Wireless LAN Networks Design: Site Survey or Propagation Modeling?

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Abstract. *There are two basic ways to deploy wireless LAN access points in an indoor scenario: manual deployment using a site survey based on empirical measurements or planning using a software tool with built-in signal propagation models. In this paper advantages and disadvantages of both ways are discussed. The planning based on propagation modeling is recognized as a highly preferable approach for design of large WLANs. Experimental data in this paper were processed in MATLAB.*

Keywords

Wireless LAN, site survey, propagation modeling.

1. Introduction

Recently wireless local area networks (WLANs) have emerged as flexible communication systems, which have been implemented as an extension or alternation for a wired LAN within buildings. Using electromagnetic waves WLANs transmit and receive data over air interface, minimizing need for wired connection, thereby it enables user mobility in covered area without losing connectivity to the backbone net.

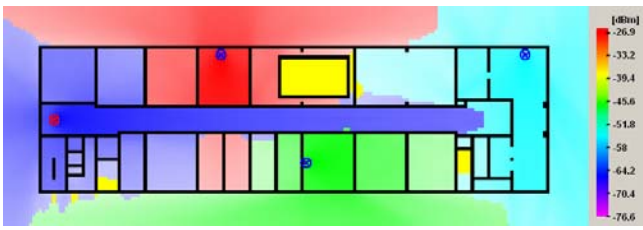

Fig. 1. Example of predicted coverage of WLAN APs

The system implementations vary from simple peer-to-peer connection between two computers to cover entire buildings by many transmitter/receiver devices - access points (AP), which are connected to the wired network [1] (Fig.1).

Most of the recently used WLAN systems are specified in IEEE 802.11 standard [2]. The IEEE 802.11 standard is divided into two main layers: the Medium Access Control layer (MAC) and the Physical Layer (PHY). These two layers allow a functional separation of the standard and, more importantly allow a single data protocol to be used with several different RF transmission techniques. WLAN systems mainly work based on these standards:

- 802.11b (802.11HR) - DSSS at 2.4 GHz with 1, 2, 5.5, and 11 Mbps data rates,
- 802.11g - OFDM at 2.4 GHz with 1, 2, 5.5, 11, and 22 Mbps data rates,
- 802.11a - OFDM in 5 GHz band with 6, 12, 18, 24, 36, 48, and 54 Mbps data rates, and
- HiperLAN2 – OFDM in 5.15-5.35 GHz and 5.725-5.825 GHz bands, similar to the 802.11a PHY (with varying convolution codes)

The indoor signal propagation differs from an outdoor case particularly in distances and in variability of the environment. Due to the multipath propagation (multiple reflections, diffractions and scatterings of electromagnetic waves from surrounding objects) the radio signal distortions and propagation losses (fading) occur.

For a small network in a limited area, only manufacturer's information on the coverage range is sufficient to deploy the APs. For a larger network, a more accurate deployment procedure is required to ensure sufficient coverage and network functionality (bit rate, capacity, interference, etc.). Basically there are two approaches. The first is based on a site survey with a lot of measurements and experimental decisions. The second method comprises of software planning using propagation models. The advantages and disadvantages of both ways are going to be discussed in the following sections.

2. Site Survey

Site survey using either a standard wireless device with a testing software tool or special sophisticated equipment is undoubtedly indispensable way to test existing WLAN networks - coverage, performance, etc.

The issue discussed here is the process of building up the network - in terms of optimal number of APs and their placement - using a site survey. So the main goal of a site survey is to measure enough information to determine the number and placement of access points that provides adequate coverage. Basically the procedure involves the deployment of temporary APs in preliminary locations, either a single AP at a time or a whole WLAN is temporarily built up based on a designer's opinion and experiences. Afterwards the coverage and/or Quality of Service (QoS) is examined using the site survey measurement. Based on the results the positions and configurations of APs are changed or new APs are introduced. Then again a site survey is repeated to find an acceptable solution iteratively.

