

## Transmit Diversity Schemes for CDMA-2000

Dinesh Rajan  
Rice University  
6100 Main St.  
Houston, TX 77005  
[dinesh@rice.edu](mailto:dinesh@rice.edu)

Steven D. Gray  
Nokia Research Center  
6000, Connection Dr.  
Irving, TX 75240  
[steven.gray@nokia.com](mailto:steven.gray@nokia.com)

**Abstract - Transmit diversity offers an advantage in the forward link of the cdma2000 system by balancing the spectrum efficiency in the uplink and downlink. Three schemes for performing transmit diversity are examined in this paper – orthogonal transmit diversity, time switched transmit diversity, and selection transmit diversity for vehicular, indoor-outdoor pedestrian and indoor office environments. Also considered are some issues related to implementation complexity in the mobile handset. Under certain channel conditions, we show that low rate feedback of antenna selection and no forward link power control offers performance advantages over transmit diversity schemes with forward link power control and no antenna selection.**

### I. INTRODUCTION

Third Generation cellular systems are expected to provide increased throughput, both for voice and packet data transmission. To achieve this goal, we must overcome the limitations inherent in a wireless channel. One of the biggest hurdles of mobile cellular communications is that of multipath fading, implying that, multiple copies of the transmitted signal are received with varying amounts of attenuation and delay.

Diversity techniques are usually employed at either the transmitter and/or receiver to overcome the problem of fading. There are many techniques for providing diversity including temporal, frequency and spatial.

In a cdma2000 system the bottleneck in capacity occurs in the forward link. This is due to the fact that the reverse link employs two antennas at the Base Station (BS) and maximal-ratio-combining of the received signals. As a result, transmit diversity schemes aid in balancing the forward and reverse links.

Three schemes for transmit diversity are Orthogonal Transmit Diversity (OTD)[1], Time-Switched Transmit Diversity (TSTD)[4], and Selection Transmit Diversity (STD)[3]. It is unclear as to which of these schemes achieves the best tradeoff of performance improvement vs implementation complexity. In this paper

we present the results of simulations of the above schemes under the context of a cdma2000 3X physical layer. The remainder of the paper is organized as follows. Section 2 gives a description of the transmitter and receiver for the three diversity schemes. The results of our simulations are given in Section 3 followed by conclusions in Section 4.

### 2. TRANSMIT DIVERSITY SCHEMES

Table 1 gives the values for different operational environments for a low and median delay spread given by channels A and B respectively [2]. The RMS delay spread increases in going from an indoor office environment to outdoor pedestrian environment and finally to the vehicular environment. The cdma2000 system considered has a nominal operating bandwidth of a 3X system (3.6864 Mcps); the resolvability of the multipaths is approximately 270 nanoseconds. A frequency selective channel exists for the vehicular environment whereas the pedestrian and indoor environments are mostly characterized by flat fading. With a suitable rake receiver, the expectation is that the performance gain from transmit diversity is less for the vehicular environment when compared to the pedestrian and indoor environments.

#### 2.1 Orthogonal Transmit Diversity

Orthogonal Transmit Diversity (OTD) is implemented in the transmitter as shown in Fig. 1. The coded and interleaved bits are split into two different streams for simultaneous transmission over different transmit antennas. Different Walsh spreading codes are used for both streams to maintain the orthogonality. In order to maintain the effective number of Walsh codes per user as in single antenna transmission, the spreading length is doubled.

Although we have considered the case of two transmit antennas, the scheme can be readily applied to any number of transmitting antenna. In addition to the normal pilot on one antenna, an auxiliary pilot is transmitted on the second antenna to aid in coherent detection at the receiver.

TABLE I - PARAMETERS FOR CHANNEL IMPULSE RESPONSE MODEL [5]

Test Environment	Rms. Average delay spread for Channel A	P (A) (%)	Rms. average delay spread for Channel B	P (B) (%)
Indoor Office	35 ns	50	100 ns	45
Outdoor to Indoor and Pedestrian	45 ns	40	750 ns	55
Vehicular	370 ns	40	4000 ns	55

## 2.2 Time Switched Transmit Diversity

Time Switched Transmit Diversity (TSTD) is implemented in the transmitter as shown in Fig. 1. Unlike OTD where both the antennas are used all the time, in TSTD each user uses only one of the antennas at any instant of time. The same Walsh code is used for transmission on both the antennas and the length of these codes is the same as in single antenna transmission.

