THE FEASIBILITY OF SPECTRUM SHARING BETWEEN DS-CDMA MOBILE RADIO SYSTEMS AND MICROWAVE POINT-TO-POINT LINKS

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Abstract General techniques are presented to investigate the feasibility of spectrum sharing between an indoor DS-CDMA mobile radio system with vertical frequency reuse and a fixed point-to-point microwave link. Using a range of system parameters, the limitations of spectrum sharing are estimated. The results indicate that, for the systems considered, spectrum sharing will be difficult to implement without sufficient geographical isolation between the two systems. It is also apparent that the feasibility of spectrum sharing depends largely on the propagation characteristics between the two systems.

I. INTRODUCTION

Radio spectrum recently allocated for many second and third generation mobile radio systems in the 1-3 GHz frequency bands (e.g. USA PCS, DCS1800 and FPLMTS) is currently used in many countries for fixed point-to-point microwave links. The implementation of a mobile radio system in these bands would usually involve moving the fixed services to other frequency bands. However because of the difficulties associated with this exercise it would be advantageous if the two systems could coexist while sharing the same spectrum [1]. This would enable the fixed services to remain in the 1-3 GHz frequency bands.

This paper investigates the feasibility of spectrum sharing between a third generation indoor DS-CDMA mobile radio system (with vertical frequency reuse) and a fixed digital point-to-point microwave link. The feasibility of spectrum sharing depends on the mutual and self interference that will be received in the fixed and mobile systems. General techniques for characterising this interference and determining the feasibility of spectrum sharing are outlined in this paper.

II. MOBILE RADIO SYSTEM

It is assumed that the mobile radio system operates in an indoor environment with vertical frequency reuse and uses a direct sequence code division multiple access (DS-CDMA) scheme to spread the spectrum of a BPSK modulated signal. Each floor in the building is assumed to use the entire allocated spectrum with Frequency Division Duplex, so that the forward and reverse mobile links occupy separate 15 MHz frequency bands. It is assumed that the antennas at the portables are omni-directional, that the base unit antennas are sectorised to 180° in the vertical plane, that the sequences used for spectrum spreading are random, that the received base-band signal has a rectangular pulse shape and that the system receivers are perfectly synchronised to the desired signal. Furthermore it is assumed that the mobile radio system serves K active users per floor and that power control is used to compensate for the path loss and log-normal shadowing associated with each signal received at the base unit. Quantisation errors and errors resulting from the response time in the power control algorithm are modelled by a log-normal variability with σ = 2 dB [2].

A. Mobile radio propagation model

The performance of the mobile radio system is assumed to be interference limited and therefore depends on the interference received at each portable (forward mobile link interference) and base unit (reverse mobile link interference), as illustrated in Figure 1. This may be composed of:

- interference from other mobile users on the same floor:
  (i) intra-floor forward mobile link interference
  (ii) intra-floor reverse mobile link interference
- interference from mobile users on other floors in the same building:
  (iii) inter-floor forward mobile link interference
  (iv) inter-floor reverse mobile link interference
- interference from nearby fixed services that share the same spectrum:
  (v) fixed service interference
- interference from nearby buildings with indoor mobile radio systems that use the same spectrum:
  (vi) inter-building interference

Models for indoor propagation in two different buildings [3,4] have been used to predict the intra-building interference (namely the intra- and inter-floor interference) at the mobile receivers. In this paper these two models are denoted by Building (A) and Building (B), respectively.
A simplified model to predict the inter-building interference at a mobile receiver has been adopted in this paper. Specifically it is assumed that the interference is only attributable to the three nearest floors in a single adjacent building. The propagation loss from the floors in the interfering building to the desired floor may change significantly with changes in the elevation angle of the interfering signal [5]. However for simplicity it is assumed that the interfering signals from all three floors are incident perpendicular to the desired floor. Furthermore the path loss between the two buildings is assumed to be approximately “free space”.

![Diagram of interference sources](image)

**Figure 1** Interference sources for an indoor mobile radio system sharing spectrum with a fixed service. (Interference components (i)-(vi) are described in the text).

The fixed service interference power at a mobile radio receiver depends on the path loss between the two systems. For an indoor mobile radio system this path loss is likely to vary significantly depending on whether there is a LOS propagation path between the two systems, or whether the propagation path is obscured. To represent the range of possible propagation paths between the two systems, this paper estimates the fixed service interference in a mobile radio system when there is:

1. “free space” path loss between the two systems, or
2. path loss which is in excess of the loss to the street level by a 13dB building penetration loss [6].

