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# An Investigation of RAKE Receiver Operation in an Urban Environment for Various Spreading Bandwidth Allocations

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## Abstract

*The renewed interest in the application of the spread spectrum technique to mobile radio systems, both in the U.S. and now within Europe through the RACE II and U.K. DTI/SERC LINK programs continues to gather momentum. To this end, an analytical performance model has been developed at Bristol in order to provide a greater insight into the operation of this technique, in particular the sensitivity of the bandwidth efficiency of the network to the form of diversity signal processing employed in the mobile transceiver. This theme is continued in this paper with an investigation of the wideband channel characteristics of an urban service area. Results are presented relating the statistics of the RAKE receiver branches to the spreading bandwidth employed.*

## 1 Introduction

As a result of the current interest in the application of CDMA techniques to future mobile cellular networks, this multiple access method has been selected by the UMTS ad-hoc group within ETSI [1] as a potential candidate for third generation mobile networks across Europe. Justification for the candidature of CDMA is further upheld by the considerable investment of several American companies, as well as the much publicised capacity and flexibility of the approach [2, 3].

An analytical performance model developed at Bristol [4] in order to assess key parameters of cellular DS-SS-SS-SS operation, identified that in order to achieve high bandwidth efficiency when compared with other

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competing technologies it is necessary to employ diversity signal processing within the transceiver. With DS-SS-SS systems, diversity can be employed without any additional antennas or spectrum. Thus it is said to be inherent (or internal) to the technique.

This contribution examines this aspect in more detail and draws some conclusions from initial DS-SS-SS urban propagation measurements in the City of Bristol.

## 2 Internal Diversity

A wideband, temporally dispersive channel may be characterised by the following complex impulse response [5]:

$$h(t) = \sum_{k=1}^n \alpha_k \delta(t - \tau_k) \exp(j\phi_k) \quad (1)$$

where  $\alpha_k$ ,  $\tau_k$  and  $\phi_k$  are respectively the amplitude weighting, excess delay and arrival angle of the  $k$ th ray. In order to determine the various channel parameters, described by Equation 1, it is usually necessary to perform wideband channel experiments to fully characterise the impulse response. Power delay profiles are often presented, such as that shown in Figure 1 which was taken in the city of Bristol using the wideband channel sounding equipment described in Section 4.

With the application of wideband modulation techniques it is necessary to consider the time dispersion characteristics, since the air interface will operate at a signalling rate well above the coherence bandwidth of the medium. Often this data is quoted in terms of the RMS delay spread providing a measure of the period during which the most significant multipath activity occurs. Generally, the RMS delay spread of the channel's impulse response is a function of the scale of the

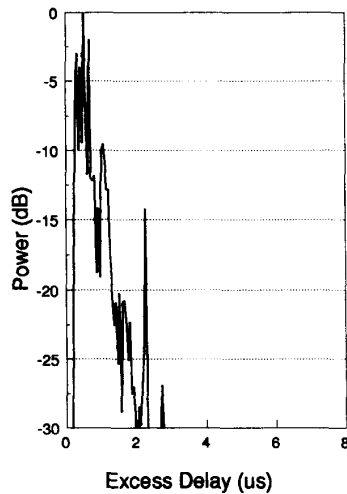


Figure 1: An Urban Environment Impulse Response

environment under consideration and for large urban cells RMS delay spread values tend to be quite high, lying between 1 and  $3\mu s$  in many European environments.

As previously mentioned, the concept of *internal diversity* is inherent to the DS-CDMA technique. This allows time-domain processing of the channel's impulse response, thus providing independently fading signals, without the need for separate antennas. The total number of resolvable multipath components,  $L$ , is related to the coherence bandwidth of the radio channel,  $\Delta f_c$ , and also to the chipping rate,  $W_{ss}$ . The coherence bandwidth of the channel is the range over which input signals separated by less than  $\Delta f_c$ , have significantly correlated amplitude and phase responses at the channel output. This quantity is inversely proportional to the total multipath delay spread,  $T_m$ , of the channel :

$$\Delta f_c \propto \frac{1}{T_m} \quad (2)$$

The time resolution of the wideband correlation process employed in the DS-CDMA system is given by :

$$T_c = \frac{1}{W_{ss}} \quad (3)$$

where  $T_c$  is more usually referred to as the spreading code chip duration.

