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COMPLETE SIMULATION OF AN IEEE 802.11 WIRELESS NETWORK USING A FULL WAVE ELECTROMAGNETIC TOOL DYNAMICALLY COUPLED TO A RF SYSTEM SIMULATOR

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Complete Simulation of an IEEE 802.11 Wireless Network using a Full Wave Electromagnetic Tool Dynamically Coupled to a RF System Simulator

J.F. Mologni [α], C.L.R. Siqueira [σ] & M.A.R. Alves [ρ]

Abstract - The purpose of this study is to fully evaluate a short range IEEE 802.11g channel at 2.4 GHz frequency by dynamic linking Ansys HFSS, a full wave electromagnet tool, and Ansys Designer, a system level design simulator. The study presented in paper shows the integration of a 3D field solver and a circuit solver that enables the calculation of radiation patterns, electric field plots, bit error rate, constellation plots while incorporates the actual transmitter and receiver antennas and devices as well as TX/RX system with numerous modulation schemes. Multipath effects are also considered because the entire physical environment is modeled. Frequency and time domain responses are seamlessly combined in order to yield a complete response of the entire system. The scenario of the WiFi network is a room comprised of a router, a notebook and a phone. The concepts shown in this paper can be applied to Zigbee, Bluetooth, WiMax and many other wireless network types.

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I. Introduction

The mainly Wireless Local Area Networks (WLANs) standards are IEEE 802.11 [1] and HyperLAN [2]. The IEEE 802.11 protocol set; commonly known as Wireless Fidelity (WiFi) can reach transmission rates up to 54 Mbps [3] using Quadrature Amplitude Modulation with 64 symbols (QAM-64). Numerous devices including notebook and smart phones can be connected to the network wirelessly and simultaneously. The network performance is affected by the surrounding environment and possible third party electromagnetic sources. If the transmission channel is found to be noisy or the path loss is too high, the router and electronic devices connected to it may adapt itself automatically using a more robust modulation in order to decrease bit error rate (BER). Usually a WiFi network is an indoor environment, and for that reason, many authors have reported experimental and theoretical studies of indoor propagation [4–9]. Nevertheless, these models tend to assume a particular feature like temporal fading or inter-floor losses. In order to create an exact model of any telecommunication channel, every geometric detail such as antenna geometry, orientation, reflections, component coupling and mismatch, needs to be modeled and calculated by a full wave 3D simulator. Ansys High Frequency Structure Simulator (HFSS), a solver based on the very well renowned Finite Element Method (FEM) is used for this purpose. A full room environment, including a router, a smart phone, a notebook and all the objects that are considered to affect the transmission channel are modeled. Two different 3D models of the room were analyzed: in the first condition the room has no walls and it is assumed to be in a free space. This first model considers the walls as an absorbing boundary condition (ABC) with perfect matched layers (PML) elements to fully absorb any incoming electromagnetic wave. In the second condition, the walls are modeled as concrete, which will likely result in a channel with multipath. The excitations of the 3D model is usually a sinusoidal source with a given frequency and phase, however, in order to obtain a realistic far field patterns and electric field distribution, the modulated WiFi time domain signal needs to be calculated in an external tool. For this purpose, the complete WiFi system design, which includes bit generator, header and preamble according to IEEE 802.11, modulators, filters, are accomplished using Ansys Designer. A full dynamic link between HFSS and Designer models enable a full system analysis, with BER and constellation plots using the 3D model as well as real far field patterns and electric field distribution due to modulated signals resulted from the system analysis showing the state of the art in terms of electromagnetic and circuit coupled simulation.

