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Evaluation of Metrics for Characterising the Dispersion of the Mobile Channel

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Abstract

This paper analyses the suitability of RMS delay spread and coherence bandwidth when characterising system Quality-of-Service of QPSK operating in a variety of wideband mobile channels. It is demonstrated that RMS delay spread is unduly affected by the presence of relatively weak signals with large excess delay, limiting its effectiveness when characterising time dispersion. Coherence bandwidth is shown to offer a more general dispersion metric.

Furthermore it is indicated that *instantaneous* system performance is poorly characterised by dispersion parameters calculated from the discrete power delay profile (such as RMS delay spread). Instantaneous delay spread incorporates the effects of pulse shaping and the vector summation which occurs in the instantaneous channel impulse response. Consequently, instantaneous delay spread is demonstrated to provide a better indication of instantaneous performance than RMS delay spread.

1 Introduction

A measure of time dispersion in a wideband channel is a fundamental statistic in characterising a mobile communications system. An ideal dispersion metric would be employed in a variety of mobile channels to determine Quality-of-Service, in terms of bit error rate (BER) or outage probability. Further applications exist in propagation measurements and models, facilitating the direct mapping of results onto system performance.

A mobile channel impulse response (CIR) will often include small paths with a large excess delay. In particular, hilly terrain profiles often exhibit a bimodal distribution. A bimodal channel comprises a first, dominant path in addition to a significant path at a large excess delay, resulting from a reflector a considerable distance from transmitter and receiver.

This paper demonstrates that RMS delay spread [1] is un-

duly affected by the presence of relatively weak signals with large delay in a wideband CIR, which do not have a commensurate effect on system performance. Coherence bandwidth [2] provides a dispersion metric that is largely unaffected by the presence of small magnitude paths at a large excess delay.

Instantaneous system performance is especially useful in certain situations, for example if the channel is stationary, or when calculating a coverage map. The instantaneous channel response which is experienced by a system is determined by the vector summation of the CIR into "bins" corresponding in size to the symbol period. Furthermore, it is necessary to account for any pulse shaping which is employed. It is shown that a given wide sense stationary channel will result in a wide variation of instantaneous delay spread, even though the RMS delay spread will remain constant. Instantaneous delay spread is demonstrated to provide a better indication of instantaneous performance than RMS delay spread. Similarly, coherence bandwidth calculated from the instantaneous CIR can be employed to accurately characterise system performance at a snapshot in time.

In this area of work the suitability of a variety of techniques for characterising the wideband channel are examined, employing a simulation of a QPSK system. In each case, the correlation between each measure of dispersion and system performance is demonstrated. An accurate technique for determining receiver performance could be integrated into a propagation model, to provide a useful prediction tool.

2 Simulation Method

The analysis contained in this contribution is carried out for a conventional QPSK system. The simulation itself is implemented using the tapped delay line approach [1].

The channel models employed include a hilly terrain profile [3], and an exponential decaying response [4]. An arbitrary CIR representative of a bimodal distribution was constructed, comprising an exponential response with a

time constant τ and an additional ray at a delay 40τ , at a magnitude 20dB less than the dominant path. This corresponds to a channel with relatively low dispersion in the initial portion of the CIR, and a small reflected path at a large excess delay.

3 Analysing Time Dispersion

3.1 Two-Ray Model

Relatively small rays at a large excess delay have a negligible effect on the system performance. However, in this section it is shown that such rays have an incongruously large impact on the delay spread. The delay spread calculation weights all rays by the square of delay, increasing the influence from rays at large excess delay. To demonstrate this phenomenon, a number of two ray profiles were constructed, with the path magnitude difference altered in each instance. The excess delay of the second ray was then scaled to provide identical RMS delay spread for all of the channel impulse responses (fixed at a delay spread of one half of the symbol period). Figure 1 shows two instances of a two-ray model, both with a delay spread of one half of the symbol period. However, it can be observed that figure 1a demonstrates a ratio of wanted-to-unwanted power (W/U) of 5dB, and figure 1b exhibits W/U of 15dB. Consequently, figure 1a would produce significantly poorer system performance than figure 1b, even though the RMS delay spread is identical.

