Chapter 12
A Generic Method for the Reliable Calculation of Large-Scale Fading in an Obstacle-Dense Propagation Environment

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ABSTRACT

The aim of this chapter is to summarize and present recent findings in the field of wireless channel modeling that provide a new method for the reliable calculation of the statistical parameters of large-scale variations of the average received signal (shadow fading). This algorithm is theoretically based on a path loss estimation model that incorporates losses due to walls and floors. This has been confirmed to be the most precise mathematical tool for average signal strength prediction for various frequencies of interest and propagation environments. The total path loss is estimated as a sum of two independent attenuation processes: free space loss and losses due to obstacles. This solution allows for a direct and reliable calculation of the deviation of the fluctuations of the average received signal in an obstacle-dense environment.

BACKGROUND

Information propagated over a wireless channel as an electromagnetic wave is subject to large-scale attenuation (path loss) due to free space loss and losses caused by interfering objects of various size, type and number. Large-scale attenuation can be calculated with path loss models (mostly logarithmic) which have been developed either theoretically (deterministic models) or based on experimental measurements (empirical models). In order to provide reliable predictions of the aver-

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age received power. The accuracy of the path loss models is of critical importance with regard to the design and implementation of wireless systems (Goldsmith, 2005).

When physical obstacles, whose dimensions are significantly larger than the wavelength of the transmitted signal, obstruct radio propagation, then the attenuation effect is known as shadowing (Rappaport, 1999). In such cases, the fluctuation of the average received signal strength can be approximated via statistical models (distributions). Shadowing occurs over a time period of minutes or hours, depending on the mobility of the obstacle and the transmitting and receiving antennas. Experimental work has confirmed that the fluctuations of the local mean strength of the received signal follow the *log-normal* distribution (Jakes, 1973).

Moreover, the transmitted Radio Frequency (RF) signal suffers small-scale attenuation (fading) over a period of milliseconds (ms) due to multipath propagation and, conditionally, Doppler spread (Parsons, 2000). Additional statistical models have been developed to describe fading phenomena (i.e. Rayleigh, Rice, Nakagami-m).

The adequate description and mathematical expression of all large-scale and small-scale variations of the received signal for a given propagation topology formulate the field of Wireless Channel Characterization.

WIRELESS CHANNEL CHARACTERIZATION: OPEN ISSUES

Many published works have raised the issue of path loss modeling in an outdoor propagation environment for the GSM/UMTS frequencies (Lee & Miller, 1998; Seybold, 2005). Various empirical and semi-empirical (deterministic) path loss models have been developed and validated in terms of mean error (%) in their predictions of average received power at any given distance from the transmitter throughout a propagation environment (Parsons, 2000; Rappaport, 1999). Intrinsic topology characteristics have been incorporated in the mathematical expressions of these models and various extensions of these models have been provided in terms of distance coverage and carrier frequency shifting (Iskander, Yun, & Zhang, 2001).

Over the years, many published works have dealt with finding the appropriate small-scale fading distribution to describe an indoor propagation topology (Cheung, Sau, & Murch, 1998; Henderson, Durkin, & Durkin, 2008; MacLeod, Loadman, & Chen, 2005; Walker, Zepernick, & Wysocki, 1998). However, there was not, until recently, a comparative validation of indoor path loss models for the estimation of the large-scale attenuation of an RF signal propagated in an indoor environment. Even more so, there had been no validation of path loss modeling for the 2.4 GHz frequency, which holds a dominant role in indoor wireless networks (802.11b/g/n) and will continue to be of importance as next-generation networks come into the forefront.

In addition, the log-normal shadowing distribution has been examined in terms of obtaining a closed-form expression for the statistical expression of the instantaneous received amplitude. The impact of shadow losses on the prediction reliability of path loss modeling, however, was not investigated any further. As a rule, the calculation of the shadowing deviation (in dB) requires an extensive set of on-site RF measurements that provide a pool of (logarithmic) local mean values out of which the mean value and the shadowing deviation (dB) are derived. In this chapter, however, a novel empirical method will be presented, allowing for the direct calculation of shadowing deviation and therefore the precise characterization of large-scale variations of the received signal strength for three different indoor propagation topologies.

INDOOR PROPAGATION TOPOLOGIES

Whereas all path loss and fading phenomena occur in both outdoor and indoor environments, the indoor propagation environment presents even more challenges for researchers and engineers alike, given the increased number of obstacles of various dimensions and material. Obstacles whose dimensions are comparable to the signal wavelength cause signal scattering, which adds to the complexity of the wireless channel characterization. Further attenuation is caused by signal penetration of walls and floors, which are also responsible for reflection phenomena.

It is more than evident that the indoor propagation channel demands a lot more than just a deterministic formula that calculates the average signal strength as a function of distance and frequency. In order to provide an accurate model that incorporates all propagation and attenuation mechanisms in its formula, it is imperative to take into consideration all obstacles and the attenuation of the propagated signal caused by these obstacles, be it walls, floors, other objects or even losses due to human bodies, labeled as human body shadowing (Mathur, Klepal, McGibney, & Pesch, 2004).

