

THE EFFECT OF PROPAGATION ON WIDEBAND DS-CDMA SYSTEMS IN THE SUBURBAN ENVIRONMENT

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ABSTRACT

Direct sequence code division multiple access (DS-CDMA) methods are being used by the cellular industry to provide a multiple access method with improved performance. Recently wideband CDMA systems have been proposed, the wideband waveforms require on the order of 5 to 15 MHz of bandwidth. In this paper the effect of channel propagation on the performance of wideband systems is examined. Since traditional narrowband analysis will not be sufficient for these systems wideband methods based on calculating the time domain channel impulse response are employed. The wideband channel response is modeled using a broadband parabolic equation propagation model. Presently, only two-dimensional range dependent propagation is considered, contributions due to out of plane scattering are not included.

1. INTRODUCTION

There has been increasing interest in using direct sequence code division multiple access (DS-CDMA) methods for both commercial and military applications. DS-CDMA has been proposed for cellular, microcellular, indoor and satellite communications, see for example Ref. [1]. The DS-CDMA techniques are defined to be those multiple access methods in which the multiple access capability is due primarily to coding. The most common form of DS-CDMA assigns each user a particular code sequence or signature code which is modulated on the carrier along with the digital data. In North America the IS-95 standard is based on DS-CDMA. The IS-95 DS-CDMA system operates in the 800 to 900 MHz band uses a chip rate of 1.23 Mcps and provides a user data rate of 9.6 kbps. Many applications are going to demand a higher data rate than that provided by IS-95, thus a wideband CDMA (W-CDMA) standard, IS-665, has been defined [2].

The design and performance of a W-CDMA system operating in the 1850 to 1990 MHz PCS band based on the IS-665 standard was discussed in Ref. [3]. A basic 5 MHz system was proposed, but options for a 10 and 15 MHz system are also available. The 5 MHz system uses a chip rate of 4.096 Mcps and provides a user data rate of 64 kbps. The impact of the channel on such wideband waveforms may be significant and will be difficult to analyze using narrowband methods.

In mobile radio environments the received signal strength

E can be expressed as a function of frequency, f , range between the base station and mobile user, r , and time, t . Reference [4] provided a relationship between the important components

$$E(f, r, t) = \eta_{sm}(f, t)\eta_s(f, t)E_o(f, r) \quad (1)$$

where E_o represents the long-term average field strength corresponding to transmission loss, η_{sm} represents the relative variation of signal strength which depends on location variability, and η_s represents the rapid fluctuation due to multipath fading. In this paper a physics based propagation model is used to evaluate the field strength term, E_o .

We consider the "forward channel," that is, the base station transmits to a number of mobile users. Each mobile receives as its input signal the sum of all the transmitted signals. For one of the transmitted signals, say the i^{th} signal, the received signal at one mobile is given by

$$y_i(t, r, z) = [s_i(t) \cos(\omega_c + \phi_i)] * h(t, r, z) + n(t) \quad (2)$$

where ω_c is the carrier frequency, $s_i(t)$ is the data modulated filtered code sequence, $h(t, r, z)$ is the channel impulse response for the channel between the base station and the mobile user, $n(t)$ is additive noise and $*$ denotes convolution. The channel impulse response is a function of time, t , and space where r is the spatial variable which is a scalar representing the distance between the base station and the mobile receiver, and z is the height of the mobile receiver antenna. The code sequence is defined by

$$s_i(t) = \sum_{n=-\infty}^{\infty} c_n^i d_n^i g(t - nT_c) \quad (3)$$

where $d_n^i = \pm 1$ is the data sequence, c_n^i the spreading sequence, $g(t - nT_c)$ the chip pulse shape, T_c the chip period and $T = NT_c$ the symbol period.

In order to evaluate the impact of the channel on the received signal, via Eq. 2, a realistic model or calculation of the channel impulse response $h(t, r, z)$ is required. In the next section we outline an approach for a physics based calculation of $h(t, r, z)$, which in turn allows the calculation of the received signal time series $s_i(t)$.

2. THE WIDEBAND CHANNEL IMPULSE RESPONSE

The parabolic equation (PE) method has been used to model EM propagation in the troposphere for many years.

