CHANNEL MODELLING AND PROPAGATION MEASUREMENTS FOR A BODYWORN 5.2 GHz TERMINAL MOVING IN THE INDOOR ENVIRONMENT

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ABSTRACT

Proposed applications for broadband wireless local area networks may include the use of bodyworn or handportable terminals. The proximity of the user's body has a significant effect on the radio propagation characteristics through spatial filtering of the multipath channel. This paper compares measurements and simulations of a narrowband 5.2 GHz radio channel with a fixed transmitter and a bodyworn receiver. The modelling technique was a site-specific ray-tracing simulator incorporating a modified three-dimensional radiation pattern of the bodyworn receiver. Two indoor environments were considered, an 18 m long corridor and a 42 m^2 office. The results show that the received power envelope and local mean values are strongly dependent on body shadowing in relation to the direct ray. In the corridor, the predicted non-line-of sight (NLOS) mean received powers was 13.6 dB lower than for line-of-sight (LOS). In the office, the predicted NLOS received power was 5.2 dB lower than LOS. The measured body shadowing effect was lower: 5.4 dB for the corridor and 3.8 dB for the office. Further analysis of level crossing rate and average fade duration showed that the prediction tool tended to underestimate the degree of fading. This was attributed to the movement limitations of the body model used.

INTRODUCTION

Advanced wireless local area networking (WLAN) systems such as HiperLAN type 2 and IEEE 802.11a operate at 5 GHz and provide high bandwidth information networks within the indoor environment. Although most terminal equipment will be designed for stationary use, it is envisaged that future applications will include bodyworn or handportable devices. Under these close proximity conditions, the terminal's radiation pattern is significantly distorted by coupling to the user's body and additional signal attenuation may occur. These effects are not only frequency dependent but will vary with the design of the terminal, its antenna and the exact positioning with respect to the body surface (1). Under the multipath conditions present in the indoor environment, the distorted radiation pattern of the bodyworn terminal can be considered as a form of spatial filter.

Substantial effort has already been directed at characterizing the indoor mobile radio propagation channel at 5 GHz, for example, Hashemi (2), Castle *et al* (3) and Nobles *et al* (4). However, the effect of using bodyworn terminal at this relatively high frequency remains obscure. This work describes the comparison of measurements and ray-tracing simulations of a narrowband indoor propagation channel at 5.2 GHz for a bodyworn terminal moving at a moderate walking speed of 0.5 m/s. The measurements results were obtained using a compact bodyworn measurement receiver and a datalogger operating at a sampling interval of 10 ms. The results were compared with predicted values calculated using an image-based site-specific 3D ray-tracing tool that incorporated a realistic 3D radiation pattern of the bodyworn radiating system.

CHANNEL MODELLING FOR THE BODYWORN RECEIVER

Proximity effects were included in the simulated results as the receiver radiation pattern was obtained from Finite-Difference Time-Domain (FDTD) modelling of the bodyworn radiating system. The simulation technique was based on our previous work, described in Villanese *et al* (5). However, to investigate the variations of the channel related only to the movement of the bodyworn receiver, pedestrians were excluded from the present study.

The FDTD model of the bodyworn radiating system was composed of an anatomically realistic phantom, conducting box (representing the receiver) and a thin-wire dipole antenna (Figure 1). The overall FDTD grid was 499 x 93 x 154 with cubic 3.6 mm voxels. The body phantom was for a 1.75 m tall adult male and incorporated 21 tissue types. The sleeve-dipole antenna used in measurements was modelled as a centre-fed 25.2 mm thin-wire (0.36 mm radius) and was positioned so that the minimum antenna body spacing was 25.2 mm. The high degree of separation (> 2λ) reduced the overall body losses with a corresponding FDTD-computed radiation efficiency of 83.3 % at 5.2 GHz. Figure 1 also shows the calculated azimuthal pattern for vertical polarisation (E_θ). The entire 3D radiation pattern was generated for 5° intervals of both azimuth and vertical angles. The pattern is strongly directional, for example in the azimuthal plane the peak gain was +6.0 dBi with a through-body null of –37.9 dBi.

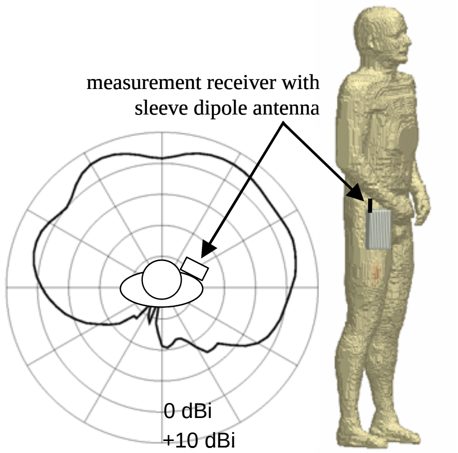


Figure 1. FDTD computational model and calculated azimuthal radiation pattern (E_θ).