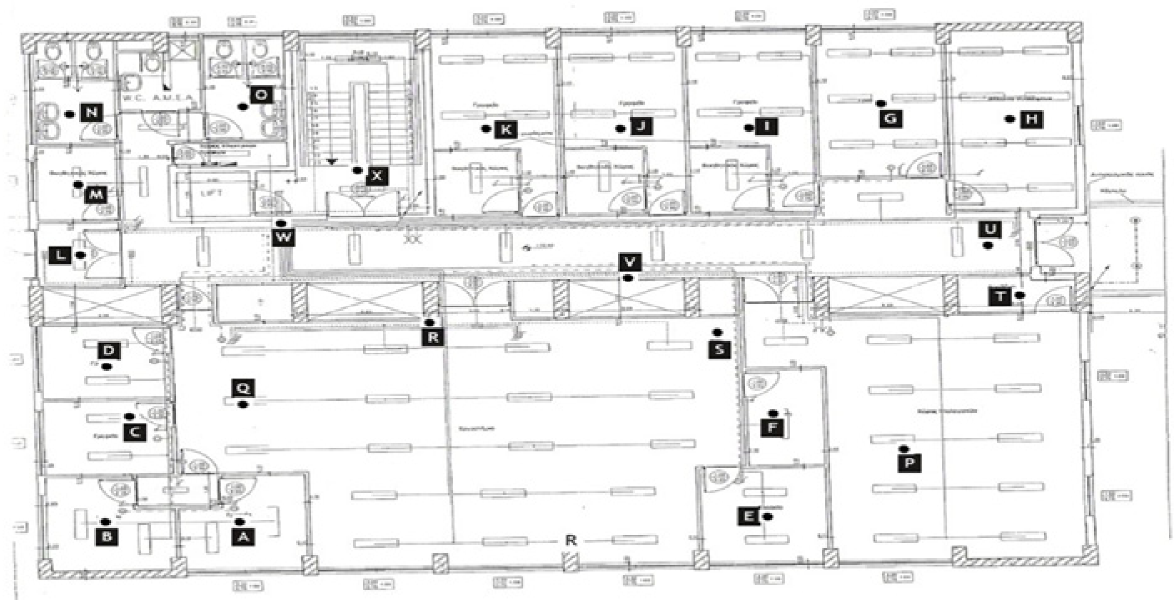
In order to examine the impact of the obstacles and overall intrinsic channel characteristics on radio propagation and signal attenuation, three different propagation topologies were chosen for extensive on-site RF measurements and validation of path loss models: an office topology (Chrysikos, Georgopoulos, Birkos, & Kotsopoulos, 2009), a commercial topology (Chrysikos, Georgopoulos, & Kotsopoulos, 2010) and a residential (home) topology (Chrysikos, Georgopoulos, & Kotsopoulos, 2011). In compliance with the indoor topologies classification of ITU (International Telecommunication Union Radio-communication Sector [ITU-R], 1999). In each case, an already operating 802.11g network providing wireless internet access (Wi-Fi, WLAN) was used for RF measurements. The Access Point (AP) served as the transmitter, and the receiver was a laptop equipped with the NetStumbler 0.40 software for recording and storing the local mean values of the received signal power in each measurement location.

The indoor propagation topologies and the corresponding measurement locations are depicted in the following figures.

Figure 1 demonstrates the office propagation topology, at the premises of the Wireless Telecommunications Laboratory, located at the second floor of a building belonging to the Department of Electrical and Computer Engineering, at the University of Patras. As it can be observed, the topology in question goes beyond the typical notion of an office scenario, with an increased degree of complexity: a large room where the AP is located (on the external wall). A total of 22 measurements were taken for the single floor measurements, 10 measurements for the one-floor difference (fixed transmitter on the second floor, moving receiver on the third floor of the building) and 7 measurements in the auditoriums and public hall of the ground floor marking a two-floor difference between the transmitter and the moving receiver (T-R separation). Overall, a total of 39 measurement locations were selected for the office propagation topology.

Figure 2 depicts the commercial topology, which is the main hall of the Public Library located at the campus of the University of Patras. The transmitting AP is located above the information desk (reception). Desks, furniture and other obstacles are also in abundance. A total of 32 measurements were performed throughout the

Figure 1. Office topology



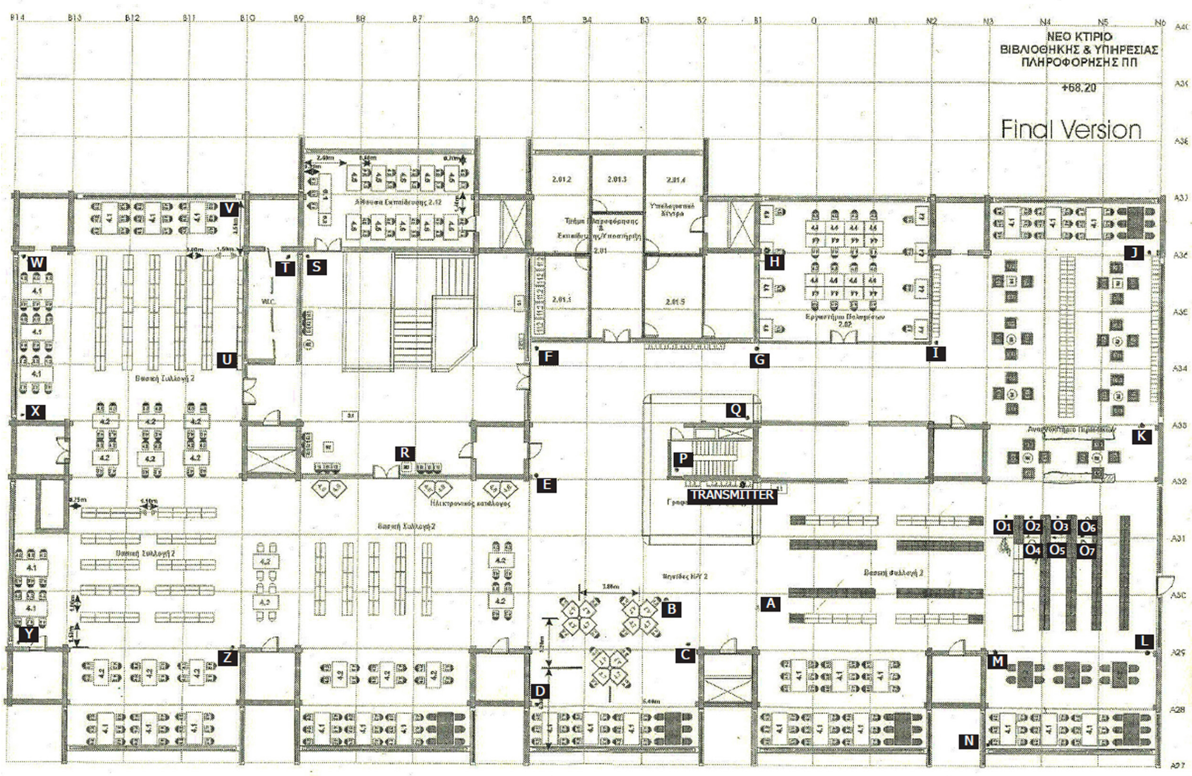
main hall (single floor measurements), providing empirical data for wireless channel characterization and validation of path loss models. Even though the Library is not a *de jure* commercial topology, it is qualified as such *de facto* by its characteristics according to ITU classification. In fact, part of the overall work in the context of Wireless Channel Characterization has been to confirm or re-evaluate, if needed, the correctness of the original ITU classification of indoor propagation topologies.