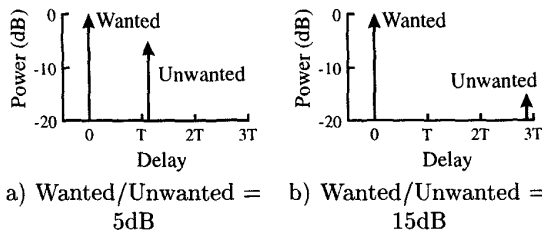


Figure 1: Two-ray model with normalised delay of $0.5T$

The BER statistic is shown for the set of two-ray channels in figure 2, indicating that as the two rays become more similar in magnitude, performance degrades. As predicted by QPSK performance criterion [5], no errors result if the ratio of wanted-to-unwanted power is greater than approximately 10dB. Delay spread provides a poor dispersion metric in this instance, as it remains constant despite the change in system performance.

3.2 Delay Spread

Since delay spread provides a poor measure of dispersion in the presence of small rays at a large excess delay, pre-

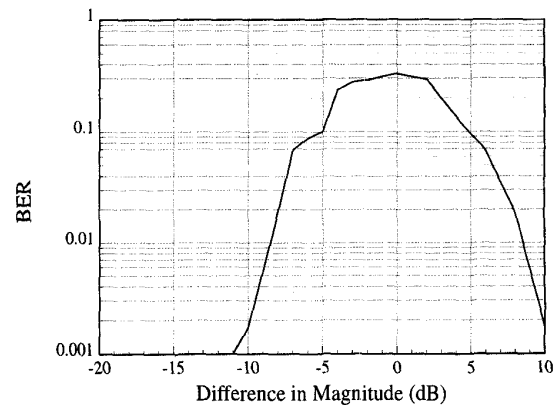


Figure 2: BER performance in a two-ray model

dicting system performance for a number of different environments is problematic. Figure 3 shows the relationship between normalised RMS delay spread [6] and BER for channel models under test.

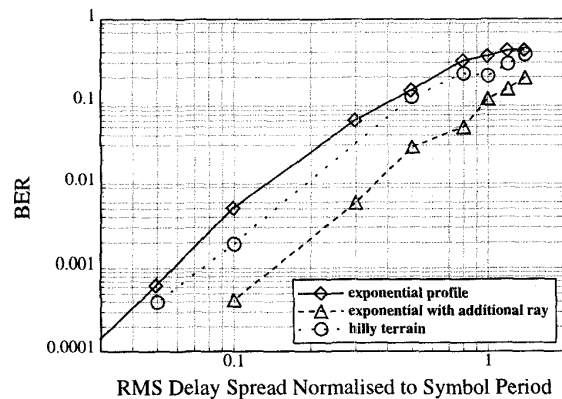


Figure 3: Normalised RMS delay spread vs. BER

It can be observed that there are trends for each particular model, relating normalised delay spread to bit error rate. As expected, the large degree of disparity between the curves demonstrates RMS delay spread to be a poor parameter for characterising dispersion in a variety of channels.

It is possible to alleviate this phenomenon by implementing windowing on the channel impulse response before delay spread is calculated. In this case, rays with a magnitude below an appropriate threshold would not be considered. However, it is inaccurate to eliminate the effect of rays with a small, but significant effect on performance, and an incongruously larger impact on delay spread. Consequently, windowed delay spread provides an improved solution, but remains unsatisfactory.