The different users could be forced to shift between antennas using identical or different pseudo random switching patterns. Switching them pseudo-randomly means that on the average half the users will use one antenna and hence the capacity and crest factor of the power amplifiers are reduced. As in the case of OTD, two different pilots are needed for coherent detection.

## 2.3 Selection Transmit Diversity (STD)

Selective Transmit Diversity (STD) is implemented as shown in Fig. 1. The instantaneous transmit antenna used in TSTD may not yield the highest SNR at the MS receiver. Ideally, we want the transmitter to choose that antenna that yields the highest received SNR. However this is not possible because the transmitter does not know the state of the channel between the BS and MS. Hence a feedback channel is used from the MS to the BS, indicating which of the two antennas has a higher SNR.

To prevent a large reduction in the reverse link capacity, a one-bit antenna selection (AS) message is sent from the mobile to the base station. An important consideration is how the performance is affected by the AS rate, the delay in implementing the AS command and error in the AS feedback. Ideally, the rate of feedback should be matched to the channel variations, the delay is zero and the feedback channel error rate is also zero. However using a variable rate feedback scheme is complicated and a fixed rate scheme must be used for ease of implementation.

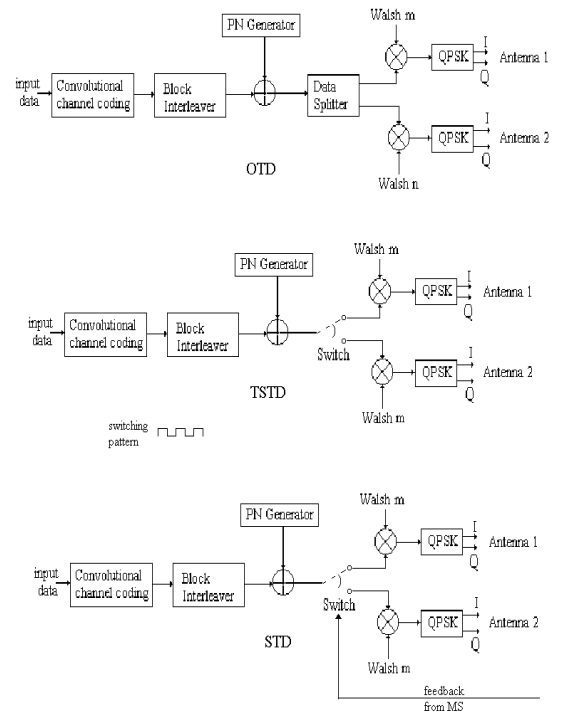


Fig. 1. Transmitter for OTD, TSTD and STD

The basic idea behind these schemes is that even if the channel between one of the antennas and the receiver goes through a deep fade, the channel code is strong enough to recover the lost information. This conjecture assumes that the fading between the antennas is uncorrelated. In reality, experimental data has shown that the correlation coefficient as seen at the mobile from the two antennas may be as large as 0.7.

The correlation between transmit antennas is affected by antenna spacing, orientation and polarization. The trade-offs of BS antenna design are such that to get maximum diversity a large antenna separation is required. However, large antenna separation may cause a time difference in multipath arrivals from each antenna causing an increase in searcher hardware at the mobile. Also in the case of TSTD and STD, if the time delay from the two antennas is large, an increase in multiuser interference will occur.

## 2.4 Receiver Issues

The structure of a typical Rake receiver is shown in Fig. 2. The following steps are taken in detecting the signal. 1. The received signal is despread by the pilot sequence to obtain a channel estimate, 2. each finger is

adjusted in delay to match the multipath profile, 3. the data channel is despread and 4. the output of each finger is weighted and combined. Considering each of the diversity schemes, modifications must be made to the mobile's RAKE receiver. The appropriate modifications shown in Fig. 3 are additional integrators for the pilot and data channels for OTD and an additional integrator for the auxiliary pilot for TSTD and STD.