Figure 3 depicts the measurement locations for the home indoor propagation topology. The majority of measurement locations are scattered in the surrounding rooms of the flat containing the router. A measurement location marked as 'R' was chosen in the reference T-R distance (1 m). In relation to the Access Point (AP). Measurement location Q is in the entrance of the residence. Four more locations were chosen in the public area outside all apartments of the given floor (V, W, X, Y) where the maximum T-R distance is being observed. Finally, locations Z, A2 and A3 were chosen in the neighboring flat. Overall, a total of 28 measurements were performed on the same floor, 15 measurements were also performed on the ground floor of the building, establishing a one-floor separation between transmitting AP and receiving laptop.

SITE-SPECIFIC VALIDATION OF INDOOR PATH LOSS MODELS

The received power in each measurement location of the aforementioned indoor propagation topologies has been measured and recorded in order to provide the necessary experimental data for the validation of path loss models. An interesting example that points out the different impact of topology characteristics on signal attenuation concerns the distance break point where the average received power drops below the threshold of $-70\,dBm$. For the residential (home) topology, the distance break point is approximately 10 meters (Chrysikos et al, 2011), for the office to-

Figure 2. Library (commercial) topology



pology the respective distance break point is approximately 20 meters (Chrysikos et al, 2009), where as for the library (commercial) topology the respective value is approximately 30 meters (Chrysikos et al, 2010).

The fundamental reference path loss model is the Free Space model, which is a logarithmic expression of the Friis formula, assuming an ideal propagation scenario with no obstacles, or terrain geographic characteristics, and no antenna heights (Goldsmith, 2005). According to path loss modeling theory, the average received power at a given measurement location is provided by (Jakes, 1973),

$$P_r(dBm) = P_t(dBm) + K(dB) - 10n\log_{10}\left(d \big/ d_0 \right) \tag{1}$$

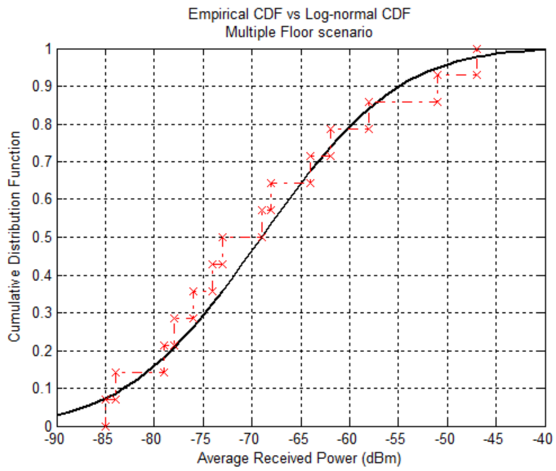
where d is expressed in meters (T-R separation), do is the reference distance which in indoor propagation schemes equals 1 meter, n is the path loss exponent (set to 2 for the Free Space model) and K is the reference path loss at 1 m, which equals $-40dB$ for $2.4GHz$ (802.11g protocol). Average path loss according to the Free Space model is given by (Seybold, 2005),

$$P_L = 32.45 + 20\log_{10}\left(f(MHz)\right) + 20\log_{10}\left(d(km)\right) \tag{2}$$

where *f* is the carrier frequency of the transmitted signal (MHz), and d is the T-R separation (in km). Equation 2 is an equivalent expression of the Free Space model. In both equations, the T-R separation distance has been calculated in order to incorporate the transmitter and receiver antenna heights.

The idealistic propagation assumptions of the Free Space model render it reliable only for Line-of-Sight (LOS) cases. Indeed. In the published

Figure 7. Empirical vs log-normal CDF for home topology (multiple floors)



$$X_\sigma = z \times \sigma(dB) = 1.645 \times \sigma(dB) \quad (8)$$

Whereas: P(do) is the reference path loss at 1 m from the transmitter, N is the slope factor and X_σ is a zero-mean Gaussian variable (dB) that expresses the losses due to (log-normal) shadowing. The parameter z stands for the percentage of coverage probability (Rappaport, 1999). For best case scenarios with a coverage probability of 98%, z equals 2. In sub-optimal, realistic schemes, as the one considered in this work, z equals 1.645 for a coverage probability of 95% (Seybold, 2005).

The Log-Distance model, however, requires a precise value assignment for both the path loss exponent and the log-normal shadowing variable in order to provide reliable estimations. Though such experimentally derived data exist in literature (Rappaport, 1999), the model's complexity does not allow for reliable predictions (Chrysikos et al, 2009).

If the path loss exponent were to be set as 1.8. In accordance with the free space model for indoor environments, then an unbiased experimental derivation of the shadowing deviation would require a large number of measured values of received signal strength throughout the propagation topology. This would require extensive on-site RF measurements, which would be time-consuming and unpractical in terms of path loss prediction.

On the other hand, the Multi-Wall-Floor (MWF) model, extended to include all major obstacles in addition to walls and floors, has been validated to be the most reliable model for path loss prediction.

MULTI-WALL-FLOOR MODEL

The Multi-Wall-Floor model is a path loss model whose formula is provided by (Lott & Forkel, 2001),

$$L = L_0 + 10n\log_{10}(d) + \sum_{i=1}^{I}\sum_{k=1}^{K_{wi}} L_{wik} + \sum_{j=1}^{J}\sum_{k=1}^{K_{fj}} L_{fjk} \quad (9)$$

where:

I, J is the number of types of walls and floors

L_{wik} is the attenuation due to kth traversed wall type i

L_{fjk} is the attenuation due to kth traversed floor type j K_{wi}

K_{wi} is the number of walls type i

K_{fj} is the number of floors type j.

The mathematical expression assumes two categories of losses: losses due to free space propagation and losses caused by all the various types of walls and floor that may come into the path of the propagated signal. Moreover, the Multi-Wall-Floor model considers different losses for different types of materials, at a given frequency of transmission.

