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FORWARD LINK POWER CONTROL IN WCDMA CELLULAR SYSTEMS USING SPACE-TIME DIVERSITY TECHNIQUE

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Abstract - One of the most effective techniques to mitigate multipath fading and inter-cell interference at a downlink wireless channel in WCDMA systems for achieving high capacity is transmitter power control. In this case, system increases the power of the subscriber when its interference increases in order to satisfy the requested signal qualities. However, when the requested signal qualities are infeasible, the power control algorithms might diverge as a result of power limitation. Another way to mitigate multipath problems is using diversity techniques. Space-time diversity offers an advantage in the forward link of the WCDMA system. In this paper, three environments for forward link power control, together with space-time diversity, are examined. These are indoor office, indoor-outdoor pedestrian and vehicular environments. The simulator takes into account 19 hexagonal cells with spatially uniform user distribution and a propagation channel characterized by distance attenuation, fast Rayleigh fading and inter-cell interference. Computer simulations are given to evaluate the effect of space-time diversity on convergence of downlink power control algorithms. Simulation results show that space-time diversity together with downlink power control have very good performance, especially in the vehicular environments with high mobile speed.

Keywords - WCDMA Power Control, Forward Link Power Control, Space Time Diversity, Space Time Coding.

INTRODUCTION

The explosive growth of the Internet and the continued increase in demand for all types of wireless services (voice and data) are fueling the demand for increasing capacity, data rates and supported services (e.g., multimedia services). Higher data rates will enable a broader range of services, beyond the traditional voice only services, provided in the deployed cellular systems. The system performance of current wireless communication systems is limited by three major channel impairments. They are signal fading, distance attenuation and co-channel interference (that is inter-cell interference in forward link). Of course, Inter-Symbol Interference (ISI) has an important role in this scenario. Signal fading and ISI arise from multipath propagation while interference is generally caused by co-channel or unknown jammer systems.

At the same time, the remote units are supposed to be small lightweight pocket communicators. Furthermore, they are to operate reliably in different types of environments: macro, micro, picocellular; urban, suburban, rural; indoor and outdoor. In other words, the next generation systems are supposed to have better quality and coverage, be more powerful and bandwidth efficient, and be deployed in diverse environments. Besides, the services must remain affordable for widespread market acceptance. Inevitably, the new pocket communicators must remain relatively simple.

Fortunately, however, the economy of scale may allow more complex base stations. In fact, it appears that base station complexity may be the only plausible trade space for achieving the requirements of next generation wireless systems. The fundamental phenomenon, which makes reliable wireless transmission difficult, is time-varying multipath fading. It is this phenomenon, which makes tetherless transmission a challenge when compared to fiber, coaxial cable, line-of-sight microwave or even satellite transmissions. To remedy this undesirable effect, two effective methods are power control and diversity.

Increasing the quality or reducing the effective error rate in a multipath fading channel is extremely difficult. In Additive White Gaussian Noise (AWGN) channels, using typical modulation and coding schemes for reducing the effective bit error rate (BER) from 10^{-2} to 10^{-3}, may require only an increase of 1-2 dB signal to noise ratio (SNR). To achieve the same result in a multipath fading environment, however, it may require up to 10 dB improvement in SNR. The improvement in SNR may not be achieved by higher transmit power or additional bandwidth, as it is contrary to the requirements of next generation systems. It is therefore crucial to effectively combat or reduce the effect of fading at both the remote units and the base stations without additional power or any sacrifice in bandwidth. Theoretically, the most effective technique to mitigate multipath fading in a wireless channel is to control the transmitter power control. If channel conditions, as experienced by the receiver on one side of the link, are known at the transmitter on the other side, the transmitter can predistort the signal in order to overcome the effect of the channel at the receiver. There are two fundamental problems with this approach. The major problem is the required transmitter dynamic range. For the transmitter to overcome a certain level of fading, it must increase its power by that same level, which in most cases is not practical because of radiation power limitations and the size and cost of the amplifiers. The second problem is that the transmitter does not have any information of the channel experienced by the receiver except in systems where the uplink and downlink transmissions are carried over the same frequency. Hence, the channel information has to be fed back from the receiver to the transmitter, which results in throughput degradation and considerable added complexity to both the transmitter and the receiver.

Power control in cellular radio systems has drawn much attention since Zander's works on centralized [16] and distributed [15] carrier-to-interference ratio (CIR) balancing.

CIR balancing was further investigated by Grandhi, *et al.* [6]. Foschini and Miljanic [4] considered a more general and realistic model in which a positive receiver noise and a respective target CIR were taken into account. Based on the Foschini and Miljanic algorithm, Grandhi, *et al.* [7] suggested distributed constrained power control (DCPC), in which a transmission upper limit was considered. Recently, a lot of research has been carried out on this topic [8,11].

Based on propagation conditions, the base station may receive a power control command that specifies at what power level the base station should transmit. However, the losses on uplink and downlink are not symmetric because Rayleigh fading is frequency-selective. To mitigate this, a closed-loop power control is needed to vary the transmitted power by the base station, based on measurements made at the mobile.

