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Agenda item : AH24: HSDPA

Source: Texas Instruments

Title: Double-STTD scheme for HSDPA systems with four transmit antennas: Link Level Simulation Results

Document for: Discussion and Approval

1. Introduction

The use of more than two transmit and one receive antennas with multi-input multi-output (MIMO) scheme was proposed by Lucent for high speed downlink packet access (HSDPA). It was demonstrated in [1-4] that Lucent's MIMO scheme offers significant performance gain over (2,1) Release 99 space-time transmit diversity (STTD) scheme. However it was demonstrated later by Fujitsu in [5] that for (2,2) systems, STTD actually outperforms Lucent's MIMO.

In this contribution, we present an alternative open-loop scheme for systems with four transmit antennas. The scheme uses two STTD encoders at the transmitter and interference cancellation at the receiver. We refer to this scheme as *double-STTD.* The receiver for double-STTD is similar to the receiver in [6] for multiuser application of STTD. As demonstrated throughout this contribution, DSTTD is a better alternative to Lucent's MIMO for the following reasons:

1. **Better Performance:** For the same data rate and the same number of transmit and receive antennas DSTTD outperforms MIMO significantly by up to 11 dB depending upon data rate and channel correlation.

2. **Lower complexity:** The improved performance of DSTTD is achieved with a lower mobile complexity as compared to MIMO.

3. **Robustness to correlated fading channels:** DSTTD performance is robust to correlated channels while Lucent's MIMO performance is sensitive.

4. **Better Flexibility:** Lucent's MIMO technique cannot be used for 4 transmit and 2 receive antennas, on the other hand DSTTD can be used even for such a configuration.

5. **Backward compatibility:** For 2 transmit 1 receive antenna, DSTTD becomes the STTD technique which has been employed for Release'99 3Gpp.

Thus DSTTD is a better open loop technique compared to Lucent's MIMO because of its better performance, lower complexity, flexibility and its robustness to correlated fading channels.

2. The Double-STTD scheme

The transmitter structure for DSTTD scheme with 4 transmit antennas is depicted in Figure 1. The data stream coming from the modulator is split into 2 streams and each stream is STTD-encoded. Then, multicode spreading is applied to each of the resulting 4 streams after twice STTD-encoding, where each stream uses the same set of spreading codes (similar to 'code reuse' concept in MIMO). The signal transmitted via antenna 1 and 2 are orthogonal due to STTD encoding. The same holds for antenna 3 and 4. Hence, signal on each transmit antenna is affected by the interference from two out of three other antennas. Also, due to STTD encoding, each data symbol is guaranteed to have (transmit) diversity of 2. It is easy to see that the regular R99 STTD (with 2 transmit antennas) is a special case of DSTTD. Hence, the transmitter for DSTTD is backward compatible with R99 STTD.

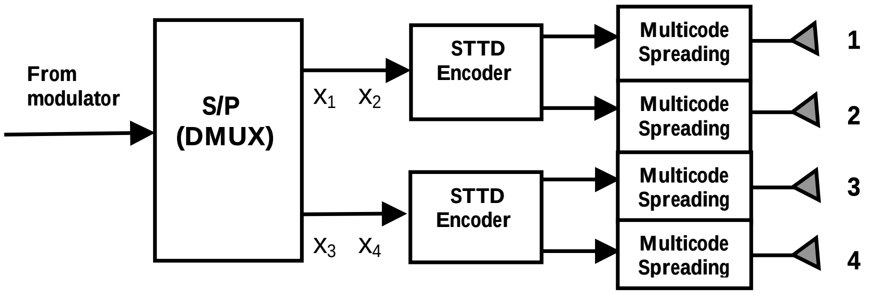

Figure 1. Transmitter structure for DSTTD with 4 transmit antennas

At the receiver (see Figure 2), the signal at each receive antenna is despread. The signal from all receive antennas after despreading are coherently combined using two STTD decoders for each receive antenna. Equivalently, direct space-time rake combining can be used by exploiting the following equation which is shown for each receive antenna:

$$[r_n(0) \quad r_n(1)] = \frac{1}{\sqrt{2}}[h_{n1} \quad h_{n2} \quad h_{n3} \quad h_{n4}]\begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \\ x_3 & x_4 \\ -x_4^* & x_3^* \end{bmatrix} + [w_n(0) \quad w_n(1)]$$

$$\Leftrightarrow \begin{bmatrix} r_n(0) \\ r_n^*(1) \end{bmatrix} = \frac{1}{\sqrt{2}}\begin{bmatrix} h_{n1} & -h_{n2} & h_{n3} & -h_{n4} \\ h_{n2}^* & h_{n1}^* & h_{n4}^* & h_{n3}^* \end{bmatrix}\begin{bmatrix} x_1 \\ x_2^* \\ x_3 \\ x_4^* \end{bmatrix} + \begin{bmatrix} w_n(0) \\ w_n^*(1) \end{bmatrix} \qquad \text{......(1)}$$

where factor $\sqrt{2}$ is needed to normalize the transmit power after STTD encoding. The first stage for each receive antenna is to do matched filter multiplication by the channel matrix in equation (1). The output of this matched filter is combined across multiple receive antennas (in the above case, 2 receive antennas). The resultant output of DSTTD combiner is contaminated with interference from two other transmit antennas. Interference-resistant detection algorithm such as iterative MMSE can be used right after the combining. Note that one DSTTD combining operation is done across 2 symbol intervals. Hence, the detector performs only 1 operation per 2 symbol intervals. Compared to a Lucent's MIMO system with 4 transmit antennas, the detector for DSTTD operates at *half the rate* of the detector for Lucent's MIMO. The soft output corresponding to all transmit antennas generated by the detector are merged into one stream and sent to demodulator. In addition, it can be inferred from (1) that each receive antenna possesses 2 (temporal) degrees of freedom, which is a consequence of STTD transmission. Hence, for systems with 4 transmit antennas, 2 receive antennas are sufficient for reliable detection when iterative MMSE detector is used. This is not the case for Lucent's MIMO, where at least 4 receive antennas are required when iterative MMSE detector is used. Notice from Figure 2 that a receiver for regular R99 STTD (with 2 transmit antennas) can be obtained by switching off all the 'STTD dec 2' blocks and interference suppression. This demonstrates the receiver backward compatibility of DSTTD with R99 STTD.