II. Full Wave 3D Electromagnetic Model

Ansys HFSS uses the FEM where a structure is subdivided into smaller subsections called finite elements. The finite elements in HFSS are tetrahedra, and the entire collection of tetrahedra is called a mesh. A solution is found for the fields within the finite elements, and these fields are interrelated so that Maxwell's equations are satisfied over inter-element boundaries,

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generating a field solution for the original 3D model. Once the field solution has been solved, the generalized S-matrix solution can be determined. HFSS solves equation 1, also known as wave equation, for each tetrahedra element on the model:

$$\nabla \times \left(\frac{1}{\mu_r} \nabla \times E_m(x,y) e^{-\gamma_m{}^2} \right) - k^2 \varepsilon_r E_m(x,y) e^{-\gamma_m{}^2} = 0 \quad (1)$$

Where $k = w/c$ is the wave number of free-space; c is the speed of light; $w=2\pi f$ is the angular frequency; $m_r(x,y)$ is the complex relative permeability and $e_r(x,y)$ is the complex relative permittivity. By solving the equation, the electric field mode pattern $E_m(x,y)$ and the propagation constant g_m are both calculated for all the modes specified. The magnetic field is calculated according to equation 2:

$$H = \frac{1}{\omega \mu_r} \nabla \times E_m(x,y) \quad (2)$$

The above implies that HFSS solve equations in terms of electric and magnetic fields and not voltages and currents. As a result, it is very important that an HFSS simulation encompasses a volume within which electric and magnetic fields exist. Voltages and currents can then be calculated by integrating field values over surfaces and volumes.

The complete 3D room geometry is modeled with all the details including the router, phone, notebook, table, file cabinet, couch, chair, monitor, computer housing, vase and external walls as ABC boundary (radiating in free space) and later as concrete. Figure 1 shows the full model including the three electronic devices (router, notebook and phone) whose communications are going to be evaluated and all the surrounding objects that affect the transmission channel.

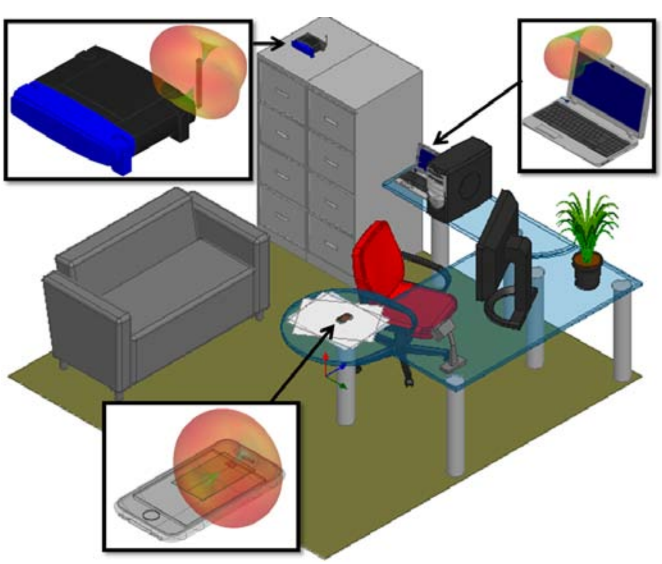

Figure 1 : Full HFSS model including the router, phone and notebook

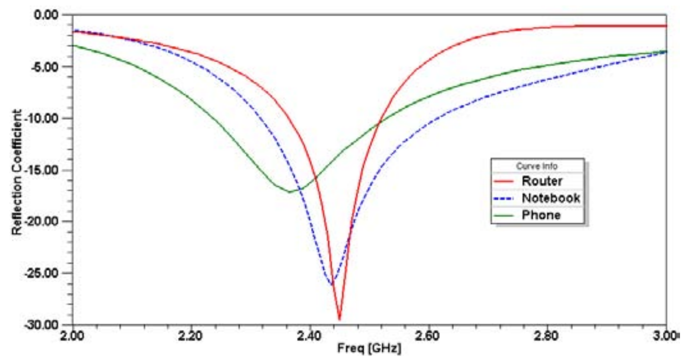

Figure 2 : Reflection coefficient S_{11} for all three electronic devices

The inset in figure 1 shows the far field pattern of all three electronic devices considering them radiating to be isolated and in a free space environment (not in the room). Note that all radiation patterns are for a 2.4GHz sinusoidal excitation. The antenna used in the notebook is a Planar Inverted F Antenna (PIFA); in the router the antenna is a monopole and in the phone it is a ceramic chip antenna. The far field patterns are in the typical shape of a "donut", which is expected for those types of antennas operating at their resonant frequency [10]. The reflection coefficient of the antennas (S_{11}) are observed in figure 2 where all values are below -10dB at the WiFi bandwidth which goes from 2.4 to 2.4835GHz and thus the devices are all operational at this frequency.

