

A comparison of the open loop transmit diversity schemes for third generation wireless systems

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Abstract- Multiple transmit antennas giving rise to diversity (transmit diversity) have been shown to increase downlink (base station to the mobile) capacity in cellular systems. The third generation partnership project (3Gpp) for WCDMA FDD has chosen space time transmit diversity (STTD) as the open loop transmit diversity technique for two transmit antennas. On the other hand, the CDMA2000 has chosen space time spreading (STS) and orthogonal transmit diversity (OTD) as the open loop transmit diversity techniques. In this paper, we compare the open loop transmit diversity techniques of 3Gpp and CDMA 2000. We show that STS involves a QPSK to non-QPSK constellation transformation followed by an STTD encoding of the resulting symbols. Thus, the performance of STS is the same as STTD, while the peak to average ratio (PAR) and complexity of STS is higher than STTD. We also show theoretically that the performance of STTD is 0.3-0.5 dB better than OTD. Further, STTD has another distinct advantage over OTD and STS in its application to the broadcast channels. During the power on and possibly during soft handoff, the mobile does not know the presence/absence of the diversity antenna on the primary/soft handoff base station. In this case, a blind detection of the diversity antenna is possible for STTD with a very small degradation in performance. This is not possible for OTD and STS. We thus show that STTD is a better open loop transmit diversity technique than OTD and STS.

1.0 INTRODUCTION

Transmit antenna diversity as a means of improving the base station to mobile performance has been an active area of research lately. Transmit diversity schemes can be broadly divided into two categories, the ones requiring mobile to base station feedback called as the closed loop transmit diversity schemes and the ones not requiring the mobile to base station feedback, referred to as the open loop transmit diversity schemes.

Standardization for third generation wireless systems has employed transmit diversity as a means of enhancing the down link (base station to mobile) capacity. The third generation partnership project (3Gpp) has developed the wideband CDMA (WCDMA) frequency division duplex (FDD) and time division duplex (TDD) systems. The CDMA 2000 based 3Gpp2 is an FDD system. Feedback from the mobile to the base station is inherent in the dedicated channels for 3Gpp TDD system wherein the base station can use the uplink (mobile to the base station) measurements for downlink transmit diversity. However, this technique is not very useful for the broadcast channels of the 3Gpp TDD

system and open loop transmit diversity has to be employed for those channels. For the 3Gpp WCDMA FDD systems explicit mobile to base station feedback is required for closed loop transmit diversity. Depending upon the feedback rate, the open loop transmit diversity schemes ultimately out perform the closed loop diversity schemes at high Doppler rates [18]. Also, only open loop diversity schemes can be employed on the broadcast channels of both FDD and TDD systems. Thus, both closed loop and open loop diversity schemes are used to enhance the performance of the 3Gpp WCDMA FDD system. Only open loop transmit diversity is used by CDMA 2000. In this paper we compare the open loop transmit diversity schemes adopted by the 3Gpp WCDMA FDD and CDMA 2000. The receiver structure for the open loop transmit diversity scheme for 3Gpp WCDMA TDD is very different from that for the FDD system, hence it is considered separately [1, 17].

An open loop transmit diversity scheme was first proposed in [2] and it includes the delay diversity scheme of [3] as a special case. The delay diversity for CDMA systems was also proposed in the distributed antenna concept of [4]. The delay diversity for CDMA has the drawback of increased multipath interference. Orthogonal spreading sequences for diversity antennas of CDMA systems was proposed in [5]. This scheme has the drawback of increased Walsh code usage/bandwidth to achieve diversity from multiple antennas. A space time block coding based approach for transmit antenna diversity (STTD) was proposed for TDMA systems in [6]. The attractive feature of this scheme is that it achieves full diversity from multiple antennas without any bandwidth increase. For CDMA systems this would imply no increase in the Walsh codes used. Further, the linear receiver for space time block codes yields soft outputs that can be easily used by any of the forward error correction schemes usually used in practice. Additional open loop transmit diversity techniques proposed in the literature include the space time trellis coding approach in [14]. However, this scheme has the drawback of increased complexity (as compared to space time block codes) when concatenated with the conventional channel codes. Another open loop transmit diversity is the fading-resistant modulation approach of [16]. However referring to figure [8] of [16] the space time block code achieves the performance of identical transmissions (but with no increase in transmission bandwidth) which implies 2 dB better performance than the optimal fading-resistant constellation. Further the implementation of the maximum likelihood receiver for the fading resistant modulation is more complex compared to the maximum likelihood receiver for space time block codes, which turns out to be a linear receiver [6].