Briefly, power control is a very effective technique to mitigate co-channel interference and multipath fading, but sometimes it needs a wide change at transmitted power to cope co-channel interference and multipath fading. In these cases, it takes a long time to adjust that transmitting power and power control would not be effective.

Other effective techniques are time, space and frequency diversity. Time interleaving, together with error correction coding, can improve diversity techniques. However, time interleaving results in large delays when the channel varies slowly. Equivalently, spread spectrum techniques are ineffective when the coherence bandwidth of the channel is larger than the spreading bandwidth or, equivalently, where there is relatively small delay spread in the channel. In most scattering environments, antenna diversity is a practical, effective and, hence, a widely applied technique for reducing the effect of multipath fading. The classical approach is to use multiple antennas at the receiver and perform combining or selection and switching in order to improve the quality of the received signal. The major problem with the receive diversity approach is the cost, size and power of the remote units. The use of multiple antennas and radio frequency (RF) chains (or selection and switching circuits), makes the remote units larger and more expensive.

Recently, some interesting approaches have been suggested for transmit diversity. For example space-time trellis coding was proposed in [13] and space-time block code was proposed in [2] and after that space-time became one of the most important topics in mobile communication.

These systems that make use of space and time diversity simultaneously are known as MIMO (Multiple Input Multiple Output) systems; a technique used to transmit and receive symbols from multiple antennas.

To evaluate effectively the performance of a transmission scheme, models which account for all the major effects of wireless channel on various signals are required. The most commonly used channel model for MIMO systems is independent quasi-static flat Rayleigh fading at all antenna elements. The simplicity of this channel model makes the performance analysis of these schemes less complicated.

In this paper, we use downlink power control algorithm and space-time diversity technique simultaneously. We use space-time diversity, that is currently very popular, together with some famous downlink power control algorithms. Results show that, especially for high speeds, power control algorithms may not be able to get enough performance, i.e., it takes a fairly long time to reach the desired point. Therefore, they have a low convergence speed. As mentioned before, this paper presents a method to solve this problem by the use of downlink power control and space-time diversity simultaneously.

This paper is organized as follows: At first system model is described along with system parameters. Forward link power control is also described in the second section. Afterwards, space-time coding and simulation results are given and the effect of space-time coding is also investigated by different algorithms in different environments. Finally, conclusions are given and discussed.

SYSTEM MODEL

Results presented in this paper were performed for a WCDMA system simulation platform compliant with the 3GPP recommendations. This section presents model and parameters used in simulations. Monte Carlo methodology has been used in this work. The following conditions are assumed:

- The service area consists of 19 cells. Base stations are located at the center of each cell.
- Base station antennas are supposed to be omni-directional.
- Mobile stations are uniformly distributed across the cells.
- Mobile stations receive their signal by DS-CDMA from the base station whose pilot signal is strongest (serving base station).
- The downlink dedicated physical channel has a frame which includes 15 slots per 10 ms frame. Synchronous acquisition of the frames and slots is perfect in all base stations. Spreading sequences used in frames are synchronous at the transmitter.
- Each radio channel suffers propagation loss with an attenuation coefficient α, multipath fading and inner-cell interference. Shadowing fluctuation (that has a lognormal distribution) is ignored.
- Interfering signals come from all base stations within service area.
- Downlink power control and space-time coding with RAKE receiver are used to alleviate the effects of multipath fading, co-channel interference and propagation loss.
- Speech characteristics used in these simulations are as follows: bit rate: 30 Kbit/s, spreading factor: 256, minimum required $\frac{E_b}{N_0}$: 9.6db.

Other parameters used in this system are shown in Table (1):

Table 1: System parameters.

System	WCDMA
Environment	Indoor Pedestrian Vehicular
Cell radius	1000m
Channel bandwidth	5Mhz
Chip rate	3.84Mcps
Maximum MS TX power	21dbm
Maximum total BS TX power	43dbm
MS sensitivity	-100dbm
Power control dynamic	30db
Power control step size	FSAPC: 1db VSAPC: according to algorithm used in power control process
BS antenna height	30m
Antenna gain(Ga)	11db
Carrier frequency	2150Mhz
Data modulation	QPSK
Channel multiplexing	Time multiplexing of data and control channels
Power control	Fast power control operates at the rate of 1500Hz and SIR-based
Antenna correlation	Uncorrelated
Speed of MS	3km/h (for indoor environment) 3km/h (for pedestrian environ) 120km/h (for vehicular environ)
Simulation length	500 frames
Diversity	RAKE and Space-time

In this system each cell is supposed to be in hexagonal shape like that illustrated in Figure 1. As mentioned before, each base station antenna is at the center of its cell.