III. IEEE 802.11 System Design

Ansys Designer was used to create the full IEEE 802.11 system due to its complete library which already includes a complete schematic including all components already set for this standard. Some IEEE 802.11 characteristics includes fixed 22MHz channels, data rates from 6-54 Mbps depending on the Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), QAM-16 or QAM-64 modulation, low sensitivity to time synchronization errors, 64 sub-carriers, coding rates of 1/2, 2/3 or 3/, channel correction through the use of pilot channels for magnitude and phase and cyclic prefix (CP) which mitigates synchronization and multi-path.

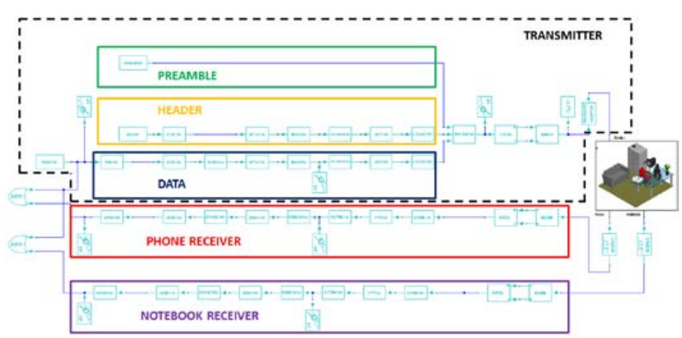

Figure 3 : IEEE 802.11 Schematic in Ansys Designer

Figure 3 shows the complete schematic including in the transmitter and receiver components plus the HFSS 3D model. The transmitter is comprised of a preamble, header and the data generation which includes a bit source that yields a random binary sequence, taking the value 1 or 0 with equal probability, followed by a convolutional encoder, a puncture to increase the coding rate [1], a interleaver since all encoded data bits shall be interleaved with a block size corresponding to the number of bits in a single Orthogonal frequency-division multiplexing (OFDM) symbol, a modulator to create a signal according to Gray-coded constellation mappings [11], a pilot addition, an inverse Fast Fourier Transform (IFFT) component that integrates OFDM signal to extract modulated data and a cyclic prefix addition component. The pilot addition is important because in each OFDM symbol, four of the subcarriers are dedicated to pilot signals in order to make the coherent detection robust against frequency offsets and phase noise. These pilot signals shall be put in subcarriers –21, –7, 7 and 21. The pilots are BPSK modulated by a pseudo binary sequence to prevent the generation of spectral lines. A data frame is then formed using this data plus the preamble and header information.