Because of its advantage over the other open loop transmit diversity schemes, Texas Instruments first proposed the STTD technique for CDMA systems to the ETSI (European Telecommunications Standard Institute) and ARIB (Association of Radio Industries and Business, Japan) standardization bodies in December 1998 [7]. Other open loop transmit diversity techniques proposed to ETSI were the orthogonal transmit diversity (OTD) by Motorola and the time switched time diversity (TSTD) by Samsung. The 3Gpp, which consists of both the ETSI and ARIB bodies as its members, accepted the STTD for WCDMA proposal of Texas Instruments in January of 1999 [8, 15]. The subsequent versions of the 3Gpp standard document are available publicly from the 3GPP website [9]. The simulation results comparing STTD performance to OTD and TSTD were presented in [10]. Space time spreading (STS) technique [11], [12], which is very similar to STTD, was introduced to CDMA 2000 by Lucent in August 1999 [13]. The other open loop transmit diversity proposal to CDMA 2000 was OTD. CDMA 2000 accepted both the OTD and the STS proposals as the open loop transmit diversity techniques.

In this paper we compare the STTD technique accepted by the 3Gpp WCDMA FDD standard and the OTD and STS techniques accepted by CDMA 2000. Both 3Gpp and CDMA 2000 employ quadrature phase shift keying (QPSK) modulation. The symbols transmitted on the two antennas for the STTD scheme are QPSK. On the other hand, we show that the STS scheme for CDMA 2000 involves a QPSK to a non-QPSK constellation transformation followed by an STTD encoding of the resulting symbols. There is no advantage in doing the QPSK to non-QPSK transformation prior to STTD encoding. This implies that the performance of STS is the same as STTD, but the peak to average ratio (PAR) and the complexity of STS are higher than those of STTD. We also present simulation results showing that STTD outperforms OTD by 0.3-0.5 dB.

Further, STTD has another distinct advantage over OTD and STS in its application to the broadcast channels. During initial power on of the mobile and possibly during soft handoffs, the mobile does not know the presence/absence of the diversity antenna on the primary/soft handoff base station. In this case, a blind detection of the diversity antenna is possible for STTD with a very small degradation in performance. This is not possible for OTD and STS. We thus show that STTD is a better open loop transmit diversity technique than OTD and STS.

2.0 The open loop transmit diversity techniques of 3Gpp and CDMA 2000

In this section we summarize the various open loop transmit diversity schemes that have been accepted by the 3Gpp and CDMA 2000.

2.1 Space time block coding based transmit antenna diversity (STTD)

A method of space time block coding for TDMA systems was proposed in [6]. However the receiver structure in [6] only addressed flat fading channels. It was observed [7, 8, 10] that the same scheme could also be applied for the WCDMA system and it was called as the space time block coding based transmit diversity (STTD). Further, it turns out that for

CDMA systems where the Gaussian assumption can be used for the interference, the optimum receiver for STTD in the presence of multi-path components is the STTD decoder [6] for individual multi-path components, followed by the rake receiver based maximal ratio combining [7,8]. For very small spreading gains of CDMA systems or in frequency selective TDMA systems, the multi-path components could imply significant inter symbol interference (ISI), and equalization for STTD encoding has to be done. This is addressed separately [1, 17]. The STTD encoder for the WCDMA system [10] based upon the STTD encoding for TDMA systems [6] is shown in figures 1, 2.

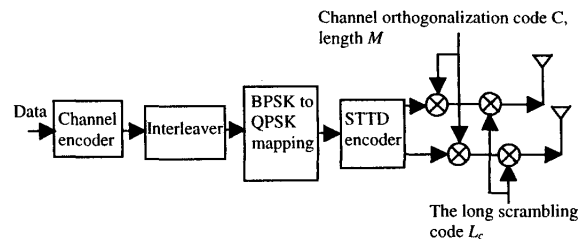


Figure 1: Block diagram of the transmitter for STTD.

