



Harrold, T. J., Nix, A. R., & Beach, M. A. (2001). Propagation studies for mobile-to-mobile communications. In Vehicular Technology Conference, 2001. VTC 2001 Fall. IEEE VTS 54th. (Vol. 3, pp. 1251 - 1255). Institute of Electrical and Electronics Engineers (IEEE). 10.1109/VTC.2001.956396

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[10.1109/VTC.2001.956396](https://doi.org/10.1109/VTC.2001.956396)

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Propagation Studies for Mobile-to-Mobile Communications

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Abstract— This paper addresses a number of key issues that affect the modelling of propagation in mobile-to-mobile communications. Current examples of such systems include Intelligent Relaying, Bluetooth and other ad-hoc solutions. The key difference in mobile-to-mobile communications is that both transmit and receive antennas are likely to be closer to the ground than those in conventional cellular networks. In addition, they may also be located in less favourable propagation positions, such as in users' pockets, bags or desk drawers. Two measurement programmes have been performed to investigate the propagation issues relating to Intelligent Relaying in the 2GHz band. The first campaign concerns path loss measurements in an indoor environment where the heights of the antennas are lower than those in conventional cellular networks. The second set of data was taken to determine variations in the terminal radiation pattern given the close proximity of the human body. A number of single ray illumination measurements were performed inside an anechoic chamber. The results indicate that for the environments under consideration, an additional attenuation factor should be added to the path loss model to compensate for the unfavourable location of the terminals in a mobile-to-mobile propagation environment. This attenuation is dependent on the heights of the antennas involved, and is in the range 0–8dB.

I. INTRODUCTION

An increasing number of communication standards (such as Bluetooth) now require mobile terminals to communicate directly with other mobile terminals, rather than exclusively with a basestation. Multiple hop techniques, such as Intelligent Relaying [1] and ETSI's ODMA (Opportunity Driven Multiple Access) [2], are being investigated in order to exploit the benefits of mobile-to-mobile communication. These include capacity enhancement, range extension and power reduction. Previous studies performed at the University of Bristol [3] have shown that by forming a mobile to basestation connection via multiple mobile-to-mobile hops, rather than via a direct path, significant benefits can be achieved such as a reduction in transmit power and an according increase in network capacity.

Existing outdoor path loss models are not appropriate for the modelling of mobile-to-mobile communications, as they are usually defined for links between a basestation situated at, or above, rooftop level and a mobile terminal held around head height. In addition, these models are usually specified for distances greater than 10m. The aim of this paper is to study the short range radio channel between two mobile terminals, each with antenna heights below 2m above ground level (i.e. head height or below). In addition to the difference in path loss resulting from low mounted antennas, the further issue of less favourable terminal location needs to be considered for unattended relay situations. In existing systems, the mobile

is positioned with a near vertical antenna in a location where the user's head becomes the dominant source of local clutter. For unattended terminals, operation may be required in less favourable locations such as users' pockets or briefcases.

The aim of the propagation measurements described in this paper are to characterise the mobile-to-mobile propagation channel at 2GHz, both in terms of the path loss between two low height antennas, and the additional losses that occur due to sub-optimal handset location. Previous researchers [4] [5] have performed outdoor measurement campaigns that concluded that the mobile-to-mobile path loss model follows a characteristic similar to that of a conventional outdoor mobile.

The measurements carried out and the associated results and conclusions are described in more detail in Section IV. Sections II and III explain the requirement for mobile-to-mobile channel models, and the effects that make the environment different from the standard propagation environment. Overall conclusions are presented in Section V.

II. MOBILE-TO-MOBILE PROPAGATION ENVIRONMENT

Just as the multipath fading in an environment is known to cause the received signal strength to fluctuate as the user moves in the X-Y plane [6], the signal will similarly vary as movement occurs in the Z (i.e. height) domain. In particular, lower antenna positions are expected to introduce propagation mechanisms such as additional interactions with low height objects. There is also expected to be less likelihood of a line of sight (LOS) path between transmitter and receiver.

