TIME VARIATION CHARACTERISTICS OF WIRELESS BROADBAND CHANNEL IN URBAN AREA

Hajime Suzuki[1], **Carol D. Wilson**[1], **and Karla Ziri-Castro**[2]

[1]*CSIRO ICT Centre, PO Box 76, Epping, NSW 1710, Australia, Email: {Hajime.Suzuki,Carol.Wilson}@csiro.au*
[2]*Faculty of Engineering and Surveying, University of Southern Queensland, Australia, Email: ziricast@usq.edu.au*

ABSTRACT

Temporal variations of iBurst wireless broadband signal at 1.9 GHz and of digital TV signal at 570 MHz measured for one week on the fifth floor of a residential building in an urban area and on the ground floor in a suburban area is reported. While an apparent correlation between the signal variation and the local wind speed was observed in the suburban site, no such correlation was found in the urban site. The investigated urban wireless broadband channels show characteristics of LoS paths, with relatively smaller temporal signal variation, and of multipath environment, with a small scale local fading. Larger signal variation was found with a shorter link (1.2 km) than with a longer link (4.4 to 11.8 km) in the urban environment.

1. INTRODUCTION

The use of wireless broadband technologies has been gaining popularity in recent years. Here, wireless broadband refers to a system where a fixed (possibly portable) user device using radio frequencies communicates with base stations (BSs), providing high data rate Internet connection to multiple user terminals (UTs). Examples of such systems include iBurst [1] and IEEE 802.16e [2] based systems.

One of the important differences between the emerging wireless broadband technologies and traditional fixed wireless services, such as wireless local loop (WLL) [3] and broadband wireless access (BWA) [4], is that the former are designed to operate in a non line-of-sight (NLoS) environment with an omnidirectional antenna while the latter in LoS with a directional antenna at the UT site. Typically the wireless broadband user device is installed by an unskilled person without taking into account an optimal siting of the antenna, while a skilled technician installs the WLL/BWA user device, ensuring that the LoS path or a dominant path exists between the user and BS antennas. Because of this, more variation of signal strength is experienced with the wireless broadband channel, due, for example, to nearby foliage blown by wind, pedestrian/car traffic, or the movement of the user. The carrier frequencies of the wireless broadband services are typically lower than 3 GHz while those of WLL/BWA can be higher than 10 GHz.

The time variation of signal quality due to movement of objects (not of antennas) in outdoor multipath environments at UHF frequencies has been investigated by several researchers, mainly with distances shorter than 1 km. Vogel *et al*. investigated the variation of propagation channels at 900 MHz in indoor and outdoor cellular mobile environments by measuring them every 5 minutes for 8 hours [7]. More variation was observed for the outdoor environment than for the indoor environment. Bertoni *et al*. analyzed the temporal signal fading experienced by a fixed terminal in an urban forested park area at 0.9, 1.2, 1.5, and 1.8 GHz using medium-term (30 seconds) statistics [5]. Dependency of Ricean K-factor on antenna height was found. Perras and Bouchard conducted the received power measurement with 500 samples per second over 45 days obstructed by trees at 2.45, 5.25, 29, and 60 GHz, and analyzed the temporal fading statistics [6]. Strong dependency of the signal variation on wind speed was observed by those measurements.

We have previously investigated the temporal variation of signal quality for a short range (130 m) outdoor-to-indoor link at 2.4 GHz [8]. The results show severe variation that approached Rayleigh distribution when nearby foliage is blown by wind at speeds greater than 2 m/s. We have also shown that temporal variations of signal strength due to pedestrian traffic in 5.2 GHz indoor channels approached Rice distribution with K-factor decreasing proportionally to the pedestrian traffic in the vicinity of the link [9]. Such effects cause a deteriorated or lost link, yet very few investigations have been reported in the literature that characterize the time variation of wireless broadband channels, especially for outdoor-to-indoor paths at larger distances.

This paper investigates the time variation characteristics of outdoor-to-indoor wireless broadband channels in urban and suburban areas by recording signal level measured by commercially available wireless broadband devices for the duration of one week. The effects of utilizing spatial diversity antennas to mitigate the detrimental effects of temporal fading on the downlink are investigated by measuring common constant pilot signals simultaneously by multiple receivers. Due to increasing inter-