MEASUREMENT ENVIRONMENTS AND SETUP

Two indoor scenarios were considered for the bodyworn receiver simulations and measurements. Location 1 was a 1.3 m x 18 m corridor and Location 2 was a 6 m x 7 m rectangular office. In Location 1, the transmitter cart was placed at 1.75 m and 0.67 m from the walls at the end of the corridor, while in Location 2 it was placed at 0.3 m and 3.5 m from the walls, in one side of the room. Location 2 was cleared of furniture to allow free movement. The measurement environments were relatively complex: e.g., metallic ducting and lockers set into the corridor walls and fluorescent lighting in the office. However, for convenience the ray-tracing simulations assumed a regular geometric structure with constant material parameters.

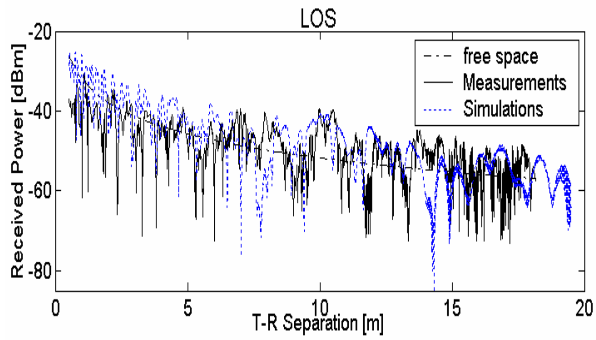
The measurements were performed using a fixed transmitter and recording the received power using a proprietary bodyworn measurement receiver. The transmitter consisted of a vector signal generator and a frequency doubler module configured to deliver +15 dBm of continuous wave (CW) at 5.2 GHz. The bodyworn terminal comprised a custom-built 5.2 GHz receiver, a 12-bit analogue to digital converter (ADC) and a notebook PC. The measurement receiver signal strength output had a linear voltage output for logarithmic input power with 65 dB of dynamic range (from –23 dBm to –88 dBm) and 46 mV/dB sensitivity. Both the transmitting and receiving antennas were commercial +2.2 dBi sleeve dipoles. The measurement receiver was positioned towards the front of the user's body (Figures 1 & 2) at the hip, while the ADC and notebook PC were placed in a backpack. A more detailed description of the measurement equipment and setup can be obtained from Ziri-Castro *et al* (6).

Two types of measurements were recorded in both locations: LOS, where the user was walking towards the transmitter, and NLOS, where the user was walking away. In all the scenarios the user walked at approximately 0.5 m/s, and the signal strength was recorded at a sampling interval of 10 ms. If only lateral movement is considered, the selected sampling interval equates to a spatial resolution of better than λ/11.

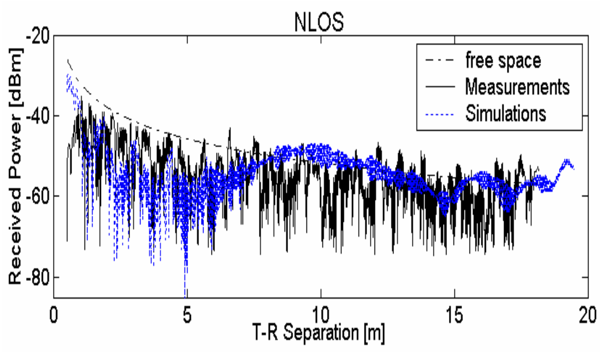
RESULTS

General Observations

Figure 2 shows a comparison between the measured and simulated received power when the user was walking along the middle of the corridor (Location 1) for LOS (Figure 2(a)) and NLOS (Figure 2(b)) conditions. Qualitatively, the correlation between measurements and simulations for Location 1 was better in the LOS case than for NLOS. Given the idealised human body model used in calculations, it would unfair to directly compare the mean received power values for simulations against measurements (Table 1). However, it is worthwhile to note that the body shadowing effect (i.e. the difference between the mean LOS power and the mean NLOS power) was only 5.4 dB for the measurement results while it was 13.6 dB for the simulation results.



(a)



(b)

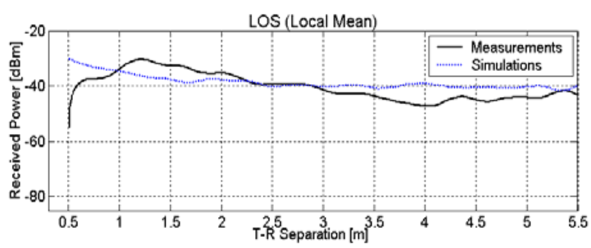
Figure 2: Measured and simulated received power for Location 1: (a) LOS, (b) NLOS.