The fact that mobiles are not usually sited in complete isolation from surrounding objects can be significant when considering mobile-to-mobile propagation. The resulting path loss is expected to vary due to the following contributions:

- a loss due to interference with the antenna radiation pattern caused by clutter in its proximity, or by a user's head or hand close to the terminal
- a polarisation loss, due to sub-optimum alignment of the terminal antenna
- a loss due to different propagation characteristics at the lower height of the terminal

Results presented in [7] suggest that at a frequency of 1.9GHz an additional 3–4dB should be included in a planned

link budget to allow for the effects of holding the antenna adjacent to the head. This work also found that the head caused significant cross-polarisation of the received waveform.

III. MOBILE-TO-MOBILE PROPAGATION MODELLING

A mobile that is active in a network that allows direct relaying between mobile terminals may be in one of two modes:

- originating, i.e. the mobile is being used by its owner for transmitting/receiving data and is most likely to be situated around head height, or around desktop height for indoor use
- unattended, i.e. the mobile is relaying data (receiving from another terminal, and re-transmitting), and is likely to be situated at waist height or below, possibly in a briefcase, shoulder bag or similar

The Intelligent Relaying (IR) technique described in [3] permits relaying to take place between terminals and basestations in either of these two states. Hence, in order to simulate the operation of IR, there is a need for loss models that consider the following scenarios:

- unattended to unattended
- originating to unattended
- originating to originating
- unattended to basestation
- originating to basestation (defined by conventional models)

IV. MEASUREMENTS

In order to address the issues raised in Section III, two sets of measurements were performed. Firstly, an investigation was conducted in an anechoic chamber to discover how the terminal location in relation to the human body affects reception. In order to extend the results to a multipath environment, and to investigate path loss, a series of measurements were also made in an indoor environment. The aim of the campaign was to conclude how much additional loss needs to be added to the path loss model in order to take account of the effect of terminal height.

A. Local Location Measurements

The terminal location measurements were carried out in an anechoic chamber and took the form of illuminating a user equipped with a test receiver terminal from various directions. The different test receiver scenarios that were investigated are as follows:

- receiver held adjacent to the head (1.73m above ground level), such as might occur for using a voice service with a conventional handset. The terminal antenna was placed in close proximity to both the user's head and hand
- receiver at waist height (0.87m above ground level), such as might occur if the mobile is unattended in a pocket, or clipped to a user's belt. The terminal was attached to the waist

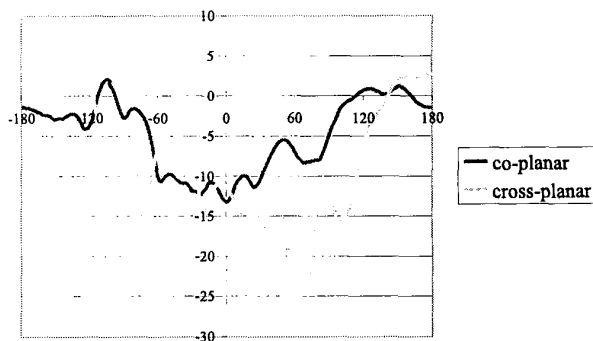


Fig. 1. Radiation pattern for terminal adjacent to head

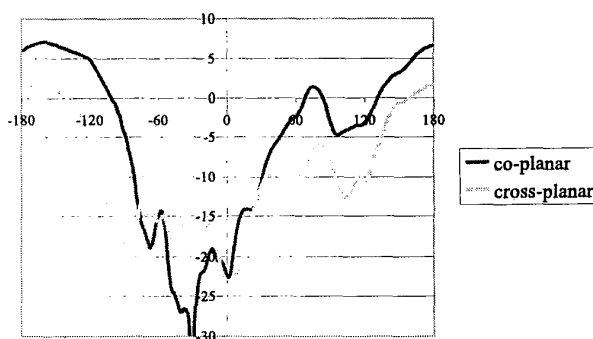


Fig. 2. Radiation pattern for terminal in user's pocket

- receiver in a fabric bag, carried by the user's side (0.69m above ground level)

For each of these local environments, measurements were taken with the transmit antenna vertically and horizontally polarised to establish co and cross-planar radiation patterns. The test receiver comprised a standard mobile telephone handset, with a substitute antenna resonant at 2.1GHz, in order to represent the sort of terminal proposed for use in 3G. The test environment was illuminated with an antenna with a 3dB beamwidth of approximately 80° mounted at a height of 1.64m. Measurements were taken at 1° intervals for incident angles between -180° and 180° degrees. A reference set of measurements were also taken to establish the radiation pattern of the monopole with no human interaction.