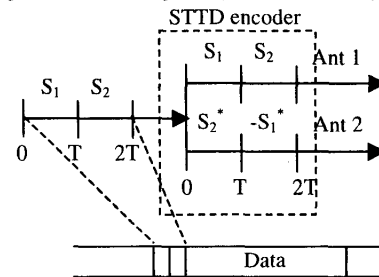


Figure 2: Block diagram of the STTD encoder.

For the STTD encoding scheme in figure 2, the symbols S_1 and S_2 can be any complex symbols, not necessarily QPSK. However, for the 3Gpp WCDMA system S_1 and S_2 are QPSK complex symbols. The T denotes the symbol time and $T = MT_c$, where T_c is the chip time and M the spreading gain.

2.2 Orthogonal transmit diversity (OTD)

The orthogonal transmit diversity scheme was proposed to 3Gpp by Motorola. It was shown in [7, 8, 10] that STTD outperforms OTD. Hence 3Gpp selected STTD as the open loop transmit diversity scheme. The OTD scheme was also proposed to CDMA 2000 by Motorola. The CDMA 2000 has selected OTD as one of its open loop diversity modes.

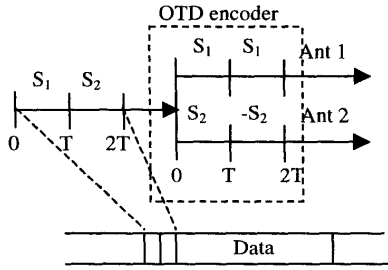


Figure 3: Block diagram of the OTD encoder

OTD exploits antenna diversity through the redundancy in channel coding and the interleaver/deinterleaver.

2.3 Space time spreading (STS)

The STS scheme was proposed to CDMA 2000 by Lucent [11-13]. CDMA 2000 has accepted STS in addition to OTD as one of its open loop transmit diversity modes. A block diagram of the STS scheme is shown in Figure (4). The input to the STS encoder is the output of the channel encoder and interleaver.

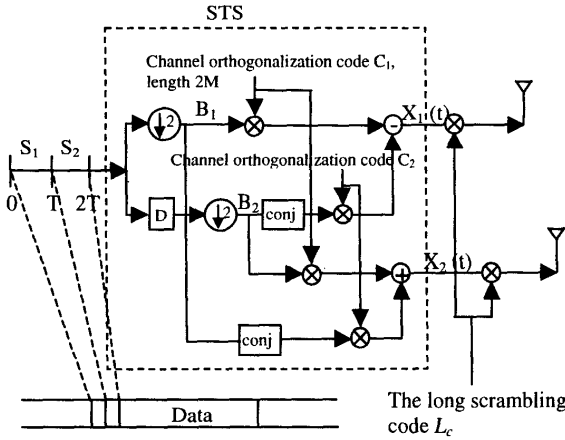


Figure 4: The STS encoder is shown

The signals B_1 and B_2 are spread over a time $[0, 2T)$ and are given by; $B_1 = \begin{bmatrix} \frac{S_1}{\sqrt{2}} & \frac{S_1}{\sqrt{2}} \end{bmatrix}$ and $B_2 = \begin{bmatrix} \frac{S_2}{\sqrt{2}} & \frac{S_2}{\sqrt{2}} \end{bmatrix}$. The orthogonal codes C_1 and C_2 are of length $2M$ chips and for CDMA 2000 are given by $C_1 = [C \ C]$ and $C_2 = [C \ -C]$ [11, 12, 13]. The signals X_1 and X_2 over time $[0, 2T)$ are given by;

$$X_1 = (B_1 C_1 - B_2^* C_2) \dots \dots \dots (1)$$

$$X_2 = (B_2 C_1 + B_1^* C_2) \dots \dots \dots (2)$$

Substituting for B_1 , B_2 , C_1 , C_2 we rearrange the terms in equations :

$$\begin{aligned} X_1 &= (B_1 C_1 - B_2^* C_2) = \frac{1}{\sqrt{2}} ([S_1 \ S_1] [C \ C] - [S_2^* \ S_2^*] [C \ -C]) \\ &= \frac{1}{\sqrt{2}} ((S_1 - S_2^*) C \ (S_1 + S_2^*) C) \end{aligned}$$