2.1 QoS and Signal Strength Measurement

"Quality of Service" is a term of wide comprehension. The ITU-T Recommendation E.800 [3] defines QoS as "The collective effect of service performance, which determines the degree of satisfaction of a user of the service." QoS is described through the selection of a set of QoS parameters, specification of QoS target values and the choice of QoS measurements and evaluation mechanisms. A QoS parameter is a variable that characterizes QoS.

The most important network parameters for the effective data transmission are delay, throughput, jitter, bandwidth, echo, and packet loss [1]. Almost all of these parameters depend mainly on proper signal strength, i.e. coverage planning. Throughput and latency are two essentials for network performance. Whereas throughput is the quantity of data that can pass from source to destination, the delay determines the latency between transmitting and receiving the packet. Jitter means the variation in arrival times between continuous packets transmitted from point A to point B. It can be caused by packet routing changes, congestion, and processing delays. Packet loss denotes the percentage of packets never received at the destination. QoS parameters have to be measured across the total network, encompassing both the wired and wireless portions of the network.

It should be pointed out that the signal propagation delay is crucial to the broadband experience because the Internet is based on the Transmission Control Protocol (TCP). TCP requires the recipient of a packet to acknowledge its receipt. If the sender does not receive a receipt in a certain amount of time, then TCP assumes that the connection is congested and slows down the rate at which it sends packets.

2.2 Measurement Equipment and Methods

As it was stated before, the site survey consists of temporary WLAN access points deployment and consequential investigation of the covered area. Many wireless LAN vendors provide free RF site survey software tools that identifies the associated access point, data rate, signal strength, and signal quality. Users can load this software on a laptop or PDA and test the coverage of each preliminary access point location. Alternatively, professional site survey tools and systems are available [4] (Fig.2).

Fig. 2. Measurement system by Symbol [4]

These wireless receiver systems are designed specifically for sweeping, analyzing and optimizing Wireless Local Area Networks. The instruments measure coverage of IEEE 802.11 standard based networks which allow the user to determine the AP, PER (Packet Error Rate), Multipath and RSSI (Received Signal Strength Indication) signal levels, aiding in locating the hub and access points of neighboring WLANs. These tools have signal strength detection both before and after the processing gain. Signal strength before the processing gain sweeps across the frequency band and detects the power in a relatively narrow bandwidth. A peak hold mode detects and displays narrow band interferers such as microwave ovens and frequency hopping systems. The signal strength detection includes the effects of multipath. The combination of these two measurements combined with portability will aid in the planning and optimization of 802.11 wireless systems.

Some of network parameters (including e.g. packet loss, throughput, jitter) can be investigated in wired part of the network as well. The methods for measurement of QoS in both wired and wireless parts can be found in [5-7].

Generally, one should be educated and experienced to carry out a complex site survey and interpret its result. The issue is not only the operation of sophisticated site survey tools but the measurement ambiguities caused by time and space variability of the environment, type and orientation of used antenna, etc. These issues are addressed in the next section.

2.3 Measurement Ambiguity

A very simple experiment was carried out to show some of the measurement difficulties that should be taken into account. The peer-to-peer connection was built up consisting of two notebooks (both supplied with identical PCMCIA card [8]) in the 6th floor of CTU Prague building. The notebooks were deployed in accordance to the Fig. 3 in two office rooms separated by a corridor.

The first notebook (no. 1) used the directional helix antenna, whereas the second utilized implemented built-in antenna. Values of the signal strength and signal to noise ratio were obtained and processed every second by no. 2 notebook via a standard measuring tool. The influence of changes in surrounding environment (opening doors) and people movement, on received signal strength have been investigated. These phenomena have high impact on proper evaluation of measurement results and consequent coverage planning. Thanks to the directional antenna the impact of the environment outside the area between the notebooks was suppressed.

