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Propagation Measurements at 2 GHz in Rural Area

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Abstract

Mobile channel data results in a rural area are presented from measurements at 2 GHz over 50 MHz bandwidth The data were analyzed to derive an empirical relationship between rms delay spread and coherence bandwidth for correlation levels of 0.9 and 0.5 and the results are compared with those in the literature.

1 Introduction

Wideband communication systems suffer from frequency selective fading which might result in inter-symbol interference and deteriorate the quality of communication. Among the techniques used to overcome frequency selective fading and increase capacity of communication systems are adaptive modulation, equalization, coding with interleaving, frequency hopping, and multiple access schemes, like OFDMA, that allocate optimum set of subcarriers for transmission [1-3]. Modern communication systems use channel state information when allocating communications resources. The channel state information depends on time and frequency selectivity of the channel. Optimum use of the aforementioned techniques requires knowledge on frequency selectivity of the channel. For example subcarrier spacing in a multi-carrier system needs to be smaller than the coherence bandwidth to ensure flat fading on each carrier. Also, there is number of pilot carriers and their spacing should be identified in a way to improve channel estimation while not exhausting signalling overheads.

Rms delay spread (τ_{rms}) and coherence bandwidth (B_c) are used for characterising the frequency selectivity of the channel. Both are small scale parameters obtained from an ensemble of consecutive impulse responses measured over a short time interval or distance over which the channel is considered to be wide sense stationary (WSS) [4]. The coherence bandwidth is a statistical measure of the frequency range over which the complex channel transfer function is correlated. Generally coherence bandwidth values for correction levels between 0.5 and 0.9 are used to estimate the appropriate transmission parameters.

Large scale statistics of frequency selectivity of the mobile radio channel for rural areas are limited. Except for the work in [5], no works on coherence bandwidth for rural areas have been reported.

This paper presents the results of rms delay spread and coherence bandwidth values from 30 measurement locations at 1945 MHz over 50 MHz bandwidth in a rural area, and an empirical model between the two variables.

2 Data Collection and Processing

The measurements were carried out in a rural area near Manchester city over a 50 MHz bandwidth at 1945 MHz by using a Frequency modulated Continuous Wave (FMCW) sounder [6]. The effective radiated power was 34 dBm, and the transmitter and receiver antennas were omni-directional vertically polarised with 7 dB and 3 dB gain, respectively. The transmitter was stationary and placed on one side of a golf course facing a hill covered by tress, and the receiver was placed in a van. The transmitter antenna was placed at 5.2 m above the ground, and the receiver antenna at 2.5 m. The data were collected over 1 s intervals at a minimum speed of 0.5 m/s. The sweep repetition rate used was 100 Hz, covering Doppler ranges of ±50 Hz. The receiver speed was kept low so that distance travelled in each measurement run did not exceed 5 m.

Details of the sounder and processing of the FMCW channel data to obtain common channel parameters can be found in [6]. In summary, the sounder employs a heterodyne detector at the receiver, resulting in a beat note for each multipath component. Spectral analysis of the receiver output reveals complex impulse responses of the channel (IR), and averaging the magnitude-squared IRs over time gives the Average Power Delay Profile (APDP).

Frequency Correlation Function (FCF) was calculated as he Fourier transform of APDP by using WSSUS channel assumption. A noise-threshold delay-window was applied prior to FCF estimation (Figure 1.a) as in [7]. The noise threshold value was set at least 5 dB above the noise floor. The time window is the interval between the first instant at which the PDP goes above the noise threshold and the final instant at which it falls below the threshold.

Figure 1.b illustrates the corresponding FCF curve. The coherence bandwidth B_c was obtained from the normalised FCF as half of the frequency separation over

which the absolute value of the FCF does not fall below a specified correlation level c. This is illustrated by the dotted lines for $B_{0.5}$ in Figure 1.b. For this data, the rms delay spread value is 1.23 μs and $B_{0.9}$ and $B_{0.5}$ are 0.28 MHz and 11.7 MHz, respectively

