Voice Over WLAN 802.11g in Presence of AWGN and Rayleigh Fading

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***Abstract* - In this paper we investigate the quality of voice communication over 802.11g WLANs (Wireless Local Area Networks) taking realistic channel models into accounts. We show that the assessment of voice over WLANs (VoWLANs) performance is overly optimistic if fading is ignored when compared with systems where fading is taking into account. Via Matlab simulation, we derive the voice performance in terms of bit error rate (BER) and packet error rate (PER) for 54 Mbps data rate specified in the IEEE 802.11g ERP-OFDM (Extended Rate Physical Layer - Orthogonal Frequency Division Multiplexing) operational mode. More precisely, we evaluate BER and PER in IEEE 802.11g ERP-OFDM operation mode versus signal-to-noise ratio (SNR) in the presence of AWGN (additive white Gaussian noise) and one-path Rayleigh fading. The results obtained from the simulation show the benefit of implementation of pilots and long training sequence, especially for Rayleigh fading compensation.**

***Keywords* – VoWLANs, BER, PER, IEEE 802.11g ERP-OFDM, AWGN, Rayleigh fading.**

I. INTRODUCTION

IEEE 802.11 based Wireless Local Area Networks (WLANs) are becoming popular in home, enterprise and public access areas primarily due to their low cost, simplicity of installation and high data rates. While WLANs continue to be predominantly data centric, there is growing interest in using WLANs for voice, especially in enterprise markets. Since conventional WLANs have been designed for packet data, communicating voice over WLANs has its own challenges. For example, packet voice communication is sensitive to delay, but relatively less sensitive to packet losses compared to communication of data packet. In addition, multiple choices of speech codec, the packetization interval and the PHY layer bit rate are available.

IEEE 802.11g standard boosts the wireless LANs speed to 54 Mbps using orthogonal frequency division multiplex (OFDM). OFDM is adopted as the mandatory modulation in the IEEE 802.11g WLANs specification [1] for a further high-speed physical layer (PHY) extension to the 802.11b standard in the 2.4 GHz Industrial-Scientific-Medical (ISM) band. This specification is backward compatible with the widely deployed IEEE 802.11b and defines multiple PHY operational modes. Our analysis consider ERP-OFDM operational mode.

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Wireless channel manifest signal variation in the form of path-loss, shadowing and small-scale fading. Path-loss is the distance-dependent attenuation in signal power. Shadowing is the large-scale variation in signal power due to large objects (objects with sizes larger than the wavelength) in the environment. Small-scale fading is the rapid variation in signal envelope due to the transmitted signal undergoing reflection(s) and scattering leading to multiples copies with different amplitudes, phases and delays summing up at the receiver [2].

This paper studies the impact of one-path Rayleigh fading and AWGN on the voice performance over IEEE802.11g ERP-OFDM operation mode. Using appropriate channel model, we evaluate BER and PER in the terms of SNR, which is defined as the ration of the desired power signal to the noise power. SNR indicates the reliability of the link between the transmitter and receiver, especially in environments with strong influences from different electronic devices.

The rest of the paper is organized as follows. Section 2 details related work. Section 3 describes the system model and frame structure used for simulation. Section 4 gives the simulation parameters and results. Section 5 comprises the conclusion.

II. RELATED WORK

Generally, research pertaining to VoWLANs has been centered on the effects that packet delay and packet loss occurring at the MAC layer and higher layers have on voice performance. In most of these studies, errors in transmission over the wireless channel are either ignored or represented by simplified models which do not necessarily reflect realistic wireless environments [3], [4].

There is prior literature on the performance of the physical layer of WLANs in realistic wireless channels, taking into account fading. In [5], [6], [7] the authors simulated the physical layers of HIPERLAN/2 and IEEE 802.11a systems (which are very similar) in fading channels using the ETSI channel models [8], and they obtained the average packet error rate (PER) by averaging over the channel fading realizations. Using the average PER, the impact of various ETSI channel models on the performance of these systems was studied. In [9] the average throughput for both systems, derived from the average PER, is used for link adaptation purposes.

Lampe et al. simulated the HIPERLAN/2 system using the ETSI channel models and showed that using average PER for link adaptation can lead to “fatal misadaption” [10]. Therefore, the authors proposed that the PER corresponding to the particular fading realization experienced should be used for link adaptation, and not the average.