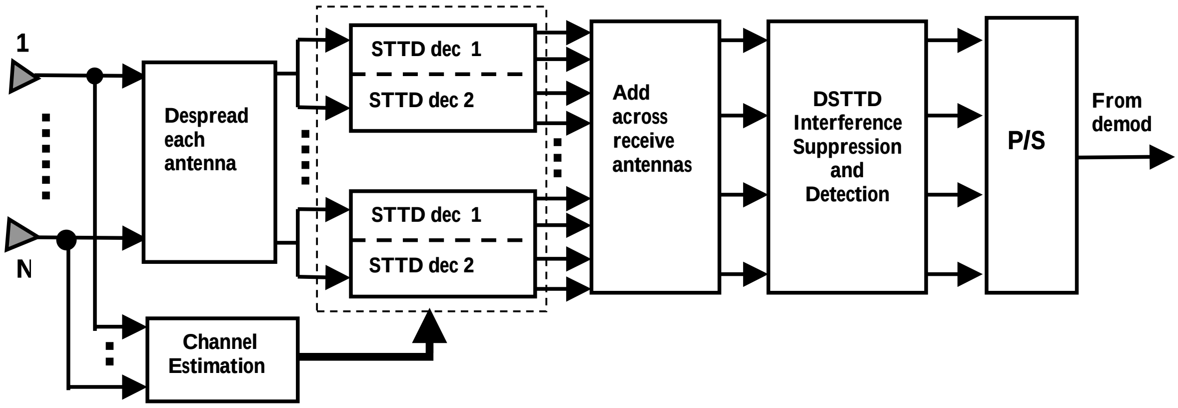

Figure 2. A receiver structure for DSTTD with 4 transmit antennas

3. Assumptions and Simulation Parameters

We consider the following schemes shown in Table 1. All the data rates that are proposed by Lucent [1-4] (up to 21.6 Mbps) are also covered by DSTTD. Here, *M* and *N* denote the number of transmit and receive antennas, respectively. Frame-error rate (FER) vs. I_{or}/I_{oc} is used as performance measure. Additional assumptions and simulation parameters are shown in Table 2. For fair comparison among different schemes, the energy per information bit and the total average transmit power are kept constant.

Table 1. Schemes considered in this contribution

	Scheme	**Code rate**	**Modulation**	**# substreams**	**Total data**
(1,1)	Conventional	3/4	64QAM	20	10.8 Mbps
(2,N)	STTD	3/4	64QAM	20	10.8 Mbps
(2,N)	Lucent's MIMO	3/4	8PSK	40	10.8 Mbps
(4,4)	Lucent's MIMO	9/16	QPSK	80	10.8 Mbps
(4,4)	Lucent's MIMO	3/4	QPSK	80	14.4 Mbps
(4,4)	Lucent's MIMO	3/4	8PSK	80	21.6 Mbps
(4,N)	DSTTD	3/4	8PSK	40	10.8 Mbps
(4,N)	DSTTD	3/4	16QAM	40	14.4 Mbps
(4,N)	DSTTD	3/4	64QAM	40	21.6 Mbps

Table 2. Simulation parameters

Carrier frequency	2 GHz
Chip rate	3.84 Mcps
Spreading factor	32
Number of multi-codes	20
Frame length	0.667 ms (1-TS) and 3.33 ms (5-TS)
CPICH power	10 % total
E_c / I_{or}	80 %
Channel coding / decoding	Turbo coding per 3GPP, R=9/16, 1/2, and 3/4. Max-Log-Map decoding (8 iterations)
Fading model	1 path Rayleigh (3kmph, 30kmph mobile speed)
Correlation model	IID, Channel A and B [3]
Channel estimation	- Perfect Channel Estimation (PCE), and - CPICH channel estimation using symbol averaging technique (symmetric window) with filter length = 81 for 3-kmph and 21 for 30-kmph.
Detector for Lucent's MIMO and DSTTD	Iterative MMSE (VBLAST in [7])

4. Simulation Results

Figure 3 and 4 depict the performance of Lucent's MIMO with 2 transmit antennas and STTD in 3-kmph IID channel assuming perfect channel estimation and data rate of 10.8 Mbps. The results indicate that STTD is superior to Lucent's MIMO in (2,2) scenario and the opposite holds for (2,4) scenario. The results for (2,2) agree with [5], except Lucent's MIMO results used in [5] is based on maximum likelihood (ML) detector. The results for (2,2) MIMO using ML detector (5-TS) from [1] is shown in Figure 4 for reference. While Lucent's MIMO is superior to STTD for (2,4) scenario by approximately 0.5-dB (at FER = 0.01) in IID channel, STTD is again superior to Lucent's MIMO in Channel B as demonstrated in Figure 5 and 6. Higher sensitivity of Lucent's MIMO scheme to channel correlation was also demonstrated for (2,2) scenario in [5]. A summary of the comparison of STTD to Lucent's MIMO with 2 transmit antennas for data rate of 10.8 Mbps assuming 3-kmph UE speed and perfect channel estimation is given in Table 3 below:

Table 3. Comparison of STTD to Lucent's MIMO for 10.8 Mbps assuming 3-kmph UE speed and perfect channel estimation for 1-TS, 5-TS: STTD outperforms Lucent's MIMO except for (2,4) IID channel scenario.

