Simulation Analysis of Radio Propagation in Big Areas using a Parallel FDTD Algorithm for Broadband Wireless Communication

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Abstract
Systems for broadband, high-speed wireless communication have been studied using a new parallel FDTD method applied to large 2-D areas. A microcell model based on FDTD results is presented. The effect of multipath interference on TDMA and CDMA signal evaluation can be calculated accurately using FDTD. Optimal system design with better modulation scheme, high Bit rate and low BER can be created with further results.

Introduction
Analysis of multipath propagation in urban areas for high-speed wireless communication is very important in order to improve the system. High accuracy is necessary, and the best kind of numerical method is a full solution of Maxwell equations as the FDTD method. We have created a parallel FDTD algorithm for dealing with big urban area models. Using this method, we have created a microcell urban model based on FDTD results and we have evaluated TDMA and CDMA modulation.

Basis of the Method
For linear materials, the 2-D TM FDTD formulation can be represented as a set of linear equations, with variables $E_z$, $H_x$ and $H_y$, as in eq.(1)-(3), where $C_a$, $C_x$, $C_y$, $D_x$ and $D_y$ are constants respect the m-th material. $X_i$ is a vector containing all the variables for time step i, the relation between variables in time step i and i+1 is

$$ X_{i+1} = A_i X_i + \phi_i \tag{5} $$

where $\phi_i$ represents source of currents and $A_i$ is a constant matrix.

The solution of FDTD becomes equivalent to solution of this system by Gaussian substitution. Substitution would require a lot of memory, but we carry out the solution in partial stages, solving eq.(5), where $x_L$ is a wanted variable ($E_z$, $H_x$ or $H_y$) at some time step t and position (i,j), depending on other variables $x_k$ of time step t-1. Substitution is done until eq.(5) becomes eq.(6). Where the variables $x_k^n$ are components of the fields in time step t-n. We repeat this process for solving each variable $x_k^n$ as a new $x_L$. The equations are stored in different arrays on many processors, computing in parallel subsets of $x_k^n$. Memory can be saved because not all the variables are required to be in memory simultaneously.

$$ x_L + c_1^n x_1^n + c_2^n x_2^n + K + c_3^n x_3^n = b_L^n \tag{5} $$

In order to improve the speed of the algorithm, numerical Green’s function were used. In a linear system, we have that the values of Green’s function $g(r,t,r',t')$ for any component of the fields is

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equivalent to the coefficients $c^n_k$ for $t'=t-n$. These values are always the same for any time and position if the surrounding space is the same. They can be calculated beforehand and stored for posterior use. The suitability of this approach has been established in [3]. Instead of doing the substitution for all points, the improved algorithm evaluates the surrounding cells for the position $(i,j)$ and if there is only free space and no sources, the stored values can be used directly for $c^n_k$. In the other case, Gaussian substitution is done.

**Impulse Response and Microcell Model based on FDTD results**

A model using concrete hollow buildings was used, as shown in fig.(1) and parameters: cell size=0.02 m, time increment $\Delta t=37.7$ ps, relative permittivity (concrete)=3.0, conductivity of concrete, $\sigma$: 0.005 S/m. A Gaussian pulse modulated with carrier $f_c=500$ MHz, $\zeta=100$ and $\alpha=-16/((\zeta\Delta t)^2$, as shown in eq.(7), was simulated, allowing for a non negligible amount of power between 0 Hz and 1 GHz. Impulse response can be obtained by using the Fourier Transforms $F(\omega)$, $G(\omega)$ of the input $f(t)$ and output $g(t)$ respectively, in eq.(8) which gives the frequency response $H(\omega)$. Then, $H(\omega)$ is filtered by a low-pass filter with cutoff at 1.2 GHz, because the components of $F(\omega)$ are practically zero at higher frequencies. Finally, a Inverse Fourier Transform is applied to get $h(t)$.

$$J^{\zeta \alpha} = J_{\max} \cos(2\pi f_c (t-\zeta\Delta t))e^{-\alpha(t-\zeta\Delta t)^2}$$

$$H(\omega) = G(\omega) / F(\omega)$$

Impulse response for the Line of Sight (LoS) point F and Non Line of Sight (NLoS) point D are shown in figs.(2) and (3) respectively. A microcell model for sub-areas was done (delay profile), and the comparison against UTD based model show a general agreement, but FDTD gives more detail.