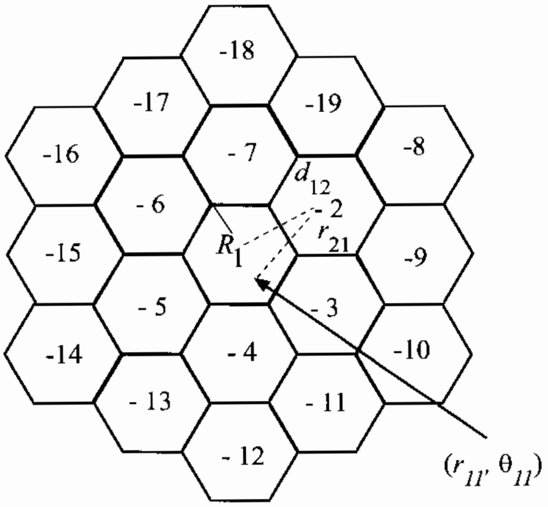

Figure 1: A set of 19 hexagonal cells.

In order to study the downlink adjacent-cell interference, a cellular system with 19 cells has been considered. Each user is assumed to be located independently from all other users and uniformly distributed over the area of the cell.

The location of a reference user in the first cell (the cell of interest) is (r_{11},θ_{11}), where r_{11} and θ_{11} stand for the distance and angle of the mobile from its base station, respectively. The distance between the base station of the i^{th} adjacent cell and reference mobile of the first cell is given by:

$$r_{i1}=\sqrt{d_{i1}^{2}+r_{11}^{2}-2d_{i1}r_{11}\cos\theta_{i1}} \qquad i=2,3,\ldots,19 \qquad (1)$$

where d_{i1} is the distance between the first base station and the i^{th} base station, and

$$d_{i1}=\begin{cases} 3R & i=2,3,\ldots,7 \\ 2\sqrt{3R} & i=8,10,\ldots,18 \\ 3R & i=9,11,\ldots,19 \end{cases} \qquad (2)$$

where R stands for radius of hexagonal cell. In (1), θ_{i1} the angle between d_{i1} and r_{11}. The relationship between θ_{i1} and θ_{11} for various values of i is given by:

$$\cos(\theta_{i1})=\begin{cases} \cos\left(\theta_{11}+(i+2)\frac{\pi}{3}\right) & 2<i<7 \\ \\ \cos\left(\theta_{11}+i\frac{\pi}{6}\right) & 8<i<19 \end{cases} \qquad (3)$$

The channel is modeled as a fading channel with Rayleigh statistics. The mobile receiver is a conventional coherent RAKE receiver with *L* resolvable paths each spaced T_c (chip period) apart.

Assuming that there are *K* active users for each cell, the received signal at the mobile user 1 (reference user) can be written as:

$$r(t|r11,\theta 11)=\sum^{19}\sum^{k}\sqrt{2P_R\zeta_{ik}r_{i1}^{r}}\,a_i(t)_e^{\varsigma i(t)}c_{ik}(t-\tau_i)b_{ik}(t-\tau_i)\cos(2\pi f_0t-\phi_i)+n(t) \qquad (4)$$

Where P_R is the transmitted power of the base station, when the reference user is located at a cell vertex ($r_{11}=$ R), and ζ_{ik}($0<\zeta_{ik}<1$) is the downlink power adjustment factor (or power control function), and $\zeta_{11}=1$ when $r_{11}=$R., c_{ik} *(t)* and b_{ik} *(t)* represent the spreading sequence with chip duration T_c and the binary data sequence with duration *T* of user *k* of cell i, respectively. τ_i and ϕ_i are the corresponding time delay and phase, respectively. Note that τ_i and ϕ_i are the same for all users of cell i because of the synchronous downlink transmission. f_0 is the CDMA carrier frequency on downlink.

As the type of frame format is very important in transmitting and receiving, we review this topic in the downlink of WCDMA systems down. Since we want to apply power control and space-time together to our system, we discuss these two very important techniques.

We consider dedicated physical channels (DPCH) consisting of dedicated physical control/data channels (DPCCH/DPDCH) in the downlink of UMTS system. The random access process and the frame synchronization are assumed finalized and the call is established in connected mode. Upon insertion of reference symbols (pilot bits), transmit power control (TPC) and transport format indicator (TFI) bits from higher protocol layers into the payload of consecutive slots, the signal transmitted by a certain base station is segmented as shown in Figure 2.

