MAXIMISING SIGNAL STRENGTH INSIDE BUILDINGS FOR WIRELESS LAN SYSTEMS USING OFDM

ERIC LAWREY
C. J. KIKKERT
James Cook University, Electrical and Computer Engineering,
Townsville, Australia, 4814
E-mail: Eric.Lawrey@jcu.edu.au,
Keith.Kikkert@jcu.edu.au

Propagation inside buildings suffer from large shadowing and high multipath effects. This is a serious problem for Wireless Local Area Network (WLAN) systems. OFDM has a high multipath tolerance and this paper shows how this can be used to overcome the problems due to shadowing. OFDM allows a base station to transmit and receive the same signal at the same frequency from multiple locations, at a low cost and without detrimental effects of Inter-Symbol Interference (ISI). The reduced shadowing and path loss allows: an increased system capacity for such a multi-transeiver WLAN cell, or a decrease in intercellular interference in a cellular WLAN.

1 Introduction

Wireless computing is an emerging technology allowing users the freedom of movement. Wireless Local Area Networks (WLAN) aim to provide users with a data rate comparable with wired networks within a limited geographic area. Currently most WLAN products are based on the IEEE 802.11 standard, which provide a data rate of 1 Mbps (IEEE802.11) up to 11 Mbps (IEEE802.11b) in the 2.4 GHz ISM band [1-2]. The next generation of WLAN systems will be based on two similar WLAN standards known as: HIPERLAN/2 (Europe), and IEEE802.11a (US). These support a physical layer transmission rate of up to 54 Mbps and use Orthogonal Frequency Division Multiplexing (OFDM) for the physical layer implementation.

Traditionally a single WLAN cell only has one access point, due to strong multipath generated when using multiple repeaters. However the use of OFDM allows a base station to have multiple repeaters within the same cell. The Access Point Repeaters (APR) all transmit and receive the same signal at the same frequency, and are spread over the area of the WLAN cell. APRs reduce shadowing and path loss by reducing the effective transmission distance.

The use of a multiple repeaters was first used in the Digital Audio Broadcasting (DAB) system [3]. DAB uses OFDM with a low symbol rate and a long guard period. In a conventional FM broadcast system, transmitters of neighbouring service areas have to be allocated different frequency bands to prevent multipath interference, even if the radio station content is the same. However in DAB all the transmitters use the same frequency and transmit copies of the same signal. At the receiver, each of the transmitted signals is delayed by different amounts and thus appear as strong multipath. To prevent inter-symbol interference (ISI) the symbol rate is made sufficiently low by using a large number of carriers, that the OFDM guard period (~25 % of the symbol period) is longer than the delay spread generated by the multiple transmissions. All multipath with delay spread less than the guard period does not cause any ISI. Using a single frequency for all transmitters reduces the effects of shadowing as the multiple transmitters effectively act as spacial diversity.

The use of multiple repeaters can be scaled down for use in WLAN systems, provided the modulation scheme used is not effected by the increased delay spread caused by the repeaters. Transmissions within indoor environments suffer large amounts of shadowing due to walls, numerous objects and generally a lack of Line Of Sight (LOS). The transparency of walls decreases with RF frequency increasing the problem of shadowing at higher RF frequencies (> 2 GHz). It is therefore important to decrease shadowing if possible.

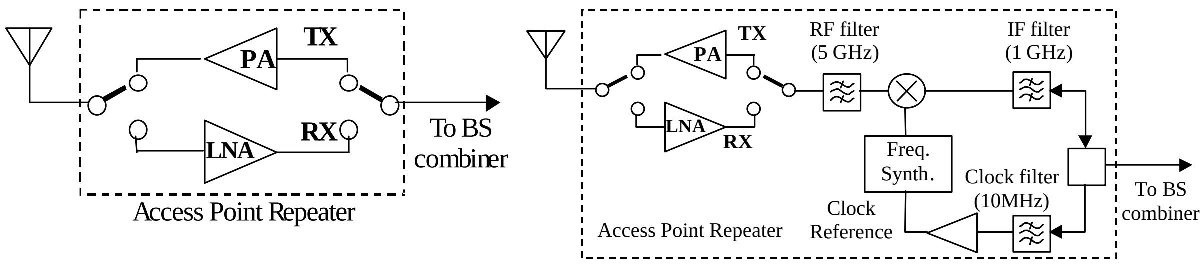

Figure 1. Possible implementation of an Access Point Repeater. **(a)** Simple APR, **(b)** High frequency APR where coax losses are too large. The signals to and from the BS are sent on the coax at a suitable IF frequency.