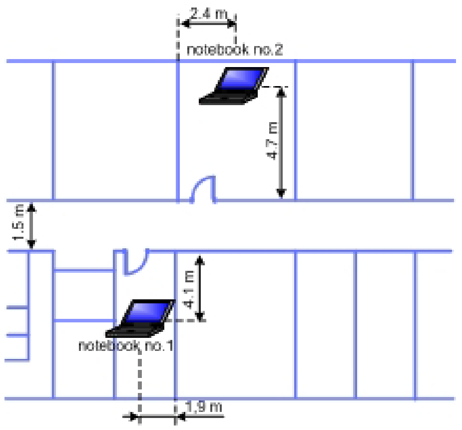

Fig. 3. Experiment geometry

At first, the measurements were performed without the presence of people. The doors were opened and closed and the orientation of the notebook was changed in order to investigate how it would distort received signal strength. In the Fig. 4 the 5 dB variations due to the "door state" can be clearly seen. Few high attenuation peeks were caused by a sporadic movement of people at the corridor which was difficult to prevent even in such a limited area.

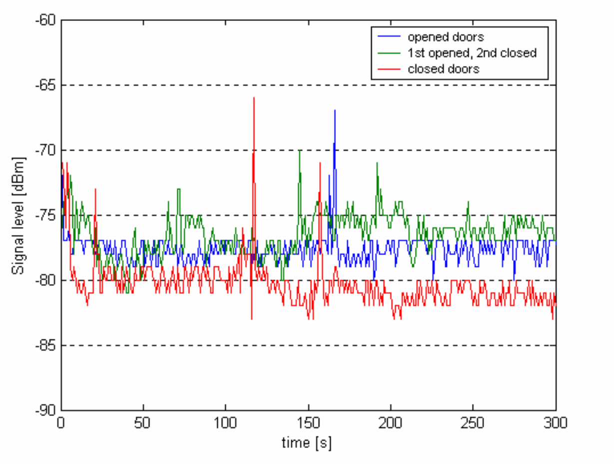

Fig.4. Influence of opening doors on received signal strength

Almost 14 dB fluctuation of the received signal have been observed when rotating the notebook. The detailed results dealing with notebook orientation measurement can be found in [9]. It must be understood, that this effect can be even more distinct when hand-held device is used. The influence on how it is held, i.e. shadowed by a user, is tremendous.

Afterwards, the measurements with moving people in the corridor have been carried out in the same arrangement of the environmental surroundings. The comparison of the received signal strength without people to signal with people disruption for opened doors arrangement is depicted in Fig. 5a and Fig. 5b, respectively. Although it is not clearly seen in figures, the movement of people temporary caused the change of mean signal level as well (4.3 dB difference).

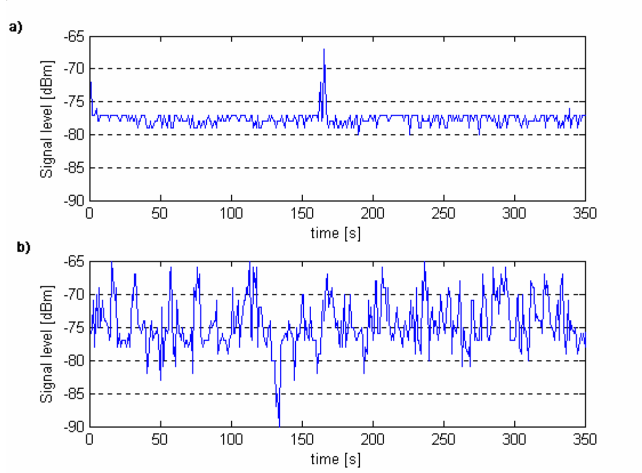

Fig. 5. Signal strength received a) without, b) with disruption by moving people

The histogram of the worst case of signal transition - arbitrary opening doors with people disruption - is shown in Fig. 6. The scale of received values reaches almost 20 dB. Similar results in were reported by other authors as well [10]. In a real environment the situation is much more complex than in the presented simple experiment.