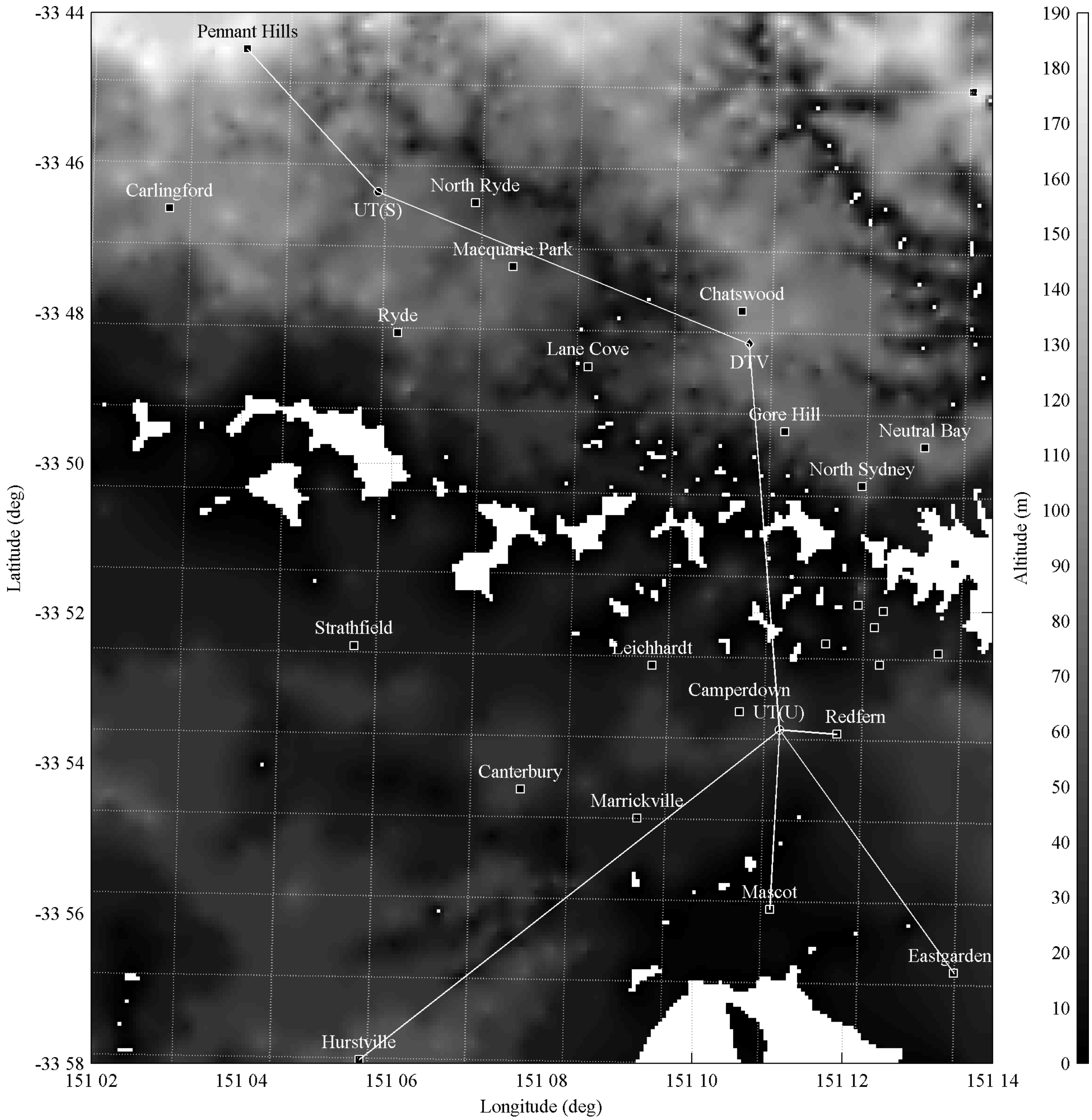


Figure 1: Locations of the iBurst BSs (square mark), DTV transmitter tower (diamond mark) and User Terminal (circle mark) in Urban area, UT(U), and Suburban area, UT(S).

Table 1: Parameters for Urban and Suburban links.

	Redfern	Mascot	Eastgardens	Hurstville	Pennant Hills
Distance from UT (km)	1.2	4.4	7.0	11.8	4.4
BS antenna height from local ground (m)	55	48	29	38	43
BS EIRP (dBm)	44.2	42.7	42.7	42.7	42.7

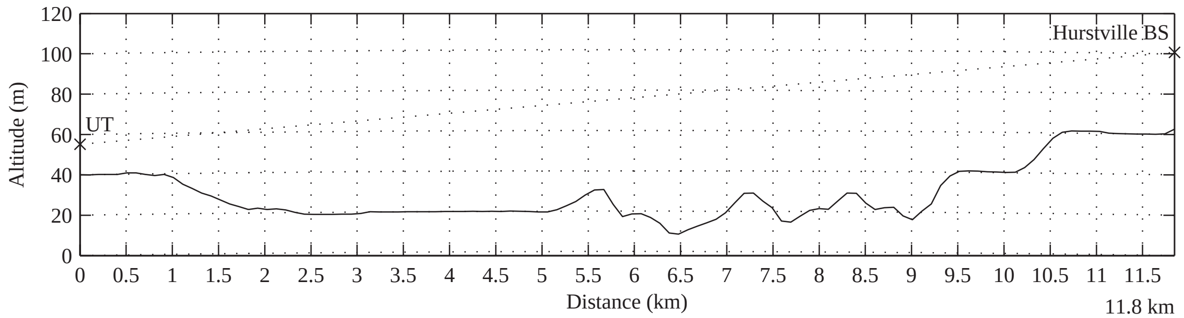


Figure 2: Terrain profile between iBurst BS in Hurstville and urban UT, 11.8 km link.