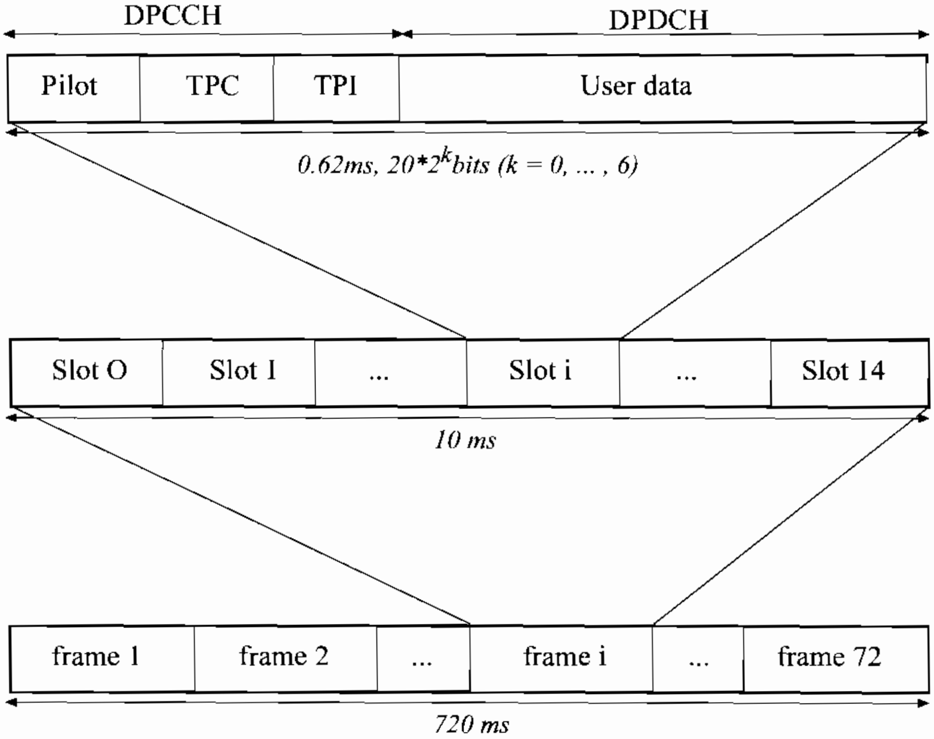

Figure 2: Frame format of a downlink DPCH.

In the downlink direction of a Direct Sequence Code Division Multiple Access System (DS-CDMA) like UTRA (Universal Terrestrial Radio Access), a Base Station (BS) simultaneously transmits signals for many different users in the same frequency band. Orthogonal spreading codes are applied to make signals separable in the code domain. Due to multipath propagation, different time delayed versions of the transmitted signals arrive at a receiving Mobile Station (MS). Conventionally, a Rake receiver coherently combines the multipath signals. Nevertheless, since time misaligned spreading codes are usually nonorthogonal, Rake receiver performance is often interference limited. Assuming perfect equalization, orthogonality between the users' signals is restored and the receiver can detect the desired signal by a simple dispreading operation. In uncorrelated frequency flat fading channels, Space-Time Block Coding (STBC) can deliver a second order diversity gain. Therefore, a two transmit antenna STBC scheme called Space-Time Transmit Diversity (STTD) was included in the UTRA FDD (Frequency Division Duplex) standard.

From the engineering standpoint, for diversity orders larger than four, increase in complexity does not pay off the achieved increase in performance. In addition, a large number of transmitting antennas imply a small average power per antenna. This is a very desirable effect if power amplifier efficiency and linearity problems are taken into account but, on the other hand, the signal-to-interference plus noise ratio per antenna is correspondingly decreased. This is a very important issue since it is related to the quality of the channel estimates obtained at the receiving end, which is required to decode the space-time coded transmitted signal. In this paper, we combine the downlink closed-loop power control with STBC diversity.

POWER CONTROL

In the downlink, multipath propagation destroys the orthogonality of the signals synchronously transmitted from a certain base station. Fast TPC, based on the measurement of SIR, can always minimize the transmit power according to the traffic load and, thus, interference with other users in the other cells can be reduced thereby increasing the link capacity. The frame structure using time-multiplexed pilot well supports SIR measurements. Both data and pilot symbols are used to measure instantaneous received signal power, but they are only used to measure instantaneous interference plus background noise power (followed by averaging using a first order filter). The channel estimation is first performed using the pilot symbols [1].

Power control algorithms can be categorized as either centralized or distributed. Current power control algorithms for wireless systems increase the power when the interference increases in order to satisfy the requested signal qualities. However, when the requested signal qualities are infeasible, the power control algorithms diverge. Such behavior results from not taking into account the fact that wireless resources are power limited.

In this paper, we apply space-time coding into some famous downlink algorithms, which are introduced in this section. The first one, taken from [16], is called distributed balancing power control algorithm (DB-PCA), which is given by

$$P^{(0)} = P_0 \qquad P_0 > 0$$

$$P_i^{(v+1)} = \beta . P^{(v)} \left(1 + \frac{1}{\Gamma_i^{(v)}}\right), \beta > 0 \tag{5}$$

where P_0 is an arbitrary positive vector, $P_i^{(v)}$ denotes the transmitting power of the base station in cell i in v^{th} discrete time, $\Gamma_i^{(v)}$ denotes the CIR at the mobile in cell i in the v^{th} discrete time, and β denotes the weighting factor.

Another distributed power control algorithm (D-PCA) proposed in [2] adapts the transmitting power according to the observed interference, i.e.,

$$P_i^{(v+1)} = \beta \mathrm{I}_i^{(v)} \tag{6}$$

where $I_i^{(v)}$ is the interference power received by the mobile in cell i in v^{th} discrete time.