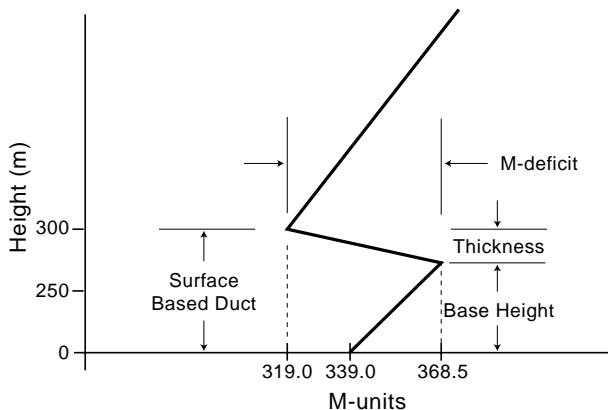


Figure 1. Modified vertical refractivity for a tri-linear profile.

The biggest advantage to using the PE method is that it gives a full-wave (amplitude and phase) solution for the field in the presence of range-dependent environments. Assuming a time dependence of $e^{-i\omega t}$ and that the atmosphere varies in range, r , and height, z , the parabolic equation for a flat earth is given by

$$\frac{\partial^2 \psi(r, z)}{\partial z^2} + 2ik_o \frac{\partial \psi(r, z)}{\partial x} + k_o^2 [n^2(r, z) - 1] \psi(r, z) = 0 \quad (4)$$

where k_o is the free-space wavenumber, n is the index of refraction, and ψ represents a complex scalar component of the electric field. The field from either a horizontal or vertical electric dipole source satisfies the same parabolic differential equation.

The propagation model employed herein is based on the parabolic equation (PE) method. The model, referred to as TPPEM, is described in Ref. [5]. This model uses the following environmental parameters: range dependent refractivity, range dependent terrain, height of the transmitter and range and height of the receiver. For range-dependent refractive environments the complex scalar component of the field at range $r + \Delta r$ and height z can be written as

$$\psi(r + \Delta r, z) = e^{ik_o(\Delta r/2)(10^{-6}M^2(r,z)-1)} \mathcal{F}^{-1} \left[e^{-i(\Delta r/2)(p^2/k_o)} \mathcal{F}[\psi(r, z)] \right] \quad (5)$$

where \mathcal{F} and \mathcal{F}^{-1} are the Fourier transforms. The transform variable p is defined by $k_o \sin(\theta)$ where θ is the propagation angle above the horizontal, and $M(r, z)$ is the modified refractivity profile, $M = ((n - 1) + (z/a)) \times 10^6$ where a is the radius of the earth.

The wideband channel impulse response was evaluated in the frequency domain using the TPPEM propagation code. The complex field of Eq. 5 was computed over a frequency band ($\omega_{min}, \omega_{max}$) at uniformly spaced samples, $\Delta\omega$, over a range interval (r_o, r_{max}) at uniformly spaced samples, Δr , and at a set of receiver heights z_1, z_2, \dots, z_m . Let $\psi(\omega_k, r, z)$ denote the channel response at one frequency (ω_k) at one range and height. The channel impulse response can be calculated at any point (r, z) by an inverse fourier transform of the frequency components. The complex envelope is is

