Correlation Characteristics for an Event/Sports Center at 3.2 GHz

Alejandro Aragón-Zavala[1], Vladan Jevremovic[2], and Ali Jemmali[3]

[1]Electronics Department, Tecnológico de Monterrey, Campus Querétaro, Querétaro, Mexico
[2]R&D Department, iBwave Solutions Inc., Houston, TX, USA
[3]R&D Department, iBwave Solutions Inc., Montreal, Canada

Abstract— This paper presents a continuation of an earlier study on auto and cross correlation characteristics for sports arenas at 850 and 2100 MHz. Radio measurements undertaken at 3.2 GHz show that signals from two base stations have correlation in the 0.04–0.43 range for small angles (below 30°), showing a positive correlation coefficient, in agreement with our previous work. De-correlation distances are in the range of 1.2 to 14.4 meters, which are strongly dependent on the presence of metallic structures in the vicinity of the tested antennas as well as on the antenna height. Autocorrelation shows an exponentially decay behavior, as previously reported.

1. INTRODUCTION

The key to reliable and fast mobile digital data connections is signal to noise + interference ratio (SINR). The degree of signal cross-correlation between the serving and interfering signal(s) has a significant impact on SINR. As shown in [1], shadowing (slow fading) cross-correlation must be quantified in order to properly calculate SINR. For significant shadowing cross-correlation to occur, the LOS requirement is essential, and as macro mobile networks have almost exclusively Non-Line of Sight (NLOS) coverage, the impact of signal cross-correlation is low. However, as distances between small cells in indoor networks are much smaller, the LOS requirement is mostly satisfied in those types of networks. While many authors have investigated shadow fading for indoor networks [2–5], very few have reported results for sports venues, such as stadiums, in which sector handover can become critical and where handover mismanagement could lead to excessive network resource usage.

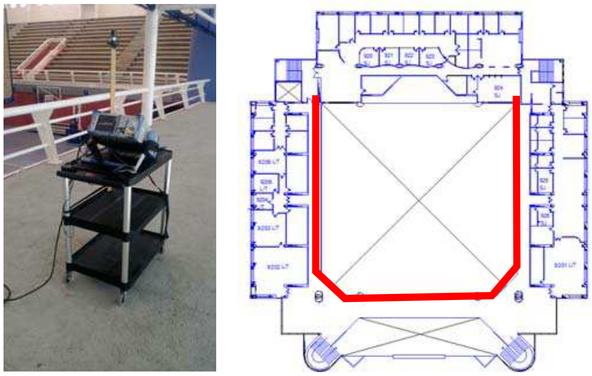
In systems that relay in a tight power control like CDMA2000 and WCDMA, shadowing autocorrelation and decorrelation distance are important as they allow a good estimate of mobile transmit power fluctuation around its mean value [1]. While there are numerous studies that measure shadowing autocorrelation and calculate shadowing correlation distance in macro networks [6, 7], there are very few such studies done for in-building networks.

A recent study [8] reports cross correlation and auto correlation measurements at 850 MHz and 2100 MHz, which are frequency bands at which a lot of stadium networks currently operate at. However, as mobile data consumption has been dramatically increased, various national spectrum governing bodies started to look into ways to allocate more spectrum bands to mobile networks outside those frequencies. An example is the Federal Communications Commission (FCC), the US Spectrum governing body, which proposed a new Citizen Broadband Radio Service in the 3.5 GHz band, specifically to allow small cells deployment on shared basis with incumbent federal and non-federal users of the band [9]. While the rulemaking has not been made yet, the proposal is a part of greater strategy to free up 500 MHz of spectrum for commercial use by 2020 [10]. Therefore, it is of interest to investigate cross correlation and auto-correlation properties of stadium networks at frequencies outside of what was reported in [8]. Likewise, 3.5 GHz spectrum is authorized for mobile use in European countries, and Japan plans to make the 3400–3600 MHz band available for mobile broadband [11].

This paper presents radio measurement results that were conducted at a university sports/event center at 3.2 GHz. These measurements were used to establish suitable auto and cross correlation models and de-correlation distances at the venue at the frequency that is reasonably close to the proposed Citizen Broadband Radio Service band. From these findings, recommendations for modelling auto-correlation and cross-correlation in sporting venues at these frequencies could be made, which then can be used to extend out study to similar venues at higher and lower frequencies.

