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Wideband Tapped Delay Line Channel Model at 3.5GHz for Broadband Fixed Wireless Access system as function of Subscriber Antenna height in Suburban Environment

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Abstract

This paper presents the results of measurements made to characterise the 3.5GHz Broadband Fixed Wireless Access channel in a suburban environment, using a sectored base station antenna and a directional subscriber antenna. A tapped delay line channel impulse response model of the Single-Input Single-Output (SISO) channel is derived from the measurements. Previously, it has been reported that the delay spread decreases with an increase in the height of the Subscriber Unit (SU) antenna [9]. In this paper, it is reported that the multipath tap gain also decreases with an increase in the SU antenna height. Furthermore, it is reported that a 3-tap channel model with tap spacing of 200ns, and maximum tap delay at 400ns can adequately describe the radio channel under investigation. The narrowband Ricean *K*-factor and wideband root mean squared delay spread are observed to correlate strongly with excess path loss.

1. Introduction

The fundamental limit that is imposed on any wireless system is due to the radio channel. Propagation and channel models are essential for the analysis and simulation of wireless systems. Knowledge of the radio channel is essential to the development and deployment of a wireless system. Radio channel models are used to support research into methods for mitigating channel impairments, such as the design of the equaliser and the choice of single-carrier or multi-carrier systems [1]. In addition, they also form an integral part of wireless system planning and deployment.

There is a large body of literature concerning the mobile radio channel, but publications concerning the Fixed Wireless Access (FWA) channel are still very limited [14],[15]. Previous works have investigated the narrowband channel characteristics of FWA systems, e.g. Crosby et al [2]. As the data rate of FWA systems increases, the effect of the wideband channel plays an increasingly important role on system performance. It is therefore necessary to characterise the wideband channel effects. Investigation into the effects of wideband channels on FWA systems have been conducted in the 2.5 GHz frequency band by Porter et al [3] and Gans et al [4], in the 1.9 GHz frequency band by Erceg et al [5]; and at 3.5 GHz by Siaud et al [6]. Models for path loss, Ricean *K*-factor and tapped delay line channel impulse response for Single-Input Single-Output (SISO) fixed wireless channel were reported in [7]. Models for Ricean *K*-factor, Cross Polarisation Discrimination and path loss at 2.5GHz for a 2x2 Multiple-Input Multiple-Output (MIMO) fixed wireless system were reported in [8].

Previous literature has reported that the directional subscriber antennas usually employed in FWA systems significantly reduce the delay spread of the channel compared with that when an omni-directional antenna is used [3]. However the influence of SU antenna height has not previously been thoroughly investigated. This paper presents the results of propagation measurements at 3.5 GHz for a SISO Broadband Fixed Wireless Access (BFWA) system with a directional subscriber antenna and a sectored base station antenna. In the previous paper [9], we have reported the statistics of the path loss and Root Mean Squared (RMS) delay spread with respect to SU antenna height. In this paper, we report on Ricean *K*-factor, excess path loss and the wideband tapped delay line channel impulse response model with respect to SU antenna height. First we describe the equipment and data processing methods used for extracting the channel impulse response. This is followed by the results of wideband channel measurements, presented in the form of the wideband tapped delay line channel models, with respect to SU antenna height.

2. Measurement Methods

The measurements were conducted in the northern suburbs of Cambridge, England, during the summer months from June to September 2002 with trees in full foliage. This area has a relatively flat terrain and few high rise buildings, and covers an area of 9 km^2. The base station (BS) is located at a height of 15 m above ground level. The SU antenna is positioned on top of a retractable vehicle-mounted mast. Two sets of readings are taken at each location separated by a horizontal distance of about 2m. At each location, the bearing of the antenna is adjusted to point in the direction with highest received power. Once the bearing is fixed, the height of the SU antenna is subsequently varied between 4 to 10 m in steps of 1 m. At each height, a total of 100 delay profiles and path loss measurement were collected over a period of 30 seconds. A total of 540 sets of measurement have been collected, from 65 subscriber locations with BS to SU distances ranging from 730 m to 3.1 km. The precise locations of the measurement sites are identified with a GPS receiver.