ests in utilizing VHF and lower UHF bands for their possibly favorable channel characteristics for wireless broadband services, the measurement of a digital television (DTV) signal is conducted at the same site.

This paper is organised as follows: Measurement systems of wireless broadband channel, DTV and local wind speed are described in Section 2. Measurement sites in urban and suburban areas are presented in Section 3. Measurement results and their analysis are given in Section 4, followed by the conclusions in Section 5.

2. MEASUREMENT SYSTEMS

2.1. iBurst

The iBurst wireless broadband system was initially developed by ArrayComm in 2001. It has been adopted as an Alliance for Telecommunications Industry Solutions (ATIS) Standard for high-capacity spatial division multiple access (HC-SDMA) in September 2005 [10].

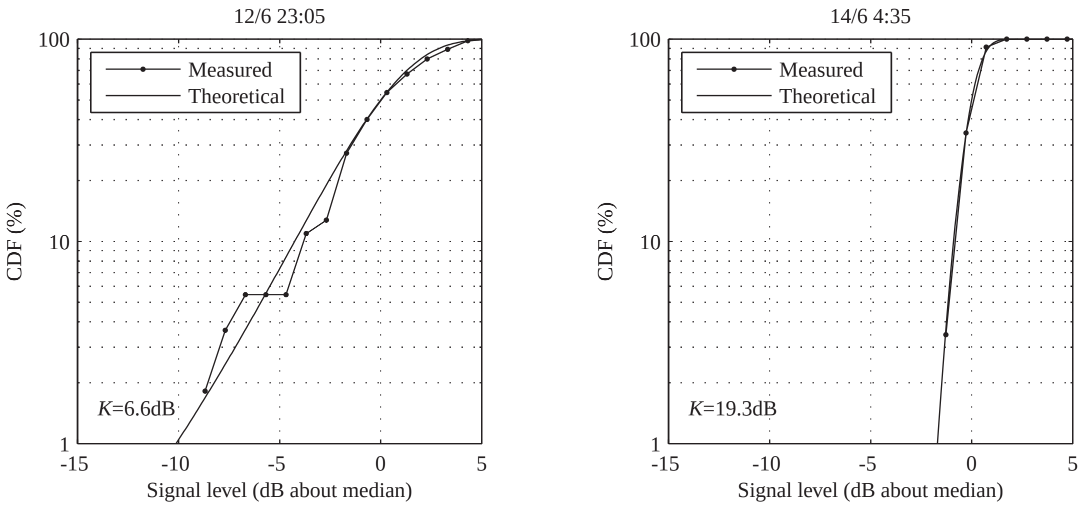
iBurst typically operates within the frequency range from 1.7 GHz to 2.3 GHz. A single carrier transmission with a carrier spacing of 625 kHz and an adaptive modulation/coding scheme providing an aggregate data rate from 106 kbps to 1061 kbps for downlink (BS to UT) and from 19 kbps to 346 kbps for uplink (UT to BS) are used. Asymmetric time division duplexing is employed with a time occupancy ratio of 2:1 for downlink to uplink, which is suitable for most common Internet applications. A time division multiple access scheme is used, combined with a flexibility of assigning one to three variable number of slots per user. In addition, a novel space division multiple access scheme is performed by using adaptive antenna arrays (up to 12 antenna elements) at the BSs, which enhance signals transmitted to and received from UTs, while suppressing interference signals from other UTs in the same time slot and in the same frequency band, but in different angles of arrival.

In March 2004, Personal Broadband Australia launched its commercial service in major Australian metropolitan cities using iBurst system in the frequency range from 1905 MHz to 1910 MHz with 8 frequency channels. The aggregate capacity per BS for 5 MHz bandwidth is 24 Mbps for downlink and 8 Mbps for uplink with 24 simultaneous users. This gives an optimal bandwidth efficiency of 6.4 bps/Hz per cell. Practical bandwidth efficiency when using multiple cells has been estimated to be reduced to approximately half of this value. As of July 2006, iBurst BSs are installed at 42 locations in NSW covering approximately 850 km^2. Fig. 1 shows the locations of some of the iBurst BSs installed in Sydney. Note that the digital elevation map (DEM) in Fig. 1 and terrain profiles as discussed below are derived from 3 second DEM published by Geoscience Australia. In this paper, the location, antenna height, and effective isotropically-radiated power (EIRP) of the iBurst BSs are derived from the Register of Radiocommunications Licences maintained by the Australian Communications and Media Authority.

