Radio Channel Characteristics for typical Environments at 5.2 GHz

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Abstract: *Propagation characteristics for the radio channel at 5.2 GHz in typical domestic and office environments are addressed in this paper. Ray tracing techniques are used, which provide realistic values for different environments. Values for the attenuation, the rms delay spread and for the power delay profile are presented for different buildings and at several positions.*

1. Introduction

Wireless ATM (WATM) is currently a subject of intensive investigation. This includes research on radio propagation at super high and extremely high frequencies (SHF and EHF). The primary reason for the use of centimetre and millimetre waves (instead of longer wave lengths) in wireless communication systems is the increasing availability of bandwidth for transmission in these bands. Furthermore, the higher attenuation at higher frequencies leads to increased reuse of the radio capacity (number of channels per cell) using space division multiplexing techniques. Wireless ATM will most likely be transmitted in the 5 GHz band, since special frequency bands within 5 GHz are already available in Europe and the US. It is also expected that WATM transmissions will typically be within indoor locations.

To derive the parameters of the modulation scheme to be used for WATM, it is important to know the characteristics of the mobile radio channel at 5 GHz. The channel characteristics depend on the carrier frequency, the bandwidth of the transmitted signal and the location of the transmitter and receiver. To determine the impact of the channel on a transmission scheme such as Orthogonal Frequency Division Multiplexing (OFDM), it is important to have information about parameters such as the coherence bandwidth and the power delay profile, so that the carrier spacing and the guard time or the length of the equalizer can be chosen appropriately [2]. In combination with the transmission scheme and the receiver techniques, the purpose of the propagation prediction is to ensure efficient coverage of the required area.

The key measurable parameters characterising the mobile indoor radio channel at 5.2 GHz are the attenuation, rms delay spread and power delay profile. These parameters are adequate to characterize the parameters of the modulation scheme such as OFDM. To determine these parameters, a ray-tracing model is used.

In the following, we first describe methods that are currently used to determine propagation characteristics. Then actual domestic and office premises are described. Finally some results of propagation studies are described.

2. Determining the propagation characteristics of the indoor channel

There are generally three ways to establish radio propagation behaviour. The first method is to rely on the data currently available in the literature. Unfortunately there is limited information for domestic or office environments in the frequency range of 5 GHz. The data that is available is either limited to frequencies below 2 GHz or above 10 GHz [4], [7], [8], [10], [11], or for non-residential environments [12], [13], or provides insufficient data on the necessary parameters for the system design [6]. Though this data can be used to give an indication of the frequency behaviour at the frequency of interest, directly-determined data is better in view of the scenario-specific nature of radio propagation.

The second approach is to perform measurements within the preferred environment using channel sounding either in the time [9] or the frequency [15] domain.

The third method is to simulate the propagation behaviour within a building by means of ray-tracing techniques [16], [5]. Given a ray-tracing package [3], then the only limits to assessing propagation behaviour are the entry of the environment description into the package and knowledge of the bulk electrical parameters of the structural materials.

In this paper the results for the channel characteristics at 5.2 GHz have been obtained by simulation with a ray tracing tool [3]. This tool is able to predict the channel characteristics of a broadband indoor radio channel. To determine the attenuation and delay values, the ray launching method [17] has been used. The basic principle behind ray-tracing techniques is to model propagation of the electromagnetic waves by rays, which are traced from the transmitting location in predetermined discrete directions. If an object intersection occurs, a reflected and transmitted ray are initiated from this point. A more detailed description of the ray tracing tool and ray launching method can be found in [17].

2.1 Empirical path loss model

An empirical channel model has been parameterized using large-scale attenuation values obtained from ray tracing experiments. This model separates the loss of penetration from the path loss due to the distance of the receiver from the transmitter by subtracting the free-space path loss. An equivalent expression is given by a formula describing the penetration loss as separate terms [18]

$$L_m = L_0 + 10n \cdot \log(d) + \sum_{i=1}^{I} K_{fi} L_{fi} + \sum_{j=1}^{J} K_{wj} L_{wj}$$

L_0 is the loss at reference point (1 meter distance) and n is the power decay index, both suggested to be fixed at their free-space values. λ is the wavelength, the distance between transmitter and receiver, K_{fi} and K_{wj} are the number of floors and walls traversed by the direct ray, and L_{fi} respectively L_{wj} are the floor and wall attenuation factors in decibels, for the floor and wall categories i respectively j. The floor and wall categories are characterized by the material.
Generally the power decay index for free space is n = 2. But measurements show a different fit, and these measured values are used instead for the power decay index.