A.1 Results

The pattern plots for the antenna located in the various test environments are shown in Figures 1, 2 and 3. In each case, the plot was calibrated using the reference pattern for the antenna mounted on the test terminal in free space with vertical (co-planar) polarisation. The position of 0° represents the case

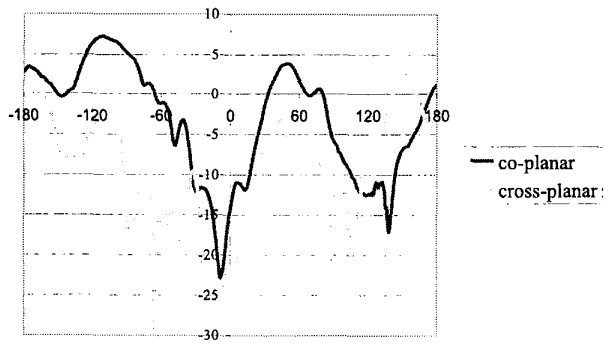


Fig. 3. Radiation pattern for terminal by user's side

where the user's body completely blocks the path between the antennas, conversely the -180° and 180° positions are the locations where the receive antenna has an unobstructed path to the transmitter.

Each of the plots shows a gain at certain angles with respect to the monopole in free space. This can be explained by the different received antenna radiation pattern when illuminated from a higher angle (as will occur when the terminal itself is lowered) and constructive interference caused by the user. In each case, the signal is seen to pass through a minimum at around 0° , the point at which the body intersects the line of sight path. The diffraction of energy around the body ensures that some signal is still received. An additional signal null occurs for the side location in Figure 3, possibly due to the effects of additional items in the bag, or as part of the bag's structure.

The head location would appear to be the most favourable, the worst case signal attenuation being only 10dB below the reference. The pocket and side location suffer similar disruption due to the presence of the body. In each case, a certain amount of de-polarisation of the signal has taken place (this effect was also observed in [7]).

Although the peak signal attenuation of 30dB would seem to be severe, this is only for illumination from a single direction. The radiation pattern could be convolved with an angular field arrival profile to establish coverage in a multipath environment.

B. Path Loss Measurements

Measurements were taken in an indoor open-plan office environment to establish a path loss model for terminals using low height antennas. The transmit station comprised a signal generator transmitting a CW signal at 2.1GHz, and the receive station comprised a narrowband receiver with its antenna mounted on a distance measuring wheel, equipped with the ability to take signal strength measurements automatically. Both stations were equipped with monopole antennas mounted on ground planes. The receive station was moved along a path away from the transmitter, with signal strength readings taken every 1m. The maximum transmitter to receiver separation dis-