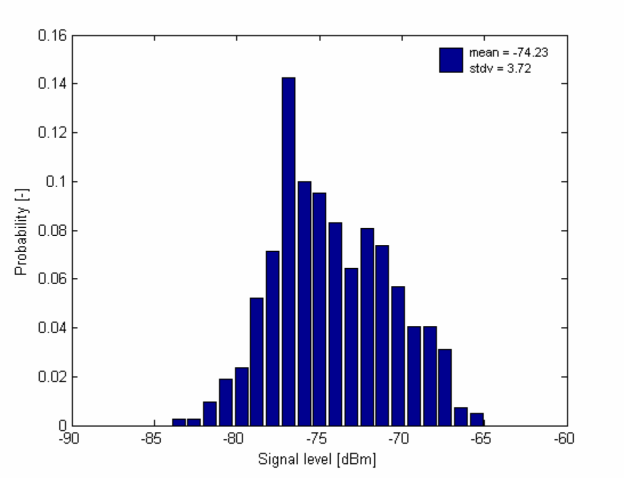

Fig. 6. Fading histogram

During an indoor site survey all these issues should be kept in mind. A simple way to handle it is the measurement averaging in terms of space, measurement antenna orientation, environment variations, etc. Some of the tools can do the averaging automatically to a certain extent but the time and complexity of the measurement increases.

3. Propagation Modeling

Software planning (using a propagation model) is much more convenient and cost-effective way to deploy a wireless network than a site survey with lots of measurements and empirical decisions. Using simulations many different configurations of the network can be tested with no expenses to find an optimal solution.

That is why efficient propagation models are required for CAD design tools to analyze or optimize a network. As it was stated the indoor propagation modeling is one of the most complicated tasks in this field. In addition, a detailed description of an indoor scenario including furnishing, doors, constitutive electrical parameters of used materials etc. is almost impossible. To find a balanced trade-off between a model complexity (computation time, requirements on input data, etc.) and reasonable accuracy is a challenge.

Quite a large number of indoor propagation models can be found in literature [11]. The models can be roughly divided into two groups: deterministic and empirical.

3.1 Deterministic Modeling Approach

Deterministic or semi-deterministic models are primarily based on electromagnetic wave propagation theory being as close to physical principles as possible.

Most of the models known as ray tracing or ray launching are based on geometrical optics. Some simplifications lead to viewing the radio wave propagation as optical rays.

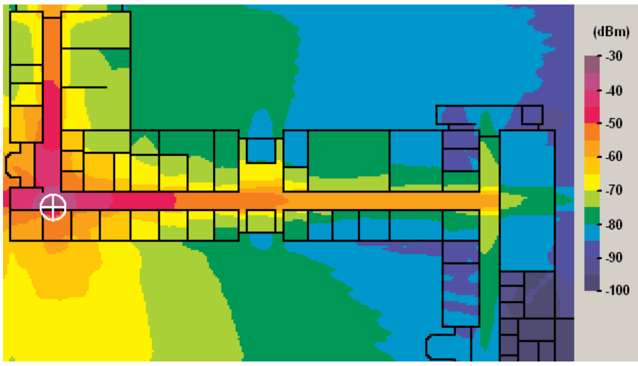

Fig. 7. Coverage prediction by a deterministic model [12]

The outputs of deterministic models show an excellent site-specific accuracy. Fig. 7 shows the example of the deterministic model coverage prediction. It can be seen that diffraction and waveguiding effect of the corridor are considered. Since the multipath propagation can be fully described, other space-time properties like time delays, angles of arrival etc. can be determined. On the other hand, for a common planning only the propagation loss is sufficient and the cost for the accuracy is enormous. The sophisticated predictions are very time consuming and require detailed description of the scenario (3D geometry, constitutive material parameters), which is not easy to obtain. That is why the deterministic models are not very popular in common praxis.