3. Wireless LAN environment models

Ray tracing depends on an exact knowledge of the physical model for domestic and office premises. Such a model must be carefully chosen to be representative of a large number of domestic and office premises.

3.1 Domestic environments

Table 1: Floor area of American households. [14]

Number of Households	Floor Area (Square Foot)	Number of Households	Floor Area (Square Foot)
697,000	less than 500	9,653,000	2,000 to 2,499
2,381,000	500 to 749	5,374,000	2,500 to 2,999
5,704,000	750 to 999	4,799,000	3,000 to 3,999
15,084,000	1,000 to 1,499	2,688,000	4,000 or more
13,414,000	1,500 to 1,999		

A domestic or residential scenario is generally more “closed” than either factory or some office environments [1]. The rooms in domestic premises tend to be smaller when compared to work environments and are more closed structures (for example, storage spaces and en-suites) within the boundary of the premises. A consequence of this is that signal decay may be higher in the domestic environment and hence the maximum transmit distance will be lower. Table 1 gives the distribution of households in the USA with respect to floor area.

Table 2: Used electrical parameters of building materials

Material	ε_r	$\varepsilon_r \tan\delta$
Wood	4.44	0.004
Glass	6.3	0.06
Concrete	6.95	0.74

The median value is 1750 sq.ft. Based on this information the house which has been investigated in this paper as typical domestic environment has a floor area of 1750 sq. ft (163 sqm) and two floors. The ground and top floor contain 7 rooms each. The walls are of concrete, where the exterior wall has a thickness of 20 cm, the internal load bearing walls have a thickness of 10 cm, and the internal divisions are 2 cm thick. The material parameters are listed in the following Table 2, where the dielectric relative permittivity ε_r and the loss tangent $\varepsilon_r \tan\delta$ are presented.

3.2 Office environments

Examples for typical office environments are presented in several paper [2], [8]. For the purpose of validation, we have chosen an actual building where in future measurements can be done. This building has a dimension of approximately 110x16 m and consists of 56 rooms, which are connected by a long corridor. For the materials the parameters are the same as those for the domestic environment. In general the walls have a thickness of 10 - 20 cm. Doors are considered to have a thickness of 5 cm wood.
As most of the simulations on propagation behaviour has been done for this building, a detailed structure of the building is presented in the following Figure 1.

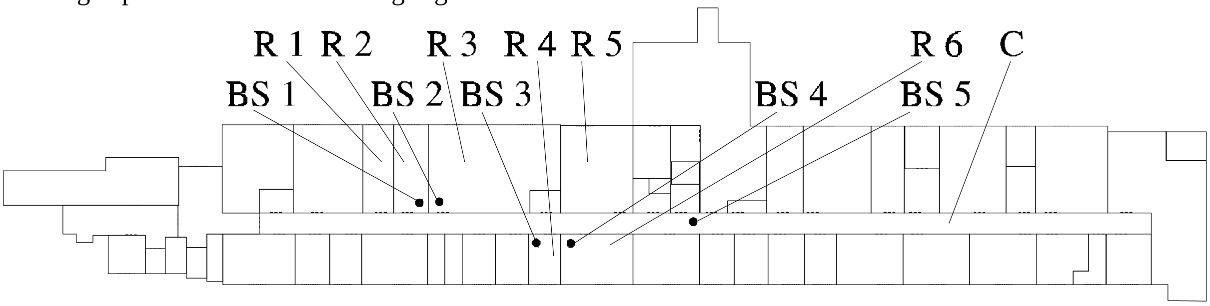

Figure 1: Office Environment

The points mark places in the rooms (R) and corridor (C), where the base station (BS) has been located for different simulation runs. The attenuation and rms delay spread values as well as some power delay profiles for the rooms (R) and corridor (C) are presented in the following section 4.