Similarly we get;

$$\begin{aligned} X_2 &= (B_2 C_1 + B_1^* C_2) = \frac{1}{\sqrt{2}} ([S_2 \ S_2] [C \ C] + [S_1^* \ S_1^*] [C \ -C]) \\ &= \frac{1}{\sqrt{2}} ((S_2 + S_1^*) C \ (S_2 - S_1^*) C) \end{aligned}$$

Now defining symbols

$$\tilde{S}_1 = \frac{S_1 - S_2^*}{\sqrt{2}}$$

$$\tilde{S}_2 = \frac{S_1 + S_2^*}{\sqrt{2}}$$

and substituting back in equations 1, 2 we get that STS symbols X_1 and X_2 are given by;

$$X_1 = [\tilde{S}_1 C \ \tilde{S}_2 C]$$

$$X_2 = [\tilde{S}_2^* C \ -\tilde{S}_1^* C]$$

Referring to figure 2, the symbols X_1 and X_2 can now be easily seen to be obtained by STTD encoding the symbols $\tilde{S}_1$ and $\tilde{S}_2$. Figure 5 shows the STS in terms of the STTD encoding pictorially. As can be seen from the figure, the STS of QPSK symbols S_1 and S_2 involves a mapping to non-QPSK symbols $\tilde{S}_1$ and $\tilde{S}_2$ followed by an STTD encoding of symbols $\tilde{S}_1$ and $\tilde{S}_2$. Further, since there is no advantage in doing the QPSK to non-QPSK mapping prior to STTD encoding, the performance of STS is exactly the same as STTD.

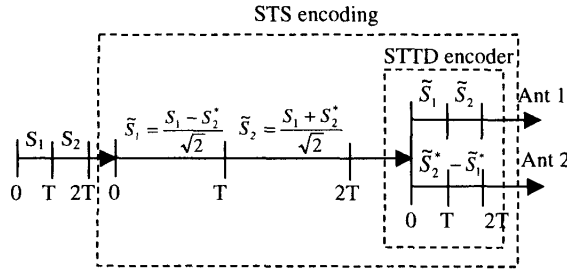


Figure 5: The STS encoding in terms of the STTD encoding is shown. We can see that the STS encoding first involves mapping of the QPSK symbols S_1 and S_2 to the non-QPSK symbols $\tilde{S}_1$ and $\tilde{S}_2$ followed by the STTD encoding of the symbols $\tilde{S}_1$ and $\tilde{S}_2$. There is no advantage to the QPSK to non-QPSK transformation prior to STTD encoding. In fact by doing this, the peak to average ratio of the non-QPSK symbols $\tilde{S}_1$ and $\tilde{S}_2$ turns out to be more than the QPSK symbols S_1 and S_2 . Thus, the STS scheme has an unnecessary increased complexity over STTD.

3.0 STTD comparison to OTD and STS

In this section we compare the STTD scheme to OTD and STS in terms of performance, complexity, peak to average ratio and applicability to the broadcast channels.

3.1 Performance comparison of STTD to OTD and STS

It is difficult to analytically compare the STTD and OTD performance including the channel coder and interleaver. Hence we only use simulations to compare the two. The 3Gpp WCDMA employs a block interleaver for interleaving gains. For OTD we divide the block interleaver into two small equal sized block interleavers, one for each antenna. The bits are read out alternately from two block interleavers. This ensures that the alternate bits at the input of the channel decoder for OTD arrive from different antennas, thus giving diversity gains.

Figure 6 gives the simulation results comparing the STTD, OTD and STS performance for 8 Kb/s speech, 10 msec. frame length, rate 1/3 coding, $K = 9$ with 16 CRC bits and 8 tail bits, 32 KSPS physical channel. A block interleaver of size 16X20 bits is used for STTD, STS and two block interleavers (one for each antenna) of size 8X20 is used for OTD. The channel model is frequency selective with two paths. The second path is 10 dB lower than the first path. This occurs in typical indoor channel scenarios. The Doppler is 5 Hz. corresponding to walking speed of 3 Km/h. For this Doppler rate the channel would appear as a block-fading channel for the coding block of 10 ms. We can see that for a desired BER of 10^{-3} the STTD outperforms OTD by about 0.5 dB.