	Required I_{or}/I_{oc} (dB) for IID channel, target FER = 1%		**Required I_{or}/I_{oc} (dB) for Channel B, target FER = 1%**	
	Lucent's MIMO	**STTD**	**Lucent's MIMO**	**STTD**
(2,1)	N/A	25.5	-	-
(2,2)	27.0	18.0	-	-
(2,4)	12.0	12.5	19.0	15.0

Figure 7 – 10 depict the performance of DSTTD and Lucent's MIMO in (4,4) scenario and assuming perfect channel estimation and IID channel (3- and 30-kmph) for various data rates (10.8, 14.4, and 21.6 Mbps). The results demonstrate that DSTTD is superior than Lucent's MIMO in virtually all cases. For 3-kmph channel, the performance for 1-TS and 5-TS frame length do not differ significantly, except for 10.8 Mbps Lucent's MIMO. This is attributed to the small turbo interleaver size for 10.8 Mbps Lucent's

MIMO with frame length of 1-TS (rate 9/16 QPSK, turbo interleaver size = 90). While the performance of DSTTD is close to Lucent's MIMO at 10.8 Mbps, DSTTD significantly outperforms Lucent's MIMO at 14.4 and 21.6 Mbps. A summary of the comparison of DSTTD to Lucent's MIMO with perfect channel estimation for IID channels is given Table 4 below:

Table 4. Comparison of DSTTD to Lucent's MIMO in (4,4) scenario, perfect channel estimation, and IID channel is shown. DSTTD outperforms Lucent's MIMO significantly in all cases.

Total Data Rate (Mbps)	**Required I_{or}/I_{oc} (dB) for 3-kmph, target FER = 1%**		**Required I_{or}/I_{oc} (dB) for 30-kmph, target FER = 1%**	
	Lucent's MIMO	**DSTTD**	**Lucent's MIMO**	**DSTTD**
10.8	10.5(1-TS), 9.7(5-TS)	9.6	10.5(1-TS), 9.7(5-TS)	9.6
14.4	14.3	12.2	14.2	12.1
21.6	24.7	17.6	24.4	17.4

The performance of DSTTD versus Lucent's MIMO using imperfect CPICH-based channel estimation is depicted in Figure 11 – 14. For channel estimation, we use a running (symbol-level) average filter on CPICH assuming orthogonal pilot sequences for different transmit antennas [2]. The filter length is 81 and 21 for 3-kmph and 30-kmph UE speed, respectively. Using this particular simple channel estimation technique, the relative performance of DSTTD to Lucent's MIMO in different scenarios are approximately the same as those assuming perfect channel estimation. Notice that the performance of both Lucent's MIMO and DSTTD are not significantly affected by channel estimation error when CPICH symbol average channel estimation is used. A summary of the comparison of DSTTD to Lucent's MIMO with imperfect channel estimation for IID channels is given in Table 5 below:

Table 5. Comparison of DSTTD to Lucent's MIMO in (4,4) scenario, CPICH symbol average channel estimation, and IID channel is shown. DSTTD outperforms Lucent's MIMO significantly in all cases.

Total Data Rate (Mbps)	**Required I_{or}/I_{oc} (dB) for 3-kmph, target FER = 1%**		**Required I_{or}/I_{oc} (dB) for 30-kmph, target FER = 1%**	
	Lucent's MIMO	**DSTTD**	**Lucent's MIMO**	**DSTTD**
10.8	10.5(1-TS), 9.7(5-TS)	9.6	10.5(1-TS), 9.7(5-TS)	9.6
14.4	14.3	12.2	14.3	12.2
21.6	24.8	17.7	24.5	17.8

Figure 15 – 18 depict the performance of DSTTD versus Lucent's MIMO in correlated channels (Channel A and B). The results demonstrate that (4,4) DSTTD is much more robust to channel correlation compared to (4,4) Lucent's MIMO. As suggested by Lucent in [3,4], when the channel is highly correlated, the performance of (4,4) Lucent's MIMO can be significantly improved by transmitting only with 2 instead of 4 antennas using higher order modulation. In Figure 17 and 18, we demonstrate for Channel B that the performance of (2,4) Lucent's MIMO obtained by choosing 2 'best' transmit antennas (which result in the lowest correlation – 'MIMO lc') from 4 available transmit antennas is close to the performance of (4,4) DSTTD (without any additional effort). We also show the performance of (2,4) STTD obtained by choosing 2 'best' transmit antennas ('STTD lc'). We observe that 'STTD lc' outperforms 'MIMO lc'. Note that to be able to choose which antennas to transmit from, the receiver needs to feedback the channel correlation information to the transmitter. A summary of the comparison of DSTTD to Lucent's MIMO with perfect channel estimation for correlated channels is given in Table 6 below:

Table 6. Comparison of DSTTD to Lucent's MIMO in (4,4) scenario, perfect channel estimation, and correlated channels is shown. DSTTD is much more robust to channel correlation.

Total Data Rate (Mbps)	**Scheme**	**Required I_{or}/I_{oc} (dB) for Channel A, target FER = 1%**		**Required I_{or}/I_{oc} (dB) for Channel B, target FER = 1%**	
		Lucent's MIMO	**DSTTD**	**Lucent's MIMO**	**DSTTD**
10.8	(4,4)	15.0(1-TS), 14.0(5-TS)	12.5	24.0(1-TS), 23.0(5-TS)	16.0
10.8	(2,4) Ic	-	-	16.0	14.0
14.4	(4,4)	21.5	15.0	30.0	19.0

The performance of DSTTD can be further improved in correlated channels by exploiting asymmetric modulation and antenna shuffling as shown in an accompanying document Tdoc 0459 [8].

