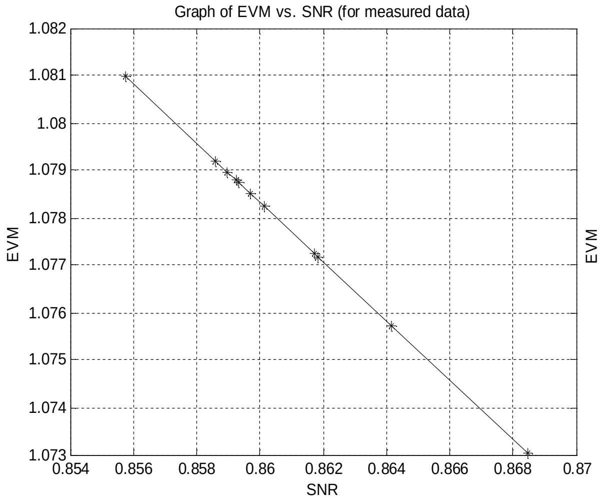


Figure 2: SNR vs. signal power in an amplified environment

Figures 3 and 4 are graphs relating EVM and SNR in ideal and amplified environments. We observe that the effect of noise experienced in the ideal environment appears to degrade the system's performance, calling for efficient signal amplification techniques. The EVM values in the ideal environment (Figure 3) are higher than that of the amplified environment (Figure 4), by a factor of 0.6. This difference could be as a result of the effect of signal and noise modulation. But for higher modulation orders at same SNR levels, the probability of symbol error rises (Proakis, 2001). Ideally, true EVM values are expected to align with the measured data values (Mahmoud, and Arslan, 2009). From this assertion, we agree that it is better to compensate noise, especially when the modulation order increases.

Figures 5 and 6 relate the BER and SNR in ideal and amplified environments, respectively. The graphs show that BER decreases with increased SNR in both environments, but the SNR in the amplified environment grows with constant BER. The SNR increase in the amplified environment can be attributed to the effective noise compensation.

Figures 7 and 8 depict the effect of BER and EVM in both environments (ideal and amplified environments). We observed in the ideal environment that BER increases with EVM, thus, causing more errors in the system. In order to minimize the error rate of the network in practice, it is important that network operators introduce best practices that would suppress errors in the system. These practices may range from proper network planning to the introduction of newer technologies for boosting the average throughput of the existing system.