The measurement of downlink signal level was performed by two identical commercially available iBurst desktop modems, which have a built-in function to report to the user various parameters, including the identification number of BSs, propagation time delay from BSs with 1 μs resolution, and absolute signal level with 1 dB resolution. Two iBurst modems were positioned side-by-side in order to investigate the effect of small-scale spatial fading. The parameters are sampled every 10 seconds for multiple of BSs.

2.2. Digital TV

DTV transmissions commenced in January 2001 in Sydney. In this paper, a commercially available digital TV tuner (TwinHan Alpha) was used to measure signal level for a free-to-air program at the carrier frequency of 571.5 MHz with 7 MHz bandwidth. An open source software (ScanChannelsBDA 2.0.0.6 [11]) was used to collect signal level approximately every 1 second. According to the documentation of ScanChannelsBDA, the signal level reported is a relative value arbitrarily determined by the tuner manufacturers. Since the main focus of this paper is the investigation of relative temporal variation of signal level, the measurement of relative signal level was considered adequate.



(a) An example CDF for a small Ricean K-factor.

(b) An example CDF for a large Ricean K-factor.

Figure 3: Example CDF of signal level measured by iBurst Urban 1.2 km link.

The location of the DTV transmitter (Ch 7/10 transmitter in Artarmon), labeled DTV, is given in Fig. 1. The height of the tower is 192 m.

2.3. Wind Speed

Our previous investigation of temporal variation of signal level in an outdoor-to-indoor link at 2.4 GHz in a suburban area showed a strong correlation between signal variation expressed by Ricean K-factor and local wind speed [8]. Hence we measured local wind speed at the location of the signal measurement in order to investigate the correlation of the local wind speed to the signal variation. The local wind speed was measured by an off-the-shelf equipment (Oregon Scientific WMR928NX) in the case of the Urban site (as explained below), and by CSIRO's on-site weather information collection facility in Marsfield in the case of the Suburban site.

3. MEASUREMENT SITES

The measurement was performed in June/July 2006 in Sydney. Note that this is a winter season in the southern hemisphere. Note also that Australian native trees still have their leaves, although deciduous trees are bare. The measurement was conducted in two locations: one in an urban area and another in a suburban area, as follows:

3.1. Urban

The first measurement was set up in a modern 11 storey residential apartment building located 2.5 km away from Sydney's central business district (CBD). The location of this site is shown in Fig. 1 as UT(U). UT antennas were positioned indoor near an outer building wall facing south on the fifth floor, clear from local clutter. Adequate signal level was observed from four iBurst BSs as indicated by the straight lines in Fig. 1. The parameters associated to different links are given in Tab. 1.

An example of the terrain profile between an iBurst BS and the UT is given in Fig. 2. Note that the curvature of the Earth is taken into account in Fig. 2 and in the following terrain profile analysis. An analysis of the terrain profile for each link shows that no link is obstructed by the terrain. However, note that the paths between the transmitter and the receiver antennas are always obstructed by at least one wall at UT site because of the outdoor-to-indoor link.

The measurement was conducted from 7th to 17th of June 2006. Due to a software failure, samples were not obtained for some parts of the measurement period. This left a set of usable data for a period of six days.

3.2. Suburban

The measurement in a suburban area was conducted at the CSIRO's Radiophysics Laboratory in Marsfield, located 14.2 km away from the Sydney CBD. Signal adequate for temporal variation measurement was observed from only one iBurst BS located in Pennant Hills. The location and the parameters associated to this BS are given in Fig. 1 and Tab. 1, respectively. The terrain profile analysis shows that the path is not obstructed by the terrain. The actual propagation paths between the transmitter and the receiver antennas are obstructed by the building walls and trees at UT site.

The measurement was conducted from 30th June to 10th

July 2006 for 11 days with very small interruption for retrieving data.

4. MEASUREMENT RESULTS

The temporal variation of received signal level in multipath environment was often found to follow Ricean distribution in indoor [12] and outdoor [5] environments at UHF band. In this paper, the Ricean K-factor was estimated by using a moment-method proposed in [14]. The method allows an efficient and accurate estimation of K-factor without performing, for example, a cumbersome and time consuming curve-fitting procedure.