4. Simulation results

4.1 Path loss and rms delay spread for domestic scenarios

Simulations have been carried out for the attenuation between the receiver and transmitter and the rms delay spread, where up to 3 reflections and 4 transmissions through walls are considered for each ray. The resolution is 0.1x0.1 sqm for each calculated value. This approximately results into more than 1500 measurement points for each room. Generally, isotropic antennas have been assumed. The transmitter was located in the corner of the room resulting in the maximum distance to the opposite room in the house.

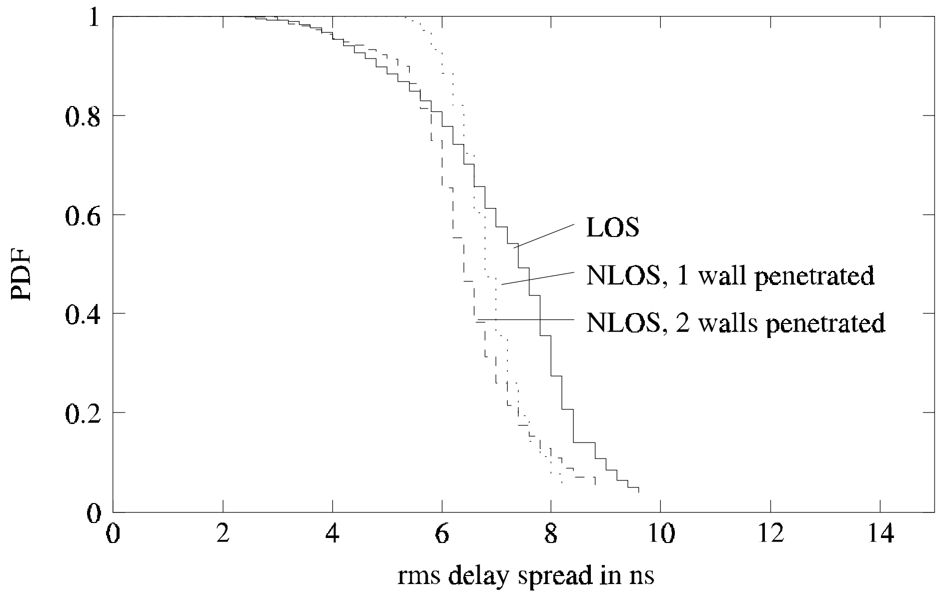

Figure 2: rms delay spread values at the ground floor

To describe the path loss with a simple model, the attenuation values received from the ray tracing simulations have been used to determine the power decay index (see section 2.1). For line-of-sight (LOS) the power decay index is approximately $n = 2$. To get the loss of the individual walls, the power decay index for LOS has been used in the formula. The result for a penetration loss of one wall of concrete with a thickness of 10 cm is approximately 15 dB. For the second wall with thickness 2 cm, the additional penetration loss is 5 dB. Using

these values to parameterize the path loss model and comparing the simulated values with the values resolved from the empirical model a standard deviation of approximately 5.5 dB can be derived.The curves depicted in Figure 2 show the complementary cumulative distribution function of the rms delay spread in the room where the transmitter was positioned and rooms on the ground floor that are separated by one and two walls, respectively. Most of the rms delay spread values are in the range of 4 to 10 ns on the ground floor. Calculations for the top floor have been found to be similar. Only a few values on the ground floor are out of this range with approximately 22ns rms delay spread. The higher delay spread values for LOS results from a larger room size.
If more than three reflections are considered, e.g. six, then it is observed that the maximum rms delay spread increases. Still, most values for a reflection depth of 6 are less than 10 ns. These values agree with the values found in the literature [4], [5].
Calculations also have been done for the room with the greatest distance from the transmitter. In this room the highest rms delay spread values of 22 ns were measured. The attenuation values on the first floor are above 130dB. Assuming a power of 1 W (30 dBm) and a receiver sensitivity of -85 dBm, transmitted signals won‘t be received correctly if the attenuation is above -115 dB. This leads to the conclusion that the coverage in a domestic scenario with selected parameters may become critical, if the transmitter and receiver are positioned in two rooms at maximum distance.