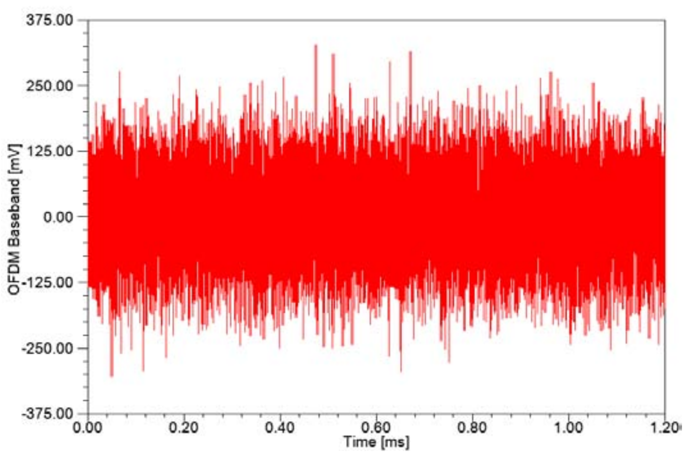

Figure 4 : OFDM Baseband transmission signal

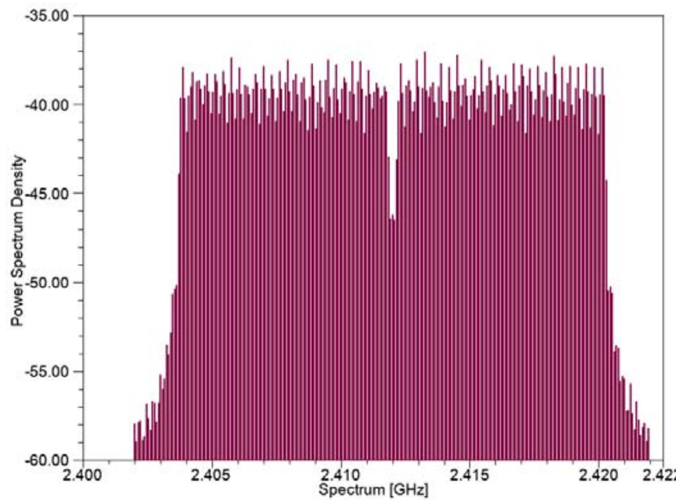

Figure 5 : OFDM Spectrum

The OFDM baseband transmission signal in time domain is extracted from the schematic and is displayed in figure 4. The OFDM spectrum showing the 64 sub carriers in the range of 2.4 to 2.4835GHz is plotted in figure 5. This data is then pushed into the router antenna in the HFSS 3D model, and the signal is then received by the phone and notebook antennas.