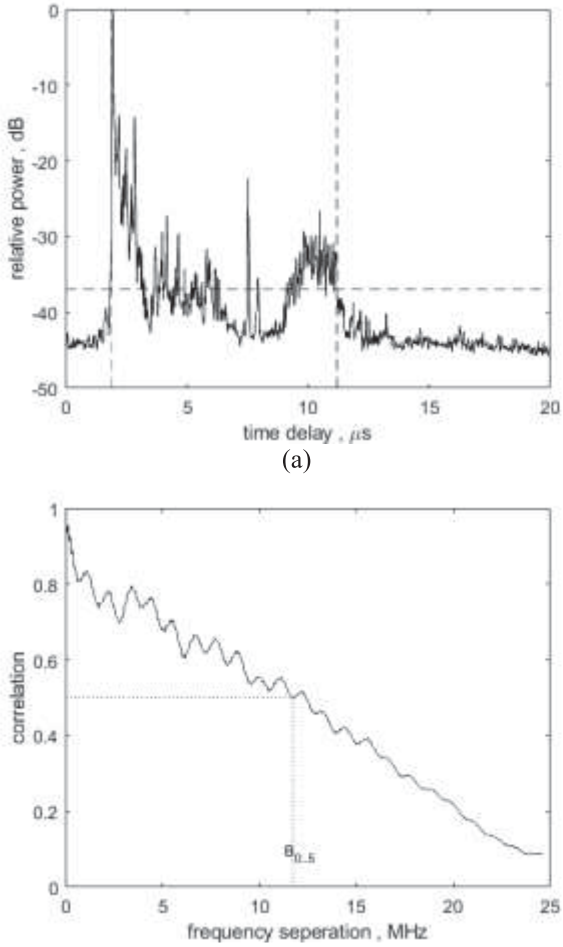


Figure 1. (a) a PDP illustrating noise threshold and delay window, and (b) Corresponding FCF illustrating the measurement of coherence bandwidth at level 0.5.

Figure 2 illustrates a PDP with high delay spread (3.9 μs). The PDP has several late arriving components, with a component having similar signal strength as the first arriving component at a relative time delay of 2.8 μs. The corresponding correlation function (Figure 2.b) has an oscillatory behaviour which is typical to channels with two dominant components.

3 Results and Discussions

The cumulative distribution functions (CDF) for rms delay spread and $B_{0.9}$ and $B_{0.5}$ are shown in Figures 3 and 4. The 10^{th}, 50^{th} and 90^{th} percentiles are listed in Table 1. The range of values are 0.03 μs and 5.6 μs for rms delay spread, 24 kHz and 5.3 MHz for $B_{0.9}$, and 48 kHz and 18 MHz for $B_{0.5}$. The results suggest that an LTE subcarrier over a 15 kHz band will experience frequency-flat fading in rural areas. The rms delay spread and $B_{0.9}$ values are lognormally distributed; the mean and standard deviation values are -0.34 and 0.617 for $\log_{10}\tau_{rms}$ (where τ_{rms} is in μs), respectively, and -0.48 and 0.76 for $\log_{10}B_c$, (where B_c is in MHz).

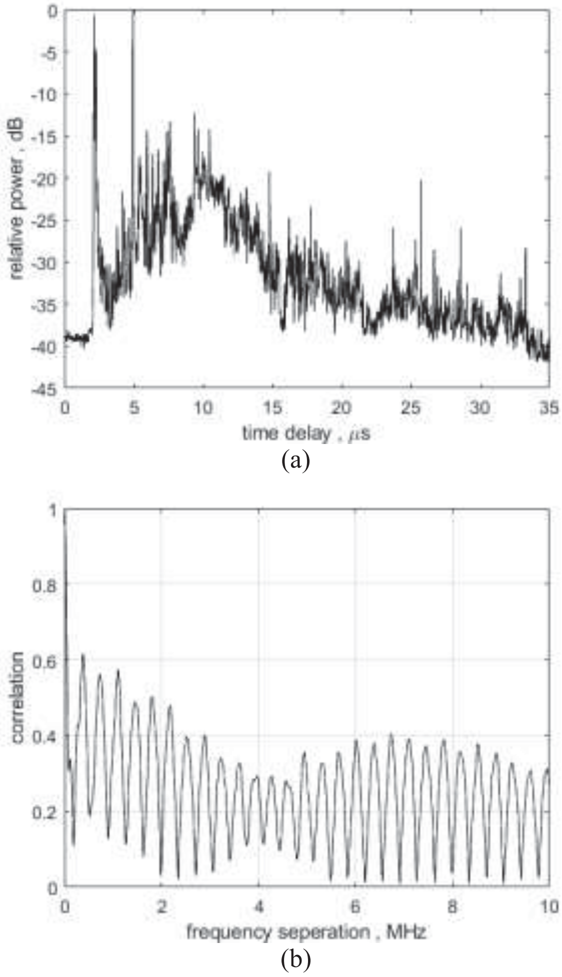
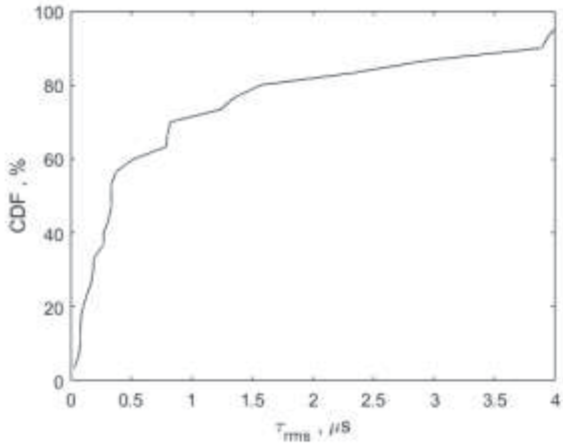