The deterministic approach is not dealt with in this paper. More information and references can be found in [11].

3.2 Empirical Modeling Approach

On the other side the empirical and semi-empirical models are primarily based on statistically processed representative measurements. As the most popular examples, One-Slope and Multi-Wall models are described in the following chapters.

These models are very easy and fast to apply because the prediction is usually obtained from simple closed expressions. Also requirements on the input environment description are "reasonable". But, at the same time, only the propagation loss without great site-specific accuracy can be predicted.

Total path loss L_{TOT} (dB) can be expressed (see [13]):

$$L_{TOT} = L(P) + \chi \,, \tag{1}$$

where $L(P)$ (dB) is the average loss based on the position P only, and χ (dB) is random fading with a zero-mean statistical distribution.

The empirical and semi-empirical models are able to predict the average path loss $L(P)$. The random fading has to be considered as a fade margin in the power budget of a wireless link.

3.2.1 One-Slope Model

The One-Slope Model (1SM) [13] is the easiest way to compute the average signal level within a building without detailed knowledge of the building layout. The path loss in dB is a function of just a distance between transmitter and receiver antennas:

$$L(d) = L_0 + 10\, n \log(d) \,, \tag{2}$$

where L_0 (dB) is a reference loss value for the distance of 1 m, n is a power decay factor (path loss exponent) defining slope, and d (m) is a distance. L_0 and n are empirical parameters for a given environment, which fully control the prediction. As an example Tab.1 presents a few values taken from various references.

It can be clearly seen that the value of the power decay factor n is highly dependent on the type of building or structure of the indoor environment and so it has the major influence on the resulting determination of the signal level coverage. A typical example of a coverage prediction using 1SM is shown in Fig. 8.

Comparing Figs. 7 and 8 it is apparent that 1SM prediction considers only the change of the signal level with distance between transmitter and receiver regardless of the actual structure of the indoor environment. The 1SM provide only a rough estimate (standard deviation usually greater than 10 dB) and the selection of proper power decay factor *n* is crucial.

f (GHz)	L_0 (dB)	n (-)	comment
1.8	33.3	4.0	office [13]
1.8	37.5	2.0	open space [13]
1.8	39.2	1.4	corridor [13]
1.9	38.0	3.5	office building [14]
1.9	38.0	2.0	passage [15]
1.9	38.0	1.3	corridor [15]
2.45	40.2	4.2	office building [9]
2.45	40.2	1.2	corridor [9]
2.45	40.0	3.5	office building [16]
2.5	40.0	3.7	office building [17]
5.0	46.4	3.5	office building [18]
5.25	46.8	4.6	office building [17]

Tab. 1. One-Slope Model empirical parameters

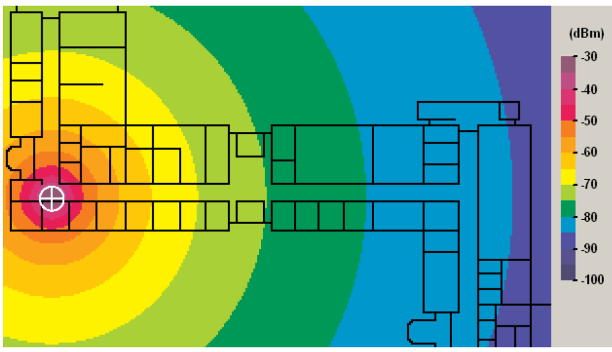

Fig. 8. One-Slope Model coverage prediction

The values of the power decay factor *n* vary depending on the type of building and indoor environment. The value n = 2 corresponds to the propagation in free space. Values smaller then 2 are utilized for prediction of the signal propagation in corridors, where the decrease of the power decay factor is caused by a wave-guiding effect. In an office environment with walls and furniture *n* is usually between 3 and 6. The 1SM gives the best results for environment with more or less uniformly distributed walls and obstacles.

The 1SM performance and the importance of proper parameter *n* selection are demonstrated in Fig. 9, 10, 11.