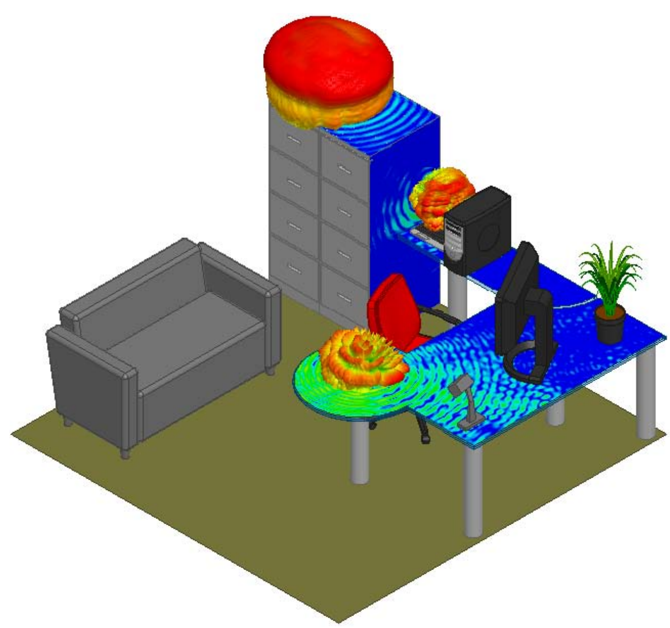

Figure 6 : E-field and radiation patterns of the room with ABC on the walls

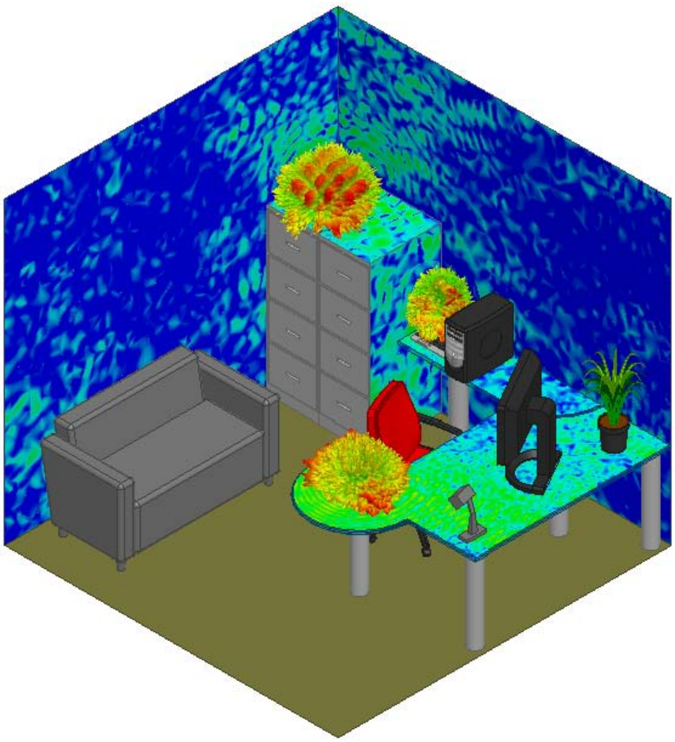

Figure 7 : E-field and radiation patterns of the room with concrete walls

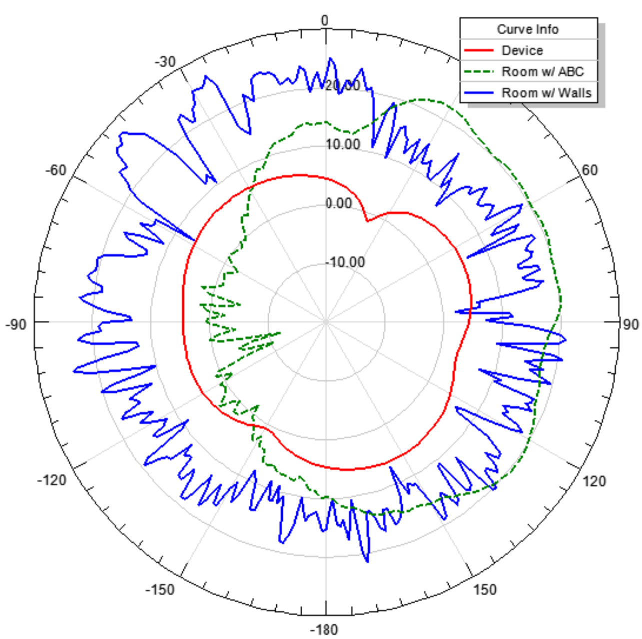

Figure 8 : Router far field pattern at $\phi = 90^{\circ}$ for three cases

Figure 6 shows the radiation patterns of the three electronic devices by having the QAM-16 modulated signal generated in Ansys Designer as an excitation in a full room environment with no walls. The walls in this model are considered as an ABC. By comparing figure 1 and 6, one can observe the distortions in the radiation patterns due to their different excitations and the objects that are now modeled in figure 6. A second case was created, where the walls are modeled as concrete, and the results are shown in figure 7. An even more evident distortion can be observed on the antenna patterns for this second case. This is mainly due to the reflections of the electromagnetic wave into the walls, which causes multipath. The distortions can be better visualized in figure 8 for the three cases where the router radiation pattern is displayed at $\phi = 90^{\circ}$. The red curve represents the far field of the router only in a free space environment excited with a 2.4 GHz sinusoidal signal. The dashed green line is the router far field excited with the QAM-64 modulated signal from Designer and within a room whose walls were modeled as an ABC (simulating free space). The blue pattern is the router with modulated signal and within a room with the walls modeled as concrete.

The communication channel can now be analyzed taking into consideration the full wave 3D electromagnetic model and the realistic waveforms. For this simulation, the second case where the room is modeled with concrete walls is taking into consideration since it represents a more realistic environment.

