Indoor Shadowing Correlation Measurements for Cognitive Radio Studies

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1 Introduction

Cognitive radio is a potential technology for increasing spectral efficiency in wireless communications systems, where in a hypothetical future overlay policy, secondary cognitive radios temporarily use spectrum that is not utilized, as long as negligible impact is caused to primary licensed users. Dependable spectrum sensing is needed to overcome the *hidden node* problem that arises when a primary transmitter is in a fade relative to the cognitive radio. Although wavelength-scale spatial diversity can overcome fast-fading due to multipath, overcoming slow-fading (or shadowing) due to obstructions requires larger separation of sensors, possible through collaboration among multiple secondary nodes [1]. The purpose of this work is to perform a detailed study of multinode shadowing for the analysis of collaborative sensing in cognitive radio.

Multinode shadowing measurements at 2.55 GHz are performed to characterize shadowing correlation for pairs of nodes, indicating required separation distance for effective collaboration. Measurement parameters and assumptions (often arbitrarily assigned in other work) are also studied, such as the smoothing window size, the choice of simultaneous cross-correlation versus autocorrelation measurements, moving primary vs. moving secondary nodes, and near vs. far primary. Although previous shadowing measurements and models lend some insight on the problem of multiuser shadowing [2]-[4], work is required to develop a detailed characterization suitable for general cognitive radio studies.

2 Measurement Scenario

Measurements were taken in the Research I building on the Jacobs University Bremen campus, as depicted in Figure 1. For the near primary scenarios the transmitter position (TX1 and TX2) is close to the receiver, and the position-dependent pathloss over the measurement track must be estimated and subtracted from the total received power. The accuracy of pathloss removal is critical, since error can affect the estimated shadowing statistics. For the far primary scenario (TX3), the pathloss over the whole measurement track remains almost constant, requiring only a single scalar to be estimated and subtracted from measurements.

All measurements in this study were taken at 2.55 GHz using $\lambda/4$ monopole antennas, and frequencies of the transmitter and receiver LOs were kept well within 1 Hz with rubidium references. For the near primary scenarios, the transmitter consisted of a single antenna connected directly to a microwave source with 10 dBm output power. For the far primary scenario, a power amplifier was used to obtain 30 dBm transmit power. Data was captured by connecting the two receive antennas to the two ports of a Rohde & Schwarz ZVB20 vector network analyzer programmed to have its internal source off and measure a single-frequency time sweep of wave quantities b_1 and b_2. The spacing between receive nodes was held constant during a measurement by attaching the antennas to a long plank fixed to a cart, and spacings of 0.25 m, 0.5 m, 1 m, 2 m, 4 m, and 6 m were considered. The data was either analyzed by taking the cross-correlation (CC) of the smoothed signal from the two

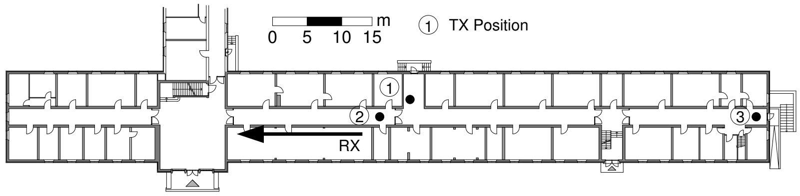


Figure 1: Floorplan of building where indoor shadowing measurements were taken

receive antenna elements or by taking the autocorrelation (AC) of the smoothed signal from one element.

Cases of moving secondary nodes (I) and moving primary node (II) were considered. Case I represents two secondary users that are trying to sense a primary user, where the ensemble of measurements is for varying position of the secondaries. The primary transmitter assumed three fixed positions in the hallway, while the receiver was moved at a nearly constant speed along a straight path in the room. The cart was pulled with a rope in order to avoid shadowing from the body of the person performing the measurements. For Case II the receiver cart was placed in the same room but kept stationary, while the transmitter was moved in a hallway, representing a single moving primary user with stationary secondary cognitive radios. The receivers were placed at the same fixed separation distances as in Case I.