The shadowing effect is dominated by the attenuation of the direct ray caused by the reduced antenna gain in the through body direction. A possible cause of the discrepancy between measurements and simulation could be the slight variations in posture as the volunteer walked along the corridor in the measurement case. This would cause a natural quasi-random fluctuation in the direct ray azimuth angle leading to attenuation fluctuations. However, in the simulated case the direct ray azimuth angle was constant throughout while the vertical angle only gradually increased towards the end of the corridor.

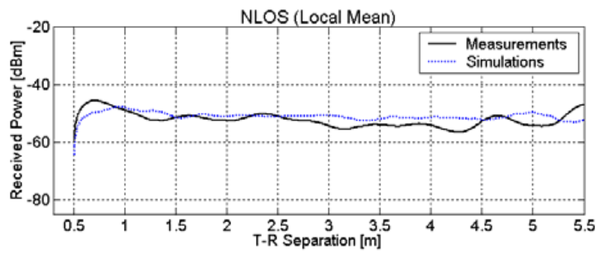
TABLE 1 – Comparison of simulated and measured mean received power.

Scenario	LOS mean (dBm)		NLOS mean (dBm)	
	Meas.	Sim.	Meas.	Sim.
Location 1	–44.6	–35.9	–50.0	–49.5
Location 2	–41.6	–41.3	–45.4	–46.5

Measurements and simulations for Location 2 were performed for 15 trajectories (0.5 m spacing) across the room under both LOS and NLOS conditions (6). Figure 3 compares measured and simulated local mean received power for the centre trajectory (in line with the transmitter). These values were calculated using a 1-Hz low pass zero-phase recursive digital filter. The effective averaging distance was 0.5 m (100 samples). Note that the values for Location 2 given in Tables 1 and 2 are for all of the data obtained over all 15 trajectories. Table 1 shows that the body shadowing effect was less severe for Location 2: 3.8 dB for the measured results, and 5.2 dB for the simulations.



(a)



(b)

Figure 3: Measured and simulated received power for Location 2: (a) LOS, (b) NLOS.

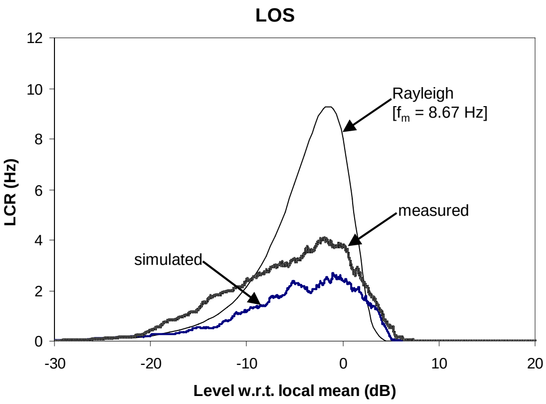
TABLE 2– Error between measured and simulated local mean power.

Scenario	Mean Error (dB)		Std. Dev. (dB)	
	LOS	NLOS	LOS	NLOS
Location 1	6.2	5.4	5.6	4.5
Location 2	3.8	3.6	2.7	2.3

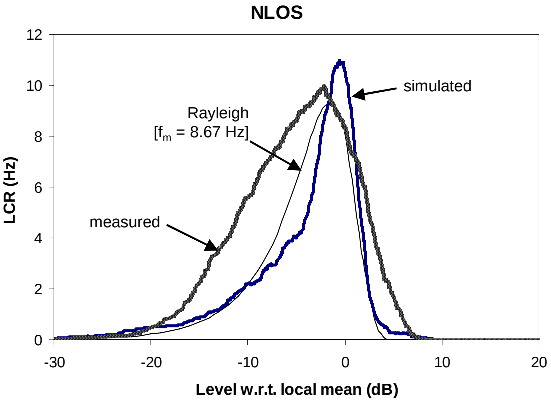
The accuracy of local mean prediction was determined by calculating the mean and standard deviation of the error between measurements and simulations for all of the data sets concerned (Table 2). For both locations, the local mean values were predicted with more accuracy for NLOS conditions. However, the overall performance was better when considering Location 2. This was assumed to be related to the increased size of the data set (more than 5 times more points than for Location 1).

Second Order Statistics

Level-crossing rate (LCR) and average fade duration (AFD) were calculated for both simulated and measured data sets. LCR is defined as the rate at which the envelope crosses a specified level with a positive slope. The average time for which the received signal is below that level is defined as AFD. In all cases, LCR and AFD results were computed for levels from –30 to 20 dB with respect to the relevant local mean in 0.05 dB steps. For calculating both LCR and AFD, local means were determined by averaging received signal power over 460 samples (40λ). The LCR results for Location 1 were compared (Figure 4) to a Rayleigh distribution with a Doppler frequency, f_m, of 8.67 Hz (for a receiver speed of 0.5 m/s). Although they had similar shapes, the peak of the measured LOS LCR curve was 53 % higher than the simulated curve. However, neither curve was Rayleigh distributed. The peak LCR values were significantly higher for NLOS conditions and were similar to the theoretical Rayleigh maximum LCR. In particular, the simulated results were relatively well matched to the Rayleigh curve. However, the measured NLOS LCR curve was more Rician thus indicating a stronger direct ray component compared to simulations. Figure 5 shows the AFD curves for Location 1.