4.2 Attenuation and rms delay spread for office environments

The results for the overall attenuation in an office environment show that if the base station is positioned in the main corridor (see Fig. 1, BS 5), the whole corridor will have a sufficient power level for reception. The rooms close to the base station are illuminated with enough power even when the transmitter and receiver are separated by one wall. For rooms more than 20 m from the transmitter, there isn’t enough power for reception, although the power level may be sufficient in the corridor.
For the same scenario, the rms delay spread has been investigated. Comparing the rms delay spread values at different positions, most values are in the range of 0 to 25 ns. But in the corridor, at several locations the values are above 50 ns and at some location they are even above 100 ns. This high delay spread is caused by the long distances which the direct and reflected rays can travel in the corridor without any penetration.

4.2.1 Results for individual rooms with LOS and Obstructed LOS (OLOS)

Calculations have also been done for single rooms with LOS and OLOS conditions. In the latter case, penetrations of one and two walls have been investigated. The rooms with different sizes are room R 3 (94 sqm), R4 (13 sqm) and R 6 (29 sqm), the rooms with one and two penetrations for the base station positioned at BS 2 are room R 1 and R 2 (see Figure 1).
It is found that there is a correlation between the attenuation and the room size. The power decay indices increase from n = 1.96 for room R 4, to n = 1.97 up to n = 2.03 for room R 3, and thus the attenuation increases slightly as the room becomes larger.
To investigate the correlation of the propagation loss with the number of penetrations, calculations for rooms have been done with a transmitter located in a room separated from a receiver by one and two walls, each with a thickness of 20 cm or 10 cm. For a penetration of one wall (BS 2, R 2) and a second wall (BS 2, R 1) each with thickness 20 cm a loss of 29 dB and 24 dB is encountered for the attenuation factor L_W, respectively. The results for the attenuation in the OLOS conditions are summarized in Table 3.

Table 3: Power decay index and wall penetration loss

thickness of wall and material	L_W **for** $K = 1$	n*	L_W **for** $K = 1$	n*
10 cm concrete	16	2.57	14	2.97
20 cm concrete	29	3.00	24	3.68

The power decay index n* indicates, that this is not the index for LOS condition but for OLOS. Thus n* combines the loss due to penetration and distance. Again, these values have been used to parameterize the path loss model. Comparison with the simulated values indicate a standard deviation of approximately 5 - 6 dB for small and medium sized rooms and approximately 8 - 9 dB for large rooms.
The rms delay spread for LOS and OLOS conditions are presented in the following Figure 3.
Again a dependency of the rms delay spread with the room size can be recognized. The larger the rooms the higher the delay spread. The mean rms delay spread values are in the range of 4 to 9 ns for LOS and in the range of 10 to 14 ns for OLOS.