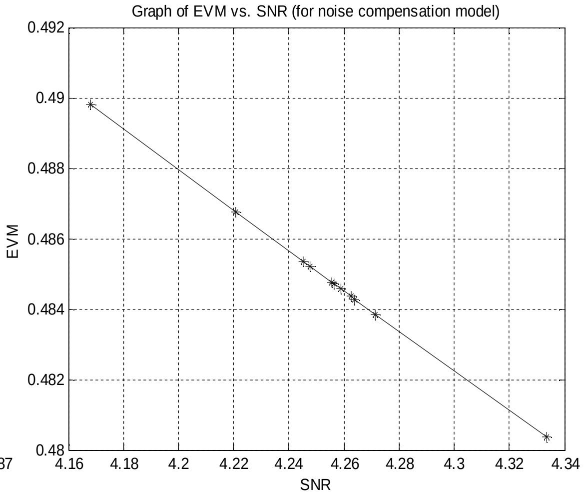


Figure 3: EVM vs. SNR for measured data

Figure 4: EVM vs. SNR in an amplified environment

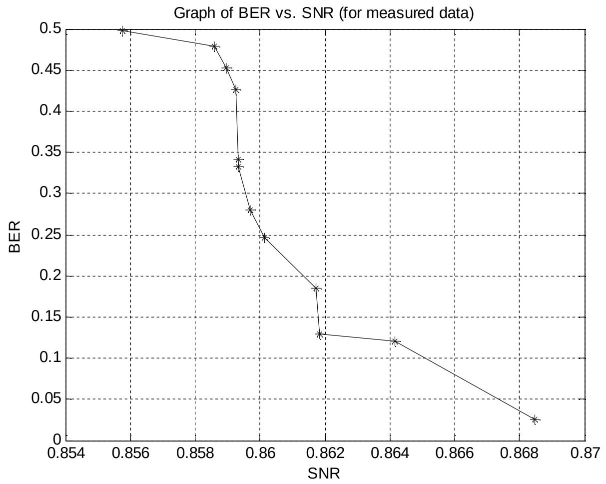


Figure 5.BER vs. SNR for measured data

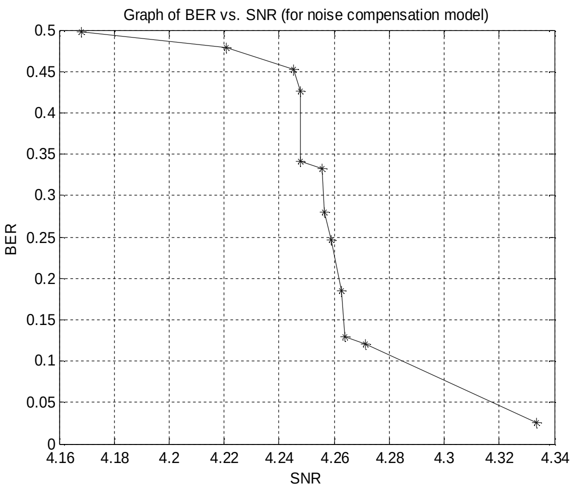


Figure 6. BER vs. SNR in an amplified environment

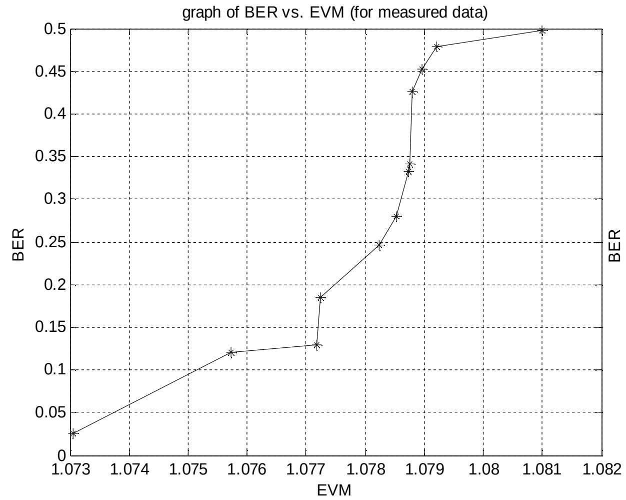


Figure 7. BER vs. EVM for measured data

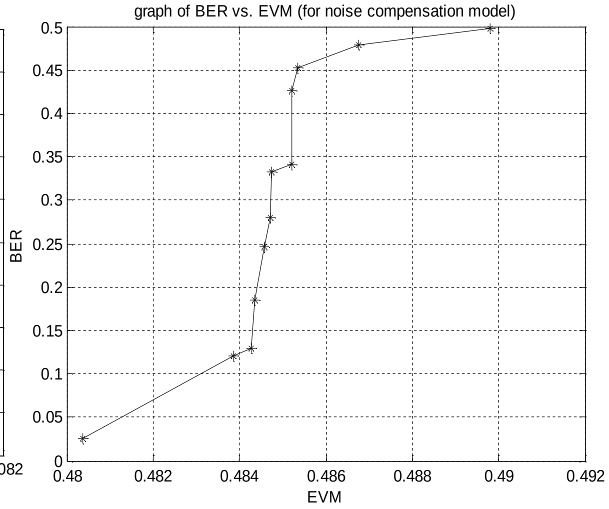


Figure 8. BER vs. EVM in an amplified environment.

CONCLUSION

The performance of radio frequency site survey involves more than ensuring that users gain access to the access points. This paper has offered a solution that checks the imbalances in the transmission of signal in wireless communication systems. We accomplished this by comparing the signal-to-noise ratio in ideal and amplified environments using SNR, EVM and BER performance metrics. A future direction of this research is to integrate the model design into functional devices that will assist network operators in quality of service management.

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