Figure 19 – 20 depict the performance of (4,2) DSTTD in different channel models. A summary of the performance of (4,2) DSTTD for different data rates is given in Table 7 below:

Table 7. Performance of (4,2) DSTTD assuming perfect channel estimation

Data Rate	**Required I_{or}/I_{oc} (dB), target FER = 1%**		
	IID channel	**Channel A**	**Channel B**
10.8 Mbps	20.0	22.5	26.5
14.4 Mbps	22.5	-	-
21.6 Mbps	28.5	-	-

4.1. Complexity comparison: DSTTD versus MIMO

As mentioned before, one DSTTD combining operation is done across 2 symbol intervals. Hence, the detector performs only 1 operation per 2 symbol intervals. Compared to a Lucent's MIMO system with 4 transmit antennas, the detector for DSTTD operates at *half the rate* of the detector for Lucent's MIMO. Hence the complexity of the interference cancellation for DSTTD is only half that of the Lucent MIMO complexity.

5. Conclusion

For systems with 4 transmit antennas, we have proposed the double-STTD (DSTTD) scheme, which significantly outperforms Lucent's MIMO in scenarios including channel estimation error, different data rates, different channel fading rates, and correlated fading channels. Further, the improved performance of DSTTD is obtained at lower mobile complexity compared to Lucent-proposed MIMO systems. DSTTD also allows the use of 2 receive antennas while using iterative MMSE detector, which is not possible for Lucent's MIMO. We have also demonstrated that DSTTD is much more robust to channel correlation than Lucent's MIMO. In addition, for (2,2) systems DSTTD reduces to STTD, which has been chosen for Release 99. We thus summarize the advantages of DSTTD over Lucent's MIMO:

1. **Better Performance:** For the same data rate and the same number of transmit and receive antennas DSTTD outperforms MIMO significantly by up to 11 dB depending upon data rate and channel correlation..

2. **Lower Complexity:** The improved performance of DSTTD is achieved with a lower mobile complexity as compared to MIMO.
3. **Robustness to correlated fading channels:** DSTTD performance is robust to correlated channels while Lucent's MIMO performance is sensitive.
4. **Better Flexibility:** Lucent's MIMO technique cannot be used for 4 transmit and 2 receive antennas, on the other hand DSSTD can be used even for such a configuration.
5. **Backward compatibility:** For 2 transmit 1 receive antenna, DSTTD becomes the STTD technique which has been employed for Release'99 3Gpp.

In light of these facts and results, we propose DSTTD as the preferred open-loop transmit diversity scheme over the Lucent-proposed MIMO for systems using 4 transmit antennas. Similarly, for systems using 2 transmit antennas, we propose to use STTD as in Release 99 as the open loop transmit diversity scheme. Our proposal is summarised in Table 8 below. Note that (4,1) scenario is not covered.

Table 8. Proposed open-loop schemes for HSDPA

System	Proposed scheme	Peak Data Rate
(2,1)	STTD (R99)	10.8 Mbps
(2,2)	STTD (R99)	10.8 Mbps
(2,4)	STTD (R99)	10.8 Mbps
(4,2)	DSTTD	21.6 Mbps
(4,4)	DSTTD	21.6 Mbps

References

[1] Lucent. Preliminary link level results for HSDPA using multiple antennas. TSG-R WG1 document, TSGR1#16(00)1218, 10th -13rd, October, 2000, Pusan, Korea.

[2] Lucent. Further link level results for HSDPA using multiple antennas. TSG-R WG1 document, TSGR1#17(00)1386, 21st - 24th November, 2000, Stockholm, Sweden.

[3] Lucent. Link level results for HSDPA using multiple antennas in correlated channels. TSG-R WG1 document, TSGR1#18(01)0078, 15th -18th January, 2001, Boston, USA.

[4] Lucent. Link level results for HSDPA using multiple antennas in correlated and measured channels. TSGR1#19(01)0302, 27th February - 2nd March , 2001, Las Vegas, USA.

[5] Fujitsu. Link Level Simulation Results for HSDPA: Comparison between MIMO and Tx Diversity. TSGR1#19(01)0286, 27th February - 2nd March , 2001, Las Vegas, USA.

[6] A. Naguib, N. Seshadri, and A.R. Calderbank, "Increasing Data Rate over Wireless Channels," IEEE Signal Processing Mag., pp. 76-92, May 2000.

[7] Lucent. MIMO physical layer description. TSG-R WG1 document, TSGR1#19(01)0306, 27th February - 2nd March , 2001, Las Vegas, USA.

[8] Texas Instruments. Improved Double-STTD scheme using asymmetric modulation and antenna shuffling. TSG-R WG1 document, TSGR1#20(01)0459, 21st – 24th May , 2001, Busan, Korea.