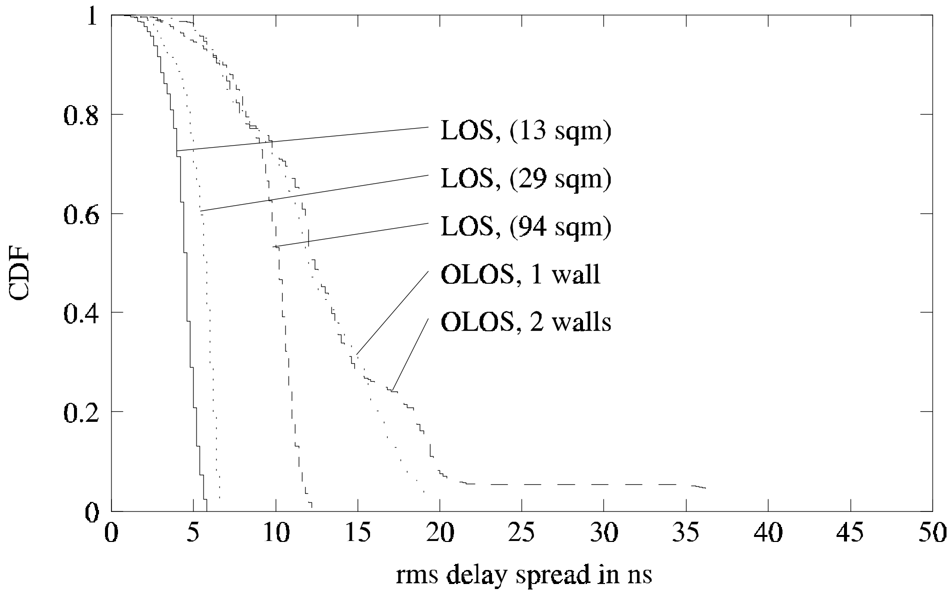

Figure 3: rms delay spread for LOS and OLOS in an office environment

4.3 Power Delay Profile for office environments

The power delay profile (pdp) at different locations for the transmitter positioned in the corridor at BS 5 are presented in this section. In the following figure, the pdp is the power density as a function of excess delay. The excess delay itself is defined as the relative delay of the multipath component as compared to the first arriving component. The points where the pdp were calculated, are in the corridor at y = 8 m and x = 70, 80, 90, 100 m (see Figure 1). The transmitter (BS 5) is located at x = 65 m, y = 9 m, and z = 2 m.

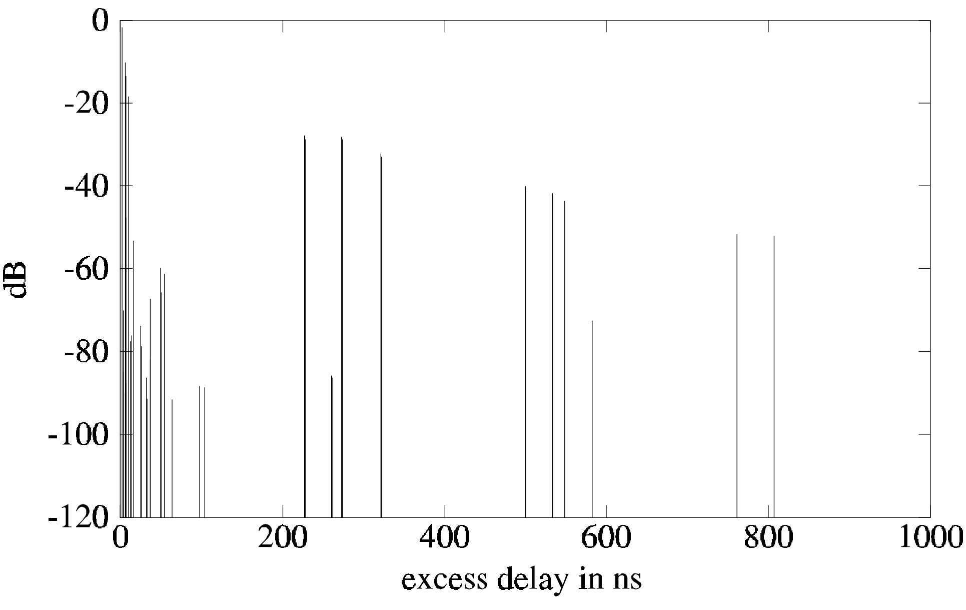

Figure 4: Power delay profile for point (70, 8)

In Figure 4 the power delay profile for receiver position y = 8 m and x = 70 at the height of 1.5 m is shown.
The strongest paths for the point (70, 8) and (80, 8) are attenuated by 61 dB and 70 dB, respectively. The shortest path has an delay of 17 ns and 50 ns, respectively.
It is observed that the multipath components display a clustering as described in several papers [7]. For the point (80, 8), there are more paths reaching the receiver with sufficient power relative to the number of paths in the cluster around the direct path resulting in a higher rms delay spread of 26.5 ns in comparison to point (70, 8) with a rms delay spread of 24.6 ns. Furthermore, the paths in the delayed clusters are less attenuated for

greater distances between transmitter and receiver. This leads to rms delay spread values of 32.8 ns and 39.3 ns for point (90, 8) and (100, 8), respectively.

5. Conclusions

Simulation results of radio channels within typical domestic and office environments for 5.2 GHz have been addressed within the Philips wireless ATM LAN project. Simulations for different rooms in typical buildings were compared. The influence of the position of the Base-Station (BS) as well as the different nature of the materials were taken into account. With the help of the ray tracing results, a simple path loss model has been parameterized.

For the majority of rooms in a home with an area size of about 160 m^2 the coverage of all rooms with only one transmitter may not be possible. For a BS oriented architecture the placement of the central controller (the BS) must then be chosen very carefully to have complete coverage.

The attenuation values in single rooms in the office environment leads to the conclusion that there won't be any critical situation using any transmission scheme. However, in large rooms, rms delay spreads up to 100 ns may have to be managed.

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