**III. FIXED SERVICE**

The fixed microwave point-to-point links considered in this paper are typical of those operating in the 1-3 GHz frequency range. Generally these links use highly directional antennas to improve signal reception and are usually sufficiently elevated so that during normal operating conditions it may be reasonable to assume that they have a “free space” path loss. However changes in the propagation characteristics of the troposphere can sometimes cause signal attenuation and multipath fading. Accordingly, a fixed service that occasionally suffers from Rayleigh distributed multipath fading is considered in this paper. The regularity of the multipath fading is approximated by a fade occurrence factor (FOF) which is given by [7],

\[ FOF = K_f \cdot Q \cdot f_e^B \cdot d^C, \]

where \( f_e \) is the carrier frequency (MHz), \( d \) is the hop length (km) and \( K_f, Q, B \) and \( C \) are scaling parameters that depend on the operating environment.

The analytical techniques outlined in this paper are applicable to a wide range of system configurations. In this paper these techniques have been used to estimate the performance of fixed services typically used for intra-city communication links in New Zealand in the 1.7-1.9 GHz frequency bands.

**IV. PERFORMANCE ESTIMATES**

**A. Mobile radio system performance**

The performance of a mobile radio system may be estimated by the average bit error rate (BER) of the received signal. In this paper the BER is averaged over the variability of the received signal and the spatial distribution of the portables in the mobile radio system. The portables are assumed to be distributed uniformly throughout the floors in the buildings. For simplicity the spatial distribution of the portables is assumed to be uniform over a circular (rather than rectangular) floor shape.

It is assumed that the mobile radio system has a sufficiently large processing gain and serves a sufficient number of simultaneous users for the instantaneous composite interference at a mobile receiver to be Gaussian distributed. Accordingly, because the base band signal is assumed to be BPSK modulated, the average BER of a received signal is given by [8],

\[ \overline{BER} = \int \phi(x) \cdot p(x) \cdot dx \]

where \( \phi(\cdot) \) is the complementary Gauss probability integral and \( x \) is the signal-to-interference-voltage-ratio which has a pdf, \( p(x) \), and is given by [8],

\[ x = \frac{E(\text{desired signal voltage})}{\sqrt{\text{var(composite interference voltage)}}}, \]
where $E(\cdot)$ and $\text{var}(\cdot)$ denote the expectation and variance respectively.

The average BER of the forward and reverse mobile links depend on the desired and composite interfering signals received at the portables and base units, respectively. The characteristics of the received signal components depend on the power control algorithms used by the mobile system and the propagation characteristics to the mobile receivers.

The composite interference at a mobile receiver may emanate from a number of sources, as illustrated in Figure 1. Each interfering signal is assumed to have a log-normally distributed signal power. Therefore the composite interference at a mobile receiver will comprise of a number of independent log-normally distributed random variables. Using the technique outlined in [9] the composite interference at the mobile receivers is approximated by another log-normally distributed signal in this paper.

### B. Fixed service system performance

The performance of a fixed point-to-point microwave link may be estimated using outage probability expressions. An outage is defined to occur when the momentary Carrier-to-Noise-Ratio (CNR) is less than the minimum ratio required for reliable reception, or when the mobile radio interference exceeds a specified threshold relative to the noise floor. The probability of an outage occurring at a fixed service receiver, $P_{\text{out}}$, is given by, [10]

$$P_{\text{out}} = \frac{\int_{0}^{\infty} \int_{0}^{\infty} p_{\gamma}(\gamma) \cdot dy \cdot \int_{1}^{\infty} p_{w}(w) \cdot dw}{\int_{0}^{\infty} \int_{1}^{\infty} p_{w}(w) \cdot dw} = \frac{1}{\int_{0}^{\infty} \int_{1}^{\infty} p_{w}(w) \cdot dw},$$

where $\varepsilon$ is the minimum CNR required for reliable reception and $\gamma$ is the momentary fixed service CNR which during multipath fading is assumed to have an exponentially distributed power variability, $p_{\gamma}(\gamma)$. The composite mobile radio interference $w$ (which has a pdf, $p_{w}(w)$) should be less than $I$ for reliable reception. In practice, the magnitude of $I$ depends on the nature of the point-to-point link and the quality of service required. However a commonly used Standard that has been adopted in this paper, requires that the interference at a point-to-point receiver should cause an effective increase in the thermal noise floor of no more than $1$dB [11].