2. METHODOLOGY

A Rohde and Schwarz ZVL-6 spectrum analyzer equipped with a portable omnidirectional antenna (Fig. 1(a)) was employed for the measurements, mounted on a mobile trolley. The spectrum analyzer was configured to take sweep measurements at 3.2 GHz taking samples at a speed of 100 samples per second on a U-shape path of the first floor of the sports/event center (Fig. 1(b)), having a frequency span of 0 Hz. Seven omnidirectional antennas were tested, as depicted in



(a) (b)

Figure 1: Measuring equipment and walk route.

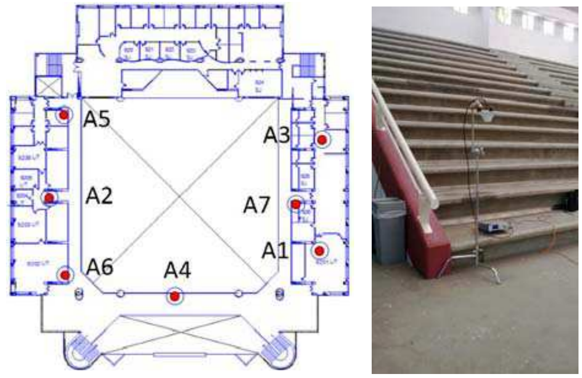
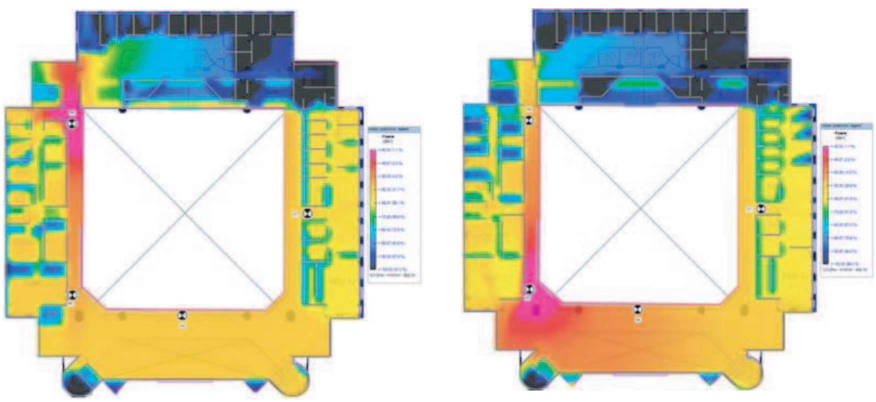


Figure 2: Antenna locations and setup.



(a) Antenna 5 (b) Antenna 6

Figure 3: Prediction maps for antennas 5 and 6.

Fig. 2, mounted on a tripod of approximately 1.9 m length, having variable heights above floor. The gain of all antennas is 4.8 dBi at 3.2 GHz. The antennas were located at the seating area and footpath level of the sports/event center, making sure they were on a LOS with the mobile receiver. A CW transmitter was used transmitting at a power of 20 dBm.

For data post-processing, an average window of 6λ was employed, to remove the fast fading effects of the collected data. Shadowing was extracted as explained in [8], at each prediction point $L_{s,i}$ by subtracting the predicted median path loss values $L_{50,i}$ at each point and measured path loss $L_{m,i}$:

$$L_{s,i} = L_{m,i} - L_{50,i} \tag{1}$$

The indoor design and prediction software tool iBwave Design was used to fit the measured data with a Fast Ray Tracing model [12] that is embedded in the tool. The tool was also used to calculate the statistics associated with (1) such as mean error and standard deviation. Signal strength predictions such as that shown in Fig. 3 were obtained, from which shadowing was extracted on every point of the desired route.

3. RESULTS

Decorrelation distances are shown in Table 1 for all the tested antennas. Comparing these results with the ones obtained for the same venue at 850 MHz in [8] a reduction in decorrelation distance is observed. More measurements are needed at exactly the same antenna locations at 850 MHz to establish a fair comparison — both sets of measurements were having slightly different conditions and characteristics, e.g., different antenna heights, locations and collection equipment; and therefore it is hard to make a solid conclusion only based on these results. Note that the "height" seen in Table 1 is the difference between antenna height (tripod + seating elevations) and the antenna.