The Ricean K-factor was derived every 10 minutes from the iBurst and DTV measured signal level. Fig. 3 shows examples of cumulative distribution of signal level in dB about median for large and small Ricean K-factor values obtained for the Urban 1.2 km iBurst link. It can be observed that the temporal distribution of the signal level in our measurement also fits closely to the Ricean distribution.

Fig. 4 shows an example section of measured parameters at the Urban site. The top eight plots show signal levels measured by two iBurst modems and corresponding Ricean K-factor values for the links with distances 1.2 km, 4.4 km, 7.0 km, and 11.8 km. Two modem results are shown by darker (Modem 1) and lighter (Modem 2) colors. The last three plots show measured DTV signal level, corresponding Ricean K-factor, and measured local wind speed.

An increase in the signal variation was expected during the day time (8:00 am to 8:00 pm) compared to the night time (8:00 pm to 8:00 am). The average iBurst Ricean K-factor during the day time decreased by 1.2 dB, 0.3 dB, 0.3 dB, and 0.15 dB for the links 1.2 km, 4.4 km, 7.0 km, and 11.8 km, respectively, in the day time compared to the night time.

Compared to measurement results obtained in the suburban environment as described below, the observed signal level variation, both for iBurst and DTV, is relatively small for our urban measurement results. This is attributed to the fact that the measurement was performed on the fifth floor of a building clear from the local clutter, especially trees. It is interesting to note that a larger signal variation was continuously observed for the shortest LoS path (1.2 km), compared to the longer paths (4.4 km to 11.2 km), the exact cause of which requires further investigation.

Comparing the two iBurst modem results, it can be seen that the signal level measured by two modems can be roughly the same (1.2 km and 11.8 km results), or apparently different (Modem 1 is larger than Modem 2 in 7.0 km result, while Modem 2 is larger than Modem 1 in 4.4 km result). This result indicates that the signal level can be quite different with a slight shift in location, which is a characteristic of a multipath propagation. Space diversity antennas are expected to improve the performance of such links.

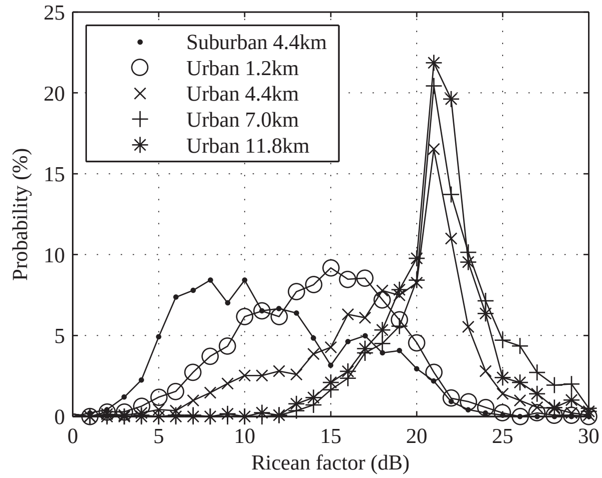


Figure 6: PDF of Ricean K-factor in different links.

Fig. 5 shows an example section of measured parameters at the Suburban site. The plots from the top to bottom show, respectively, signal levels measured by two iBurst modems, corresponding Ricean K-factor values, measured DTV signal level, corresponding Ricean K-factor, and measured local wind speed. Again, the two iBurst modem results are shown by darker (Modem 1) and lighter (Modem 2) colors.

As noted above, both the iBurst and DTV signal level exhibit larger variation in our Suburban results, compared to Urban results. This is attributed to the fact that our suburban results are obtained on the ground floor. Nearby foliage blown by the wind might have caused substantial scattering which caused larger signal variation. This is confirmed by the correlation analysis between the Ricean K-factor and the local wind speed as described below.

The probability density function of Ricean K-factor is plotted for iBurst links in Fig. 6. It can be seen that the Ricean K-factor tends to be smaller for our Suburban results than our Urban results, with shorter links producing smaller Ricean K-factor in Urban results.

A scatter plot of the local wind speed and corresponding Ricean K-factor for Suburban site is given in Fig. 7. Here, results from both iBurst Modem 1 and 2 are superimposed. An apparent negative correlation, similar to the one reported for a short range (130 m) 2.4 GHz link in [8], was observed for this 4.4 km link at 1.9 GHz. This is attributed to the foliage blown by the wind near UT.