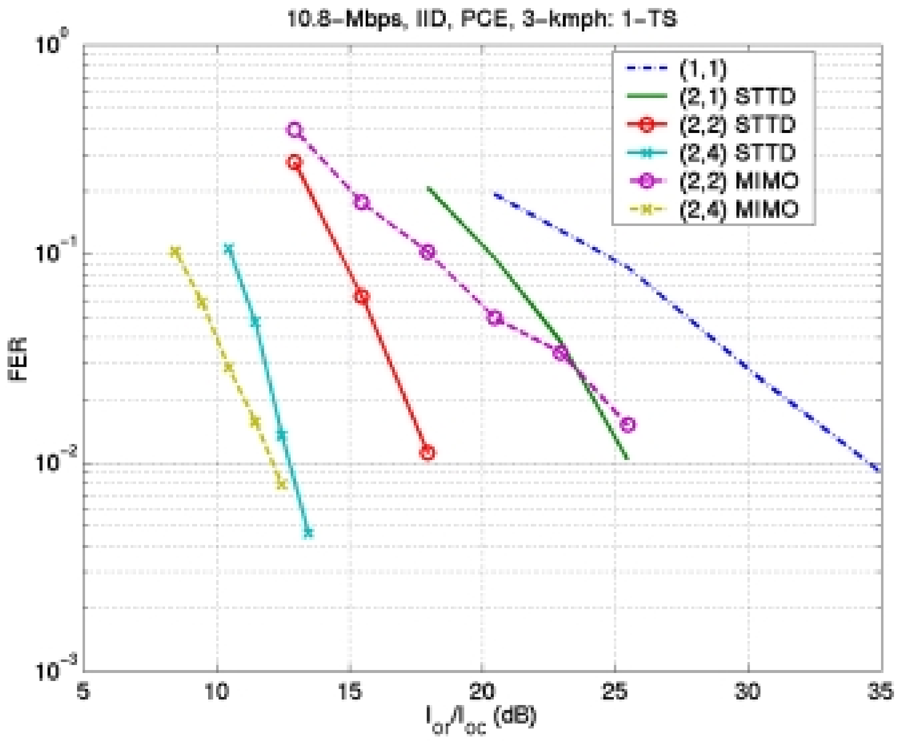

Figure 3. STTD vs. MIMO with 2 transmit antennas, frame length = 1-TS

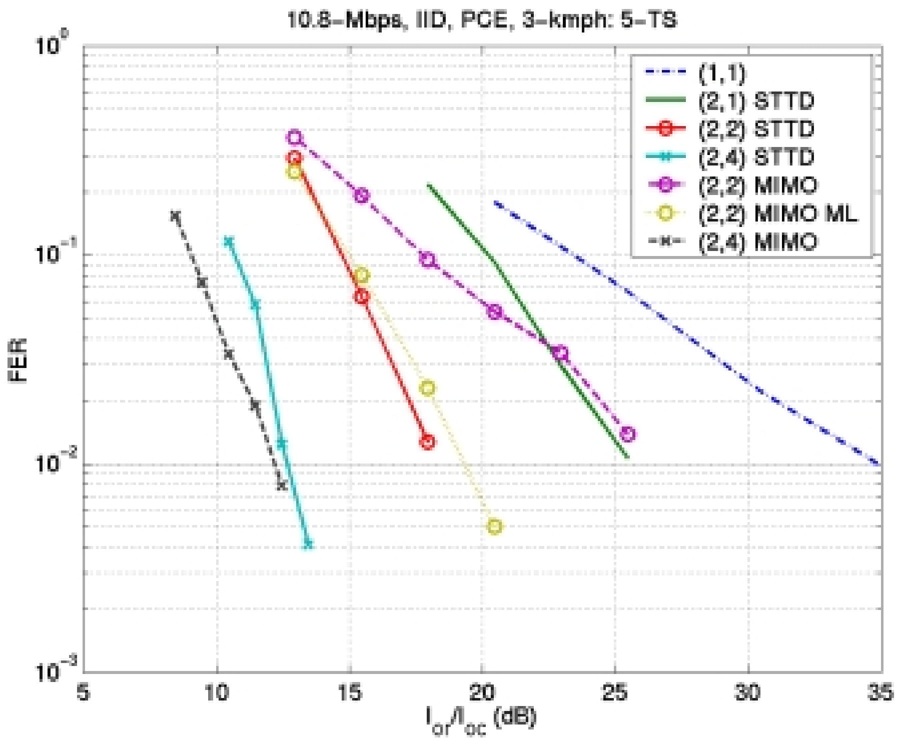

Figure 4. STTD vs. MIMO with 2 transmit antennas, frame length = 5-TS

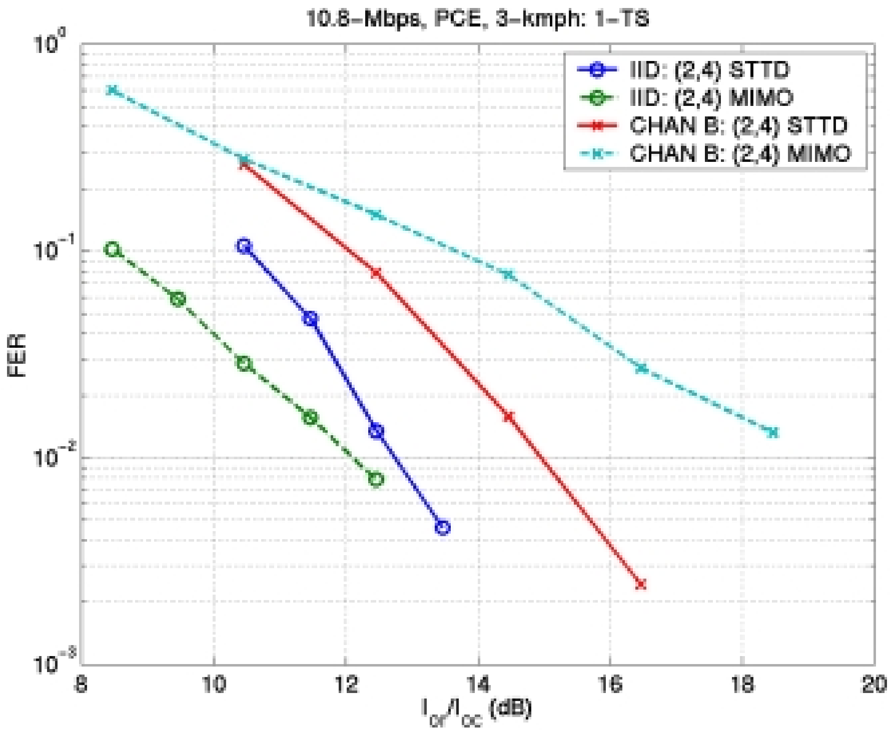