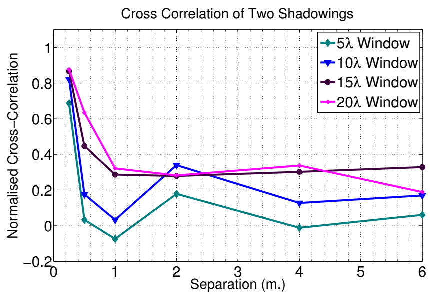
3 Measurement Results

Although cross-correlation (CC) and autocorrelation (AC) both exhibit the expected decreasing trend with distance, correlation generally does not decrease monotonically, but rather shows rise and fall in a somewhat periodic manner (possibly due to periodic structures like doors and windows), complicating the identification of the required decorrelation distance. To define a threshold for the non-monotonic correlation functions, the decorrelation distance is defined as the separation beyond which the peak correlation is always observed below the threshold.

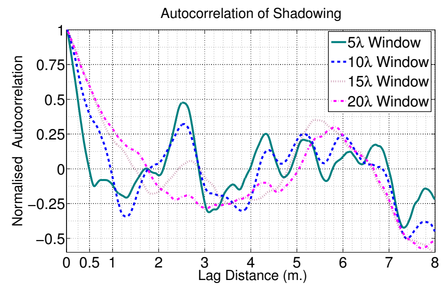
3.1 Effect of Smoothing Window Size

A smoothing window must be applied to the single frequency measurements in order to remove the multipath (fast fading) effect and estimate the average local area power or *shadowing level*. The window size should be small enough to track changes in the shadowing level, but not so small that multipath effects are not removed. In terms of correlation, a large window leads to artificially long decorrelation lengths (shadowing fades are spread), while a narrow window gives artificially low correlation (multipath is still present).

Figure 2(a) plots an example result from Case I-CC, indicating that although the correlation trends are similar, the exact correlation levels depend on the window size for the same data sequence. Note that the 5λ and 10λ windows give similar results, whereas the 15λ and 20λ results appear to be much more smoothed out. For this work, a 10λ window appears to be a good compromise between resolution and error in the local area power estimate. This also illustrates the result that the shadowing has a decorrelation distance (for a threshold of 0.5) in the range of 2-4 m, with most cases below 2 m, regardless of the window size or the way correlation is measured.

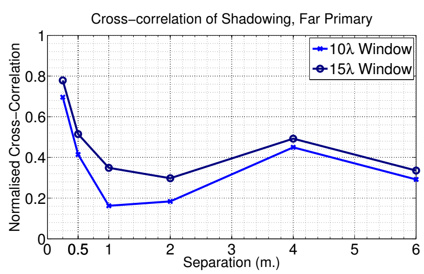


(a) Cross-correlation

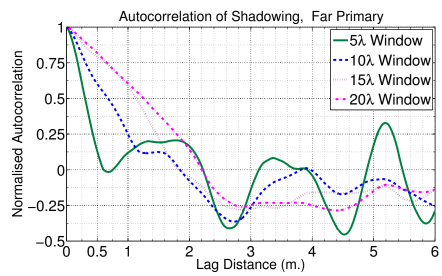


(b) Autocorrelation

Figure 2: Effect of window size on shadowing correlation for Case I



(a) Cross-correlation



(b) Autocorrelation

Figure 3: Shadowing cross-correlation for far primary, moving secondaries (Case I)