The maximum number of resolvable multipath components that can be obtained using internal diversity is thus given by [6]:

$$L \leq \frac{T_m}{T_c} + 1 \quad (4)$$

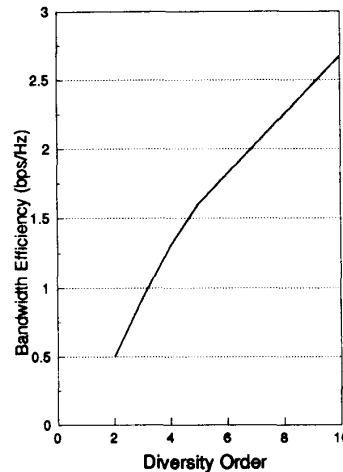


Figure 2: Bandwidth Efficiency of Cellular DS-CDMA versus Diversity Order in an Urban Environment

Hence a maximum of  $L$  statistically independent paths can be resolved directly from the channel, and subsequently utilized in an internal diversity combining scheme in order to maximize the total wanted signal-to-noise energy at the input of the demodulator. Clearly, whilst it is possible to resolve components up to the total multipath spread of the channel, those components that occur within the RMS delay spread of the channel contain the most significant proportion of the signal energy. Optimum diversity performance can be obtained if a Maximal Ratio Combining (MRC) technique is implemented in the form of a RAKE receiver [6]. The bandwidth efficiency, and hence system capacity, of a cellular DS-CDMA network can be shown to be a function of the diversity order employed in the receiver architecture [4] and it is therefore necessary to consider the channel requirements in order to obtain sufficient internal diversity order.

The graph shown in Figure 2 assumes a maximal ratio diversity combining scheme for a receiver operating in an urban radio channel.

### 3 Fading Envelope

Within any propagation environment the transmitted signal may arrive at the receiver's antenna by several different paths. Except for the possible Line-Of-Sight (L.O.S.) ray, all other rays will arrive having undergone possible reflection, refraction and diffraction. Each of these rays will suffer from varying amounts of attenua-

tion and phase-shifts, corresponding to their electrical length, before arriving at the receiver. The superposition of each of the resulting waves of differing phase and amplitude creates a quasi-stationary wave pattern of varying signal strength, giving rise to the term *multipath* or *fast fading*.

The variation in received signal amplitude can be characterised by the general form of the Rician distribution [7]:

$$p(A_l|y) = \frac{A_l}{\sigma_{mu}^2} \exp\left[-\frac{(A_l^2 + y^2)}{2\sigma_{mu}^2}\right] I_0\left(\frac{A_l y}{\sigma_{mu}^2}\right) \quad (5)$$

where  $A_l$  is the received amplitude,  $y$  is the amplitude of the deterministic component,  $\sigma_{mu}^2$  is the variance of the distribution and  $I_0$  is the zeroth order modified Bessel function. Furthermore, it is usual to define a  $K$ -factor for the Rician distribution, which is given by [8]:

$$K = \frac{\text{Power in Deterministic Component}}{\text{Power in Scattered Components}} = \frac{y^2}{2\sigma_{mu}^2} \quad (6)$$

If there is no deterministic component present between the transmitter and receiver pair,  $y \rightarrow 0$ , then the Rayleigh probability density function results :

$$p(A_l) = \frac{A_l}{\sigma_{mu}^2} \exp\left[-\frac{A_l^2}{2\sigma_{mu}^2}\right] \quad (7)$$

## 4 Wideband Channel Sounding

In order to assess the performance of high bit-rate multiple access techniques it is often necessary to carry-out wideband channel sounding experiments in order to determine the RMS delay spread of the channel. This is an important parameter with such systems since it provides a measure of the amount of Inter-Symbol Interference (ISI) that can be expected.