Table 1: Decorrelation distances for all antennas.

Antenna	Location	Height [m]	Distance [m]
1	Seating area	6.9	14.4
2	Seating area	6.7	8.4
3	Seating area	3.85	3
4	Level 2 footpath	1.9	1.2
5	Level 2 footpath	1.9	2.8
6	Level 2 footpath	1.9	3.8
7	Level 2 footpath	1.9	3.6

Our expectation was to see de-correlation distance decrease as the frequency is reduced, since the first Fresnel zone radius is larger at smaller frequencies and thus more reflections and diffractions are expected to enter the zone from nearby objects, such as seating areas. Antenna 4 has the lowest de-correlation distance since metallic objects were located in the vicinity of the antenna — therefore, this consideration should be taken into account since many sector antennas are placed closed to metallic structures in stadiums and sports arenas, which indeed is a bad practice as it creates PIM (Passive Inter Modulation) distortion effects as well. On the other hand, the first two antennas were tested at increased height, and the effect on de-correlation distance is noticeable compared to the others; i.e., more clearance is obtained. Finally, autocorrelation shows an exponential-decay behavior as suggested in [13] and as can be seen in Fig. 4.

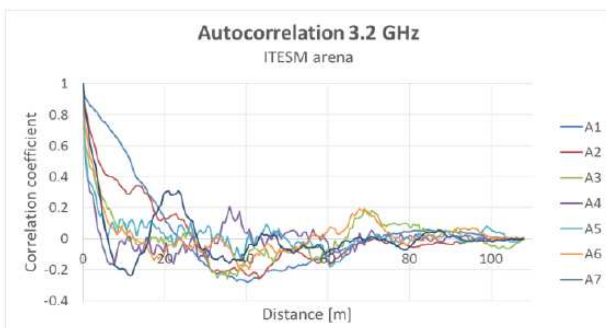


Figure 4: Autocorrelation plots for antennas 1 to 7.

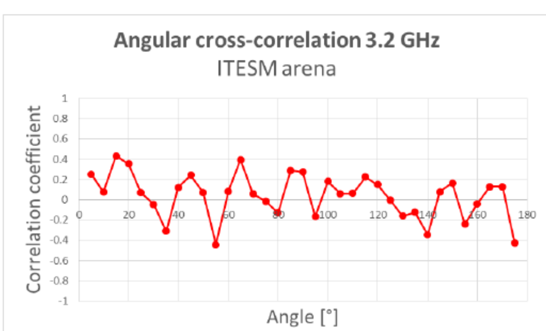


Figure 5: Cross-correlation aggregate for all antennas.

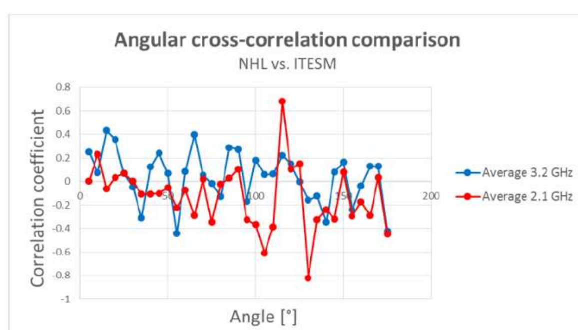


Figure 6: Cross-correlation comparison NHL vs. ITESM.

Cross-correlation was calculated for every possible pair of antennas to include a wide range of angles, as defined in [8]. From all these pairs, an average for all angles was obtained and reported in Fig. 5. When comparing these results with those observed at 2.1 GHz and reported in [8], an oscillatory behavior is seen again, having low cross-correlation values on average at small angles, in agreement with [14]. In fact, such oscillatory behavior is observed almost for every antenna pair, crossing through zero in a co-sinusoidal way, depending on angle of γ as:

$$h(\gamma) = A\cos\gamma + B \tag{2}$$

where A and B are two tunable parameters ($A \geq 0,\ B \geq 0$ and $A + B \leq 1$).