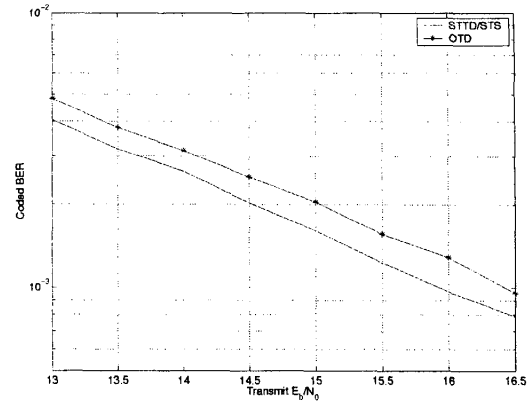


Figure 6: The performance of STTD is compared to OTD and STS for an 8 Kb/s 3Gpp WCDMA speech channel, with rate 1/3 coding and 32 KSPS physical channel rate. The channel model is frequency selective block fading with 2 independent Rayleigh fading channels. The second path is 10 dB lower than the first path. The interleaver for STTD, STS is a 16X20 block interleaver and for OTD we use two block interleavers of size 8X20, one for each antenna. We can see that the STTD performance is the same as STS and STTD outperforms OTD by about 0.5 dB for a desired BER of 10^{-3} .

3.2 Peak to average ratio comparison of STTD to OTD and STS

The QPSK symbols transmitted on the antennas over the interval $[0, 2T]$ for the STTD scheme are S_1, S_2 over antenna 1 and S_1^*, S_2^* over antenna 2. Similarly, for OTD the QPSK symbols transmitted on the antennas are S_1, S_1 on antenna 1 and $S_2, -S_2$ on antenna 2. On the other hand, for STS the non-QPSK symbols $\tilde{S}_1, \tilde{S}_2$ are transmitted on antenna 1 and $\tilde{S}_1^*, \tilde{S}_2^*$ are transmitted on antenna 2. Figure 7 plots the STTD, OTD QPSK and the STS non-QPSK symbols. The number of occurrences for each constellation point of the STS constellation is also shown. The peak to average ratio (PAR) of the STTD QPSK constellation can be seen to be higher than the STS constellation.

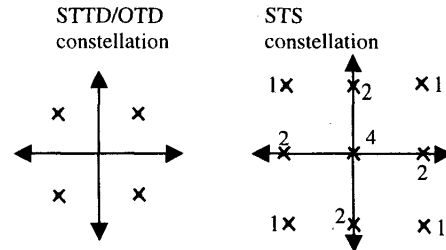


Figure 7: The STTD QPSK constellation and the STS non-QPSK constellation are shown. The number of occurrences for each of the constellation points of STS is shown. The

STTD constellation has a lower peak to average ratio compared to STS.

The PAR for the downlink of CDMA is quite high due to the simultaneous transmission of a large number of users, even for a single antenna system. Hence it may be argued that the incremental increase in PAR at the base station for the STS scheme may not be significant overall. However recall from figure 5 that the QPSK to non-QPSK mapping in STS prior to STTD encoding does not give any advantage over straight forward STTD encoding shown in figures 1,2. Hence, any increase in the PAR at the base station due to STS can be avoided by doing STTD encoding instead.

3.3 Transmit diversity on broadcast channels

STTD encoding in the 3Gpp WCDMA is applied on the broadcast channels in addition to its application to the dedicated channels of the individual mobile [15]. The 3Gpp WCDMA has a common pilot channel with all zero data and uses Walsh code 0. The mobile uses the common pilot channel for channel estimation for demodulating the data on the broadcast and the dedicated channels. In the presence of the diversity antenna, the pilot channel is orthogonally coded, in order to allow the mobile to perform channel estimation for both the transmitting antennas. When the mobile is turned on, it does not have the knowledge of the presence/absence of the diversity antenna. It can accumulate the energy output from the orthogonal patterns on the common pilot channel to detect the presence of the diversity antenna. This accumulation has to be done for more than the fading duration in order to reduce the probability of error in detecting the diversity antenna. When the mobile is moving slowly, for example for walking speeds of 3 Km/h implying a Doppler of 5 Hz., it implies that the accumulation should be done for more than 200 msec [15]. During this time the mobile does not know whether to demodulate the broadcast channel as a single antenna transmission or a two antenna transmission thus increasing initial acquisition time for STS and OTD. It turns out that this is not a problem for STTD encoding. In figures 1, 2 notice that the STTD encoded pattern on antenna 1 is the same as a single antenna system. If the mobile *a priori* assumes the presence of the diversity antenna (even when the antenna is not present) this would imply extra fingers in the maximal ratio combiner. Hence in the case of ideal channel estimation no loss in mobile performance would occur even if the mobile mistakenly assumes two antenna transmission when indeed only a single antenna was transmitting. In practice, due to imperfect channel estimation, there will be a small degradation of less than 0.3 dB in the mobile performance [15] compared to single antenna transmission. This is shown in figure 11 wherein the raw bit error rate (BER) of STTD decoding a single antenna transmission (that is the mobile presumes the presence of the diversity antenna even though it is absent) is compared to single antenna reception (that is the mobile knows the absence of the diversity antenna). The channel model for the simulations is two independent Rayleigh fading paths.