Olufunmilola et al. study the impact of fading in the wireless channel on packet loss and the performance of VoIP over IEEE802.11a using a realistic channel model. VoIP performance is measured in terms of the user- perceived quality over a speech period comprising a number of VoIP packets. They consider VoIP stationary users that are subjected to a particular fading realization; this leads to a particular value for PER which in turn translates to a mean opinion score (MOS) value representing the voice quality for calls under that fading realization. By considering a large number of fading realizations, they derive a distribution for voice quality across users.

III. SIMULATION MODEL

This section describes the end-to-end simulation model shown in Fig. 1. The model contains all elements used in IEEE 802.11g WLAN network. The both transmit and receive side are explained. The major blocks are Scrambler, Encoder, Puncturer, Interleaver, and Modulator. In addition, we describe the frame structure, coding and modulation techniques used in IEEE 802.11g ERP-OFDM operational mode. The simulation of this model is performed in Matlab.

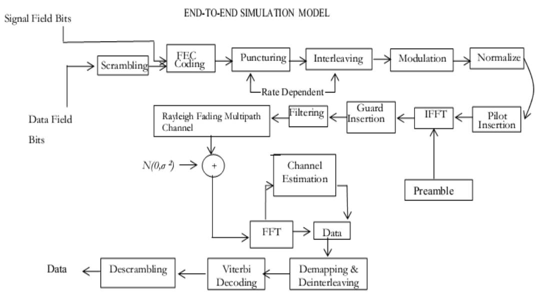

Fig.1 End-to-end simulation model

Simulation model elements: *Scrambler* is a block that prevents long runs of 1s and 0s in the input data being input to the remainder of the modulation process. The data are scrambled with pseudo random sequence of length 127.

The *Convolutional Encoder* block encodes a sequence of binary input vectors to produce a sequence of binary output vectors. This block can process multiple symbols at time. If the encoder takes k input bit streams (that is, can receive 2^k possible input symbols), then this block's input vector length is L*k for some positive integer L. Similarly, if the encoder produces n output bit streams (that is, can produce 2^n possible output symbols), then this block's output vector length is L*n. The input can be a sample-based vector with L=1, or a frame based column vector with any positive integer for L.

Puncturing is a procedure for omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy "zero" metric into the convolutional decoder on the receive side in place of the omitted bits.

Interleaver is the next important block. The interleaver is defined by a two-step permutation. The first permutation ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The second ensures that adjacent coded bits are mapped alternately onto less and more significant bits of the constellation and, thereby, long runs of low reliability (LSB) bits are avoided. Interleaving is a key component of many digital communication systems involving forward error correction (FEC) coding. Applications that store or transmit digital data require error correction to reduce the effect of spurious noise that can corrupt data. Digital communication systems designers can choose many types of error-correction codes (EECs) to reduce the effect of errors in stored or transmitted data depending upon the type of modulation desired.

OFDM is a *modulation technique* that uses a large number of parallel narrowband subcarriers instead of a single wideband carrier to transport information, i.e. OFDM is a parallel transmission scheme, where a high-rate serial data stream is split up into a set of low-rate substreams, each of which is modulated on separate subcarriers. Thereby, the bandwidth of the subcarriers becomes small compared with the coherence bandwidth of the channel, i.e. the individual subcarriers experience flat fading, which allows for simple equalization. To overcome the effect of multipath propagation, short guard interval is introduced.

Frame structure: The look of IEEE 802.11g ERP-OFDM frame format is shown in Fig. 2. The short and long training sequences (STS, LTS), and 64-point Inverse Fast Fourier Transform (IFFT) are used to generate short and long training sequences of the preamble. STS is used for used for AGC convergence, diversity selection, timing acquisition, and coarse frequency acquisition in the receiver. The duration of the short training sequence is 8 μs and it consists of ten identical patterns, each 16 samples long. LTS are used for used for channel estimation and fine frequency acquisition in the receiver. The duration of the long training sequence is also 8 μs and it consists of three parts. The second and third parts are identical and are obtained directly from the 64-point IFFT of the long training sequence. The first part, however, is the second half of the second or third parts. The header or SIGNAL field is twenty-four bits long and contains the data rate and packet length information. This information is protected by one parity bit. The SIGNAL field also contains six tail bits to flush the convolutional encoder. The SIGNAL field is first protected by rate ½ convolutional code, then interleaved and finally modulated by binary phase shift keying. The SIGNAL field is then passed through the 64-point IFFT and the last one-quarter of the signal is appended to make and packet length information. This information is protected by one parity bit. The SIGNAL field is then passed through the 64 point IFFT and the last one-quarter of the signal is appended to make the length of the SIGNAL field 80 samples. The duration of the SIGNAL field is 4 μs [guard interval plus one OFDM symbol]. The DATA field contains information about seeding the descrambler, the random data and tail bits - to return the trellis in the Viterbi decoder to the all zero state.