A transmitter was located on the left side in the corridor so that strong wave-guiding effect along the corridor can be observed in Fig. 9. Then two 1SM predictions were performed and compared with the measurement. First, the *n* for corridors n = 1.4 was utilized (Fig. 10). Very good agreement between measurement and prediction can be seen in the corridor. On the other hand very poor prediction accuracy is provided for the offices since the signal attenuation is much stronger than in the corridor and the prediction is overestimated. If the n = 4.0 suitable for office environment is used instead (Fig. 11), the coverage prediction is perfect in the offices but strongly underestimated in the corridor. To handle this problem either the different parameter *n* is used for corridor and offices or an averaged *n* value between 1.4 and 4.0 can used as a trade-off, then the prediction will be valid for the whole floor but at the lower accuracy.

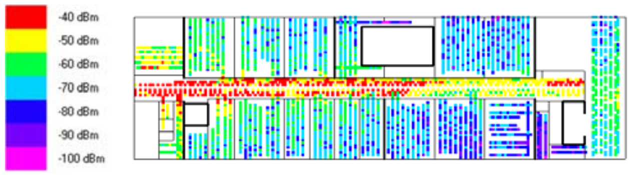

Fig. 9. Measured signal level

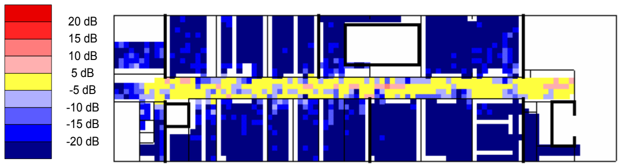

Fig. 10. Prediction error (difference between 1SM prediction and measurement) for n = 1.4

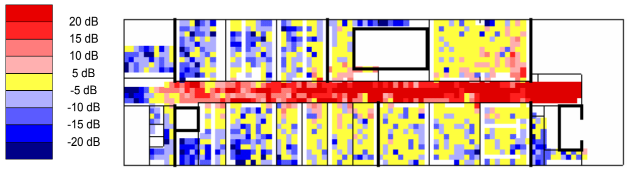

Fig. 11. Prediction error (difference between 1SM prediction and measurement) for n = 4.0

In spite of the strong dependence of 1SM on used empirical parameters, it provides an excellent tool when no information on an indoor scenario is available or when a very fast draft design is needed.

3.2.2 Multi-Wall Model

A semi-empirical Multi-Wall Model (MWM) [13] provides much better accuracy than 1SM. The results are site-specific but at the same time floor plan description is needed as an input.

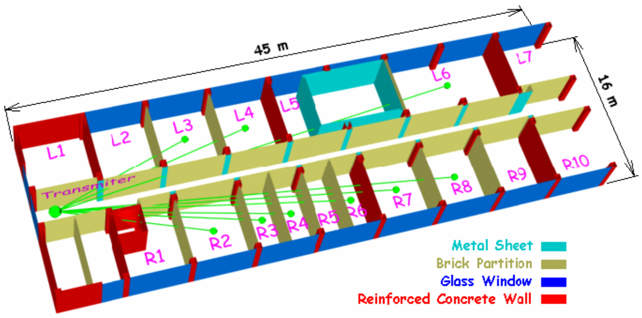

Fig. 12. Multi-Wall Model geometry

The basic idea of MWM is illustrated in Fig. 12. The path loss between a transmitter and receiver L_{MW} is given by

$$L_{MW} = L_{FSL}(d) + \sum_{i=1}^{N} k_{wi} L_{wi} + k_f L_f \,, \tag{3}$$

where L_{FSL} (dB) is the free space loss for the distance d (m) between transmitter and receiver antennas, which is in fact 1SM prediction with power decay factor n = 2.0, k_{wi} is a number of walls of i-th type between transmitter and receiver antennas, L_{wi} (dB) is attenuation factor for i-th wall type, N is a number of wall types, k_f is a number of floors between transmitter and receiver and L_f (dB) is the floor attenuation factor. Since the floor attenuation is not dealt with in this paper the original MWM [13] floor attenuation calculation was simplified in equation (3). Floor attenuation analysis can be found in [19].