3.3 Coherence Bandwidth

Unlike RMS delay spread, coherence bandwidth is not unduly influenced by the presence of negligible rays at a large excess delay, since these paths are not weighted by the square of the delay. The relationship between coherence bandwidth and bit error rate was evaluated using the standard correlation threshold of 0.9 (shown in figure 4). Standard channel models were again employed, and comparison of the RMS delay spread characteristic (figure 3) with these results shows a greater similarity between the coherence bandwidth characteristics of the three environments.

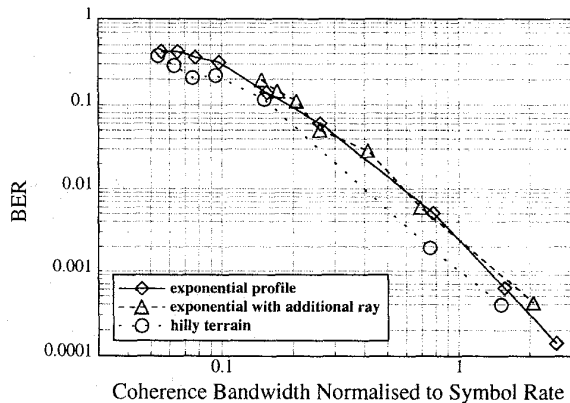


Figure 4: Normalised coherence bandwidth vs. BER

Coherence bandwidth is largely unaffected by the presence of insignificant paths at a large excess delay. The main problem associated with employing coherence bandwidth as an accurate dispersion measure is the choice of correlation threshold (set at 0.9 in this analysis). Results indicate that the actual value of the threshold is unimportant, provided it is high enough to ensure the spaced-frequency correlation function is monotonically decreasing in the initial portion of the characteristic. If this condition is not satisfied the calculated coherence bandwidth is artificially extended, and the value observed would indicate a much less dispersive channel than is experienced by the system.

4 Instantaneous Characteristics

Instantaneous system performance is particularly useful in certain situations, for example when calculating a coverage map, or when the channel is stationary. Whilst average statistics are often more useful in predicting overall system performance and trends, it is advantageous to have the facility to characterise the channel and modem at any time snapshot.

Any communication system under examination will have a finite bandwidth, consequently it is extremely unlikely

that all individual incoming rays will be resolved. The receiver will experience an impulse response where all rays in a given symbol period will be summed vectorially. Furthermore, it is necessary to convolve the channel impulse with both transmit and receive filters to accurately observe the effect of “sounding” the entire system with an impulse. Convolution of the impulse response with transmit and receive filters, as well as vector addition (or “binning”) of all components in each symbol period results in the *instantaneous* impulse response experienced by the receiver.

Figure 5 shows a discrete CIR for the hilly terrain profile [3]. Plotted on the same figure is the profile at an arbitrary instant in time, resulting from a system with a bandwidth resolution of 500 kHz (ie. symbol period is $2\mu s$), with raised cosine filtering ($\alpha = 1.0$). It can be observed that there is considerable difference between the profile shapes, resulting in a delay spread of $4.98\mu s$ for the discrete power delay profile, and $7.84\mu s$ for the instantaneous CIR.

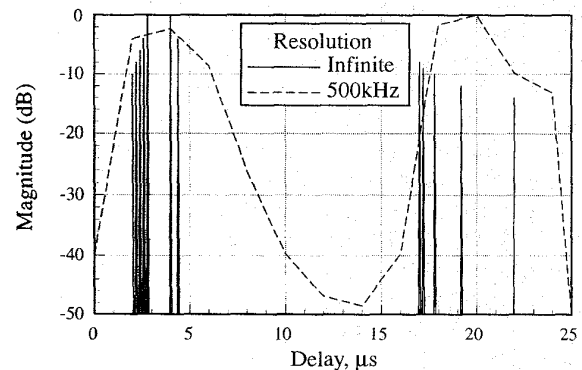


Figure 5: Channel Impulse Response with Infinite and Finite Bandwidth Resolution

To accurately represent the CIR experienced by a system at a particular instant in time, it is necessary for the “sounder” to have a finite bandwidth resolution equal to the symbol period. This applies to real propagation data, as well as simulations, including both the *n*-ray model [4] and the *ray-traced* approach [7]. Channel parameters calculated from a discrete power delay profile can be employed to provide an indication of average system performance over distance and time.