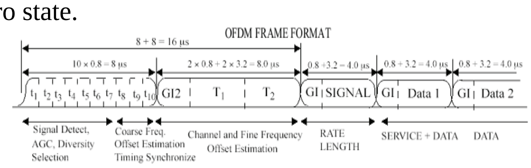

Fig.2 ERP-OFDM frame format

Coding techniques: The baseband supports three coding techniques in addition to four modulation formats. The basic coding rate is $^1/_2$ while the derived rates, through puncturing, are $^2/_3$ and $^3/_4$. The data rates vary from as low as 6 Mbps [BPSK, $^1/_2$] to as high as 54 Mbps [64-QAM, $^3/_4$]. The coding, puncturing and modulation are done according to the IEEE 802.11g section in the specification. The data is scrambled, encoded, punctured [depending on the rate], interleaved, modulated and then passed through the IFFT. The DATA field is divided into an integer number of OFDM symbols where each OFDM symbol is 4 µs in duration and 80 samples long. The scrambler is again IEEE 802.11g compliant and scrambles the information in the DATA field only. The same scrambler is used to scramble transmit data and to descramble receive data.

For the purpose of our simulation, the DATA field is composed of 5 OFDM symbols, which is modulated using 64-QAM with coding rate ¾ that gives data rate of 54Mbps. The long training sequences are used for channel estimation and DATA field compensation. The data is passed through the fast Fourier transform, and is then compensated by the estimated channel gain and phase - frequency domain equalization. The relevant data in each OFDM symbol only occupies 48 subcarriers and four subcarriers are reserved for the pilots. The pilots' subcarriers are used in order to make the coherent detection robust against frequency offsets and phase noise. The pilots shall be BPSK modulated by a pseudo binary sequence to prevent the generation of spectral lines.

The SIGNAL field is demodulated, deinterleaved and decoded using a hard decision Viterbi decoder. The DATA field on the other hand is also depunctured [depending on the rate] before decoding and finally descrambled. The pilots in SIGNAL field are used for SIGNAL field data compensation. The descrambler seed is extracted from the received signal. The performance simulation metric is the BER and PER.

IV. Simulation Parameters and Results

The model presented in Fig. 1 is able to simulate IEEE 802.11g ERP-OFDM operational mode at 54Mbps using OFDM modulation technique. Numerical values for the OFDM parameters are given in Table 1 [9]. In order to prevent intersymbol interference (ISI), a guard interval is implemented by means of a cyclic extension. Thus, each OFDM symbol is preceded by a periodic extension of the symbol itself. The total OFDM symbol duration is $T_{total}=T_g+T_U$ where T_g is the guard interval and T_U is the useful symbol duration. When the guard interval is longer than the excess delay of the radio channel, ISI is eliminated.

We introduced noise and Rayleigh fading where only amplitude is fluctuated. The Rayleigh fading raises the error rate of the received data. In this simulation we use one-path Rayleigh fading as described in [12]. Noise is modeled as additive white Gaussian noise (AWGN). The propagation characteristics can be estimated by *pilot subcarriers insertion* or by *using long training sequences* of the preamble. In this simulation, the first method is applied for SIGNAL field and the second for DATA field.