Figure 2. (a) a PDP with high delay spread (3.9 μs), and (b) Corresponding FCF ($B_{0.9}$=24 kHz, $B_{0.5}$=52 kHz).

In [5] coherence bandwidth results were presented for 862 MHz from a 5-tone measurement system. Two out of eight measurement sites were in rural areas. The minimum, mean and maximum coherence bandwidth values ($B_{0.37}$) were 520 kHz, 636 kHz and 1050 kHz for one site, and 100 kHz, 265 kHz and 780 kHz for the other site. The minimum values for both sites are higher than the minimum $B_{0.37}$ value from our data which is 70 kHz (see Figure 2.b). This may be due to the 5-tone measurement approach used in [5], which may result in overestimation of the coherence bandwidth for non-monotonic frequency correlation functions. On the other hand the maximum coherence bandwidth values from our data are significantly higher than those given in [5]. This can be attributed to the wide bandwidth used in ourselves measurements which enabled the estimation of large coherence bandwidth values.



(a)

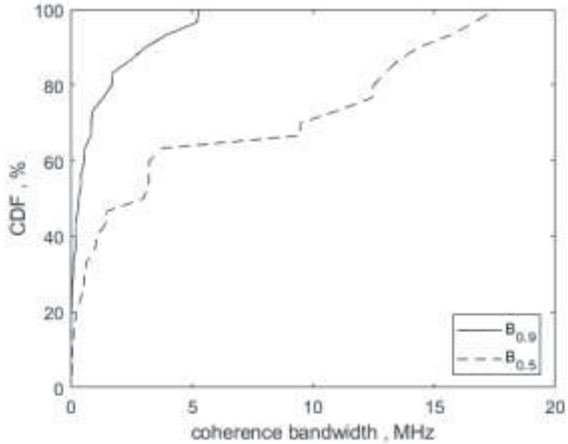


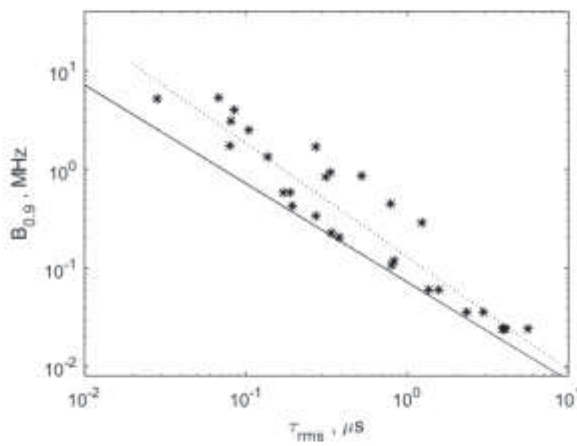
Figure 3. (a) CDF of rms delay spread, and (b) CDF of coherence bandwidth.