HIPERLAN/2 has a guard period of 800 ns and an effective protection of up to 250 ns of delay spread. This would allow APRs to be placed up to maximum of 30-40 m apart within each cell. This is sufficient for coverage of most buildings.

2 Implementation of an Access Point Repeater

All APRs within the same cell transmit and receive the same signal, thus only one base station (BS) is needed per cell. For transmission, the signal generated by a base station is split N ways, where N is the number of APRs. Coaxial cable or some other medium such as optic fibre is used to deliver the signal to each APR, which are spread over the area of the cell. The signal then is amplified at the APR to compensate for any losses in the coax transmission. For reception the reverse process is used. Each APR has a Low Noise Amplifier (LNA) to compensate for losses in the coax, in order to maintain a low noise figure. The received signals from all APRs are combined then demodulated at the base station. Phase differences between the APRs have little or no effect as they corrected for in the OFDM demodulation process.

Figure 1(a) shows a simple implementation of an APR when the loss in the coaxial cable is low (< 20 dB). Using satellite TV coax (CT100) the loss in the cabling will be approximately 1 dB/m at 5 GHz, thus the attenuation for 20 m will be 20 dB. This will allow a simple APR as shown in Figure 1 (a) to be used. However in larger systems where the cable losses become too large the loss can be reduced by mixing the RF signals to a lower Intermediate Frequency (IF) such as 1GHz for a 5GHz RF. This will reduce the losses in the coax by ~5 times. Figure 1(b) shows one possible implementation for an IF APR. A common clock reference must be used by all APRs to ensure frequency synchronisation, otherwise frequency errors will reduce the orthogonality of the OFDM causing inter-carrier interference. For such a design care must be taken to ensure the phase noise of the clock reference is low and that the clock signal does not interfere with the received signal.

3 Experimental Setup

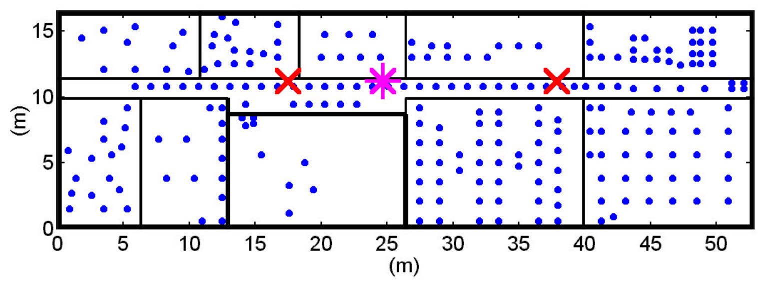

Figure 2. Pathloss measurement locations with in the ECE building. Lines represent internal walls.
$*$ Single Transmitter $\times$ Dual Transmitter • Measurement Location

An experiment was setup to test the effectiveness of using multiple transmitters (APR) to minimise shadowing in an indoor environment. The forward link from the base station to the mobile stations was tested, by measuring the path loss from fixed transmitters to a mobile receiver. The path loss from a single transmitter (simulating a single Access Point) was compared with the path loss when using two transmitters (simulating two APRs).

The path loss was measured at 235 locations on the second floor of the Electrical and Computer Engineering (ECE) building at James Cook University. The measurement locations and the building layout are shown in Figure 2. The internal walls are shown as dark lines. The thin walls are constructed from plasterboard with the thicker walls constructed of concrete block.

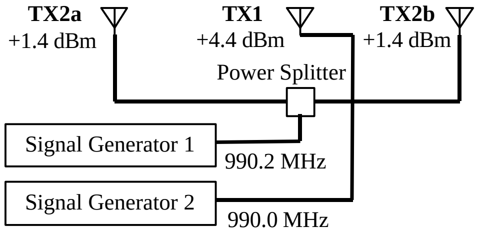

Figure 3. Transmitter Measurement for Access Point Repeaters. The transmitter power from Tx2a plus Tx2b is the same as the Tx1 Power.

