HIGH FREQUENCY SIGNAL ATTENUATION THROUGH MATERIALS

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Abstract: *Due to the growth of high-frequency signal usage in recent years, limiting the coverage of these signals in the common household environment has become an issue. The paper proposes a set of simulations and measurements aiming to determine the attenuation of the GSM and Wi-Fi signals as they pass through different types of construction materials. Using MATLAB Simulink© and experimental studies using different scenarios, it was concluded that a combination of materials may be used to restrict the area of influence of the Wi-Fi signal, without affecting the GSM signal.*

Key words: *attenuation, GSM, Wi-Fi.*

1. Introduction

Considering that wireless communication is becoming common and more available in every day use, not just for enterprises, but also for household consumers, signal containment has become a necessity.

More and more people have a wireless router, two or more mobile phones, a wireless thermostat, cordless phones etc.; henceforth the interferences between these devices in neighboring homes represent a real problem nowadays.

2. Objectives

The purpose of this work was the development of a set of simulations and measurements aiming to study the behavior of different carrier signals through building materials. The simulation set gives a basic understanding of the way different signals react when passing through the same type of channel. Our work is based on two types of signals, the GSM 900 carrier and the 802.11g WI-FI signal. These are the most common signals in modern households, and the need for their containment is becoming a real issue.

The simulation set is followed by a set of experimental measurements of different materials that have the properties to contain the WI-FI signal while having little effect on the GSM signal

3. Material and Methods

3.1. GSM 900 Signal

GSM is a TDMA digital technology deployed first in Europe. Today 65-70% of all wireless voice networks use GSM technology. GSM uses a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). In FDMA, the 25 MHz band is divided into 125 frequencies of 200 kHz each. One or more of those frequencies are assigned to each base station. In TDMA, each of those frequencies uses 8 time slots. GSM uses GMSK modulation. GMSK stands for Gaussian Minimum Shift Keying. This

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is a modulation scheme in which the phase of the carrier is instantaneously varied by the modulating signal. GMSK differs from MSK in that a Gaussian Filter of an appropriate bandwidth (defined by the BT product) is used before the modulation stage. The time-domain impulse response of the filter is described as follows:

$$h(t) = \frac{k_1 B}{\sqrt{\pi}} \, \mathrm{e}^{-k_1^2 B^2 t^2}, \quad (1)$$

where:

$$k_1 = \frac{\pi}{\sqrt{2 \ln 2}}, \quad (2)$$

and B is the half-power bandwidth.

GMSK uses a pre-modulation Gaussian filter which makes the output power spectrum more compact. The pre-modulation Gaussian filter has narrow bandwidth and sharp cutoff proprieties which are required to suppress the high-frequency components. Moreover, it has a lower overshoot impulse response which allows protecting against excessive instantaneous deviation [5].

3.2. 802.11 Signal

The 802.11 signal, known as Wi-Fi, defines standards for wireless LANs which provide half-duplex (not simultaneous bidirectional) connections that are shared, not switched.

Orthogonal frequency division multiplexing (OFDM) has become the standard of choice for wireless local area networks (LANs) such as HIPERLAN/2 and IEEE 802.11a; it has been adopted in Europe for Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB), Multimedia Mobile Access Communications (MMAC) in Japan, and fixed wireless; and is being considered for several IEEE 802.11 and 802.16 standards, including wideband metropolitan area networks (MANS). The popularity of OFDM stems from its ability to transform a wideband frequency-selective channel to a set of parallel flat fading narrowband channels, which substantially simplifies the channel equalization problem. Because of the time-frequency granularity that it offers, OFDM appears to be a natural solution when the available spectrum is not contiguous, for overlay systems, and to cope with issues such as narrowband jamming. In the multi-user context, this granularity also accommodates variable quality-of-service (QoS) requirements and burst data.

Orthogonal frequency division multiplexing (OFDM) is a wideband modulation scheme that is specifically designed to cope with the problems of multipath reception. It achieves this by transmitting a large number of narrowband digital signals over a wide bandwidth. In OFDM, the data is divided among a large number of closely spaced orthogonal carriers, which results in high spectral efficiency. In this scheme, only a small amount of data is carried on each carrier, and this significantly reduces the influence of inter-symbol interference. Here, the parallel transmission gives the capability of supporting high-bit-rate environments. Because of the orthogonal property among the carriers, the OFDM signal can be arranged in such a way so that the sidebands of the individual carriers overlap and the signals can still be received without adjacent carrier interference. The OFDM signals can be easily transmitted and received using the fast Fourier transform (FFT) devices without increasing the transmitter and receiver complexities [1-3].

4. Simulation Models

4.1. The GSM 900 Model

The GSM model consists of a transmitter/receiver based on a handset model. The Bernoulli Binary Generator block generates random binary numbers using a Bernoulli distribution.

The Differential Encoder block encodes the binary input signal. The output is the logical difference between the present input and the previous output.

The GMSK Modulator Baseband block modulates using the Gaussian minimum shift keying method.