Figure 5. (2,4) STTD vs. MIMO, frame length = 1-TS

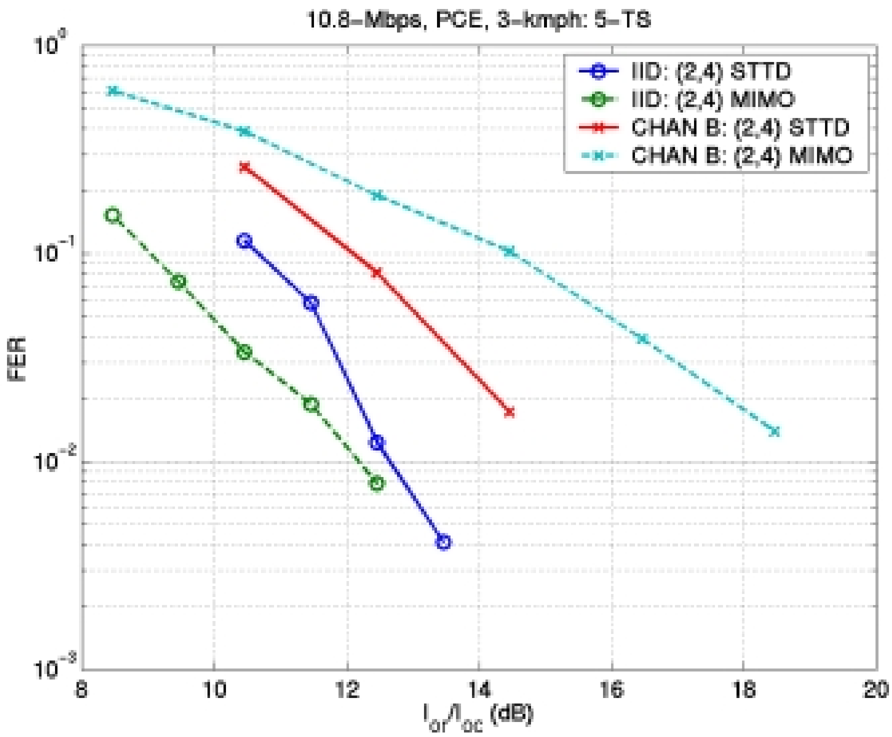

Figure 6. (2,4) STTD vs. MIMO, frame length = 5-TS

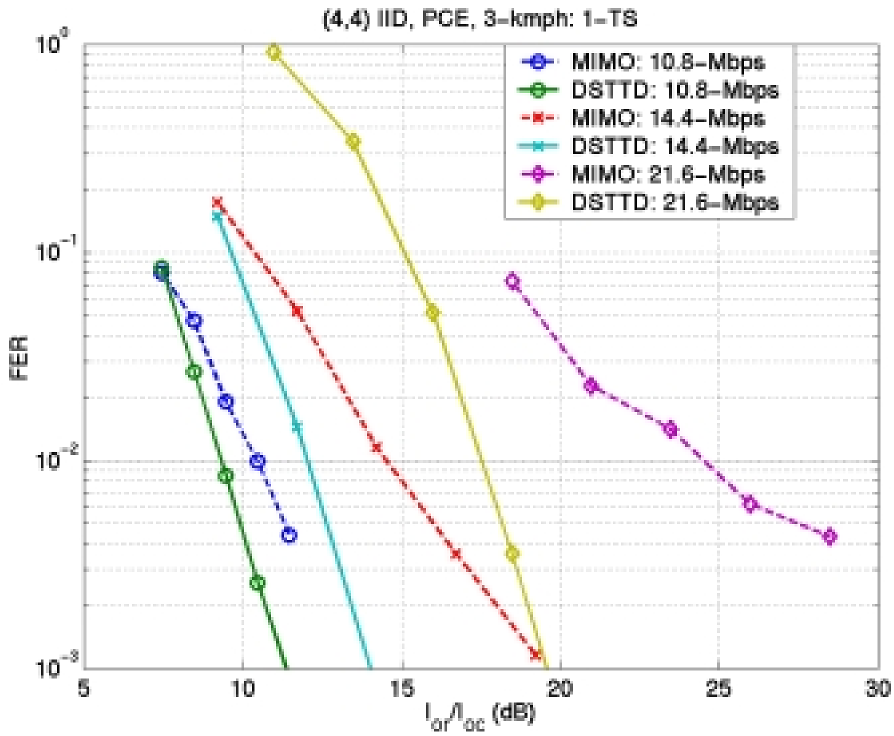

Figure 7. (4,4) MIMO vs. DSTTD in 3-kmph IID channel, frame length = 1-TS

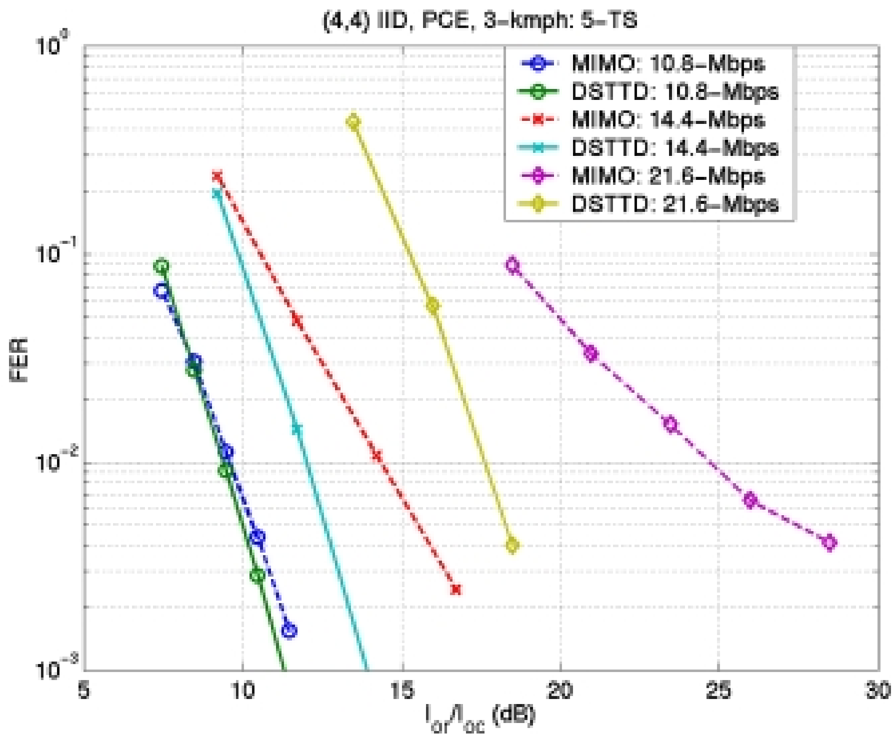