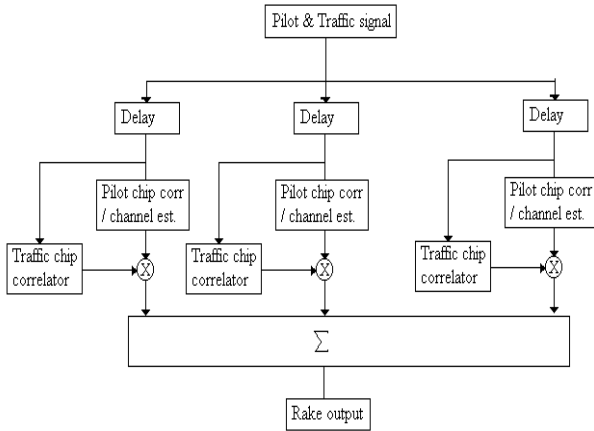


Fig. 2. Structure of a RAKE receiver

Based on a first order approximation, the complexity of OTD and TSTD are comparable. The switch in TSTD replaces the combiner in OTD. Also there is an additional multiplier and traffic integrator needed in OTD. We feel there is not much difference in hardware complexity between TSTD and STD. We use the AS message in STD to control the switch at the transmitter.

**3. SIMULATION RESULTS**

The parameters used in the simulations are given in Table II. All simulations were done in COSSAP.

We carried out the simulations for the indoor-outdoor pedestrian channel A and vehicular channel A as specified in [1]. First, for the pedestrian channel A, we compared the difference in performance between OTD, TSTD and STD. The Frame error rates (FER) given in Fig. 4 indicate that TSTD has about 0.1–0.2 dB gain over OTD. STD is about 0.3-0.5 dB better than TSTD.

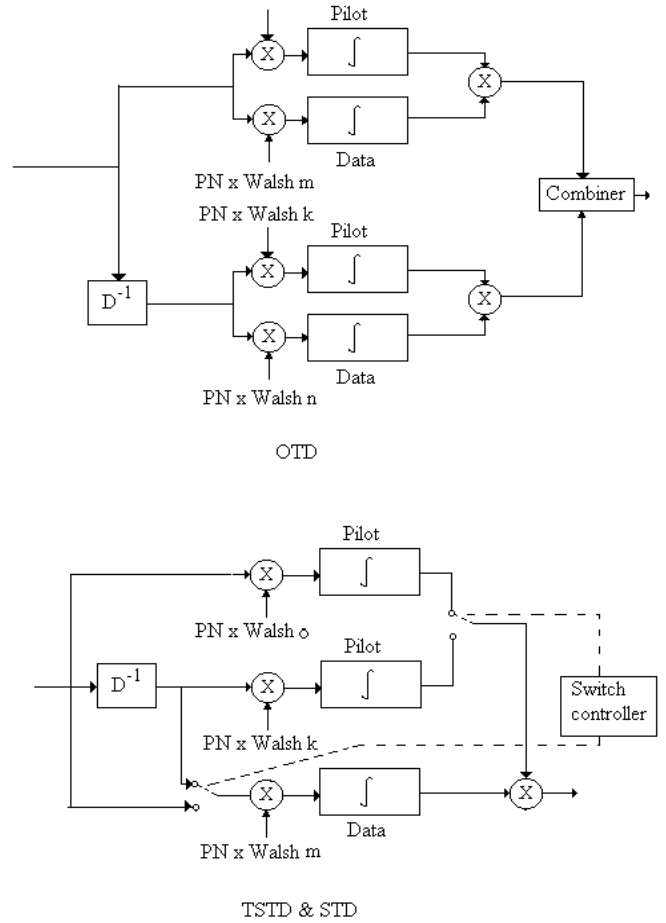


Fig. 3. Rake finger modifications for OTD, TSTD and STD

TABLE II SIMULATION PARAMETERS

Carrier Frequency	2 GHz
Chip Rate	3.6864 MHz
Information Bit Rate	9600 bits per second
Walsh Code Length	256 ( TSTD, STD) 512 ( OTD )
Frame Size	20 ms
Convolutional Channel Coding	Rate = 1/3 , K = 9
Antenna Correlation's	0, 0.5 and 0.75
Number of interfering users	20
$\hat{I}_{or} / I_{oc} + N_0$	8 dB
Pilot Power	- 7 dB
Rake finger assignment	Fixed, known multipath position
AS signaling rate	800 Hz
AS error rate	4 %