4.1 The Problem of Using Discrete CIR Parameters

It is often useful to be able to predict system performance at a snapshot in time (or space), instead of calculating the average characteristics over a longer span. This is especially the case when the mobile is stationary, and channel response variations are assumed to be negligible. Since the instantaneous channel response is produced from the vec-

tor sum of all rays in a given symbol period, this response will vary as the interference pattern changes, even if the discrete power delay profile remains constant. If the channel is *wide-sense stationary*, then discrete channel parameters will remain fixed as the mobile moves, even as instantaneous values will change. Consequently, discrete channel dispersion parameters (such as coherence bandwidth and delay spread) will only provide an approximation to the instantaneous channel characteristic. Figure 6 shows the distribution of instantaneous delay spread calculated from the instantaneous CIR, in relation to the average RMS normalised value of approximately 0.7.

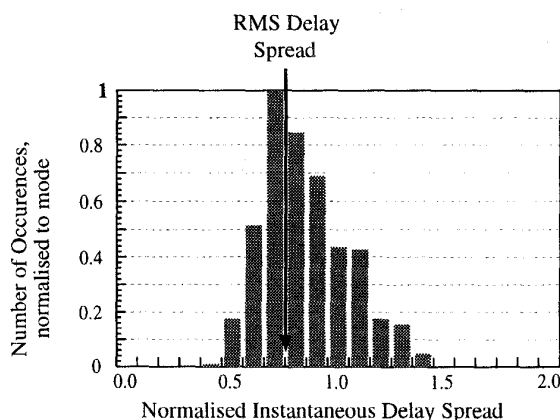


Figure 6: Variation of Instantaneous Delay Spread

The distribution of instantaneous parameters around the discrete CIR value is of particular importance when attempting to predict the bit error rate performance of the channel at a particular instant in time. Delay spread calculated with an infinitely narrow time impulse will only provide an approximate indication of the system performance observed at a snapshot in time. Figure 7 shows the variation in the observed values of instantaneous BER and normalised RMS delay spread. The large variation of system performance at a fixed value of normalised RMS delay spread indicates the unsuitability of using this parameter to predict performance at a snapshot in time. The simulation was carried out for an exponential decaying CIR, thus removing the problem of rays at a large excess delay and low power, as described in section 3.

Coherence bandwidth calculated from the instantaneous CIR will exhibit a distribution around the parameter calculated from the discrete CIR. Consequently, the “average” coherence bandwidth will provide a poor indication of instantaneous system performance.

4.2 Instantaneous Delay Spread

If the RMS delay spread is calculated using the instantaneous channel impulse response, the resulting statistic

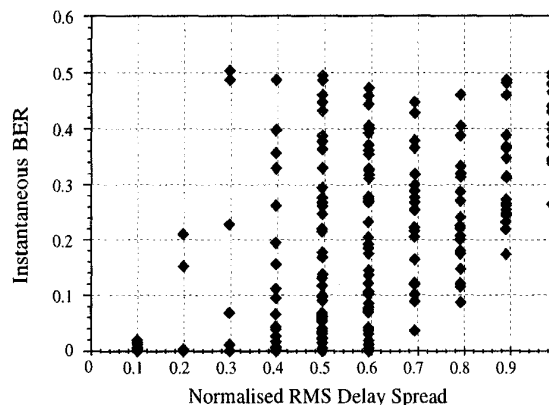


Figure 7: Normalised RMS Delay Spread vs. Instantaneous BER for QPSK

will demonstrate the dispersion at an instant in time and space. It is then possible to relate *instantaneous delay spread* to the system BER performance at a particular instant in time (figure 8). Comparing these results to the performance of the discrete CIR parameter, shown in figure 7, indicates the superiority of the instantaneous measure when predicting the instantaneous BER statistic. In general, it is far more meaningful to relate instantaneous delay spread to instantaneous system performance. The relationship produced can then be employed to predict both bit error rate and outage for the system at an instant in space and time.

