

# Direct Calculation of Coherence Bandwidth in Urban Microcells Using a Ray-Tracing Propagation Model

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**Abstract** - An important parameter in characterizing radio communications channels is the coherence bandwidth. This paper presents an analysis of the coherence bandwidth in a urban microcell environment where the dynamic channel response is determined by a site-specific ray-tracing propagation model. Such an analytical model provides a direct calculation of signal fading envelope correlation as a function of frequency and location. The analysis here shows that coherence bandwidth is strongly dependent on location within a particular propagation environment and only weakly related to RMS delay spread. Typical results for frequency diversity gain for various frequency separations are also presented.

## 1. Introduction

Much of the effort in designing robust and reliable communications systems focuses on choosing modulation, coding and receiver architecture schemes which mitigate the deleterious effects of the radio propagation channel. In free space, the propagation channel has a flat amplitude response (attenuation) and linear phase shift as a function frequency. When the propagation environment is not free space but contains any other elements, including the atmosphere or a single reflecting surface, the frequency response of the channel is no longer flat over all frequencies. A single reflection results in the so-called "two-ray" model in which significant nulls in the amplitude response can occur at particular frequencies depending on the reflection coefficient and ray geometry.

With highly complex propagation environments, signal energy arrives at the receiver along a variety of paths with varying amplitudes, phases, and time delays. The result is a channel frequency response which varies from place to place. One measure of the varying frequency response is the coherence bandwidth ( $\Delta f_c$ ). The coherence bandwidth is the frequency separation between two frequency tones which results in a given de-correlation in signal envelope amplitudes. The de-correlation is usually defined as the point where the correlation coefficient  $\rho_f$  between the fading envelopes

at the two frequencies is reduce to 0.9 or 0.5. For the studies done here, a correlation coefficient of 0.9 is used to defined the correlation bandwidth. As explained in Section 2, a site-specific ray-tracing propagation model is used to find the fading envelopes and correlation coefficient.

The coherence bandwidth of the channel is particularly relevant to frequency-hopping spread spectrum (FHSS) systems[1], and to other multi-carrier systems, including OFDM. In both cases robust transmission is achieved by choosing multi-carrier frequency separations, or frequency hop distance, such that frequencies are sufficiently de-correlated that the probability of simultaneous fading impairments on multiple frequencies is low. This is the fundamental improvement which frequency diversity has to offer[2].

For the hypothetical dense urban environment studied here, coherence bandwidths ranging from 30 kHz to 130 kHz were found. The coherence bandwidth was found to be site-dependent and only weakly related to the inverse of the RMS delay spread of the power delay profile.

## 2. Ray-Tracing Propagation Model

A general model for the low-pass impulse response for an urban radio channel is:

$$h(t) = \sum_{n=1}^N A_n \delta(t - \tau_n) \exp(-j(\theta_n + \Delta\theta_n)) \quad (1)$$

in which the impulse response  $h(t)$  is the sum of a set of  $N$  impulses arriving at delay times  $\tau_n$  with amplitudes  $A_n$ , phases  $\theta_n$ , and phase displacements  $\Delta\theta_n$ . The phase displacements result from the motion of the receiver or other spatial change of the receiver location relative to the rest of the propagation environment which may itself including moving objects (reflections from cars and buses, etc.). For a mobile receiver the displacement term is given by  $\Delta\theta_n = (2\pi v t / \lambda) \cos(\phi_n + \phi_v)$ , where  $\phi_n$  is the arrival angle of the  $n^{\text{th}}$  impulse,  $v$  is the speed of motion, and  $\phi_v$  is the direction of motion.

To use the channel model in (1), it is necessary to identify the amplitudes, time delays, and absolute phase shifts of the  $N$  components of  $h(t)$ . The received

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