The Multi-Wall-Floor (MWF) model takes also into account the decreasing penetration loss

Figure 5. Log-normal distribution of average received power for home topology (multiple floors)

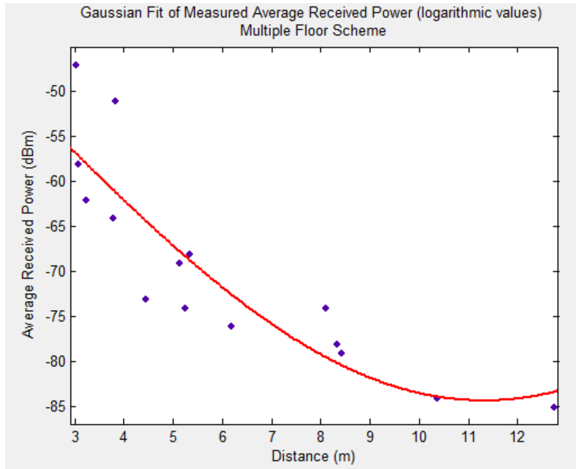
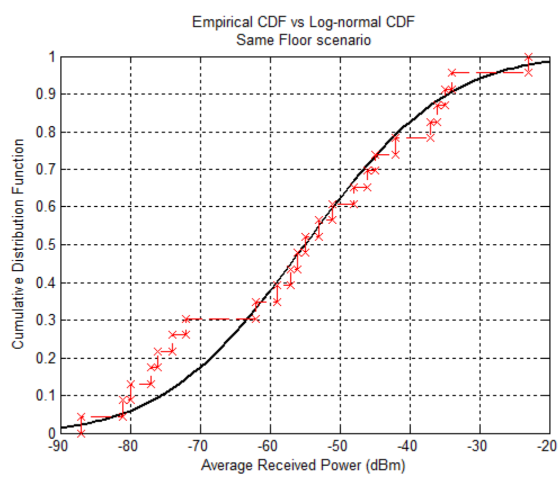


Figure 6. Empirical vs log-normal CDF for home topology (same floor)



rived out of the measured local mean strength values) therefore the Outage Probability can be reliably calculated.

From the above it is more than apparent that the accurate prediction of received power fluctuations around a mean value is of critical importance in order to achieve a robust network planning in terms of Outage Probability calculation. It is necessary, therefore, to develop a reliable mathematical tool for taking into consideration the impact of log-normal shadowing when estimating the average path loss for a given propagation scenario.

Shadow fading losses can be incorporated in the logarithmic path loss formula with a Gaussian variable. This is the mathematical expression of the Log-Distance path loss model (Rappaport, 1999),

$$P_L = PL(d_0) + N \log_{10}\left(d \middle/ d_0 \right) + X_\sigma \tag{7}$$

measurement locations in a propagation topology, the mean value and standard deviation of the distribution of these values can be calculated by (Parsons, 2000; Seybold, 2005),

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{5}$$

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n} (x_i - \overline{x})^2 \tag{6}$$

On the grounds of these empirical calculations, it is possible to compare the distribution of the i received power values (in dBm) with the Gaussian distribution in order to confirm the logarithmic nature of the large-scale fluctuations of the propagated radio signal due to shadowing. In order to provide unbiased results, a significantly large number of i samples are required (Rappaport, 1999).

For the home topology, such a comparison has been accomplished (Chrysikos et al, 2011) and the results are demonstrated in the Figures 4 and 5.

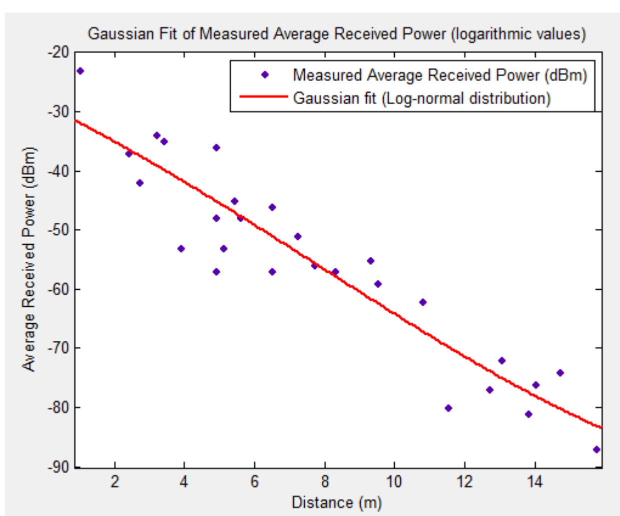
Figures 4 and 5 confirm that the fluctuations of the received power for the total of the measurement locations of the home propagation topology are indeed of log-normal nature (Gaussian distribution of the logarithmic values).

Being able to describe the shadow fading phenomena and their impact on signal propagation is critical in order to predict in reliable manner the outage probability, i.e. the probability that the received power will drop below a defined threshold, the Outage Probability is mathematically linked to the Cumulative Distribution Function (CDF) of the fading distribution that describes signal propagation in the said topology (Rappaport, 1999).

Figure 6 and Figure 7 depict the CDF of the Log-normal distribution (with mean value and shadowing deviation provided by Equations 5 and 6) for the same floor and multiple floor measurements of the home topology respectively, versus a CDF derived empirically from the measured received power values.

The results confirm that the log-normal distribution with a shadowing deviation calculated from the measured received power values is indeed in compliance with the empirical data (CDF de-

Figure 4. Log-normal distribution of average received power for home topology (same floor)



which in turn demand extensive RF measurements in order to provide enough samples for a reliable, unbiased empirical value of the path loss exponent (Jakes, 1973; Rappaport, 1999; Seybold, 2005). In order to provide a lightweight and reliable path loss model as opposed to the measurement-based one-slope model, the ITU indoor path loss model has been validated and adjusted accordingly for each indoor propagation topology.

ITU INDOOR PATH LOSS MODEL

The ITU indoor path loss model is described by the following formula (Seybold, 2005),

$$P_L = 20\log_{10}(f) + N\log_{10}(d) + Lf(n) - 28dB \quad (3)$$

where: f is the carrier frequency expressed in MHz, $N = 10n$ is the slope factor and $Lf(n)$ the floor penetration factor. For the same floor measurements, $Lf(n) = 0$. ITU specifications (Seybold, 2005) provide a number of values for the slope factor (path loss exponent), for different carrier frequencies.

However, these original specifications have been proven to be inaccurate for the 2.4 GHz frequency band for all indoor propagation topologies (office, library, home). Numerical adjustments have been provided for the slope factor values for each topology, and for the multiple floors measurements in the office topology, the floor penetration factor has also been corrected, with empirically derived values (Chrysikos, Georgopoulos, & Kotsopoulos, 2009a).

The aforementioned numerical corrections to the original ITU formula have increased the reliability of the model predictions, providing better results than the Free Space and the One-Slope model, without the latter's need for a substantial pool of measured values of local mean strength of the received signal. However, this site-specific method is suitable as a lightweight, on-the-fly method for reliable estimations of the average received power, with a mean error ranging from 5% to 10% depending on the indoor topology (Chrysikos et al, 2009a; Chrysikos et al, 2010; Chrysikos et al, 2011), and does not allow for estimating the large-scale variations of the average received signal. The ITU model does not explicitly express. In its mathematical formula, the impact of topology characteristics and obstacles on the signal attenuation, other than trying to incorporate those losses on the slope factor and the floor penetration factor, albeit in approximation. Hence, it is essential to provide a more direct and reliable mathematical expression of the shadow fading losses due to obstacles, walls, floors and other topology characteristics.