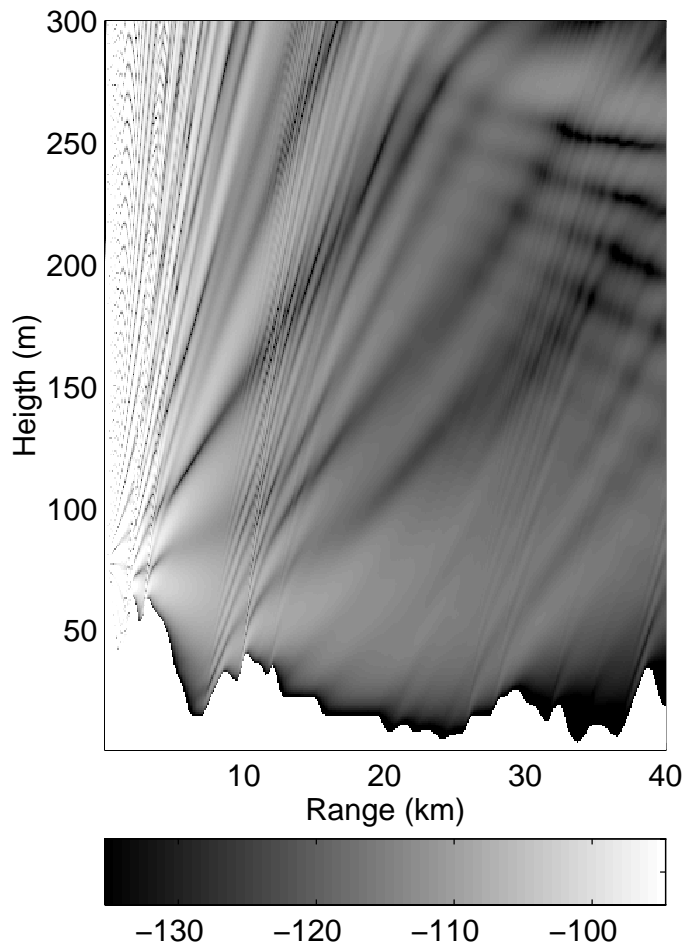


Figure 2. Range-height field strength for terrain case, source height is 25 m above terrain and frequency is 900 MHz.

calculated by mapping the channel frequency response to baseband (frequency translation of the center frequency of the band to zero frequency) and then taking the inverse Fourier transform. The inverse Fourier transform yields the complex envelope, denoted by $h(t, r, z)$, that is

$$h(j\Delta t, r, z) = \sum_{k=0}^{N-1} \psi(\omega_k - \omega_c, r, z) \exp(i2\pi jk/N) \quad (6)$$

where Δt is the sampling interval and $t = j\Delta t$, ω_c is the band center frequency, and N is the number of samples, (i.e., $N = 2\pi/(\Delta t \Delta\omega)$).

3. WIDEBAND CHANNEL PROPERTIES

The parabolic equation method allows a straightforward full-wave calculation of the wideband channel impulse response over complex terrain. The refractivity profile used herein was that of a surface duct caused by an elevated trapping layer at 300 m. Figure 1 illustrates the tri-linear M-profile that characterizes such an environment. Figure 2 illustrates a two-dimensional coverage diagram (magnitude of the complex field) based on the tri-linear refractivity profile

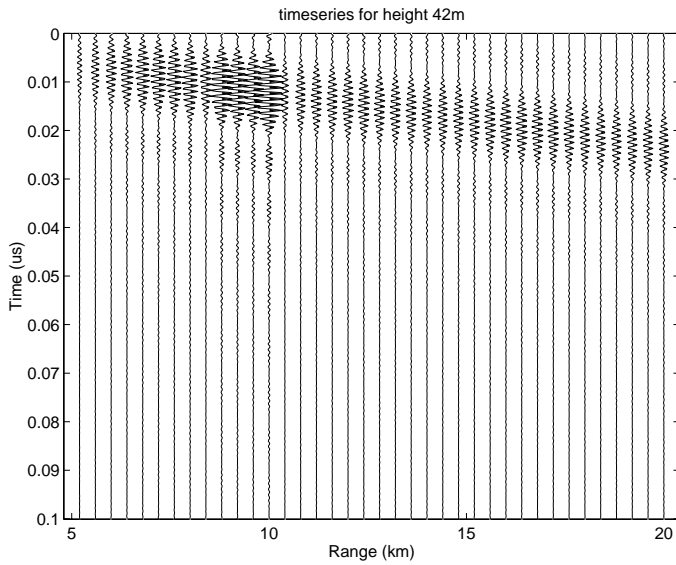


Figure 3. Impulse response for 800 to 900 MHz signal at a height of 42 m.

of Fig. 1 for an example with fairly complex terrain. This example used a horizontally polarized source at a height of 25 m above the local terrain (100 m above msl) at a frequency of 900 MHz. As a result of the ducting condition it is seen that the field strength near the terrain surface is fairly uniform across the range interval. It is also seen that some of the terrain features cause significant perturbations of the field structure, in addition reflections from the elevated duct are also apparent.

The time impulse response for a set of receivers placed at 42 m height and a range from 5 to 20 km are shown in Fig. 3. The receiver at 5 km is in the shadow from the nearby hill and thus little response is received. Around 10 km the scattering from the front of the hill increases the signal strength, whereas shortly after the receivers are behind the hill and little signal is received. In this example the carrier was included in the time response.