The third algorithm investigated here is the so called "bang-bang" power control (B-BPC) [3] that is used for uplink power control of the IS-95 system [14] and currently being considered for uplink and downlink of the WCDMA system. This algorithm is given by:

$$P_i^{(v+1)} = \min\{P_{max}, \; max \; \{P_{min}, \; \Delta_i^{(v)} \, P_i^{(v)}\}$$

$$\Delta_i^{(v)} = \begin{cases} \Delta & \gamma_i^{(v)} \le \gamma_i^t \\ \frac{1}{\Delta} & \gamma_i^{(v)} \ge \gamma_i^t \end{cases} \tag{7}$$

where $P_i^{(v)}$= denotes the transmitting power of the base station in cell i in v^{th} discrete time, γ_i^t is the target value, $\gamma_i^{(v)}$ denotes the received CIR of the mobile at iteration v and Δ is step size.

The last algorithm called fully distributed power control, (FDPC) [16] is described below.

$$P^{(0)} = 1$$

$$P_i^{(v+1)} = \eta^{(v)} * P_i^{(v)}$$

where

$$\eta_i^{(v)} = \frac{\min\,(\Gamma_i^{(v)}, \psi)}{\Gamma_i^{(v)}} \qquad 0 < \psi < \infty$$

In this algorithm, as long as the value of ψ is determined (a priori), base stations do not need to exchange information to perform the power control algorithm.

The idea of the above FDPC algorithm is to increase or decrease transmitting power (in db) of base station i in proportion to the difference of CIR at mobile i and a constant. Furthermore, if , then the above algorithm can be expressed as

$$P^{(0)} = 1$$

and

$$dbP_i^{(v+1)} - dbP_i^{(v)} = -\,(db\Gamma_i^{(v)} - db\psi)$$

However, in order to avoid a normalization procedure to make the algorithm fully distributed, we choose $\eta_i^{(v)}$ as given in (9). It is obvious when $\psi \to \infty$, FDPC algorithm becomes the fixed transmit power algorithm (i.e., without power control).

SPACE-TIME CODING

Space-time coding was first presented in 1998, using trellis codes by Tarokh et al. [13]. It is a new coding framework for wireless communication systems with multiple transmit and multiple receive antennas. This new framework has the potential of dramatically improving the capacity and data rates. In addition, this framework presents the best tradeoff between spectral efficiency and power consumption. Space-time trellis codes offer the maximum possible diversity gain and a coding gain without sacrifice in the transmission bandwidth. The decoding of these codes, however, would require the use of a vector form of the Viterbi decoder. On the other hand, space-time block codes offer a much simpler way of obtaining transmit diversity without any sacrifice in bandwidth and also without requiring huge decoding complexity. The new signal processing framework offered by space-time codes can be used to enhance the data rate and/or capacity in various wireless applications.

Figure 3 shows a basic model for a communication system that employs space-time coding with *N* transmit antennas and *M* receive antennas.

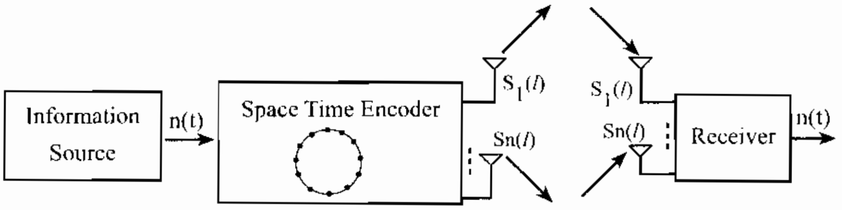

Figure 3: Space-Timel Coding.

The information symbol *s(l)* at time *l* is encoded by the space-time encoder as *N* code symbols $s_1(l), s_2(l), \ldots, s_N(l)$. Each code symbol is transmitted simultaneously from different antenna. The encoder chooses the *N* code symbols to transmit so that the coding gain and diversity gain at the receiver are maximized. Signals arriving at different receive antennas undergo independent fading. The signal at each receive antenna is a noisy superposition of the faded versions of the *N* transmitted signals. We assume a flat fading channel.

Schemes which use multiple transmit and receive antennas for communicating over a wireless channel are usually called Multiple Input Multiple Output (MIMO) schemes.

In this paper, we have used a new space-time scheme proposed by Alamouti [2]. Figure 4 shows the block diagram for this scheme.