LARGE-SCALE VARIATIONS OF AVERAGE RECEIVED POWER

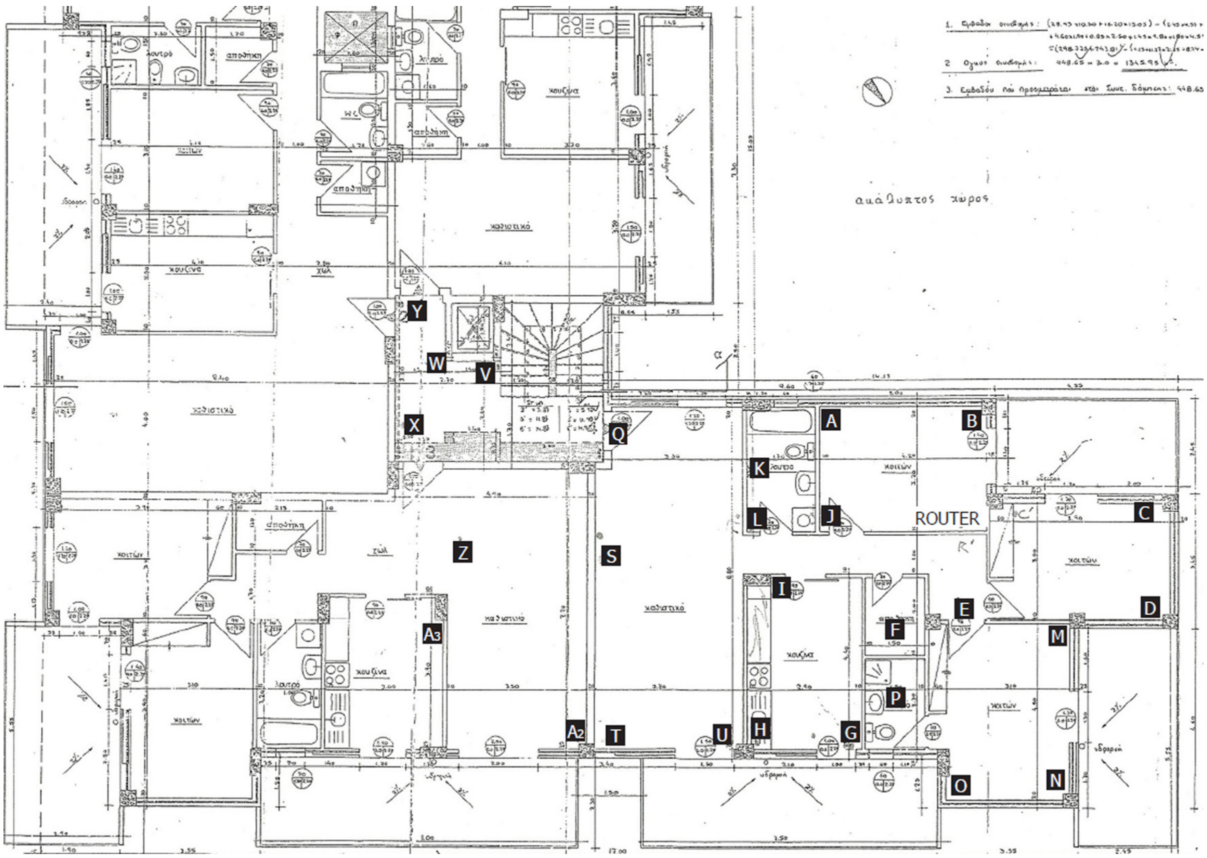
As mentioned in the background section of the chapter, the large-scale variations of the received power have been confirmed to follow the log-normal distribution. Hence, the logarithmic values of the local mean power (dBw or dBm) comply with the Gaussian distribution. The Probability Density Function (PDF) of the Gaussian distribution for the logarithmic values of the received power values is derived by (Jakes; 1973),

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\overline{x})^2}{2\sigma^2}} \quad (4)$$

where x is the received power (logarithmic value) in each measurement location (local mean strength), $\overline{x}$ is the average received power (logarithmic value) for all measurement locations (median value of the received power overall the topology in question), and σ is the standard deviation of the shadowing losses (in dB).

Given a pool of experimentally obtained i received power values corresponding to respective

Figure 3. Home topology



results the Free Space model is highly erroneous and unreliable with the exception of measurement locations where there is LOS propagation between transmitter and receiver. In the original Free Space formula, the path loss exponent is set to $n = 2$, which is in accordance with the inverse-square law, derived out of the Friis equation (ideal propagation of electromagnetic wave into free space).

Our measurements however have confirmed that in all three indoor propagation topologies, the path loss exponent for the Free Space model needs to be set to 1.8 in order for the model to be reliable in its estimations for LOS cases (Chrysikos et al, 2009, Chrysikos et al, 2010, Chrysikos et al, 2011).

It should be noted that especially for the office propagation topology (same floor measurements) where three specific locations comply with the LOS scenario, the path loss exponent is set to a value of 1.73. This has been validated via mean square error techniques (Chrysikos et al, 2009).

Expanding the mean square error technique for the total of the available measurement locations, an empirical path loss exponent can be derived for all cases: Line-of-Sight (LOS), Obstructed-Line-of-Sight (OLOS) and Non-Line-of-Sight (NLOS), providing a universal adjustment of the free space model that complies with all propagation scenarios. This has been described as the one-slope empirical model (Seybold, 2005).

Mean error values for the one-slope model for all three indoor propagation topologies demonstrate a much more reliable behavior than the original Free Space model and the Free Space model with $n = 1.8$. The main setback, however, of this model is that it requires experimental data (local mean values of average received power) of walls and floors of the same material as their number increases (Lott & Forkel, 2001). This marks a significant departure from other schemes, most notably the Motley-Keenan model (Lima & Menezes, 2005) that eventually becomes unreliable because it fails to incorporate this decrease in its mathematical formula (Chrysikos et al, 2009).

The fundamental concept of the Multi-Wall-Floor model can be extended and applied to estimate reliably the large-scale variations of received signal strength in a given propagation topology.