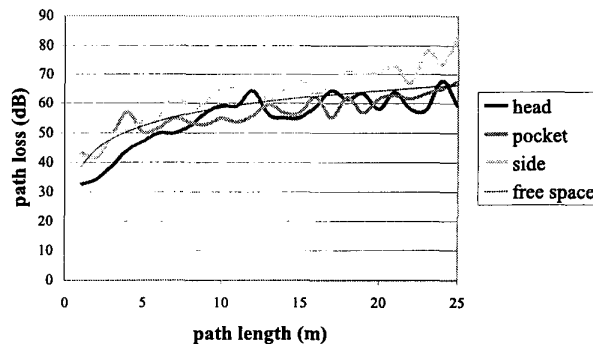


Fig. 4. Path loss for transmitter at head height, LOS path

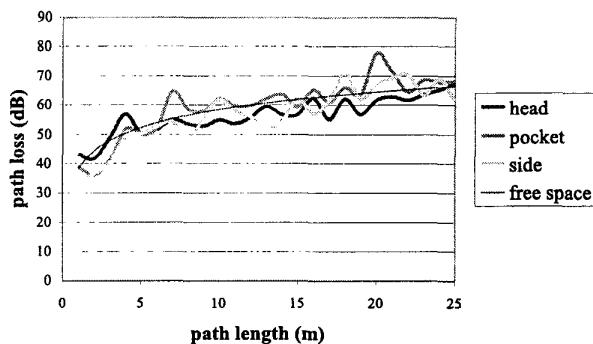


Fig. 5. Path loss for transmitter at pocket height, LOS path

tance was 25m.

Two sets of measurements were taken; for the first, a LOS path existed between the antennas at all time. For the second set of measurements, the transmit station antenna was repositioned so that the path between the antennas was obstructed by a desk for the majority of the measurement route.

Readings were taken at three different heights for both the transmit and receive antennas; 1.73m, 0.87m and 0.69m. These heights were chosen to simulate locations where a terminal might need to be used for both the originating and unattended modes of operation. They also corresponded to the antenna heights used in the previous anechoic chamber measurements.

Measurement of the cable losses and antenna gains allowed the measured receive signal strength to be converted into path loss.

B.1 Results

The results are shown in Figures 4–9 for the LOS and non-LOS cases. Each figure represents a different transmit antenna height, the different curves on each graph represent the three different receive antenna positions. On each graph, the theoretical free-space path loss is also plotted.