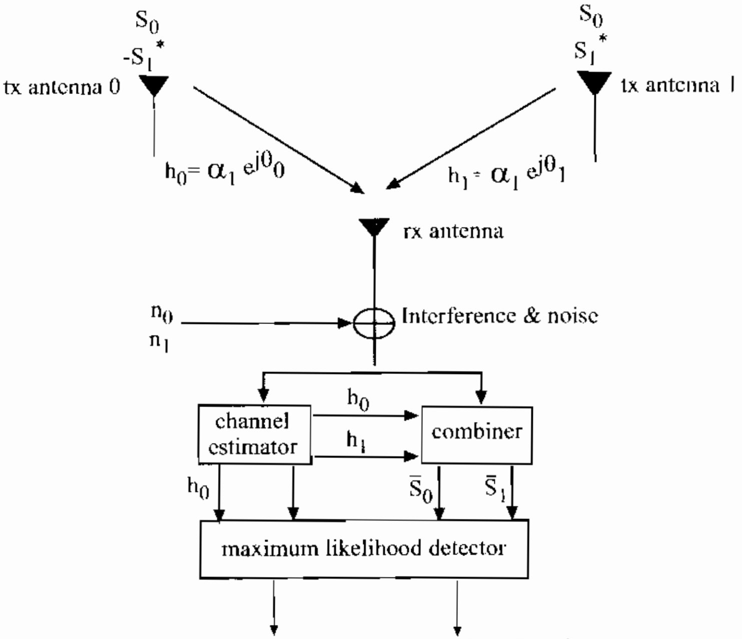

Figure 4: Alamouti's scheme in MIMO systems.

In this scenario with two transmit antennas, the STBC encoder matrix is

$$S = \begin{bmatrix} S_0 & S_1 \\ -S_0^{*} & S_1^{*} \end{bmatrix} \tag{11}$$

Here, since $SS^H = \alpha I$, we have two orthogonal signal sequences. This helps us separate the two sequences easily at the receiver.

As mentioned earlier, space-time block coding ensures that transmissions from various antennas are orthogonal. This allows even a single element receiver to exploit a transmit diversity gain, which is similar to the gain obtained by using Maximal Ratio Combining (MRC) in multiple receive antenna systems. The advantage of space-time codes lies in the fact that diversity advantage is obtained by shifting the complexity of adding additional antennas to the transmitter while allowing the complexity of receiver to be reasonably low. The spectral efficiency of STBC schemes depends on the type of modulation and the coding scheme which is employed.

SIMULATION RESULTS

The parameters used in the simulation are given in Table 1. The simulation is done based on Monte Carlo methodology for 500 frames and data rate is 30kbps. We carried out the simulation for indoor office channel A, indoor-outdoor pedestrian channel A and vehicular channel A environments. First, for the indoor channel A we compared the difference in performance between DB-PCA, D-PCA, B-BPC and FDPC algorithms. Then, we applied space-time coding to the last three algorithms and observed the performance results in each. The bit error rates (BER) given in Figure 5 indicate that in indoor channel with simple antennas at the center of each base station, FDPC algorithm has the best performance. Figure 6 shows results when we applied space-time coding at the center of each cell. It is obvious that D-PCA, B-BPC and FDPC algorithms give much better performance in comparison with previous case. DB-PCA is used as a reference for other algorithms, so it is without STC. Figures 7 and 8 show the results for pedestrian A and vehicular A channels. DB-PCA without STC with respect to indoor channel has a better performance. It can be seen again that STC improves the performance. In Figure 8, at the first glance, we can see that DB-PCA performance that is without STC is poor with respect to two earlier cases. This shows the strong impact of power control delay at high delays, which increases the negative effect as the Doppler frequency increases. D-PCA, B-BPC, and FDPC algorithms show a pretty good performance when STC is used. Therefore, for high speeds, power control may not be able to perform well without STC, i.e., it takes a fairly long time to reach the desired point. In other words, they have a low convergence speed without STC. In this paper, we presented a method for increasing convergence speed in different channel conditions, especially when high speed, multipath fading, inter-cell interference and propagation loss degrades the system performance.