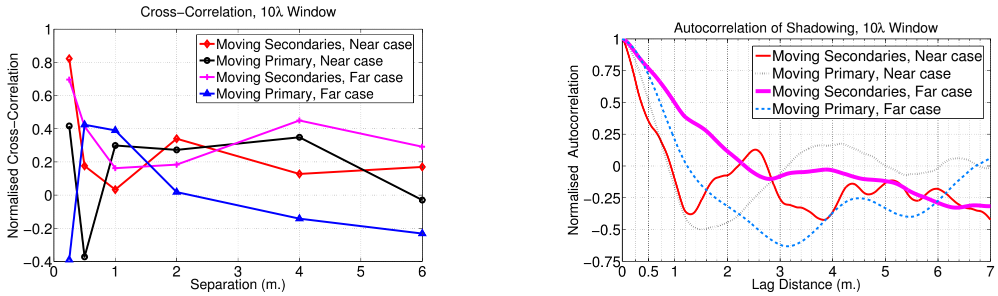
3.2 Cross-correlation (CC) vs. Autocorrelation (AC)

Although actual simultaneous measurement of the power level at multiple nodes (CC) most nearly approximates a true cognitive radio scenario, having a single moving node (AC) may be more convenient. Figure 2(b) plots the autocorrelation from a single receiving antenna element which can be compared with Figure 2(a). The results show that although the short-time correlations are similar for the AC and CC cases, the long-term behavior looks quite different, possibly due to time-variation of the shadowing (e.g. from people). However, below 2 m, the AC and CC curves are similar.

3.3 Near vs. Far Primary

The distance between the secondary users and the primary user will determine how much change in the power level is simply due to changes in the bulk pathloss (signal spreading). When the primary is far away from the secondaries, pathloss should not vary significantly and can be estimated as the average power over the measurement record. For the case when the primary is close, the deterministic change in the power level due to spreading should be removed. This was performed using a simple power-law model, where the distance along the track was estimated from geometrical considerations. The value of the pathloss exponent n was estimated to be 2.64 from the analysis of the recorded data.

A measurement was also carried out for the far transmitter case. The result of shadowing cross correlation and autocorrelation are shown in Figure 3(a) and Figure 3(b), respectively. Interestingly, the cross-correlation of the shadowing versus separation for the near case (with pathloss removed) is quite similar to the far case where pathloss does not change.



(a) Cross-correlation

(b) Autocorrelation

Figure 4: Shadowing correlation for near and far transmitter case with moving primary versus moving secondaries

3.4 Moving Primary vs. Moving Secondaries

The autocorrelation for moving primary vs. moving secondaries for either a near or far primary is plotted in Figure 4. For the case of a near primary, the results are quite close to each other. For a far primary, the results are somewhat different, likely due to the fact that the hallway and room environments look quite different for far transmit-receive separation. Also plotted for comparison is the autocorrelation for the moving primary case, giving shadowing versus primary (as opposed to secondary) separation, which may have different characteristics. Note that the unusually low correlation at 25 cm and 50 cm for the far and near moving primary cases is not well understood, and requires further investigation. However, it appears clear that decorrelation distances are below 2 m for this case as well.

4 Conclusion

This paper presented an initial study on the correlation of multiuser shadowing in an indoor environment at 2.55 GHz. The results indicate that although window size plays a strong role in the absolute correlation levels, shadowing is mostly uncorrelated after 2-4 m in this indoor environment, indicating that collaboration will be effective at this or greater separation of secondary nodes. It was also found that autocorrelation of a single moving sensor can be employed instead of multiple moving sensors below 2 m, simplifying the measurement system. Finally, similar shadowing correlation was obtained for a moving primary (versus moving secondaries) as well as near and far primary measurements.

References

[1] D. Cabric, *Cognitive Radios: System Design Perspective*. PhD thesis, Doctor of Philosophy in Engineering, University of California at Berkeley, Berkeley, California, Dec. 2007.

[2] J. Liberti and T. Rappaport, "Statistics of shadowing in indoor radio channels at 900 and 1900 MHz," in *Proc. IEEE Military Communications Conference, MILCOM '92*, pp. 1066–1070, Oct. 1992.

[3] M. Gudmundson, "Correlation model for shadow fading in mobile radio systems," *Electronics Letters*, vol. 27, pp. 2145–2146, Nov. 1991.

[4] D. Giancristofaro, "Correlation model for shadow fading in mobile radio channels," *Electronics Letters*, vol. 32, pp. 958–959, May 1996.