A NOVEL EMPIRICAL METHOD FOR THE CALCULATION OF SHADOWING DEVIATION

The excess path loss is defined by Jakes (1973) as the difference (in decibels) between the computed value of the received signal strength in free space and the actual measured value of the local mean received signal (pp. 120). If the large-scale variations of the average received power are log-normal, the excess path loss is also log-normal (Jakes, 1973).

Therefore, the losses (in decibels) caused by walls and floors and expressed by $\sum_{i=1}^{I}\sum_{k=1}^{K_{wi}} L_{wik} + \sum_{j=1}^{J}\sum_{k=1}^{K_{fj}} L_{fjk}$ in the MWF model formula, are Gaussian. This serves as the basis of a novel empirical method for the calculation of shadowing deviation (Chrysikos, Georgopoulos, & Kotsopoulos, 2009b),

$$\sigma(dB) = \frac{\sum_{i=1}^{I}\sum_{k=1}^{K_{wi}} L_{wik} + \sum_{j=1}^{J}\sum_{k=1}^{K_{fj}} L_{fjk}}{z} \qquad (10)$$

Thus, the shadowing deviation (in dB) is calculated directly from the losses caused by obstacles along the signal propagation path. This method does not require extensive RF measurements. It only requires limited measurements near the obstacles in order to obtain the respective penetration losses.

In order to validate the method's robustness, the obstacle losses must be experimentally obtained for all indoor topologies (at $2.4GHz$ since this is the carrier frequency of the $802.11g$ networks), then employed in order to validate the model's reliability compared to the total of the measured values of the received signal strength. To that end, not only walls and floors, but also all other obstructing materials of significant proportions (compared to the wavelength of the RF signal) will be taken into account. Hence, a more extended, generalized application of the MWF model will be employed.

By performing limited measurements near and around the obstacles in each propagation environment, Tables 1 through 3 are derived (Chrysikos et al, 2009b; Chrysikos et al, 2010; Chrysikos et al, 2011),

Table 1. Measured obstacle losses for office topology

No.	Internal Walls	Pillar	Wide Wall	Elevator
1	7-8 dB	10 dB	7-8 dB	10 dB
2	5-6 dB			
3	3-4 dB			
4	1-2 dB			

Table 2. Measured obstacle losses for library topology

No.	Walls	Internal Walls	Bookcase
1	15 dB	7 dB	3 dB
2	8 dB	5 dB	
3	3 dB		

Table 3. Measured obstacle losses for home topology

No.	Internal Walls (in Flat)	Walls Separating Flats	Floor Penetration	Elevator
1	8 dB	15 dB	15 dB	13 dB
2	6 dB	12 dB	12 dB	
3	4 dB			
4	2 dB			
5	1 dB			

From the results presented in the tables, it is apparent that the penetration losses of same type obstacles decreases as their number increases. This is a fundamental concept of the MWF model which is confirmed by our experimental measurements near and around the obstacles, not only for walls and floors as in the original model (Lott & Forkel, 2001) but also for all other significant obstructing materials. Taking into account all these aforementioned losses and incorporating them into the path loss formula, the results shown in Figures 8 through 12 are obtained, which are compared to the measured values of the received signal strength for each topology.

It is obvious that the predictions of the MWF model (including obstacles) are very close to the measured values. The mean error for each case study has been calculated and is depicted in Table 4 (Chrysikos et al, 2009b; Chrysikos et al, 2010; Chrysikos et al, 2011),

The mean error (%) of the MWF model ranges from 1.88% to 3.44% for all case studies except the library topology, where the mean error increases up to 6.36%. Still, it is significantly

Figure 8. MWF performance for office topology (same floor)

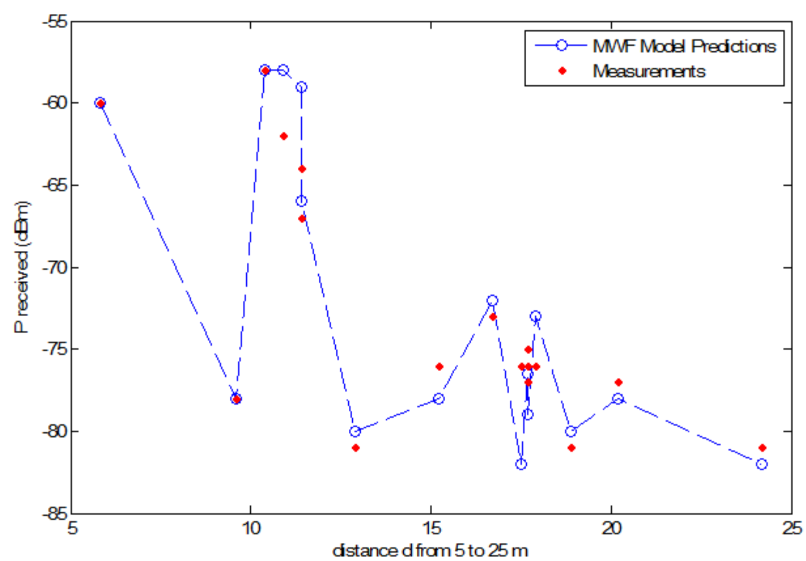


Figure 9. MWF performance for office topology (multiple floors)

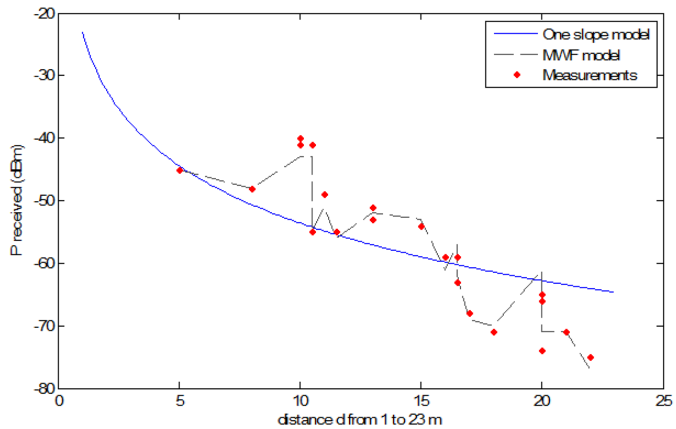
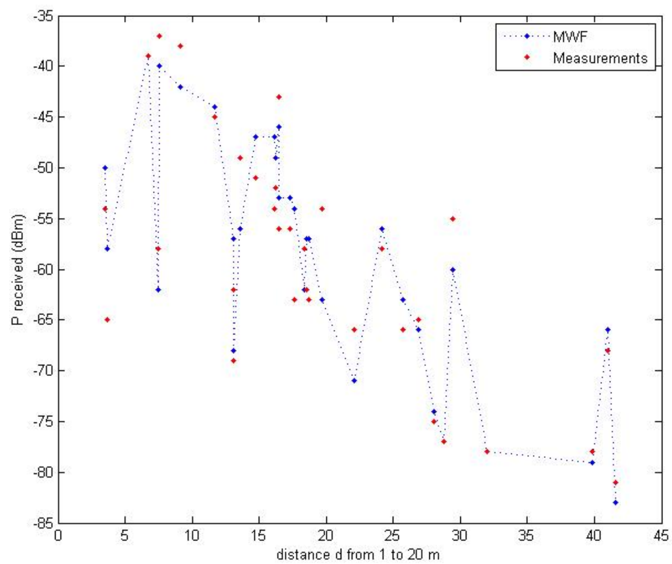