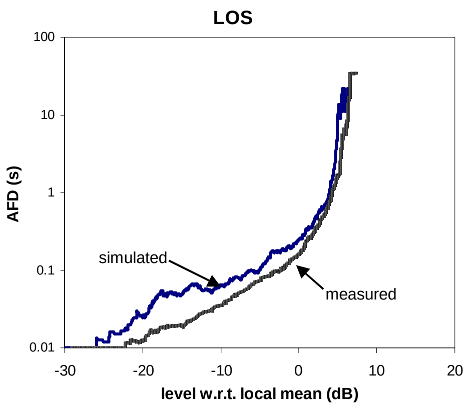


(a)

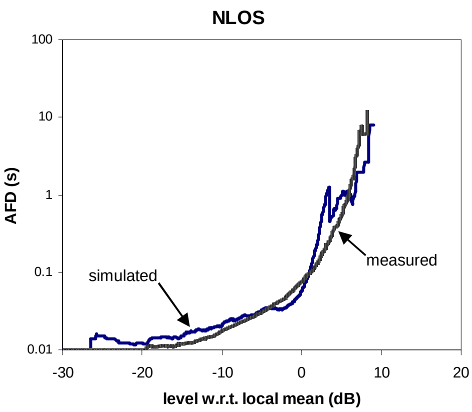


(b)

Figure 4: Location 1 LCR: (a) LOS, (b) NLOS.



(a)



(b)

Figure 5: Location 1 AFD: (a) LOS, (b) NLOS.

Measured LCR values were found to be significantly higher than predicted within Location 2 (Figure 6). Furthermore, the highest LCR values were associated with the LOS curves rather than with NLOS. Inspection of the raw fading profiles confirmed that the measured results experienced significantly more fading than was predicted. This suggests that the additional body movements associated with walking and the increased role of multipath reflections in the small room had led to more rapid envelope variation. As it considered only lateral movement, the simulation tool was unable to faithfully represent these variations. Likewise, the AFD results for Location 2 (Figure 7) indicate that the predicted fade duration was consistently longer than that measured.

CONCLUSIONS

A comparison between propagation measurements and simulations of an indoor narrowband channel with a bodyworn receiver at 5.2 GHz was presented. The results showed good agreement between the predicted and measured results in terms of local mean values with a maximum mean error of 6.2 dB. However, in terms of LCR and AFD the prediction tool was less accurate. An analysis of the results suggests that the cause of the discrepancy with the simulation technique is related to the inability to model natural variations in body posture during walking.

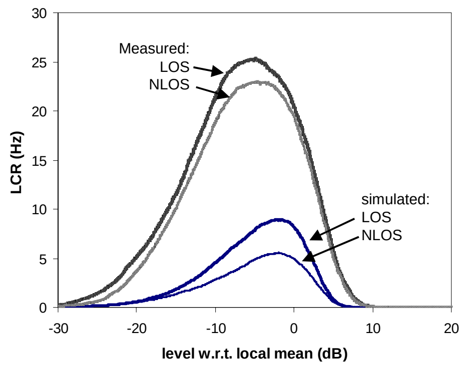
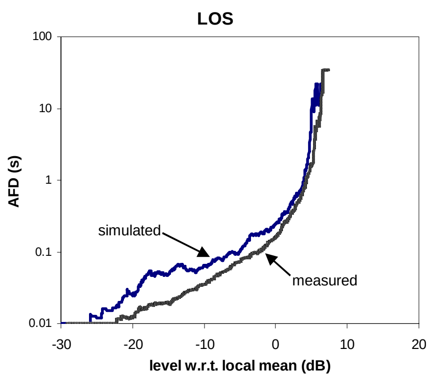
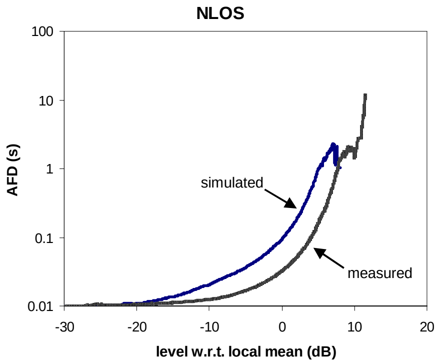


Figure 6: Location 2 LCR.



(a)



(b)

Figure 7: Location 2 AFD: (a) LOS; (b) NLOS.

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