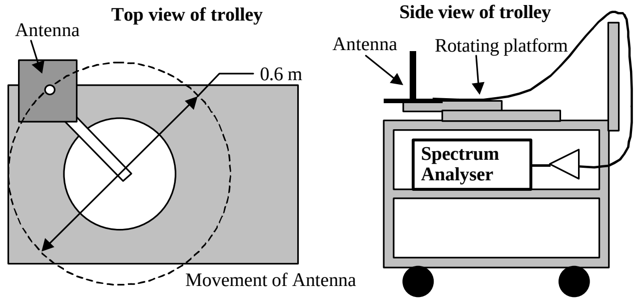

Figure 4. The receiver antenna was moved along a circle to average out the effect of fading.

The transmitter setup is shown in Figure 3. The path loss at each location was measured using a spectrum analyser on a trolley. A different frequency was used for the single transmitter and dual transmitters to allow simultaneous measurements of the path loss. The receiver antenna was placed on a rotating platform that was turned during the received power measurement (see Figure 4). The video averaging on the spectrum analyser was used to average the power over the 1.9 m path swept by the antenna. This was done to remove the effects of frequency selective fading. The measurements were performed at 1 GHz, rather than 5 GHz, due limitations of the equipment available.

4 Discussion of Results

Figure 5 (a) shows the path loss when only a single transmitter was used. The path loss increases rapidly with distance from the transmitter. The path loss at (5,5) m has a high path loss of over 100 dB, which is equivalent to 1 km of free space loss, even though it is less than 20 m from the transmitter. Figure 5 (b) shows the path loss when two transmitters was used. In this case the path loss is lower and much more even. The worst case path loss is more than 10 dB better when using two transmitters as compared with one.

Figure 6 shows the probability distribution of the path loss. It shows that the path loss is > 7 dB lower when using two transmitters as compared with one. This result is to be expected as the average distance to the transmitter is approximately half. In the experiment performed the longest distance to a transmitter was reduced by 1.62 times. The typical path loss exponent of an obstructed path within a building is 4-6 [4], as compared to a path loss exponent of 2 for free space loss. We would therefore expect the path loss to be reduced by 8.4-12.6 dB for a reduction in distance of 1.6 times. Since the transmission power is split over two transmitters this will reduce the received power by 3 dB, thus resulting in an overall improvement of 5.4-9.6 dB. This compares well with the measured improvement of 7 dB.

The path loss could be further decreased if more transmitters were used. Using 3 transmitters we would expect an improvement up to 10-16 dB. Extending the number of APR so that we had one per room (10 APRs) we could expect 20-30 dB improvement.

5 Reduction in Cellular Interference

The path loss from the multiple APRs at a large distance will be the same as when using a single Access Point. Thus the interference to neighbouring systems using one or more transmitters will be same for the same transmission power. The near field path loss within the building is lower by 7 dB for two APRs, allowing the total transmitted power can be reduced by up to 7 dB for the same signal to noise ratio. This will reduce the overall interference to nearby WLAN systems by 7 dB. Further improvements could be made using a higher number of APRs. Using one APR per room could potentially decrease the near field path loss by 20-30dB, allowing a large reduction in external interference with suitable power control. The reduced interference will allow a lower frequency reuse in a cellular system, greatly increasing the spectral efficiency and data rate of the WLAN system.

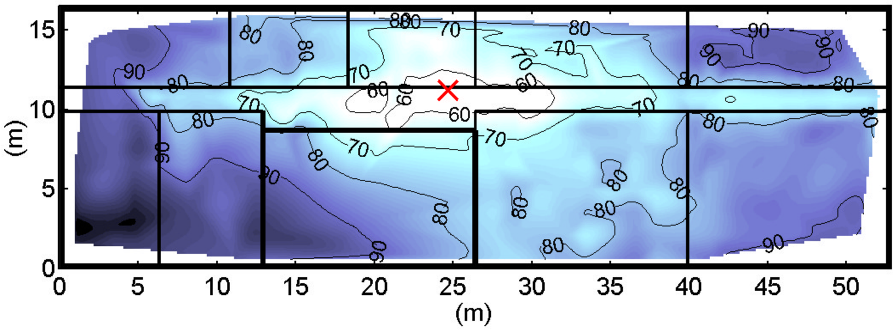

Figure 5 (a). Measured path loss at 990 MHz using a single transmitter. The X shows the transmitter location. The scale for the path loss is the same as for Figure 5(b).