It is assumed that the total mobile radio interference at a fixed service receiver emanates from the three floors in each of the interfering buildings which are closest to the elevation of the fixed service receiving antenna. Furthermore it is assumed that the path loss between each interfering building and the fixed service receiver is approximately “free space”.

The bandwidth of each transmitted mobile radio signal (15 MHz) is significantly wider than the bandwidth of each fixed service channel (3.5 MHz). Accordingly the interference from the forward and reverse mobile links to a fixed service receiver are treated separately in this paper. This is illustrated in Figure 2, where (I) and (II) are the total forward and reverse mobile link interference components at the fixed service receiver, respectively.

![Figure 2](image)

**Figure 2** The composite interference at a fixed service receiver.

### V. RESULTS

The performance of a particular spectrum sharing arrangement may be related to the required separation distance (coordination distance) between the two systems for reliable reception. Coordination distance contours for reliable reception of the forward and reverse mobile and fixed service links are presented in this section. The assumed parameters of the two systems are outlined in Table 1.

<table>
<thead>
<tr>
<th>System</th>
<th>Mobile</th>
<th>Fixed Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. transmitted power</td>
<td>-30dBm</td>
<td>-3dBW</td>
</tr>
<tr>
<td>Floor radius</td>
<td>40 metres</td>
<td></td>
</tr>
<tr>
<td>Floor height</td>
<td>5 metres</td>
<td></td>
</tr>
<tr>
<td>Receiver noise figure</td>
<td>4 dB</td>
<td></td>
</tr>
<tr>
<td>Activity factor</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Fade occurrence factor</td>
<td>$6.4 \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>Active users per floor</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1** System parameters for the fixed and mobile systems analysed

The shape of each of the coordination contours presented in this section is the same as the shape of the assumed radiation pattern of the fixed service antennas [12].

The performance of the mobile radio system is estimated for two different buildings, described by the propagation models for Buildings A and B, respectively. Coordination contours for the forward and reverse mobile links operating with a “free space” path loss to a fixed service are illustrated in Figure 4. These contours indicate that the building characteristics have a significant effect on the required coordination distance.
between the two systems. In particular the reverse mobile link requires a coordination distance of approximately 2.5 km for Building A and 5 km for Building B, when operating outside of the fixed service bore-sight. This implies that a mobile radio system operating in Building B is more sensitive to fixed service interference than the same system operating in Building A. The forward link coordination contour for Building B is not shown because the estimated coordination distance was in excess of 20 km for a portable operating outside of the fixed service bore-sight. This coordination distance is regarded as being unrealistic for spectrum sharing between the systems considered in this paper.

Figure 5 illustrates the coordination distances required for reliable reception in the mobile radio system when the fixed service interference signal is obscured and attenuated by a 13 dB building penetration loss. A comparison of Figures 4 and 5 indicates that when the fixed service interference signal is obscured from the mobile radio system, there is a significant reduction in the coordination distance required for the mobile radio system to operate reliably.

In both Figures 4 and 5 the coordination distances required for reliable reception at the base units are less those required for reliable reception at the portables. This is because the reverse link power control algorithm compensates for the path loss and log-normal variability of the desired signal received at a base unit. Furthermore, in Figure 4 the performance of the forward link is estimated for a portable next to a window with a LOS path to a fixed service transmitter.

The required coordination distances for reliable reception at a fixed service receiver when the interfering mobile radio system is located outside of the fixed service bore-sight are shown in Figures 6 and 7 when there are 1, 5, and 10 interfering buildings. Both Figure 6 and 7 illustrate the significant decrease in the fixed service performance when there is an increased number of interfering buildings.
VI. CONCLUSIONS

General techniques for estimating the performance of an indoor DS-CDMA mobile radio system and a fixed service simultaneously sharing the same spectrum have been outlined in this paper. These techniques have been used to investigate a range of spectrum sharing scenarios from which the following conclusions can be drawn:

1. The path loss between the fixed and mobile systems has a significant effect on the overall feasibility of spectrum sharing.
2. The building propagation characteristics can have a significant effect on the performance of a mobile radio system sharing spectrum with a fixed service.
3. Power control improves the performance of the reverse mobile link and the overall performance of the mobile radio system is limited by signal reception at the portables.
4. The coordination distance required for the mobile radio system to operate reliably is reduced significantly when the fixed service signal is obscured.

The results in this paper suggest that for the systems considered, spectrum sharing may be difficult to implement, unless sufficient isolation between the two systems can be provided.

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REFERENCES