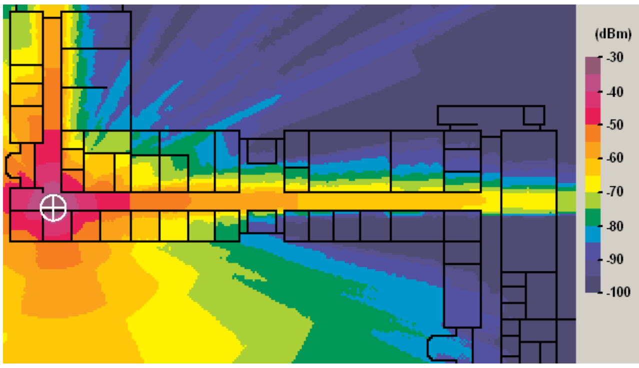

Fig. 13. Multi-Wall Model coverage prediction

Fig. 13 presents an example of a coverage prediction using MWM. The MWM can be marked as site-specific since particular walls are considered during the prediction. But still, it must be understood that the MWM introduces only an estimate of the real wave propagation. In (3) only walls and obstacles located directly between transmitter and receiver are considered with their attenuation factors. Particular reflections and diffractions are not taken into account so the accuracy is limited in certain cases. As an example the wave-guiding effect of bending corridor cannot be modeled in Fig. 13 (compare to Fig. 7).

A comparison with the 1SM shows a significant improvement of the site-specific accuracy; see Figs. 9, 10, 11, 14, and 15. No change of model parameters is needed.

For good prediction accuracy the proper wall attenuation factors L_w - empirical parameters for (3) - must be used. The attenuation factors do not represent actual physical attenuations of the walls but statistical values obtained from representative measurement campaigns. It means if the receiver is hidden behind a metal wall with limited dimensions, the prediction cannot result in an infinite attenuation, even so metal itself can be considered as a total reflector of the electromagnetic energy. But in the real scenario the wave can find its way around the metal obstacle due to reflection, diffraction and diffuse scattering, while the MWM considers only walls along a line connecting the transmitter and receiver.

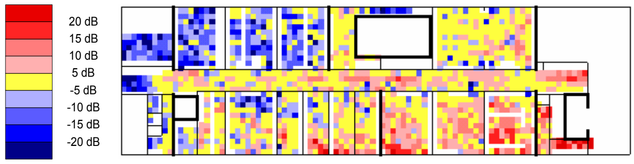

Fig. 14. MWM prediction error - difference between MWM prediction and measurement (Fig. 9)

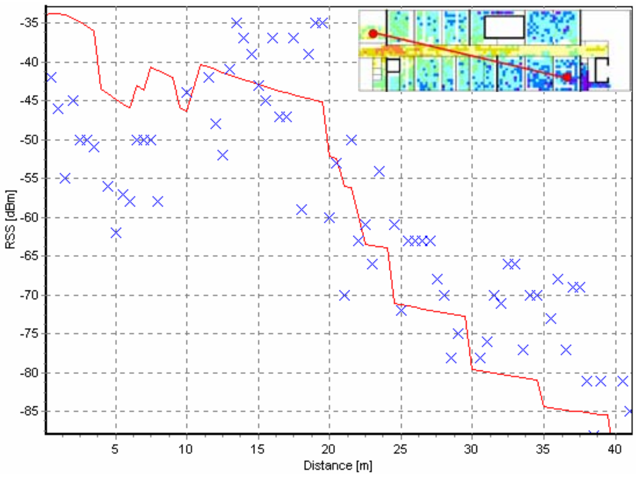

Fig. 15. Multi-Wall Model prediction compared to measurement

f (GHz)	L_1 (dB)	L_2 (dB)	L_f (dB)	comment
1.80	3.4	6.9	18.3	office building [13]
1.90	2.1	4.4	13.6	office building [14]
1.90	0.5	4.2		half open space [15]
2.45	5.9	8.0		office building [9]
2.45	6.0			office building [16]
2.50	5.4			drywalls [21]
5.00	6.5	11.7		office building [20]