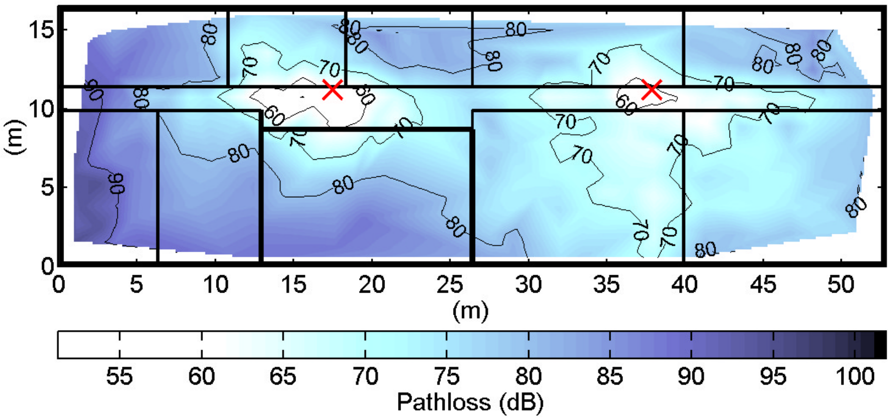

Figure 5 (b). Measured path loss at 990 MHz using two transmitters. X indicates the transmitter locations

5 Conclusion

Using multiple Access Point Repeaters is a low cost method that can be used reduce shadowing and near field path loss within a building. This allows a reduction in intercellular interference with suitable power control. It was shown experimentally to decrease the near field path loss by 7 dB @ 1GHz within an indoor environment, using two repeaters as compared with a single transmitter. For OFDM systems, including HIPERLAN/2 and IEEE 802.11a, the multipath signals generated by the multiple APR does not lead to ISI, provided the distance between the repeaters is smaller than guard period used. This allows a maximum spacing of 30-40 m between any two APRs for a HIPERLAN cell.

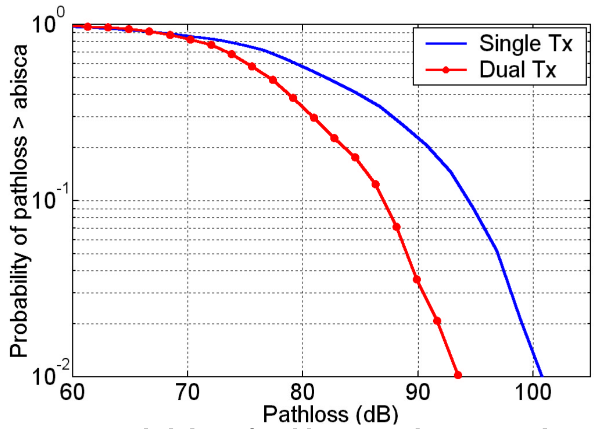

Figure 6. Probability of pathloss over the measured area of the building.

References

[1] Johnsson, M., “HiperLAN/2 – The Broadband Radio Transmissioin Technology Operating in the 5 GHz Frequency Band”, http://www.hiperlan2.com/site/specific/specmain/specwh.htm, 1999.

[2] Crow, B., Widjaja, I., Kim, J. G., Sakai, P., “IEEE 802.11 Wireless Local Area Networks”, IEEE Communications Magazine, pp 116-126, September 1997.

[3] “Digital Audio Broadcasting - Overview and Summary of the DAB System”, World DAB Forum, http://www.worlddab.org/public_documents/eureka_brochure.pdf

[4] Gibson, J., “The Mobile Communications Handbook”, CRC Press, pp 355-369, 1996.