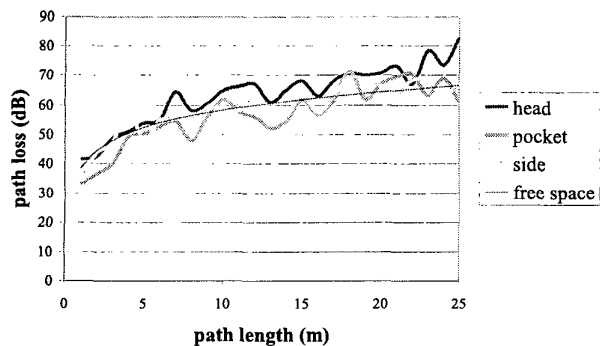


Fig. 6. Path loss for transmitter at side height, LOS path

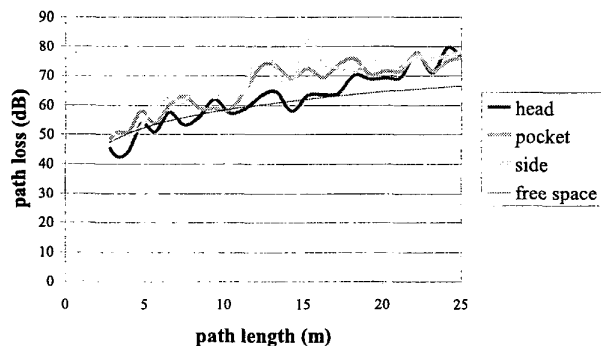


Fig. 7. Path loss for transmitter at head height, non-LOS path

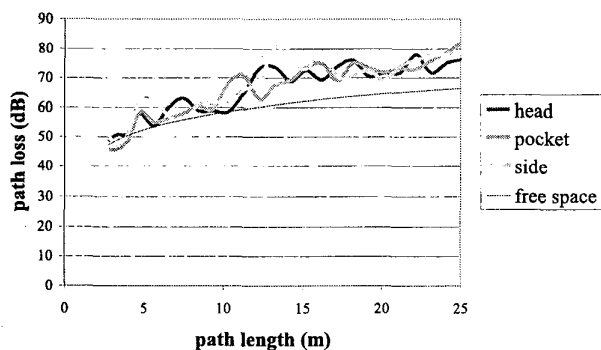


Fig. 8. Path loss for transmitter at pocket height, non-LOS path

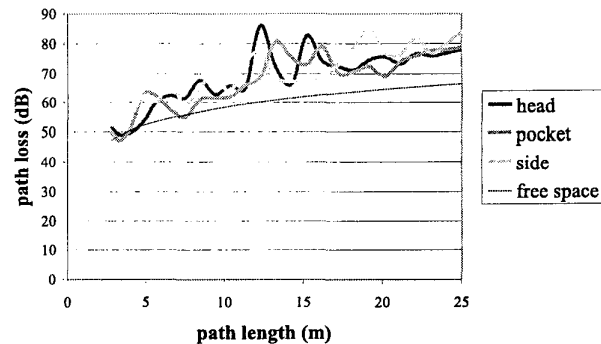


Fig. 9. Path loss for transmitter at side height, non-LOS path

All of the measurements display an amount of multipath ripple due to interactions with objects in the environment. The fluctuations are more severe where the antennas are situated closer to the ground. Figure 9, where the transmit antenna height is the lowest, shows fades of 20dB, presumably occurring due to greater interactions with lower objects such as chairs and waste paper bins, which do not affect propagation between the head height antennas to such an extent.

For the LOS case, the results are close to the free-space trace; although for the situations where the vertical displacement between antennas is at its greatest (i.e. when the transmitter is at head height and the receiver is at side height or vice versa), the path loss is increased accordingly. This can be seen best in Figure 4 where there is 8–10dB of additional loss for the side height antenna with respect to the head height case. For the non-LOS case, the results show a greater path loss than for the free-space case. The additional path loss due to greater vertical displacement between the transmit and receive antennas is also increased.

For the measured environment, a summary of the average loss in dB relative to that of free-space loss is given for the LOS case in Table I, and for the non-LOS case in Table II. In each case, a negative figure implies a path gain with respect to the free-space value.

		transmitter		
		head	pocket	side
receiver	head	-2	-1	7
	pocket	-1	1	0
	side	7	0	-1

TABLE I
LOS PATH LOSSES (dB) WITH RESPECT TO FREE SPACE

		transmitter		
		head	pocket	side
receiver	head	0	5	6
	pocket	5	3	5
	side	6	5	8

TABLE II
NON-LOS PATH LOSSES (dB) WITH RESPECT TO FREE SPACE

- [4] Gandhi Situmorang, *Intelligent Relaying Simulation*, University of Bristol, MSc Thesis, 1999.
- [5] Neal Patwari, Gregory D Durgin, Theodore S Rappaport, and Robert J Boyle. "Peer-to-peer low antenna outdoor radio wave propagation at 1.8GHz." *Vehicular Tecnology Conference*, 1999.
- [6] Bernard Sklar. "Rayleigh fading channels in mobile digital communication systems part 1: Characterization." *IEEE Communications Magazine*, vol. 35, no. 7, pp. 90-100, July 1997.
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The data given in Tables I and II could be used in conjunction with existing indoor and outdoor propagation models to produce the required models for Intelligent Relaying terminals in the originating and unattended modes. These modified propagation models would be of considerable benefit when simulating the performance of indoor mobile-to-mobile networks.

V. CONCLUSIONS

This paper has investigated the additional propagation effects that occur when antenna heights closer to the ground are used and when antennas interact closely with objects such as the human body. These scenarios are likely for direct mobile-to-mobile communications. The analysis was based on single ray illumination measurements in an anechoic chamber, and signal strength measurements in an indoor multipath environment. Values for the additional losses that should be taken into account in any planning or modelling tool have been presented. For the case where a LOS path exists between the transmitter and receiver, these values fall within the range of -2-7dB with respect to the free-space path; for the non-LOS case, the loss can be up to 8dB. This value is dependent on the heights of the antennas involved, the greatest loss occurring when the vertical separation between the antennas is the greatest.

ACKNOWLEDGEMENTS

This work has been performed under the auspices of the BT Virtual University Research Initiative on Mobility (BT VURI) to whom the authors would like to express thanks. The authors would also like to thank Dr. Ben Allen for his advice on propagation measurements, and Dr. Geoff Hilton for his assistance with the body interaction measurements.

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