Figure 10. MWF performance for library topology



smaller than the mean error of all other path loss models for that topology (Chrysikos et al, 2010). In all topologies, therefore, the predictions based on free space losses and losses due to walls, floors and obstacles, are very close to the actual measured values. As a result, the (log-normal) excess path loss can be approximated with an acceptable percentage of error. Thus, the shadowing deviation (in dB) can be reliably calculated according to Equation 10, including the losses from all other obstructing material in addition to walls and floors.

Employing this method for all propagation topologies, Tables 5 through 10 are derived (Chrysikos et al, 2009b; Chrysikos et al, 2010; Chrysikos et al, 2011),

The results demonstrate a rather dynamic distribution of the values of the shadowing deviation throughout the topologies. It is evident that the shadowing deviation does not increase

Figure 11. MWF performance for home topology (same floor)

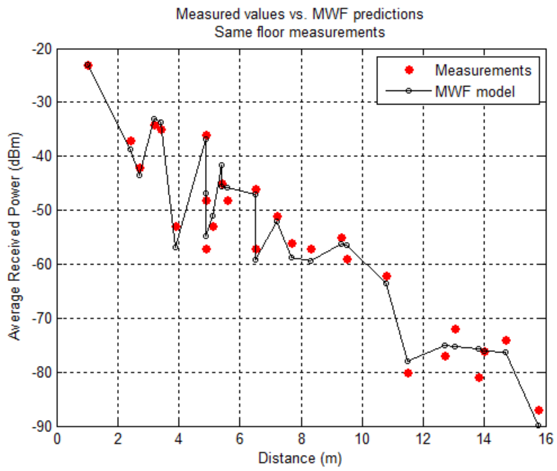


Table 4. Mean error of multi-wall-floor model

Topology	MWF Mean Error
Office (same floor)	2.41%
Office (multiple floors, 1 floor T-R separation)	1.88%
Office (multiple floors, 2 floors T-R separation)	2.22%
Library	6.36%
Home (same floor)	3.44%
Home (multiple floors)	2.14%

with distance, confirming similar outdoor experimental findings (Jakes, 1973; Seybold, 2005). The shadowing deviation depends on the topology intrinsic characteristics and expresses the penetration losses caused by all obstructing materials (walls, floors and other obstacles). This marks a departure from the conventional log-normal concept, where the shadowing deviation is a statistical metric of the fluctuations of the received power values (Jakes, 1973).

Table 11 depicts the shadowing deviation (in dB) for the home propagation topology (same floor and multiple floor measurements) for both methods (Chrysikos et al, 2011). The second column shows the values of shadowing deviation (in dB) as a product of Equation 6, that is in the context of the classic log-normal scenario, where the shadowing deviation (in dB) is calculated on the basis of an experimental data set of measured values of the received signal strength. The third column features the dB values of the shadowing deviation as a product of the novel empirical method, where the shadowing deviation is calculated on the basis of penetration losses of obstructing materials (walls, floors and other obstacles).

The classic log-normal concept can actually be employed in order to calculate the distribution

Table 5. Shadowing deviation (in dB) for office topology (same floor)

Location	σ (dB)
A	6.04
B	8.38
C	6.52
D	6.37
E	6.7
F	5.3
G	12.15
H	14.93
I	15.74
J	9.07
M	11.54
N	17.11
O	17.01
P	8.86
Q	0.35
R	0
S	0
T	11.34
U	14.22
V	4.97
W	6.37
X	8.91

Figure 12. MWF performance for home topology (multiple floors)

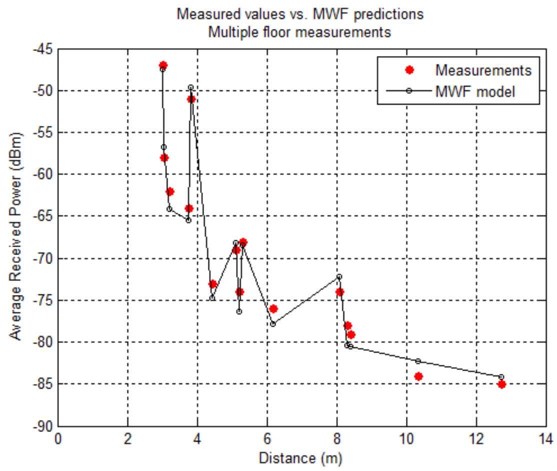


Table 6. Shadowing deviation (in dB) for office topology (one floor T-R separation)

Location	σ (dB)
A'	15.03
B'	15.72
C'	12.92
D'	10.74
E'	15.72
F'	18.78
G'	19.48
H'	18.26
I'	17.35
J'	18.87

CDF and therefore the Outage Probability for a given signal strength threshold. This, however, as mentioned earlier, requires an extensive number of on-site RF measurements – a grid of measurements throughout each given propagation topology – which is time consuming and more prone to error.

In addition, the shadowing deviation in this case cannot be applied to the Log-Distance path loss model in order to predict the local mean strength at any given distance from the transmitter throughout the topology (Chrysikos et al, 2009). This is due to the fact that each measurement locations, or each cluster of selected measurement locations, correspond to cases with different shadow losses due to a different number and type of obstacles meddling with the signal path (given the relative locations of transmitter, receiver and obstacles for each measurement case study).

On the other hand, application of the novel empirical method leads to a reliable calculation of the shadowing deviation for each such measurement location (or cluster of measurement locations) by assuming a logarithmic excess path loss which can be approximated (with an acceptable mean error less than 3.5% with the exception of the library commercial topology, where it is still significantly smaller than the mean error of all other path loss models) by the sum of losses of all walls, floors and obstacles meddling with the propagation path of the transmitted signal.