The BS antenna and the SU antenna have half power beamwidths of 90° and 20° respectively, and are both vertically polarised. The gains of the BS and SU antennas are 12.5dBi and 15.6dBi respectively. The bandwidth of the system is 5 MHz, giving rise to a delay spread resolution of 200ns. The length of the pseudo-random sounding sequence used is 128 symbols and the maximum excess delay that can be measured with the system is 12.8 μs. The sounding sequence is modulated using QPSK. At the subscriber, the in-phase and quadrature components of the received sounding burst are captured on the hard disk of a computer for later processing. A post-processing method based on correlation processing extracts the power delay profiles and the RMS delay spread from the stored data [9].

3. Data Processing Methods

The processing method involves Fourier transformation of the correlation between sounding sequence and received signal. The radio channel is often modelled as a linear time-variant filter with impulse response $h(t,\tau)$ or equivalently by its frequency response $H(f,t)$, where $h(t,\tau)$ and $H(f,t)$ are a Fourier transform pair, [10]. Without loss of generality, consider a linear time-invariant system that is characterised by its impulse response $h(\tau)$, as shown in Figure 1.

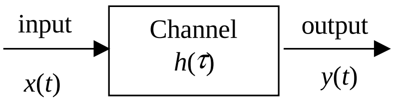

Figure 1. Linear single input/single output system

The complex envelope of the channel output $y(t)$ is the convolution of the impulse response $h(\tau)$ with the complex envelope of the channel input $x(t)$, i.e.

$$y(t) = x(t) \otimes h(\tau) = \int_{-\infty}^{\infty} h(\tau) x(t-\tau) d\tau \qquad (1)$$

The time-invariant impulse response $h(\tau)$ is a special case of the time-variant impulse response $h(t,\tau)$ if the unit impulse response function is independent of the time an input is applied, i.e.,

$$h(t,\tau) = h(\tau) \qquad \text{for } -\infty < t < \infty \qquad (2)$$

To estimate the channel impulse response $h(\tau)$, the first step is to cross-correlate the input of the channel with its output, assuming that the input to the channel, i.e. the transmitted signal, is known. For jointly stationary stochastic processes $x(t)$ and $y(t)$, it can be shown [11] that their cross-correlation $\phi_{xy}(\tau)$ is related to the autocorrelation of the input $\phi_{xx}(\tau)$ as

$$\phi_{xy}(\tau) = \int_{-\infty}^{\infty} h(\alpha) \phi_{xx}(\tau - \alpha) d\alpha \qquad (3)$$

which is a convolution integral. Since convolution in time domain is equivalent to multiplication in frequency domain, the relation (3) becomes

$$\Phi_{xy}(f) = \Phi_{xx}(f) H(f) \qquad (4)$$

where $\Phi_{xy}(f)$ denotes the Fourier transform of $\phi_{xy}(\tau)$, $\Phi_{xx}(f)$ denotes the Fourier transform of $\phi_{xx}(\tau)$ and $H(f)$ is the frequency response of the channel. Hence, the channel impulse response $h(\tau)$ is found via the inverse Fourier transform of its frequency response $H(f)$. This forms the basis of the technique used in the post-processing algorithm.

The power delay profile is the expected value of the magnitude squared of $h(\tau)$, i.e.,

$$P(\tau) = \frac{E[|h(\tau)|^2]}{2} \qquad (5)$$

The RMS delay spread of the channel is calculated according to

$$\tau_{RMS} = \sqrt{\frac{1}{P_T}\sum_{i=1}^{n} P_i \tau_i^2 - \tau_0^2} \qquad (6)$$

where

$$\tau_0 = \frac{1}{P_T}\sum_{i=1}^{n} P_i \tau_i \qquad (7)$$

A Blackman window is applied to the signals before Discrete Fourier transformation. This enhances the signal to noise ratio of the power delay profile to more than 30dB. Since RMS delay spread is known to be sensitive to noise components on the power delay profile having large excess delays [12], a noise exclusion threshold is applied on the power delay profile so that any components more than 30dB below the peak response are excluded before calculating the RMS delay spread. Using this criteria, 330 sets of measurements out of a total of 540 sets were processed and the results are presented as follows.