Fig. 8 shows scatter plots of the local wind and corresponding Ricean K-factor for the Urban 1.2 km link. It can be seen that the large Ricean K-factor value is maintained even for large local wind speed. As mentioned above, this is attributed to the fact that our Urban links are above local tree heights, and the reflections from the

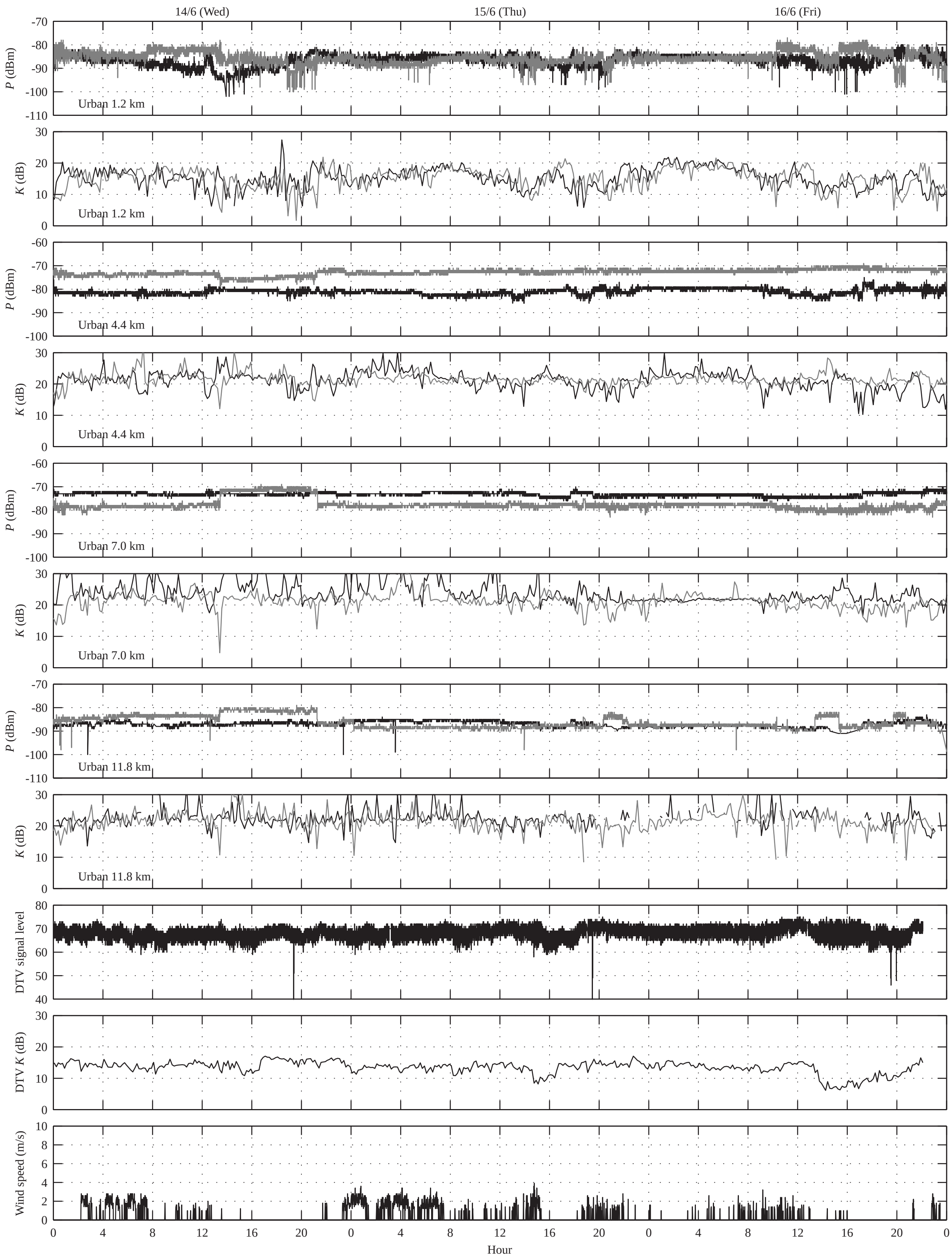


Figure 4: An example section of measured parameters at Urban site.