Thus the important point to note is that the mobile can demodulate single antenna transmission (with small degradation in performance) by *a priori* assuming it to be STTD encoded. On the other hand in case of both, the OTD and STS encoding, the mobile needs to know *a priori* whether

the diversity antenna is present or not before OTD, STS decoding. This implies that no demodulation of the OTD, STS encoded broadcast channel is possible when the diversity antenna detection is in progress. A similar problem can also occur during handoffs, in the absence of the current base station providing this information to the mobile of the soft handoff base station. Thus, it is possible to STTD encode all the broadcast channels of the 3Gpp WCDMA FDD system without the mobile being notified of the presence/absence of the diversity antenna. This is not possible with the OTD and STS encoding.

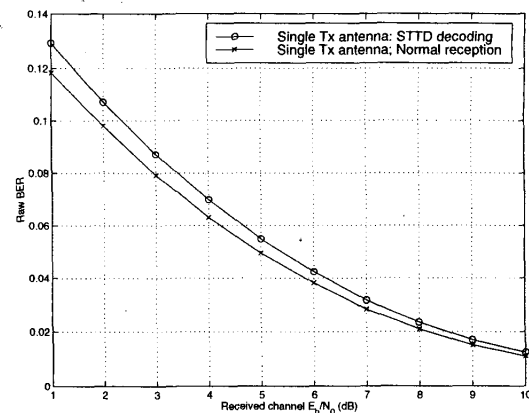


Figure 11: The raw BER performance of single antenna transmission with STTD decoding (that is the mobile presumes the presence of the diversity antenna even though it is absent) is compared to the performance of single antenna reception (that is the mobile has the knowledge of the absence of the diversity antenna). The channel model for the simulations is two independent Rayleigh fading paths. We can see that there is a small degradation of less than 0.3 dB in STTD decoding a single antenna transmission. This is useful during power on of the mobile for blind detection of the diversity antenna when STTD encoding is used on the broadcast channels. Note that such a technique cannot be used for OTD and STS.

4.0 Conclusions

The space time block coding based transmit diversity scheme was originally proposed for TDMA systems with flat fading channels [6]. Texas Instruments applied it to multi-path WCDMA systems and called it the space time transmit diversity (STTD) [7, 8, 10, 15]. The third generation partnership project (3Gpp) accepted STTD as the only open loop transmit diversity scheme in January 1999. After STTD was accepted by 3Gpp, the space time spreading (STS) was proposed by Lucent for the CDMA 2000 system [11, 12, 13] in August 1999. CDMA 2000 has accepted both Motorola's orthogonal transmit diversity (OTD) and STS as the open loop transmit diversity techniques.

In this paper we show that the STS scheme for CDMA 2000 involves a QPSK to non-QPSK symbol transformation followed by STTD encoding. Hence, STS performance is exactly the same as STTD. Further STS suffers from higher

peak to average ratio and it requires more complexity for decoding, as compared to STTD encoding. Simulation results show that STTD outperforms OTD by 0.3-0.5 dB. The complexity and PAR of OTD and STTD is comparable. Further, STTD has another distinct advantage over OTD and STS namely that STTD encoded data on the first antenna is the same as a single antenna transmission. Hence when STTD is applied on broadcast channels and the mobile has no knowledge of the presence/absence of the diversity antenna, then a blind detection of the diversity antenna is possible while receiving the broadcast channel with a very small degradation in performance. This is not possible for the OTD and the STS schemes. Due to the above reasons, STTD encoding is a better open loop transmit diversity scheme for CDMA systems as compared to OTD and STS.

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