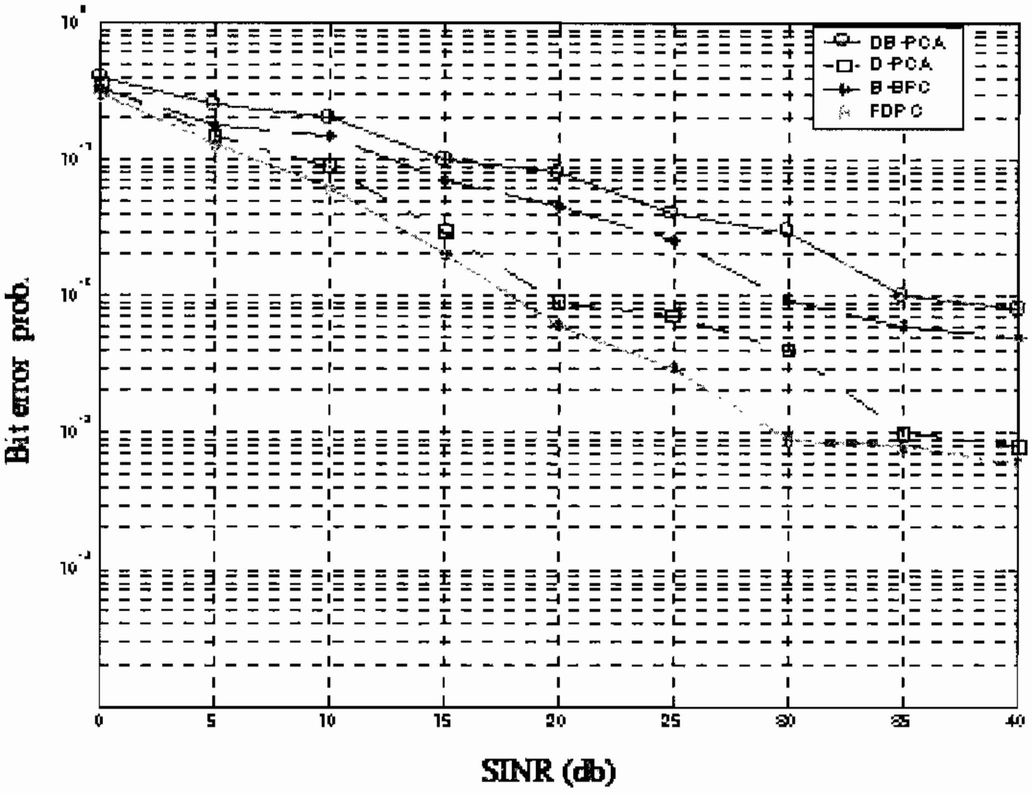

Figure 5: Comparison of 4 algorithms in indoor channel A without STC.

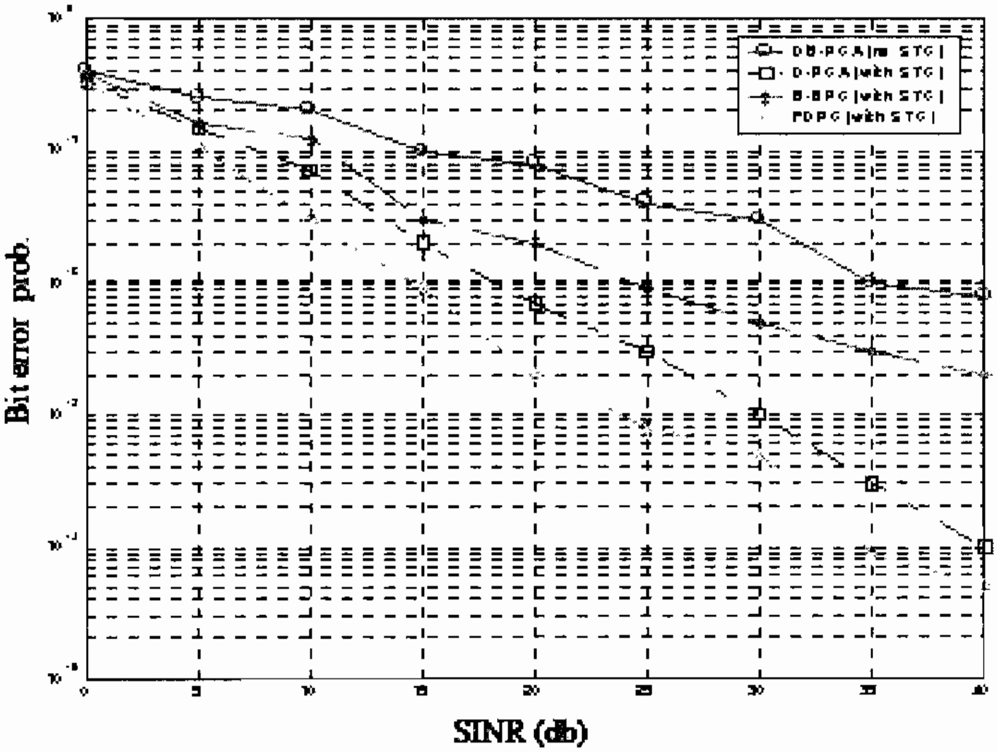

Figure 6: Comparison of 4 algorithms in indoor channel A with applying STC to all except DB-PCA.