Parameter	Value
Sampling Rate (f_s)	20 MHz
Useful Symbol Duration (T_U)	3.2 µs
Guard Interval Duration (T_g)	0.8 µs
Total Symbol Duration (T_{Total})	4.0 µs
Number of data sub-carriers (N_D)	48
Number of pilot sub-carriers (N_P)	4
FFT Size	64
Sub-carrier spacing (Δ_f)	0.3125 MHz
Total Bandwidth (B)	16.875 MHz

Table 1. OFDM Parameters

Speech data generated by the encoder is packetized incurring overheads at the various layers (transport, network and MAC layers). We consider G.711 which generates speech data at the rate of 64 Kbps, and consider each packet to contain 10 ms of speech, or 80 bytes of data. At the transport layer, the RTP and UDP protocols introduce 12 byte and UDP 8 byte headers, respectively. At the network layer, the IP protocol introduces a header of 20 bytes. All headers and voice data are included in DATA field MAC frame (Fig. 2) requiring 5 OFDM symbols. This means that the length of DATA field is 135 bytes. At the MAC layer the header is 34 bytes. Hence a 10 ms voice packet in our simulation is 169 bytes long.

For a given channel model, we simulate 1000 fixed size frames, i.e. packets. To determine the system performance, we evaluate the BER and PER. BER is defined as a ratio of number of error bits and number of transmitted bits. The transmitted bits are the bits included in the DATA and SIGNAL field. Packet is defined as the number of transmitted bits in one frame unit. In our case, three OFDM symbols exist in one frame unit. The packet error occurs when at least one of the transmitted bits in one frame is erroneous.

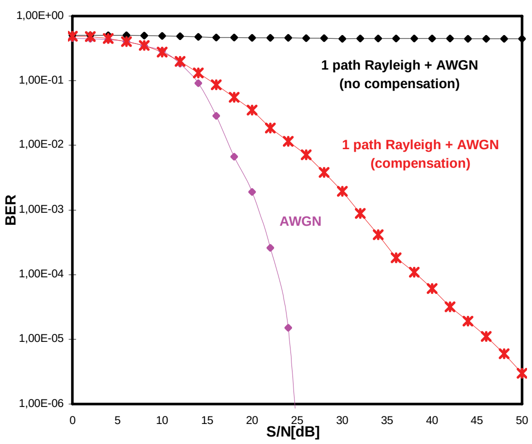

Fig.3 Bit error rate (6 waves generate fading)

Our simulation scenario includes:

- BER and PER in presence of AWGN.
- BER and PER in presence of AWGN and Rayleigh fading without compensation, i.e. we don't use the pilot symbols in SIGNAL field compensation and long training sequences DATA field compensation.
- BER and PER in presence of AWGN and Rayleigh fading with compensation.

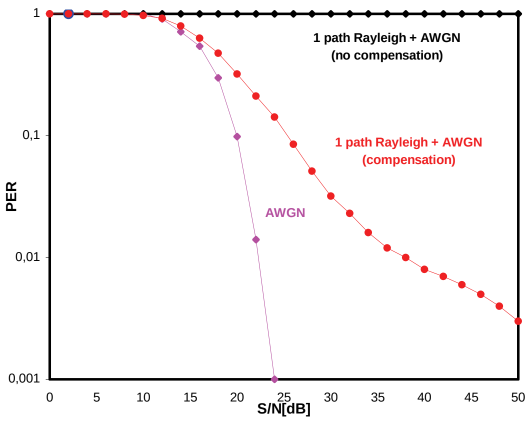

Fig.4 Packet error rate (6 waves generate fading)

The results from the simulation are shown in the Figure 3 and 4. From the curves we conclude that the BER and PER decreases when we increase the signal-to-noise ratio. When wireless channel is subjected to low SNR we obviously will have huge BER and PER. Moreover, if wireless channel is affected with Rayleigh fading and we assume no compensation we also get huge BER and PER values. When we use pilots and long training sequence for AWGN and Rayleigh fading compensation in SIGNAL and DATA field, respectively, the BER and PER experienced lower values. This shows the benefit of implementation of pilots and long training sequence, especially for Rayleigh fading compensation.

V. CONCLUSION

This simulation work was performed to derive BER and PER in order to assess the minimum SNR for good voice performance in IEEE 802.11g ERP-OFDM operational mode. We showed the impact of AWGN and Rayleigh fading in wireless channels on the performance of voice over IEEE 802.11g ERP-OFDM system and how overly optimistic the assessment of voice performance could be if fading is ignored. We also showed the benefit coming from long training sequence and pilots for fading compensation. The results obtained from the simulation suggest that the training sequences specified in the standards are adequate for near-to-perfect channel estimation in a time-invariant channel.

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