Between the two handsets two types of channel were placed to simulate the attenuation of the GSM signal. The two blocks, AWGN channel and Multipath Rayleigh Fading Channel, were tuned in order to replicate indoor call conditions, as follows: in the additive channel the signal to noise ratio (SNR) is set to 30 dB the signal having 1 W power, and the Doppler Effect used in the Multipath Fading Channel is set to 3.36 Hz corresponding to the normal walking speed of a man. The complete GSM model is presented in Figure 1 including the emitter, receiver, the two channel types and additional elements such as signal probes and an error rate calculation block.

4.2. The Wi-Fi Model

The complete OFDM model is presented in Figure 2 including the emitter, receiver, the two channel types and additional elements such as signal probes and an error rate calculation block.

The Data Source Block consists of: a Random Integer Generator block that generates uniformly distributed random integers and an Integer to Bit Converter block that maps each integer in the input vector to a group of bits in the output vector.

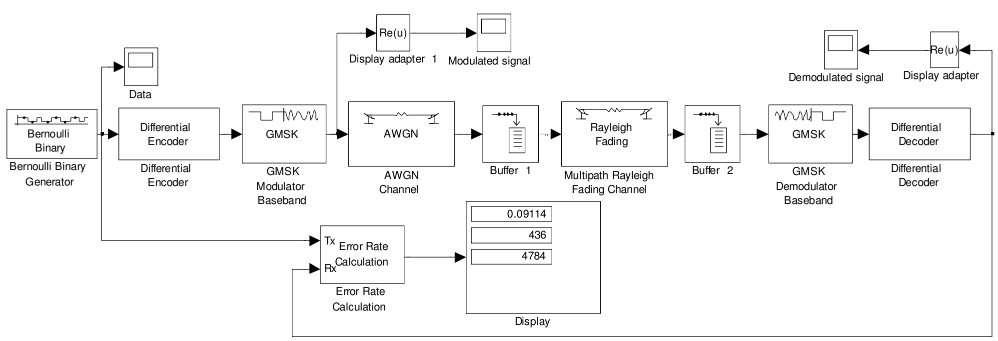

Fig. 1. *Complete GSM Simulation model*

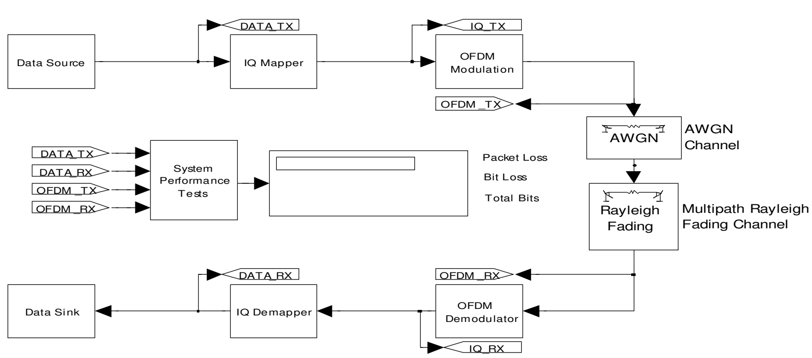

Fig. 2. *Complete GSM Simulation model*

The IQ Mapper separates the modulated signals into In-Phase signal and Quadrature signal using a General QAM Modulator Baseband block that modulates using quadrature amplitude modulation. In the OFDM Modulation Block the signal generated by the IQ Mapper is demuxed into 10 different streams. In order for the transmission to take place a buffer of 28 complex zeros is added at the start of the sequence and after each signal stream a pilot is inserted in the form of a complex 1, −1 and a complex zero in the middle of the sequence.

The resulting signal will then be multiplexed and passed through an IFFT block.

The Cyclic Prefix block is a selector that formats the signal for transmission, placing the second half of it in front of the entire sequence. This creates a cyclic prefix of the signal itself to accurately obtain the entire length of the sequence.

In order to simulate the propagation of the signal the same channels were used: AWGN and Multipath Rayleigh Fading Channel using the following values: a SNR of 30 dB, the signal having 1 W power, and a maximum Doppler Shift of 0.02 Hz corresponding to the natural frequency offset in bad weather conditions.

The receiver part of the model consists of two parts: the OFDM Demodulator and the IQ Demapper.

When the signal is received, any redundant information is removed in the first block, and after some digital signal processing the padding is removed and the signal is reordered. In the last block all the pilots that were inserted are removed.

In this last part of the processing, the input is a 16QAM signal which is demodulated and additional elements such as signal probes and an error rate calculation block. The final block converts the integers generated by the demodulator into bits that represent the actual data that was transmitted. This is then outputted into a Data Sink.

4.3. Simulation Results

After running the simulations with the given parameters we obtained the following results:

For the GSM model, an error rate of 9.114% representing 436 symbols out of a total of 4784 analyzed symbols.

For the Wi-Fi model, an error rate of 44.334% representing 1702770 symbols out of a total of 3860768 analyzed symbols.

Given the used channel parameters we can state that, regarding attenuation, for the same conditions, the models behave differently. Thus, while the OFDM signal is considerably affected, the GSM signal has an acceptable error rate.

Based on this, we can state that there is a possibility to use a type of screening consisting of a certain combination of materials, either metallic or with carbon insertions, in order to induce the desired attenuation for the studied signals.