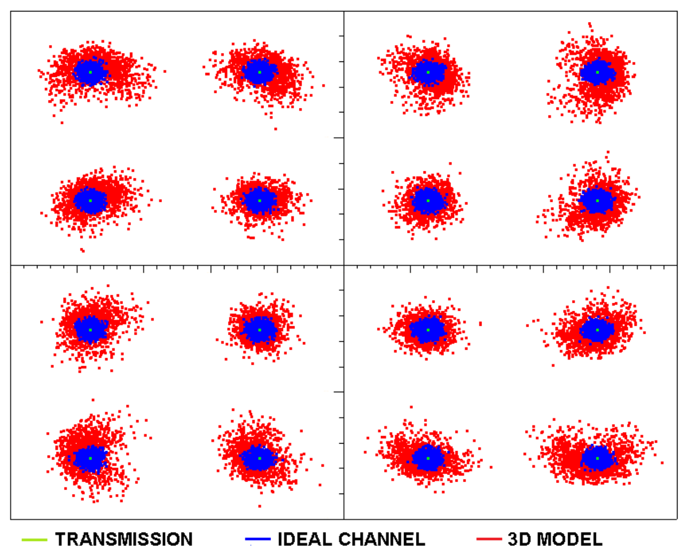

Figure 9 : QAM-16 constellation plot at the phone receiver

Figure 9 shows the QAM-16 constellation plots at the transmitter, the notebook receiver and in an ideal channel. An ideal channel, where a numerical additive white Gaussian noise (AWGN) is mathematically inserted into the system design is modeled for comparisons purposes.

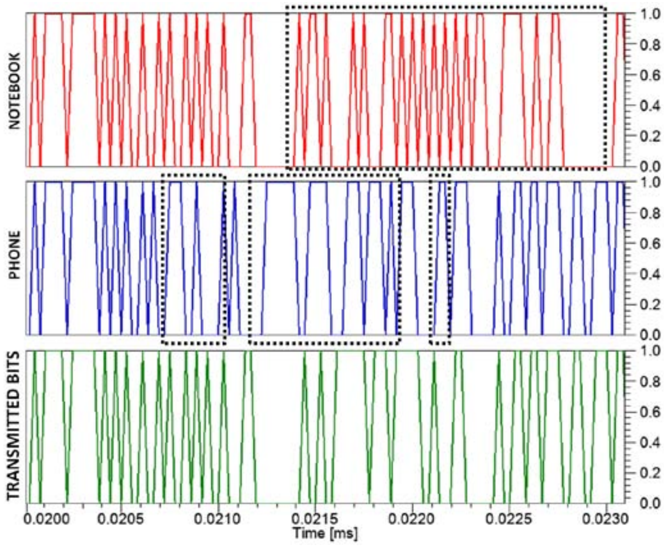

Figure 10 : Transmitted and received bit waveforms

Pilot subcarriers contain signal values that are known in the receiver. These pilot signals are used in the receiver for correcting the magnitude and phase shift offsets of the received symbols. For the phone demodulator, the sensitivity was calculated to be 290 for magnitude correction and the phase offset is 2.04 degrees; for the notebook demodulator these values are 50 and 2.6 degrees respectively. A phase distortion, frequently caused by multipath, is clearly observed in the red constellation, where the 3D model is considered. Also, the red constellation plot shows that there is a higher probability of intersymbol interference (ISI) to occur, which accurately represents the real world environment. When there is an ISI, a symbol, which carries 4 bits in a QAM-64 signal, is incorrectly received (typically by an adjacent symbol in the constellation) and as a result there is also a bit error at the receiver. BER is the ratio between the counts of wrong received bits divided by the total number of bits. A time frame of the bit sequence of all devices is displayed in figure 10. The black dotted line shows some wrong bits received by the notebook and the phone. This simulation was performed with QAM-16 and a SNR (signal to noise ratio) equal to 10 to force a high BER. For this scenario, the BER at the notebook is 25E-2 and at the phone is 18E-2.