Tab. 2. Multi-Wall Model parameters

Even though there are a lot of building materials, due to the statistical nature of the wall attenuation factors in (3) only a very few wall types are necessary to define for MWM. In fact in [13] only two wall types are considered: Light wall (L_1) - a light wall or partition, and Heavy wall (L_2) - a structural thick wall. Of course more wall types can be introduced for a specific application or software tool (metal walls, glass, etc.). Some empirical parameters of MWM for miscellaneous types of interiors are summarized in Tab.2.

4. Site Survey vs. Modeling

Without a doubt most of the WLANs today are deployed manually without a foregoing software planning. Initial design is (after temporary deployment of APs) tested using a site survey. Using experimental iterations, with the help of the measurements, satisfactory locations of APs are determined. As it was shown above, the measurement itself is not such a straightforward process which could be performed by an uneducated user. Space and time variations (doors, windows, and people) as well as the orientation of the measurement device and the user highly influence the results. It brings a necessity of measurement averaging which makes the measurement even more time consuming. Let us summarize the advantages and disadvantages of this approach:

Advantages:

- The actual "real" network performance can be measured during the site survey, not only the coverage.

Disadvantages:

- Very time consuming (expensive).
- Usually it is feasible to perform measurements in limited number of locations, i.e. it is impossible to comprehend the whole indoor scenario.
- Measured values due to time and space variations of the environment as well as the different traffic load during the survey and "real" conditions can lead to significant errors if not handled by a trained user during the survey.
- Due to the experimental nature of the design the optimal network deployment cannot be guarantied. The quality of the design is directly proportional to skills and experiences of the designer. Redundant or misplaced APs lead to higher costs.

Another option is to perform WLAN software planning prior to the actual deployment. As it was shown above there are powerful propagation models widely available which allow testing of many deployment variations within seconds to find the optimal solution. This can be done even automatically. In [22] a web-based easy-to-use tool for WLAN planning was introduced including automated optimization of number of APs and their placement. Tools like this do not require such an educated user or any additional hardware as the site survey approach does. It is obvious that mainly time savings are tremendous. Let us summarize the advantages and disadvantages of this approach:

Advantages:

- The modeling enables very fast and flexible trials of network arrangement taking into account coverage throughout the whole scenario and additional parameters (interference, frequency plan, coverage in neighboring floors, etc.) as desirable.
- Minimum required input is necessary for the propagation modeling. The planning can be performed without a need to visit the site to provide a customer with a network cost estimate, to plan WLAN in building under construction, etc.
- Easy-to-use software tools can be built based on the propagation prediction to enable even an untrained user to design a WLAN efficiently. Most of the design can be automated.
- The CAD nature of the WLAN planning using a propagation modeling offers an efficient way to find optimal solutions which can obviously lead to cost savings and finest network performances.

Disadvantages:

- In certain complicated environment the accuracy of the propagation model can be poor if not handled by an educated user.
- Based on modeling; the "real life" overall performance should be verified by a site survey after the network deployment since some phenomena, e.g. interference from alien networks or interferers, cannot be simply modeled.

5. Conclusion

The two methods for the design of large wireless local area networks - site survey and software planning - were described and compared. The drawbacks of site survey due to the time and space varying environment were investigated using a simple experiment. The overview of available propagation models and its usage was given. Advantages and disadvantages of both approaches were discussed.

As a result the planning based on propagation modeling is recognized as a highly preferable approach for design of large WLANs in an indoor scenario to provide optimal and cost effective solutions.

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