**Figure 1.** Urban Model of Size 500m x 500m

**Figure 2.** Impulse Response $|h(t)|$ for LoS point F

**Figure 3.** Impulse Response $|h(t)|$ for NLoS point D

**Figure 4.** Calculated log(BER) for 1 Mbps TDMA
System Analysis for TDMA signals

For the calculation of BER for 1 Mbps TDMA systems, the same model and parameters as in the previous section were used. We assumed a point antenna, generating a Gaussian pulse with a carrier $f_c = 900$ MHz and $\zeta = 6631$ as shown in eq.(7), which is the signal for symbol of bit 1. Symbol of bit 0 has no signal. Basic signal can be considered as a set of pulses $c(t)$ for symbol 1, affected by the sequence of bits $b(t)$. For any $b(t)$, the modulated signal $d(t)$ to be transmitted can be obtained from the addition of the basic signal for all bits with value 1 adjusted with time shift, as in eq.(7). For any point, if the dynamic response of the signal in eq.(7) is $E_z^*$, the dynamic response for the sequence of bit represented in eq.(9) is shown in eq.(10).

$$d(t) = \sum_j \sum_i J_{\text{max}} \cos(2\pi f_c (t - \zeta \Delta t - \tau)) e^{-\alpha t} c(t)$$

$$E_z^*(t) = \sum_j E_z^*(t - \tau_j)$$

The period between signals is $T=1 \mu s$, bit rate is 1 Mbps, and $\tau = (i-1)T$. For the generation of the received signal, we used the result of the FDTD simulation for only one modulated pulse (symbol 1). Then we generated the signal for a sequence of bits, using eq.(9). To recover the data, we used envelope detection, signal correlator and a detector. BER=$[P(0|1)+P(1|0)]/2$, where $P(0|1)$ is the probability of error when the original bit is 1, and $P(1|0)$ is the opposite error. Thermal noise is an important source of errors; $<\sigma_V^2>=4kTB$ is the expected variance of voltage, $K=1.38x10^{-23}$ J/ºK is Boltzmann's constant, $T$ is temperature in Kelvin (290ºK= 17ºC), $R=73 \Omega$ is the resistance, $B=80$ MHz is the bandwidth.

Multipath interference affects $P(0|1)$ and $P(1|0)$. Both receptor and emitter use same antenna; power = 1 W. We generated all sequences of 6 bits ($2^6=64$ sequences), and evaluated the probability of error for the last 5 bits. The total number of bits evaluated per position is 320 bits. The calculated BER is shown in fig.(4). The reception of the data is good on most of the model, except on the opposite area from the emitting antenna.

System Analysis for CDMA signals

The original digital data for one channel is $b_k(t)$; it is modulated by the carrier $\cos(w_c t)$, $w_c=2\pi f_c$ and by a high bit rate code sequence $c_k(t)$, as in eq.(10) for QPSK, and eq.(11) for D-QPSK. This signal $d_k(t)$ is transmitted and affected by multipath interference. The total transmitted signal $d(t)$ is the union of many $d_k$, with a different $b_k$ and $c_k$. In QPSK and QAM case, the value of $\phi(c_k(t))$ is 0, $\pi/2$, $\pi$ and $3\pi/2$ for the bits 00, 01, 10 and 11. In D-QPSK the shift is relative (cumulative), with $\psi_k(t)=\psi_k(t+T_k)+\phi(c_k(t))$. $T_k$ is period between chips. If CDMA uses a QPSK or D-QPSK, then $\rho(c(t))=1$. If it uses QAM, $\rho(c(t))$ is variable. We use D-QPSK here.

$$d_k(t) = b_k(t) \cos(w_c t + \phi(c_k(t)))\rho(c_k(t)))$$

$$d_k(t) = b_k(t) \cos(w_c t + \psi_k(t))\rho(c_k(t))$$

Simulation was done for 2 Mbps CDMA wireless systems, with carrier= 900 MHz, chip rate= 8 Mcps, downlink, code-set is a Gold code, 120 channels. We generate random data sequences $b_k(t)$ of 8 bits for each point, then modulated it using the $c_k(t)$ and the carrier. The summation of all channel signals $d_k(t)$ is the signal $d(t)$ to be transmitted. The signal $d(t)$ (and all $d_k(t)$) is modified by the channel into the received signal $d^r(t)$ (signal received by k-th channel is $d^r_k(t)$). The diagram for the generation of the system is shown in fig.(5). Total transmitted signal $d(t)$ is shown at fig.(6), the total received signal for point F (LoS) and D (NLoS) is shown in figs.(7) and (8) respectively. The multipath scattering deforms the signal more for point D than for point F(LoS). The original $d(t)$ has two "gaps" or time intervals without signal. In the case of point F, these gaps are visible, but for point D, only the first gap is noticeable. The original $d(t)$ has two main bursts of power. For point F, these bursts do not change much, but for point D, the second burst changes a lot. Therefore, it can be said
that the multipath scattering affects more the signal in NLoS points by altering more the relative magnitude of the signal and the delay spread.

Conclusions
This research began looking for a convenient algorithm for simulation of big problems using FDTD. Because of the characteristics of FDTD method, parallel processing using a new approach focused on saving memory seemed to be the best option. Parallel FDTD method is useful in the modeling of big urban channels and in the design of better systems for high-speed data communications. The merit of FDTD is better accuracy than other methods, which is important for high data rates because the broadband signals are not well simulated with other methods. The extension of this research will allow optimal system design. By changing the method of modulation and the bit rate, the best modulation and the fastest Bit Rate with good BER can be found.

REFERENCES