5. Experimental Measurements

The measurements performed have been exclusively focused on the Wi-Fi signal. According to the simulation results, the materials' influence on this signal shouldn't have a significant effect on the GSM signal.

The following instruments have been used for accomplishing the experiments: an ASUS WL-320gE wireless router was selected as emitter, which was deployed with its standard antenna, a dipole with 5 dBi gain, an ASUS WL-ANT168 directional antenna with 6 dBi gain, and without an antenna. The PC utilized in the experiments featured an INTEL Wireless Wi-Fi Link 4965AGN network interface card. As for measurement equipment an AARONIA SPECTRAN HF-6060 spectrum analyzer with a HiperLOG 7060 antenna was used. The software utilized in the experiments: AARONIA LCS Analyzer and Intel PROSet/Wireless (the NIC's driver). The usage of two simultaneous measurement procedures gives us the opportunity to study how the PC interprets the signal strength in relation with the actual spectrum of the signal. During the experiments plasterboard was used as a representation of common building materials. This type of material was chosen after several comparisons between different building material types. The measured values have demonstrated that plasterboard introduces the same attenuation as a concrete plate with the same width and in the same measurement conditions. Thus, based on the fact that plasterboard is much easier to manipulate than concrete, it was used to represent common building materials.

In order to prevent false results, during each experiment, the distance between the emitter and the receiver-was measured to be exactly one meter. Also, because of the high frequency of the studied signal, the position of the test materials relative to the emitter/transmitter is highly important. During the measurements we found that the materials induce the best attenuation when placed at the maximum points of the signal. Thus, the samples were placed at the following distance from the emitter:

$$d = \frac{3\lambda}{4}, \tag{3}$$

where λ is the wavelength of the signal.

A special procedure was implemented in order to obtain a single value that would summarize the spectrum fluctuations of each measurement. The spectrum analyzer was set to record three maximum values of the signal for each sweep. Each measurement was recorded for five minutes per each scenario using the LCS software. The output file was then processed as follows: the average of the three maximum values was calculated, and a global average was calculated using these values. The latter is considered as the value of the signal measured by the spectrum analyzer.

The first step of the measurement process was to determine the reference signal levels of the setup. After testing all the possibilities in regards to the type of antenna used and the output power of the router, the reference value of −24 dBm was considered the basis for any further experiments. This value was obtained using the directional antenna and maximum power output of the wireless router. One must consider the fact that this value is between the normal limits for wireless reception. The typical maximum received power of a wireless network is between −10 and −30 dBm [4].

The second step was to determine the minimum power at which the network fails. The typical minimum received power of the network is between −60 and −80 dBm. But, due to the short distance between the emitter and receiver, the tested network ceased to function at around −90 dBm. At this point the Intel PROSet driver reported a 99% error rate and WPA-PSK (the security mechanism used on the network) failed.

The first scenario performed has involved a plasterboard (12 mm) plate measuring 28x29 cm. The dimensions of the plate assured that the entire emitting range of the antenna (70° horizontal/vertical) was covered. The material was placed at 9 cm from the router according to formula (3). In order to increase the attenuation effect, an aluminum foil was placed on the side facing the router. Using the aforementioned measurement procedure, the following results were obtained. The Intel PROSet recorded a signal power of −30 dBm. Using the LCS software and the subsequent data processing, a value of

−33.4151 dBm was obtained. By subtracting this value from the abovementioned reference, we can conclude that the induced attenuation of the materials is 6 dBm.

The second scenario involved the use of a box made from plasterboard measuring 20x19x22 cm. The inside of the box was covered with aluminum foil in order to contribute to the attenuation effect of the box. This setup was used in order to try to eliminate the reflections introduced by the plasterboard plate. These reflections could bounce back of the surrounding walls and still reach the receiver. The router was placed inside the box and the measurement method was applied. Using Intel PROSet we obtained a signal value of −35 dBm, while LCS provided an average value of −38.1995 dBm. Thus the attenuation of the materials consists of 11 dBm.

A significant difference was obtained between the two values that were measured in the two scenarios. This difference points out the importance of reflected waves when it comes to limiting the range of a Wi-Fi network.

6. Conclusions and Further Work

As we initially assumed, the possibility to contain the Wi-Fi signal is feasible, while the GSM signal passes with little attenuation. The two presented scenarios prove that by using simple, affordable materials one could restrict the propagation of the 802.11g signal. Also, choosing thicker materials can increase the attenuation.

As a continuation of this study, we intend to repeat the experiments by using polymeric nanomaterials with carbon insertions created for the specific purpose of attenuating high frequency signals. In the presented measurements, it was possible to test small samples of nanomaterials, but a definitive result cannot be stated until a larger sample is obtained. The attenuation produced by these materials is a lot more significant than that of classic building materials.

Our simulation method proved efficient, anticipating the experimental results, thus this type of method can be used to compare any type of signal transmission.

As a conclusion we can state that the correct configuration of materials can be used to contain the Wi-Fi signal, without affecting the GSM signal, and that this can be achieved within reasonable cost limits, having the potential of being implemented on a large scale.

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