The measurements are separated into groups having a range of 1m according to the SU antenna height. Thereafter, the tap gains of the tap delay line channel models for each height group are computed by taking the average of tap gains at the same tap position for all power delay profiles in each group.

The Ricean *K*-factor is computed using the moment-method [13]. The Ricean *K*-factor for each tap of the wideband tapped delay line in each height group is the average of all *K*-factors of the power delay profiles at the same tap position.

4. Results

The narrowband Ricean *K*-factor is plotted against the excess path loss (path loss in excess of free space loss) in Figure 2. The result shows that Ricean *K*-factor decreases, (approaching Rayleigh fading) as excess path loss increases (due to heavy shadow fading).

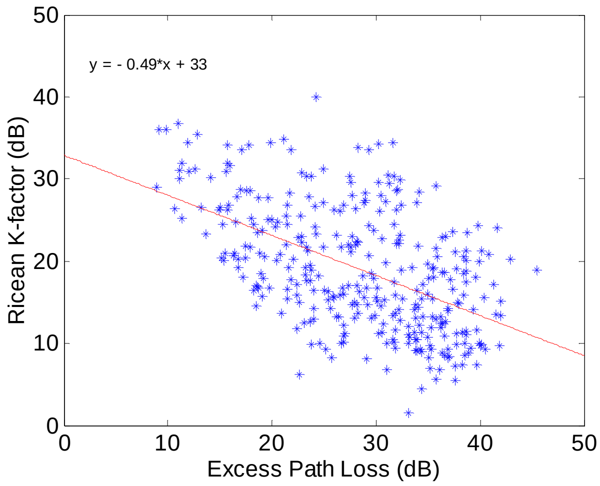

Figure 2 Ricean K-factor vs. Excess Path loss

Figure 3 shows the RMS delay spread as a function of excess path loss. The delay spread is observed to be highly correlated to excess path loss. However, Figure 4 shows that RMS delay spread does not significantly depend on distance between SU and BS.

The wideband tapped delay line channel model is summarised in Table 1. The tapped delay line channel model at a 5m SU height is shown in Figure 5. The results show that the tap gain at delays of 200ns (2nd tap) and 400ns (3rd tap) diminish as the SU antenna height is increased. The Ricean *K*-factors of the second tap are very small, whilst the value for the third taps are very close to zero, showing that the amplitude of the multipath echoes is close to Rayleigh distributed.