There are two basic techniques that are commonly used for wideband channel sounding :

- Pulse Sounding
- Correlation Sounding

With a pulse sounding system a Radar-like pulse is transmitted and the channel's impulse response is determined directly using an envelope receiver. The resolution obtained is primarily limited by the minimum pulse width that can be achieved and the sampling bandwidth of the receiver. With a correlation sounder the impulse response is determined by a less direct method; the transmitted signal consists of a bi-phase carrier modulated by a PN sequence and coherent detection is performed using an identical sequence

clocked at a slightly slower rate. This cross-correlation of the transmitted signal with the received signal yields an approximation to the bandlimited channel impulse response.

Besides the correlation sounding measurement technique being much easier to implement, it also has many similarities with a DS-CDMA air interface, thus this is the approach that has been adopted here.

A block diagram of the channel sounding transmitter is shown in Figure 3 and a block diagram of the channel sounding receiver is shown in Figure 4. With a code length of 2047 and a chipping frequency of 20 MHz it is possible to obtain a dynamic range in excess of 40 dB and a time delay resolution of 50ns.

### 4.1 DS-CDMA Correlation Sounding

There is a need to be able to identify the fading envelope and mean signal level of any diversity branch, for a given chipping rate. If the amplitude and phase of all rays arriving at the receiver's antenna are known, *i.e.* complete knowledge of all parameters in Equation 1, then it is a relatively simple task to determine these fading envelopes and the corresponding mean signal levels. Unfortunately, in order to do this using correlation sounding techniques could require an infinite chipping rate to obtain a non-fading cross-correlation response. With the correlation sounder described in the previous section, there is a maximum chipping rate of 20 MHz which gives a differential path resolution of 15m. This is insufficient resolution, in most cases, to distinguish between a direct path and a groundwave and thus fulfil the requirement of a non-fading cross-correlation response.

The alternative is to *reduce* the chipping rate of the correlation sounder, thus emulating the functionality of a RAKE receiver, and perform a statistical analysis on a series of cross-correlations.

The channel sounder constructed at Bristol can be programmed with PN sequence lengths of 255, 511, 1023 and 2047 together with programmable chipping rates of 1.25, 2.5, 5, 10 and 20 MHz.

## 5 Propagation Environment

For all the results presented in this paper a channel sounding transmitter, as depicted in Figure 3, was placed on the roof of Queen's Building and a mobile channel sounding receiver, Figure 4, was moved along St. Michael's Hill, Bristol at a constant speed of approximately 20  $cms^{-1}$ . The location of the channel

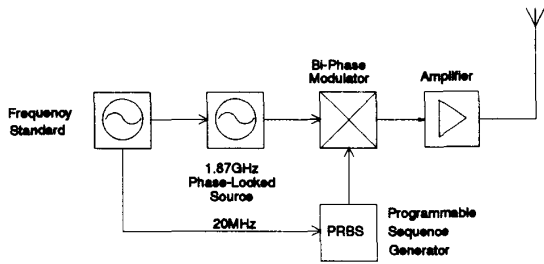


Figure 3: Channel Sounding Transmitter

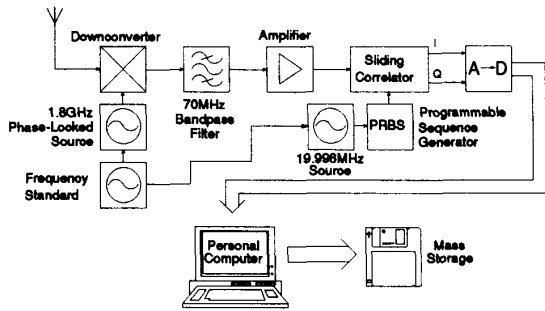


Figure 4: Channel Sounding Receiver

sounding equipment ensured that there was no L.O.S. component present between transmitter and receiver. The first incoming strong correlation peak is tracked for the remainder of the analysis and all other internal diversity profiles are obtained using the RAKE receiver approach [9].

For an urban environment this test site has a low RMS delay spread ( $< 1\mu s$ ) [10]. This means that it is sufficient to use a sequence length of 255 to provide unambiguous impulse responses and minimize correlation time. Further trials will consider propagation environments with larger RMS delay spreads.