Table 1.Percentiles for B_c (MHz) and τ_{rms} (μs)

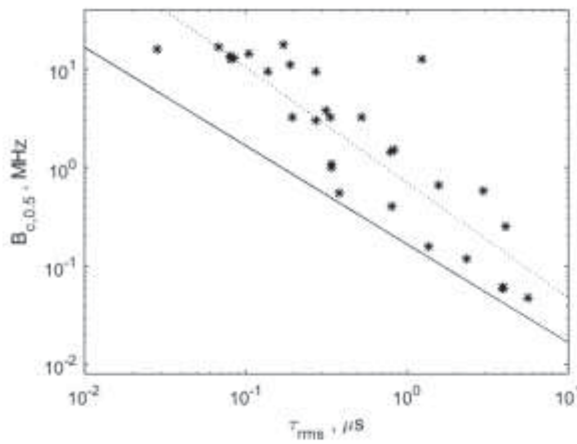
	10%	50%	90%	Mean	Std
τ_{rms}	0.08	0.34	3.89	1.1	1.5
$B_{0.9}$	0.03	0.33	3.1	1.04	1.5
$B_{0.5}$	0.06	3.0	14.3	5.67	6.2

3.1 Dependence of Coherence Bandwidth on Delay Spread

The scatter plots of the coherence bandwidth and τ_{rms} are presented in Figure 4. The Fleury's lower bounds [8] are indicated by the solid lines; which indicates that the lower bounds are valid for our data, hence $B_{0.9} \geq 0.072/\tau_{rms}$ and $B_{0.5} \geq 0.167/\tau_{rms}$. The Pearson correlation coefficient between the logarithm of coherence bandwidth and rms delay spread values is $\rho = -0.94$ with $CI\ (-0.97, -0.88),\ p < 0.001$ for $B_{0.9}$ and $\rho = -0.87, CI\ (-0.94, -0.75), p < 0.001$ for $B_{0.5}$. Note that the correlation level for $B_{0.5}$ is higher than that for urban areas which is -0.64 [7].



(a)



(b)

Figure 4. Scatter plots of coherence bandwidth versus the rms delay spread. The solid lines illustrate Fleury's lower bound and the dotted lines are regression fit lines.

The high correlation levels suggest a linear relation of the form $log\ B_c = a + b\ log\tau_{rms}$. Ordinary least squares (OLS) regression gave

$$B_{0.9} = \frac{0.13}{\tau_{rms}^{1.15}}. \tag{1}$$

$$B_{0.5} = \frac{0.70}{\tau_{rms}^{1.17}}. \tag{2}$$

where $B_{0.9}$ is in MHz and delay spread, τ_{rms} , is in microseconds. The R^2 values, i.e. squared correlation between actual and predicted values, are 0.89 for the model in (1) and 0.76 for (2). After excluding data points with $B_{0.5} > 5\ MHz$ as in [7] the model for $B_{0.5}$ becomes

$$B_{0.5} = \frac{0.56}{\tau_{rms}^{1.17}}. \tag{3}$$

For a given rms delay spread value, we obtained higher coherence bandwidth values for rural areas than that for urban areas [7]. This can be seen from both the percentiles and the models in (1) – (3). For example the median values were 0.33 MHz and 3 MHz, respectively, for rural data as compared to 0.12 MHz and 0.55 MHz for urban data. Again the nominator values in the models for the rural area are higher than those for the urban models which were 0.13 as compared to 0.09 for B_{09}, and 0.56 as compared to 0.32 for $B_{0.5}$. The possible reasons for these might be the range of rms delay spread values observed and the difference in propagation mechanisms in a rural area and a city centre. The rms delay spread values in the current work ranged from 0.03 μs to 5.6 μs, with considerable number of points below 0.2 μs whereas for the urban data almost all of the data points were above 0.2 μs. Path loss can be lower in rural areas than urban areas when a line of sight (LoS) path is present. On the other hand radial streets in the city centre may act like a guide for electromagnetic waves. Although $B_{0.37}$ values were presented in [5], no model was provided.

As compared to the other models for urban areas in the literature, the model in (2) gives smaller estimates than that in [9], i.e. $B_{0.5} \cong 1.42/\tau_{rms}^{1.57}$, and gives smaller estimates for $\tau_{rms} < 1\,\mu s$ but greater estimates for $\tau_{rms} > 1\,\mu s$ than that in [10], i.e. $B_{0.5} = 0.73/\tau_{rms}^{1.42}$.

4 Conclusions

We presented large-scale statistics of the rms delay spread and coherence bandwidth, and derived empirical relations between them $B_{0.9} = 0.13/\tau_{rms}^{1.15}$ and $B_{0.5} = 0.7/\tau_{rms}^{1.17}$. The models were derived by using rms delay spread values in the range from 0.03 to 5.6 μs, and, therefore, are valid for this range. These models should be validated by using more data, and the dependence of *Bc* on distance should be investigated in future research.

5 Acknowledgements

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6 References

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