The terrain example of Fig. 2 was also used for the evaluation of the complex envelope. Using the terrain and surface duct refractivity profile of Fig. 2 the complex channel frequency response was evaluated for the band from 800 to 900 MHz using a frequency spacing of 1 MHz. Figure 4 illustrates the complex channel impulse response for the 800 to 900 MHz band at a range of 10 km (a local maximum of the terrain) for receivers spaced every 2 m above the local terrain, the terrain height at 10 km is 40 m. In most cases the major oscillations of the impulse response are damped out by 0.05 μsec and completely damped by 0.15 μsec , thus the plots have been truncated at that point. It is seen from Fig. 4 that the variability of the channel impulse response as a function of height is fairly significant. Note also that at the lower heights the contribution of the impulse response is equally distributed between the real and imaginary parts. The imaginary part of the response is fairly uniform with height. Figure 5 illustrates the same case but at a range of 16 km, a point that should be in the "shadow" of the local maximum at 10 km. The terrain height at 16 km is 15 m.

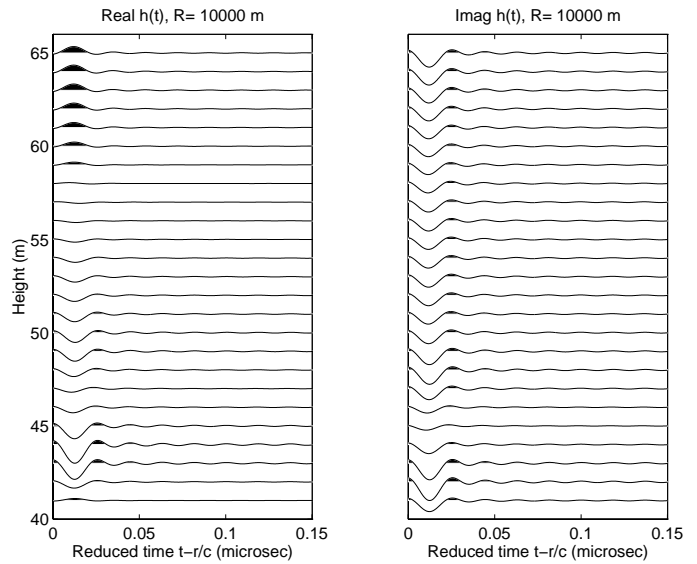


Figure 4. Complex envelope for 800 to 900 MHz at a range of 10 km, (a) real part and (b) imaginary part.

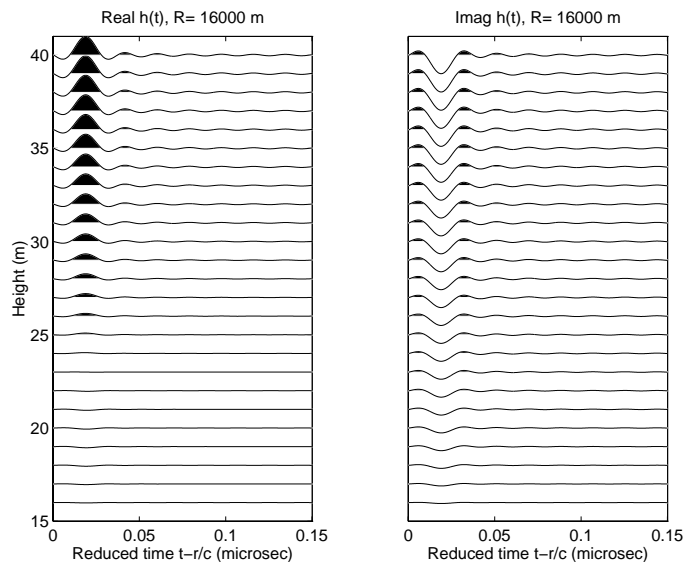


Figure 5. Complex envelope for 800 to 900 MHz at a range of 16 km, (a) real part and (b) imaginary part.

Examining Fig. 2 it is seen that due to the ducting the field strength is not significantly reduced on the back side of the peak and thus it is not surprising to see a fairly significant impulse response except at the lowest receivers (first 5 m above the terrain) at this range. The structure of the real and imaginary parts of the impulse response as a function of receiver height is significantly different at 16 km than at 10 km. There seems to be more information in the signal at 10 km than at 16 km.

4. SUMMARY

It has been shown that it is feasible to use full-wave (amplitude and phase) propagation models to calculate the wideband channel impulse response even for complex terrain cases with ducting refractivity. These computations of the wideband channel impulse response can be substituted into the relationship for the wideband received signal, see Eq 2, to precisely calculate the propagated time series and evaluate the impact of channel propagation effects on the transmitted signals.

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