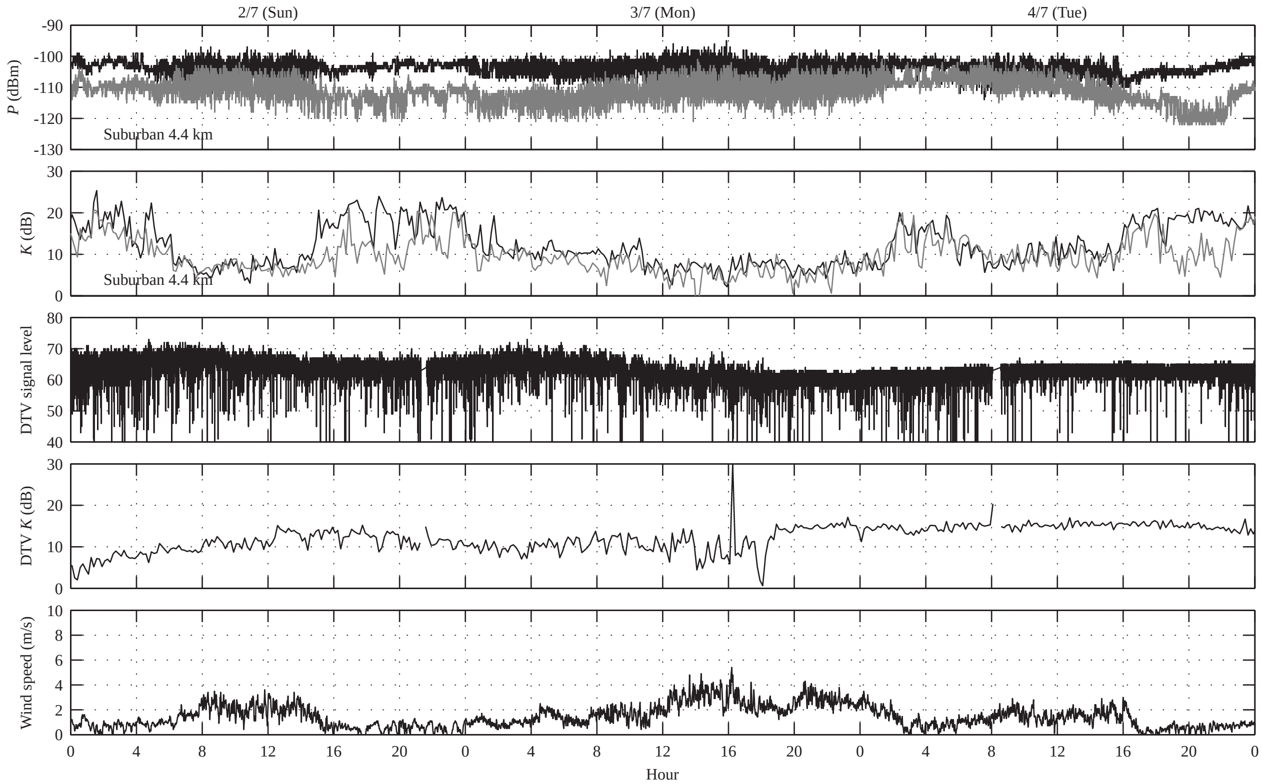


Figure 5: An example section of measured parameters at Suburban site.

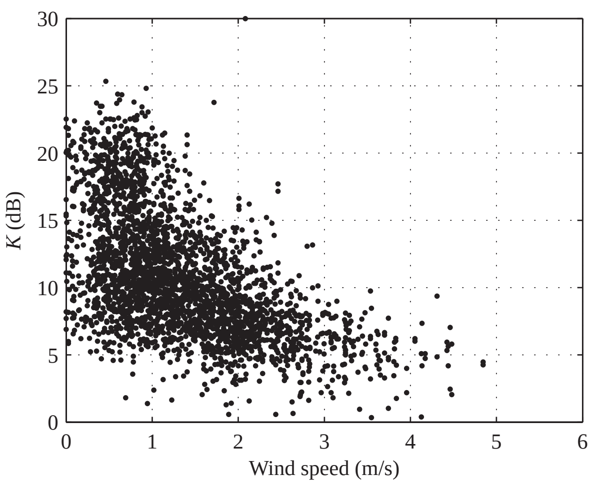


Figure 7: iBurst Ricean K-factor versus local wind speed in Suburban site, 4.4 km link

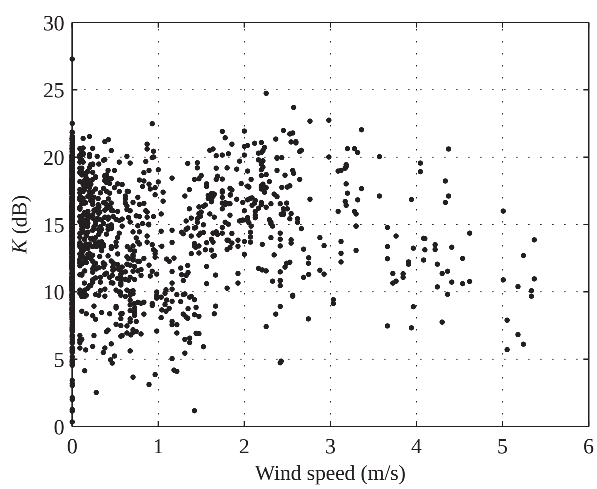


Figure 8: iBurst signal Ricean K-factor versus local wind speed for Urban 1.2 km link.

top of moving trees appear to have little effect on the signal variation. Similar results were obtained for longer Urban links with smaller Ricean K-factor values.