Figure 8. (4,4) MIMO vs. DSTTD in 3-kmph IID channel, frame length = 5-TS

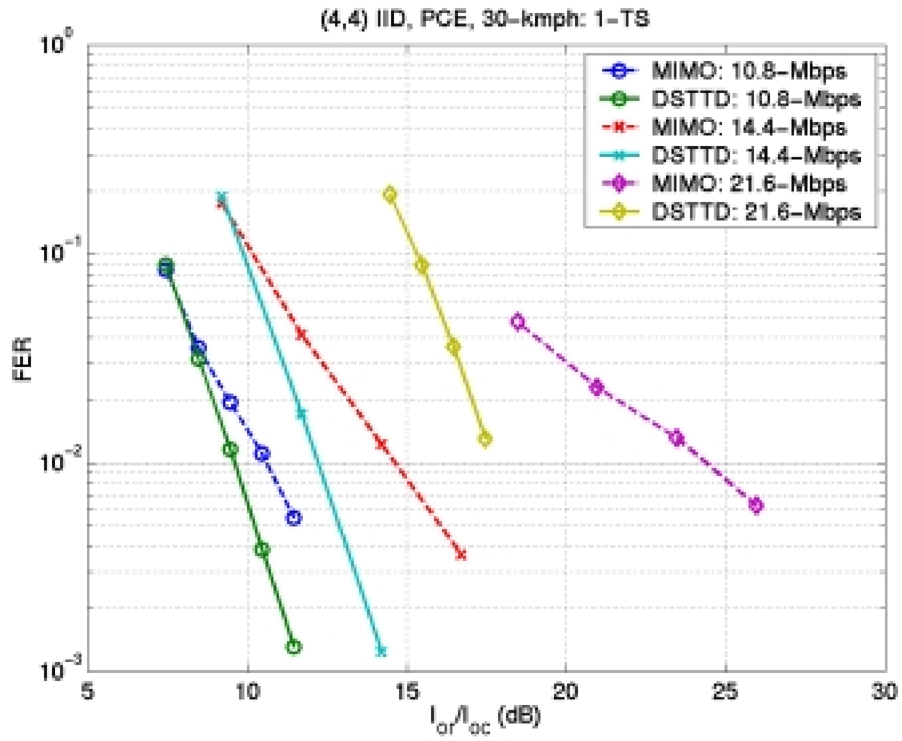

Figure 9. (4,4) MIMO vs. DSTTD in 30-kmph IID channel, frame length = 1-TS

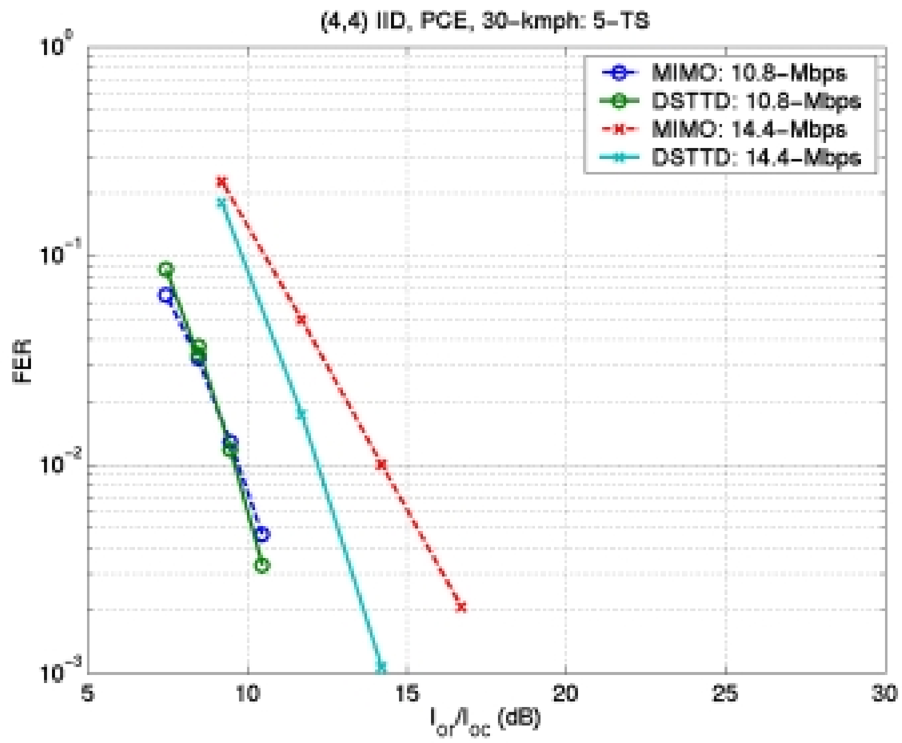

Figure 10. (4,4) MIMO vs. DSTTD in 30-kmph IID channel, frame length = 5-TS