4. CONCLUSIONS

Autocorrelation and cross-correlation characteristics were extracted for seven antennas at 3.2 GHz in a sports/event center. Autocorrelation strongly depends on antenna height and frequency, increasing de-correlation distance as the height is increased. No conclusive statements can be made yet when comparing the effect of frequency in de-correlation distance at these venues, and more measurements are required to establish a fair comparison with previous published work in [8]. Also, since the 2.1 GHz sports venue was much larger than the 3.2 GHz, de-correlation distances are bigger since less obstructions and multipath is encountered. For a fair comparison, measurements at 2.1 GHz need to be taken at ITESM and ideally having the same characteristics as for the 3.2 GHz campaign.

On the other hand, similar behaviour has been observed in cross-correlation characteristics for both 2.1 GHz and 3.2 GHz, suggesting the use of a co-sinusoidal model for cross-correlation for which parameters need to be tuned, as shown in Fig. 6. Although some similarities can be observed, a direct comparison cannot be made since the 2.1 GHz measurements were undertaken in a much larger and open sports arena, hence altering the correlation characteristics of both venues which are in fact strongly dependent on the size of the venue.

5. FUTURE WORK

More measurements are required at 850 MHz since in [8] not enough bins could be obtained for cross-correlation, and ideally seven antennas would need to be tested at this frequency and at the same antenna locations as for 3.2 GHz. Also, additional measurements at 2.1 GHz would need to be conducted using the same antenna locations, venue and route, so that a direct comparison can be established with these results. The effects of antenna height were observed here using omnidirectional antennas, but further testing is required at these bands with the use of directional antennas, as it is actually employed at stadiums when sectorisation is implemented, and the effects of local clutter need to be assessed in the correlation properties of the signal.

REFERENCES

1. Saunders, S. and A. Aragon-Zavala, *Antennas and Propagation for Wireless Communication Systems*, 2nd Edition, 200–201, Wiley & Sons, 2007.
2. COST 231 final report, COST Action 231, "Digital mobile radio towards future generation systems," European Commission/COST Telecommunications, Brussels, Belgium, 1999.
3. International Telecommunication Union, ITU-R Recommendation P.1238, "Propagation data and prediction models for the planning of indoor radio communication systems and radio local area networks in the frequency range 900 MHz to 100 GHz," Geneva, 1997.
4. Keenan, J. M. and A. J. Motley, "Radio coverage in buildings," *BT Technology Journal*, Vol. 8, No. 1, 19–24, 1990.
5. Fiacco, M., "Intelligent picocells for adaptive indoor coverage and capacity," Ph.D. Thesis, University of Surrey, 2001.
6. Marsan, M., G. Hess, and S. Gilbert, "Shadowing variability in an urban land mobile environment at 900 MHz," *El. Lett.*, Vol. 26, No. 10, 646–648, 1990.
7. Szyszkowicz, S., H. Yanikomeroglu, and J. S. Thompson, "On the feasibility of wireless shadowing correlation models," *IEEE Trans. Veh. Tech.*, Vol. 59, No. 9, 4222–4236, Nov. 2010.
8. Aragon-Zavala, A., V. Jevremovic, and A. Jemmali, "Auto-correlation and cross correlation analysis for sports arenas at 850 MHz and 2100 MHz," *EuCAP 2014*, 428–432, Apr. 6–11, 2014.
9. The Federal Communications Commision, "Proposed rulemaking 12-148," Apr. 2014, http://www.fcc.gov/rulemaking/12-148.

10. US Department of Commerce, "Plan and timetable to make available 500 MHz of spectrum for wireless broadband," Oct. 2010, http://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf.
11. Federal Communication Commision, "FCC internation spectrim white paper," Feb. 26, 2103, http://www.fcc.gov/document/international-spectrum-white-paper.
12. Jevremovic, V., "Fast ray tracing algorithm in ibwave design," white paper published by iBwave Solutions Inc, 2012.
13. Gudmundson, M., "Correlation model for shadow fading in mobile radio systems," *IEE Electron. Lett.*, Vol. 27, No. 23, 2145–2146, Nov. 1991.
14. Weitzen, J. and T. J. Lowe, "Measurement of angular and distance correlation properties of log-normal shadowing at 1900 MHz and its application to design PCS systems," *IEEE Trans. Veh. Tech.*, Vol. 51, No. 2, 265–273, Mar. 2002.