## 6 Results

Figure 5 shows the diminishing signal amplitude with diversity branch and also highlights the importance of a high chipping rate in order to obtain sufficient significant diversity components. Figure 6 emphasizes the distinction between the statistics of the first and second branches at a 10 MHz chipping rate, in addition to showing the independence of the fading patterns. As

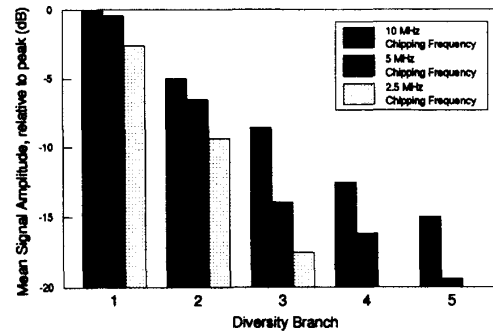


Figure 5: Mean Signal Amplitude versus Diversity Branch

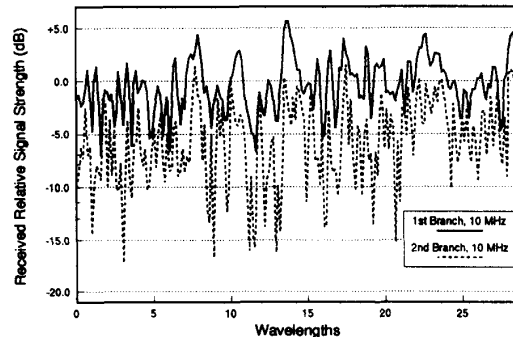


Figure 6: Fading Envelopes at 10 MHz

well as showing the lower mean signal energy of the second branch when compared with the first, there is a marked difference in the variance of the two signals.

In order to examine the statistics of the various diversity branches for given chipping rates, a Least Squares Error (LSE) curve fitting algorithm was used to compare ideal Rician statistics with the measured results.

An example statistical comparison between the 1st branches at chipping rates of 5 and 10 MHz is shown in Figure 7. A table of Rician K-factors for the various chipping rates and diversity branches is shown in Table 1. This table shows the reduction in K-factor of the first branch with chipping rate, as would be expected, in addition to the largely unpredictable nature of the other diversity branches.

## 7 Conclusions

A high chipping rate primarily ensures that a larger number of diversity branches have significant mean sig-

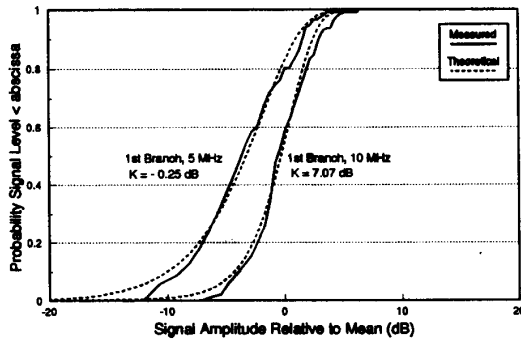


Figure 7: Fading Statistics at 5 and 10 MHz

Branch	10 MHz	5.0 MHz	2.5 MHz
1	7.07	-0.25	-7.49
2	-20.88	-8.43	-23.55
3	-8.45	2.73	-9.17
4	-7.03	-21.86	-9.43
5	-7.78	-8.24	5.15

Table 1: Rician K-factor (dB) for 10.0, 5.0 and 2.5 MHz Chipping Rate

nal energy levels. A secondary effect is to increase the Rician nature of the first diversity branch, which automatically allows the network to attain a higher spectral efficiency than would be possible with Rayleigh fading diversity signals [11]. Thus a high chipping rate, together with a powerful FEC code, would eliminate the need for complex front-end receiver structures.

Many propagation studies conducted in the USA have shown frequent occurrences of strong, much delayed multipath activity, principally due to the nature and location of its cities. Comparable studies in the U.K. have detected similar activity in certain locations, although this activity is not as common as with the cases in the USA. In such situations, a twin RAKE receiver architecture (the first handling near-in multipath activity, the second handling more distant multipath activity) might allow more optimum internal diversity processing.

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