By choosing a more robust modulation (e.g. BPSK) the BER values decreases, as well as the trasmittion rate. Figure 11 shows the BER as a function of the SNR plots for the notebook, phone and the ideal channel using BPSK, QAM, QAM-16 and QAM-64. These modulations yields a transmittion rate of 9Mbps, 18Mbps, 36Mbps and 64Mbps, respectively. Higher transmittion rates requires more bits per symbols, which in turn increases the ISI probability. According to figure 11, the network performance is very similar for the phone and notebook when using BPSK, QAM and QAM-16 modulations. Nevertheless, for QAM-64, the performance of the phone is higher than the notebook due to the transmittion link, which in the case of the notebook is done through multipath because there is no direct path to the router. In this scenario, the ideal channel also permforms better, as expected.

IV. Conclusions

A full simulation integrating the IEEE 802.11 system with a full wave 3D electromagnetic room model where the the performance of a router, a notebook and a phone is evaluated in details. Multipath, component coupling, wave reflections and scaterring parameters may only be obtained through the use of a full wave simulation tool, in this case Ansys HFSS, and these parameters are dynamically coupled to the system design in order to characterize the IEEE 802.11 communication channel in terms of BER as a function of SNR and constellation plots. When using BPSK, QAM and QAM-16 modulations, the network performance is very similar for the notebook and the phone, however, when using QAM-64, the transmittion rate is higher and the phone performs slightly better than the notebook due to a direct link between the router and the phone. Far field patterns and electric field plots were also calculated by having an accurate IEEE 802.11 signal as excitation. The depth of this analysis is only possible with a dynamic link between a 3D full wave electromagnetic simulation and a system design tool. The concepts presented in this paper can also be applied to numerous wireless networks including Zigbee, WiMax, Bluetooth, WCDMA and GSM among many others.

References Références Referencias

1. IEEE, “Wireless LAN medium access control (MAC) and physical layer (PHY) specifications,” IEEE Standard 802.11, 1997.
2. G. Halls, “HIPERLAN: the high performance radio local area network standard,” Electronics and Communication Engineering Journal, vol. 6, pp. 289–296, December 1994.
3. IEEE, “Wireless LAN medium access control (MAC) and physical layer (PHY) specifications- Amendment 4: Further higher-speed physical layer extension in the 2.4 GHz band,” IEEE Standard 802.11g, 2003.
4. M. Iskander, Z. Yun, and Z. Zhang, “Outdoor/indoor propagation modeling for wireless communications systems,” IEEE Antennas and Propagation Society International Symposium, vol. 2, pp. 150–153, July 2001.
5. Theodore S. Rappaport, "Wireless Communications, Principles and practice", Second Edition, ISBN 0-13-042232-0.
6. H. Zepernick and T.W ysocki, “Multipath channel parameters for the indoor radio at 2.4 GHz ISM band,” IEEE Veh. Technol. Conf., vol. 1, pp. 190–193, May 1999.

7. S. Kumar, B. Farhang-Boroujeny, S. Uysal, and C. Ng, “Microwave indoor radio propagation measurements and modeling at 5 GHz for future wireless LAN systems,” Microwave Conference, 1999 Asia Pacific, vol. 3, pp. 606–609, 30 November-3 December. 1999.
8. A. Kotanen, M. Hännikäinen, H. Leppäkoski, T. Hämäläinen, “Positioning with IEEE 802.11b wireless LAN”, IEEE Personal, Indoor and Mobile Radio Communications, vol.3, pages 2218- 2222, 7-10 Sept. 2003.
9. B.H. Fleury, P.E. Leuthold, “Radiowave propagation in mobile communications”, IEEE Communications Magazine, vol. 34, no. 2, pp. 70-81, Feb. 1996.
10. C. A. Balanis, “Advanced Engineering Electro-magnetics”, John Wiley and Sons, 1989.
11. IEEE, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band,” IEEE Std 802.11a, Part 11, ISO/IEC 8802-11:1999/Amd 1:2000(E).