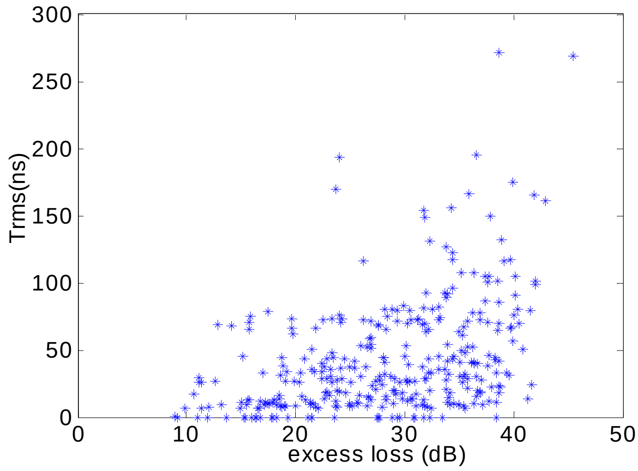

Figure 3 RMS delay spread vs. Excess Path loss

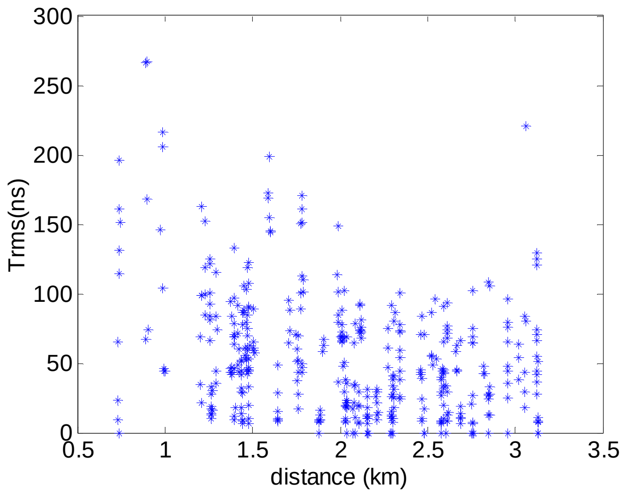

Figure 4 RMS delay spread vs. distance between subscriber antenna and base station

SU Height (m)	4.5<h<5.5 31 samples		5.5<h<6.5 48 samples		6.5<h<7.5 65 samples		7.5<h<8.5 43 samples		8.5<h<9.5 78 samples		9.5<h<10.5 57 samples	
Tap delay (ns)	Tap gain (dB)	K-factor (dB)	Tap gain (dB)	K-factor (dB)	Tap gain (dB)	K-factor (dB)	Tap gain (dB)	K-factor (dB)	Tap gain (dB)	K-factor (dB)	Tap gain (dB)	K-factor (dB)
0	0	43.8	0	44.1	0	44.6	0	45.6	0	46.0	0	46.7
200	-19.8	5.5	-21.0	8.6	-21.6	7.05	-22.5	9.0	-23.2	7.7	-24.3	9.6
400	-25.5	-0.34	-26.0	1.54	-26.9	1.9	-25.5	2.8	-28.4	3.6	-28.5	3.5

Table 1 Summary of Wideband Tapped delay line channel model

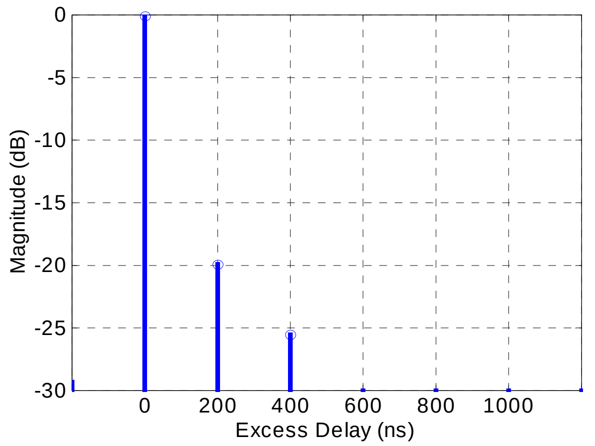

Figure 5 Wideband tapped delay line channel model at 5m SU antenna height

5. Conclusions

This paper has shown the influence of SU antenna height on a BWA system employing directional SU antennas and sectored BS antennas at 3.5 GHz. It has been previously reported that the average RMS delay spread is observed to decrease with increasing SU antenna height [9]. This paper further elaborates on the wideband characteristics of outdoor SISO BFWA radio channel at 3.5GHz, by showing the average tapped delay line channel impulse response. Similarly to [7], it is confirmed that a 3-tap model can adequately describe the channel. However, due to the relatively few high rise building and flat terrain of the environment and the narrower SU antenna beamwidth (20^o cf. 30^o in [7]), the maximum average channel tap delay observed is 400ns. The individual tap gains of the multipath components are observed to decrease with an increase in the SU antenna height. This is consistent with [9] which reported that the RMS delay spread decreases with an increase in the SU antenna height.

The narrowband Ricean *K*-factor is observed to correlate strongly with excess path loss, which is similar to the finding in [8]. In summary, the influence of distance between SU and BS on the delay spread is less significant than is the height of the SU antenna.

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