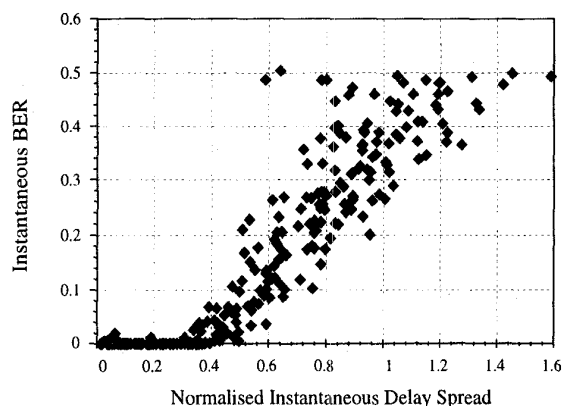


Figure 8: Normalised Instantaneous Delay Spread vs. Instantaneous BER for QPSK

Since results indicate there is a high correlation between the instantaneous delay spread and the instantaneous system performance exhibited, this parameter can be successfully employed to predict outage. For an outage threshold of 10^{-3} , the system will fail if the normalised instantaneous delay spread exceeds 0.333, with an error of less than 5%.

Similarly, coherence bandwidth can be calculated from the instantaneous CIR. The instantaneous parameter can then be employed to characterise performance at a particular instant in time and space.

5 Conclusions

This paper sets out to investigate the suitability of a coherence bandwidth and RMS delay spread in characterising time dispersion in the mobile environment. The analysis is undertaken for the parameters in predicting both average and instantaneous system performance.

5.1 Average Characteristics

It is desirable for any dispersion parameter employed to have near identical mapping onto system performance, despite the type of channel experienced by the system. The limitation of employing RMS delay spread as a measure of time dispersion is demonstrated for a variety of wideband channel models in section 3. The presence of small paths at a large excess delay has a much greater effect on the delay spread than is reflected by a negligible change in system performance. This effect is mitigated by windowing the CIR before calculating RMS delay spread. Nonetheless, windowed delay spread remains affected by the delay-squared weighting placed on all paths. Consequently, windowing provides a better solution than conventional RMS delay spread, but remains non-ideal.

In a variety of channels, coherence bandwidth was shown to provide a superior approach to predicting system performance. The presence of small paths at a large excess delay does not have a deleterious impact on coherence bandwidth as a prediction parameter. Consequently, coherence bandwidth has been indicated as the most generic dispersion metric analysed.

5.2 Instantaneous Characteristics

The limitations of the dispersion metrics are examined for characterising instantaneous system performance, which is of particular importance in static channels. It was demonstrated parameters calculated from the discrete CIR, such as RMS delay spread, are poor indicators of system performance at a particular instant in space and time, although are useful in characterising *average* performance. Consequently, the necessity to accurately predict instantaneous performance prompted the development and analysis of an instantaneous dispersion metric.

It is possible to calculate instantaneous parameters from the instantaneous CIR. Comparison of bit error rate with

instantaneous delay spread provides a far better correlation than that exhibited by the average, discrete CIR parameter. Indeed, the parameter could be employed to predict instantaneous outage performance, with less than 5% error. Consequently, this analysis implies that instantaneous delay spread can successfully characterise the instantaneous mobile channel. A similar analysis has been carried out for coherence bandwidth, confirming that the instantaneous parameter more accurately characterises instantaneous system performance.

Finally, it is possible to characterise time dispersion using an number of alternate techniques, such as delay window and delay interval [3]. In all cases, it necessary to retain the distinction between instantaneous and averaged characteristics.

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