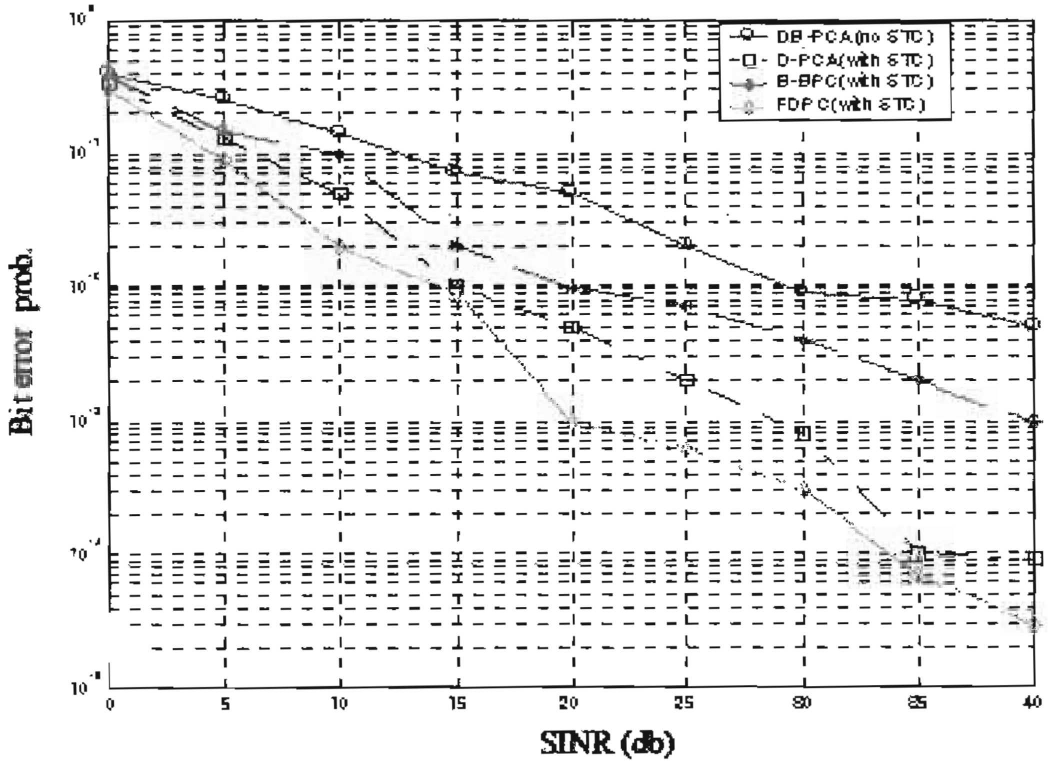

Figure 7: Comparison of 4 algorithms in pedestrian channel A with applying STC to all except DB-PCA.

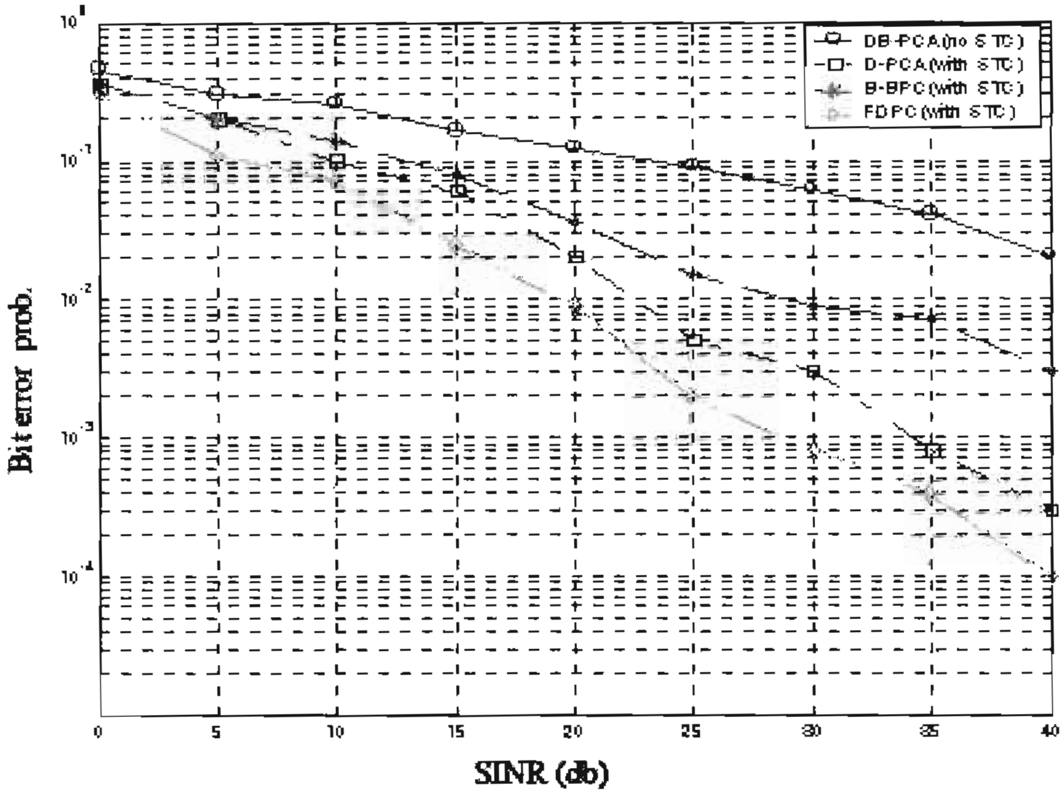

Figure 8: Comparison of 4 algorithms in vehicular channel A with applying STC to all except DB-PCA.

CONCLUSIONS

In forward link of a WCDMA system, subscribers need various types of service that should be in a good quality. But some factors like multipath fading, inter-cell interference and propagation loss are against these wishes especially when speed rises. In this paper, we showed that these problems can be solved by using power control and space-time coding together in a system. We did not, however, consider some other factors such as channel coding and interleaving that can be effective to solve these problems.

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