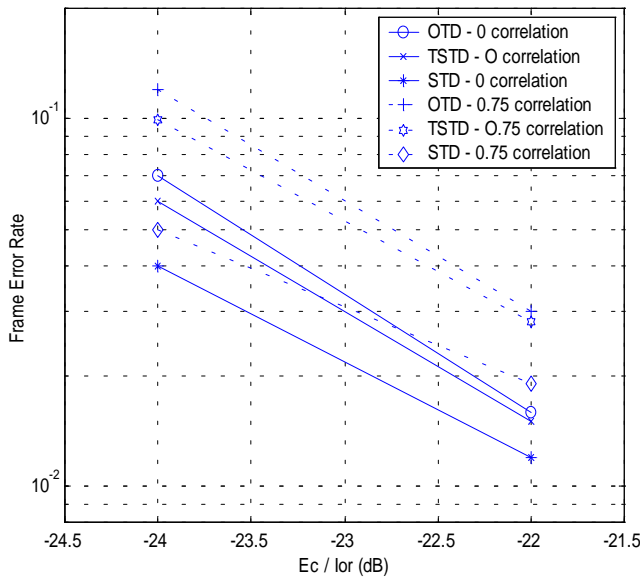


Fig. 4. Performance of OTD, TSTD and STD, indoor-outdoor pedestrian A channel, 3.0 kmph, no power control

Fig.4 also shows that for antenna correlation of 0.75, OTD and TSTD suffer a loss between 0.7 – 0.9dB at antenna correlation of 0.75. However, STD is only about 0.3-0.5dB worse. Hence at a correlation of 0.75, STD is about 1dB better than TSTD, which in turn is about 0.2dB better than OTD. However for antenna correlation of 1, the performance of STD is the same as that of having no diversity. Hence the performance of STD deteriorates rapidly for correlations higher than 0.75. In practical situations, the antennas can be placed such that the antenna correlation is less than 0.75.

The performance of OTD, TSTD and STD in the vehicular A channel, for a mobile speed of 120.0 kmph is given in Fig. 5. The results indicate that there is not much difference between OTD and TSTD. Further more their performance is close to the no diversity case. The performance of STD is much worse than the no diversity case. This is because the channel changes so fast that the AS message is outdated and the inferior antenna is often selected.

OTD and TSTD are relatively insensitive to antenna correlation, in the vehicular case as evidenced from Fig. 5. However, as shown in Fig. 5, the performance of STD improves with increasing correlation. This is because for zero correlation, the performance of STD is worse than the no diversity case and for a correlation of one, the performance of the two are identical. Although counter intuitive at first, this can be explained by the fact that whenever the AS message is outdated, if the wrong

antenna goes through a fading state that is closer to that of the better antenna, then the performance is better.

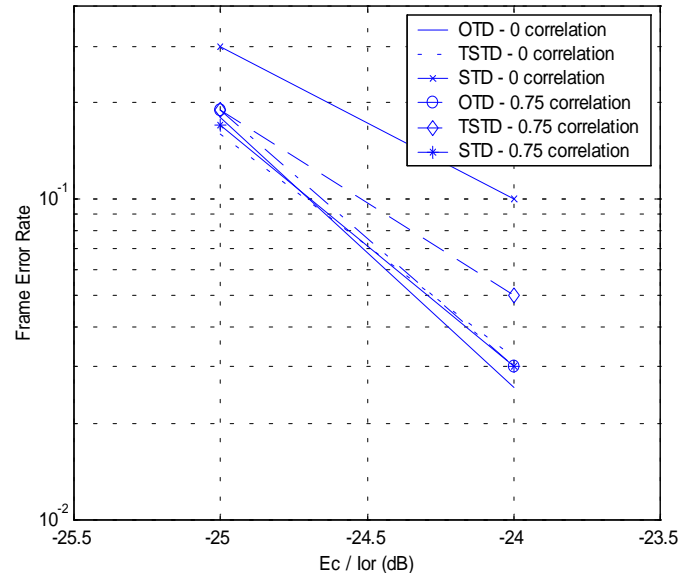


Fig. 5. Performance of OTD, TSTD and STD, vehicular A channel, 120.0 kmph, no power control

Next, we studied the effects of switching frequency on the performance of TSTD. We found that the optimum switching frequency in terms of FER for TSTD depends on the Doppler rate of the channel, which is highly dependent on the speed of the mobile. Due to the difficulties in dynamically changing the switching frequency, a nominal frequency of 800 Hz was chosen due to good average performance. (Note - we chose 800 Hz because it is the same as one Power Control Group period)

Fig. 6 shows the effect of improving the quality of the feedback channel on STD performance. For purposes of simulation the feedback channel is modeled as a Binary Symmetric Channel (BSC) with 4% crossover probability, under all conditions (outdoor and vehicular). As the error rate on the feedback channel is reduced from 4% to 1%, approximately 1dB improvement in STD performance is observed. One possible way of improving the feedback rate is by using channel coding. For reducing delay, we suggest the use of a simple repetition code.