Fig. 9 shows scatter plots of the local wind and corresponding Ricean K-factor for DTV signal in Suburban site. No apparent correlation is found in this case. A possible cause can be attributed to the lower frequency used for the DTV signal (571.5 MHz) compared to that of the iBurst signal (1.9 GHz). It is known that the attenuation

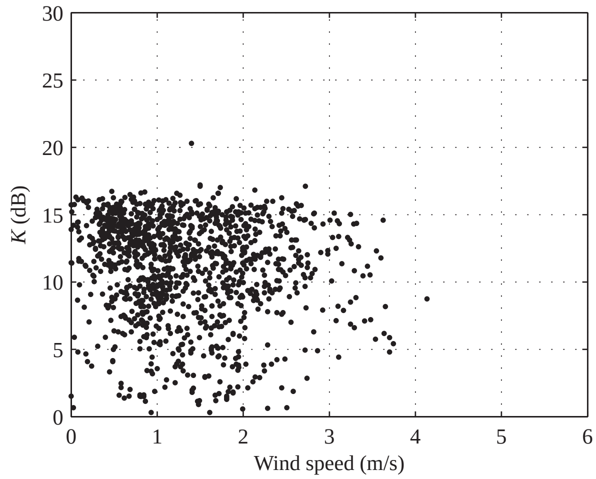


Figure 9: DTV signal Ricean K-factor versus local wind speed in Suburban site.

through trees is less for lower frequency [13], which may cause smaller signal variation.

5. CONCLUSIONS

An investigation of the temporal signal variation observed by wireless broadband channels in urban and suburban areas is reported in this paper. For the urban environment, on the fifth floor of a residential building, no apparent correlation was found between the signal variation and local wind speed, as was found in the suburban environment on the ground floor. The investigated urban wireless broadband channels show characteristics of LoS paths, with relatively smaller temporal signal variation, and of multipath effect, with a small scale local fading. Larger signal variation was found with a shorter link (1.2 km) than with a longer link (4.4 to 11.8 km) in the urban environment. Further studies are called for to clarify the effects of operational frequency band or link distance on the temporal signal variation of wireless broadband channels.

REFERENCES

[1] iBurst, http://www.iburst.com.au.

[2] IEEE Std 802.16e-2005, "Physical and medium access control for combined fixed and mobile operation in licensed bands," February 2006.

[3] A. R. Noerpel and Y-B. Lin, "Wireless local loop: Architecture, technologies and services," *IEEE Personal Communications*, vol. 5, no. 3, pp. 74-80, June 1998.

[4] C. Eklund, R. B. Marks, K. L. Stanwood, S. Wang, "IEEE Standard 802.16: A technical overview of the WirelessMAN™ air interface for broadband wireless access," *IEEE Communications Magazine*, vol. 40, no. 6, pp. 98-107, June 2002.

[5] J. C. R. Dal Bello, G. L. Siqueira, and H. L. Bertoni, "Theoretical analysis and measurement results of vegetation effects on path loss for mobile cellular communication systems," *IEEE Transactions on Vehicular Technology*, vol. 49, no. 4, pp. 1285-1293, July 2000.

[6] S. Perras and L. Bouchard, "Fading characteristics of RF signals due to foliage in frequency bands from 2 to 60 GHz," *In Proceedings of the International Symposium on Wireless Personal Multimedia Communications*, vol. 1, pp. 267-271, October 2002.

[7] S-S. Jeng, G. Xu, H-P. Lin, and W. J. Vogel, "Experimental studies of spatial signature variation at 900 MHz for smart antenna systems," *IEEE Transactions on Antennas and Propagation*, vol. 46, no. 7, pp. 953-962, July 1998.

[8] H. Suzuki, "Diurnal signal fading characteristics of IEEE 802.11b outdoor fixed link," *In Proceedings of the ClimDiff '03*, Diff.34, November 2003.

[9] K. I. Ziri-Castro, N. E. Evans, and W. G. Scanlon, "Propagation modelling and measurements in a populated indoor environment at 5.2 GHz," *In Proceedings of the AusWireless*, March 2006.

[10] ATIS-PP-0700004-2005, "High capacity - spatial division multiple access (HC-SDMA) radio interface standard," September 2005.

[11] ScanChannelsBDA, http://nate.dynalias.net/ScanChannelsBDA/.

[12] R. J. C. Bultitude, "Measurement, characterization and modeling of indoor 800/900 MHz radio channels for digital communications," *IEEE Communications Magazine*, vol. 25, no. 6, pp. 5-12, June 1987.

[13] Recommendation ITU-R P.833-5, "Attenuation in vegetation," August 2005.

[14] L. J. Greenstein, D. G. Michelson, and V. Erceg, "Moment-method estimation of the Ricean K-factor," *IEEE Communications Letters*, vol. 3, no. 6, pp. 175-176, June 1999.