This method does not require but a limited number of on-site measurements near and around each obstacle. If there is already an available data set of measured obstacle losses such as in Tables 1 through 3, then no additional measurements are required and the link budget can be immediately calculated on the basis of these known penetration losses. The shadowing deviation (in dB) is confirmed to be independent of distance as with previous experimental findings and is dependent solely on the number of type of obstacles for each measurement location (or cluster of measurement locations). These directly calculated values of shadowing deviation can be employed for path loss prediction throughout the topology.

Moreover, this method confirms the notion that shadow fading should not be considered as merely the quantitative residue that is left over when implementing path loss prediction for a set of measured received power values, at a given distance and frequency, as proven already for

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chapter. Moreover, as already mentioned, the impact of different frequency employment on the obstacle losses, and therefore on the (dB) values of the shadowing deviation, needs to be further investigated for both outdoor and indoor propagation topologies.

CONCLUSION

In this book chapter, a novel empirical method was presented that allows the direct calculation of the shadowing deviation (in dB) as a product of the penetration losses of walls, floors and obstacles at a given propagation topology. The reliability of the method in terms of excess path loss estimation was confirmed to be within acceptable mean error values, and significantly more precise in comparison to all other existing path loss models. The direct calculation of the shadowing deviation allows for the characterization of the large-scale variations of the local mean strength of the received signal throughout the propagation topology. The nature of these variations was confirmed to be log-normal. The Gaussian distribution was employed for approximation of the logarithmic values of the received signal acquired over extensive on-site measurements.

This method, however, does not require but a limited number of on-site measurements near and around each obstacle and it can be employed for any given propagation topology and any given frequency of interest, as long as the respective losses for all significant obstructing materials are measured. Immediate and on-going research work will address more open issues in the ever-important field of wireless channel characterization.

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Table 9. Shadowing deviation (in dB) for home topology (same floor)

Location	σ (dB)
R	0
E	4.35
F	6.83
B	1.16
J	1.48
M	11.77
A	0.35
C	7.65
P	13.12
I	10.49
D	5.36
L	5.36
K	7.01
O	5.09
G	11.77
N	7.64
H	10.36
U	10.61
S	8.86
Q	11.19
T	12.40
A2	23.04
V	20.75
Z	17.58
A3	22.79
W	19.68
X	18.23
Y	25.80

has been proven that in this case, perfect secrecy is available even when the average Signal-to-Noise ratio (SNR) of the main channel is less than the average SNR of the wiretap channel, albeit with a probability less than 0.5 (Barros & Rodrigues, 2006).

Recent work has demonstrated that the WITS scheme is actually very dependent on the intrinsic channel characteristics and that its performance is radically influenced by different propagation scenarios (Chrysikos & Kotsopoulos, 2009). It is therefore imperative to investigate the specific impact of shadowing, as a product of the intrinsic channel and topology characteristics, on Wireless Information-Theoretic Security, and confirm theoretical deductions with experimental findings from on-going measurements.

In addition, the novel empirical method must be put to test for outdoor propagation topologies where different channel scenarios apply and compare the results with those presented in this

Table 10. Shadowing deviation (in dB) for home topology (one floor T-R separation)

Location	σ (dB)
R'	9.37
I	15.98
L	18.18
C	18.64
N	10.66
M	23.32
J	20.20
H	23.15
K	19.42
G	23.57
B	21.07
A	23.38
F	23.93
E	25.98
D	25.60

Table 11. Shadowing deviation (in dB) for home topology

Home Propagation Topology	Shadowing Deviation (dB) [Equation 6]	Shadowing Deviation (dB) [Equation 10]
Same Floor	16	10.74
Multiple Floor	11	20.16

Table 7. Shadowing deviation (in dB) for office topology (two floors T-R separation)

Location	σ (dB)
A''	23.32
B''	19.67
C''	18.81
D''	21.56
E''	20.26
F''	20.54
G''	21.97

outdoor propagation case studies (Salo, Vuokko, El-Sallabi, & Vainikainen, 2007).

Overall, this method can be employed for any given propagation topology and any given frequency of interest, as long as the respective losses for all significant obstructing materials are measured. At different frequencies of interest (i.e. 2.1 GHz, 3.5 GHz, 5.2 GHz), the same type of materials may cause different penetration losses, so that should be taken into consideration. Previous experimental works have demonstrated that the shadowing deviation (in dB) is frequency-dependent (Jakes, 1973; Seybold, 2005). Confirming that notion is one of the future research directions in relation to this empirical method.

FUTURE RESEARCH DIRECTIONS

Immediate future work consists of expanding the findings of this empirical method in the field of Wireless Information-Theoretic Security (WITS). WITS has been suggested (Bloch, Barros, Rodrigues, & McLaughlin, 2008) as an information-theoretic solution against eavesdropping that can be implemented as complementary to cryptography schemes or independently, especially in an infrastructure-less scenario (ad hoc networks) or in the case of an emergency scenario (emergency services, physical disasters). Instead of the classic Gaussian eavesdropping scenario, Rayleigh fading is assumed for the main channel (channel established between transmitter and legitimate receiver) and the wiretap channel (channel established between transmitter and eavesdropper). It

Table 8. Shadowing deviation (in dB) for library topology

Location	σ (dB)
A	0
B	0
C	0
D	0
E	0.48
F	2.19
G	10.49
H	14.52
I	10.26
J	9.49
K	10.22
L	4.93
M	5.53
N	3.47
O1	3.03
O2	4.41
O3	5.30
O4	3.18
O5	9.47
O6	8.62
O7	9.18
P	11.65
Q	18.10
R	6.22
S	8.67
T	14.56
U	15.64
V	15.75
W	16.33
X	14.71
Y	8.50
Z	2.16

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KEY TERMS AND DEFINITIONS

Channel Characterization: The field and methodology of qualitative and quantitative expression of the mechanisms and effects that alter in any way the transmitted signal in any given propagation topology.

Fading: The small-scale variations of the received signal strength, mostly due to multipath.

Multipath: The amplitude and phase distortion of the received signal due to the arrival of many different wave components at the receiver with different amplitude and time delay.

Path Loss: The ratio of attenuated signal due to free space propagation, obstruction and other mechanisms.

Shadowing: The large-scale variations of the received signal strength due to obstacles of significantly larger dimensions than the signal wavelength.

Shadowing Deviation: The deviation (usually in dB) of the large-scale fluctuations of the received signal strength values.