We found that the trends exhibited by TSTD and OTD with power control are similar to that without power control. For a fair comparison between STD and the other schemes, we fixed the rate of AS commands and compared TSTD with power control information at 800 Hz and STD without power control. Since STD is more sensitive to errors in the feedback channel, we use 400 Hz feedback with rate  $\frac{1}{2}$  repetitive coding, rather than 800 Hz feedback and no coding. The comparison is given in Fig. 7. We see

that STD performs about 1dB better than TSTD, with power control at an FER of 10%. Also in the range of FER's that we are interested in (between 10 % and 1 %) STD performance is better. We noted that going to lower information rate and higher code rates will not give much further gain in STD performance.

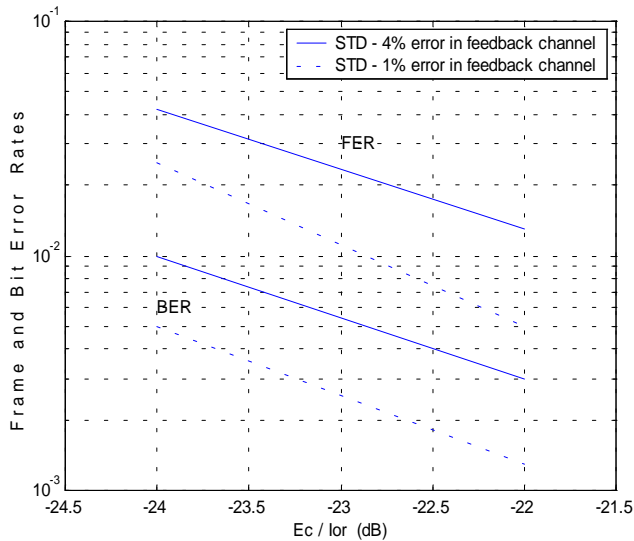


Fig. 6. Effect of error in AS message on STD performance, outdoor A channel, 3.0kmph

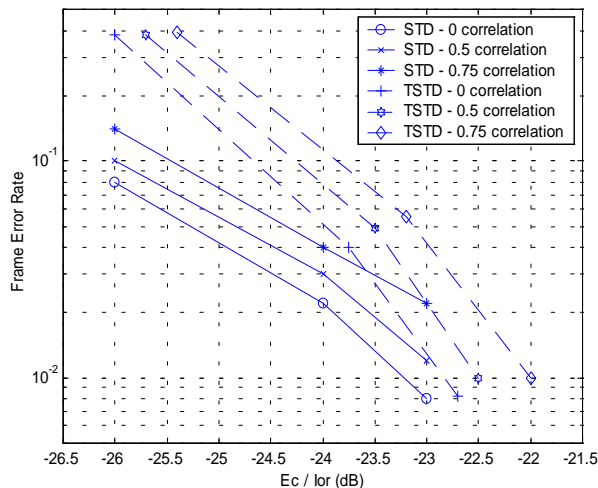


Fig. 7. Comparison of TSTD with power control and STD without power control, outdoor A channel, 3.0 kmph.

A different approach to improve the performance of STD is to implement a verification process. Verification is achieved by distinguishing the signal on the two antennas by suitable means (ex. using different pilot symbols). The receiver determines which antenna was used for transmission, and uses this information for decoding purposes, rather than assume that the AS message that it sent to the transmitter was error free. We feel that if the AS

messages are channel coded, resulting in very low error rates, then the gain from antenna verification is minimal. In addition it increases the software and hardware complexity at the mobile station.

Another interesting result of this simulation study is that there appears to be no monotonic relationship between the FER and BER. This may be due to correlated bit errors and block interleaver used was designed for a single antenna system. To optimize performance for systems with antenna diversity, the interleaver design must be changed.

#### 4. CONCLUSIONS

Results from this study indicate that the performance of STD is better than OTD and TSTD in the indoor-outdoor pedestrian environments. Although STD performance is poor in fast fading channels, our initial goal was to add diversity gain in slowly changing flat fading channels.

The comparison of STD without power control and TSTD with power control, clearly shows that it is better to use the feedback channel to send antenna selection messages, rather than power control messages. We know that power control offers no performance gain in the vehicular case and hence even in that scenario, STD without power control is better than OTD or TSTD with power control. A first order hardware complexity analysis has not been conclusive in favor of any of these three schemes. Thus, from a pure performance perspective in slow fading, STD with 400Hz feedback and rate  $\frac{1}{2}$  repetitive coding offers cdma2000 a performance boost over other transmit diversity schemes.

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