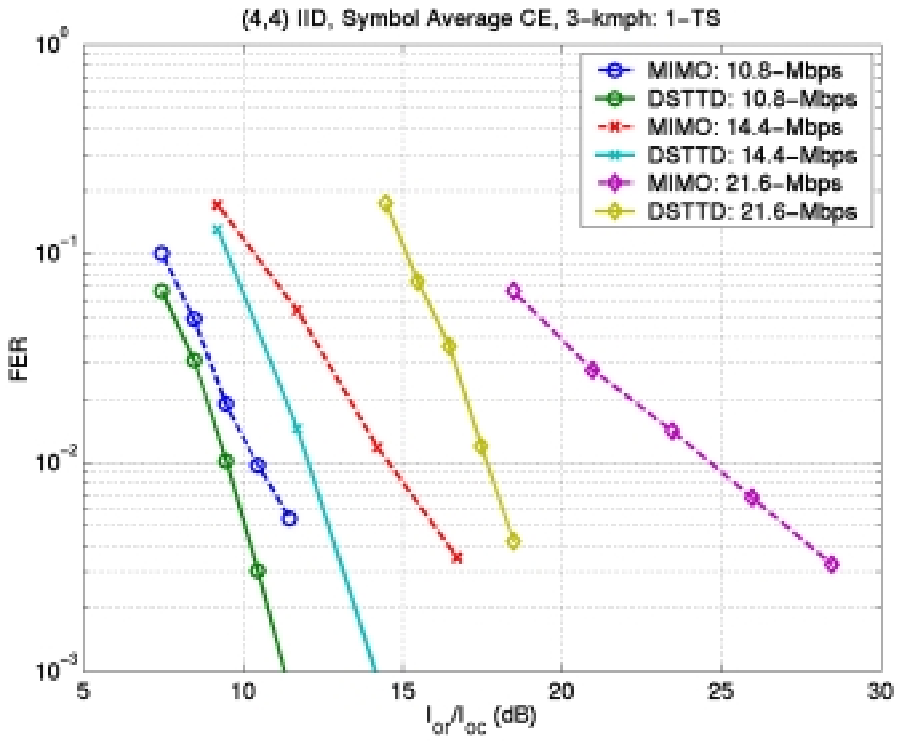

Figure 11. (4,4) MIMO vs. DSTTD with imperfect channel estimation (3-kmph), frame length = 1-TS

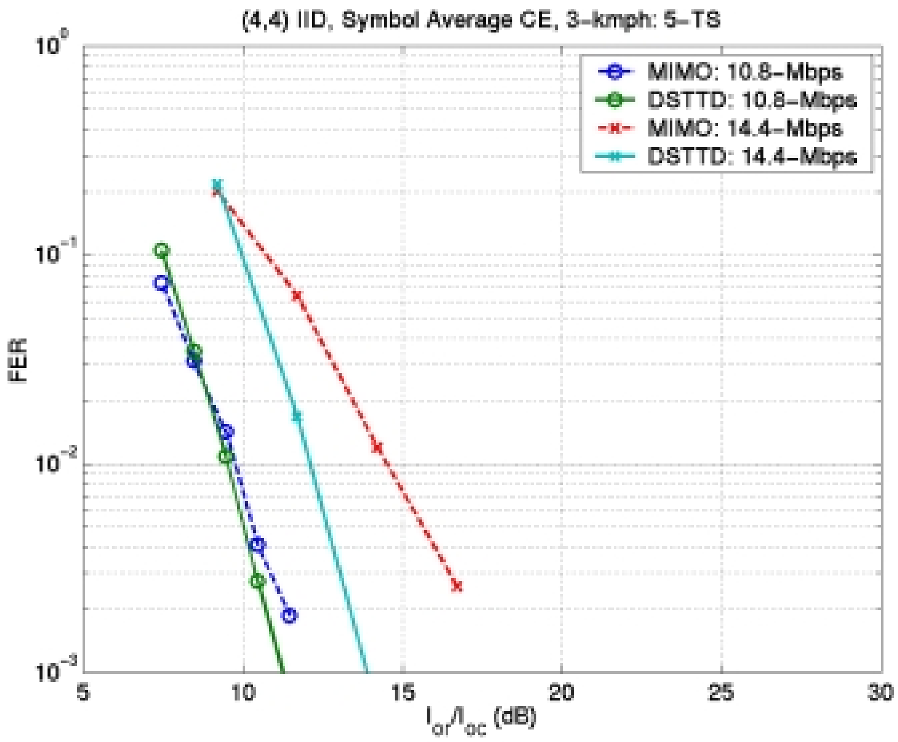

Figure 12. (4,4) MIMO vs. DSTTD with imperfect channel estimation (3-kmph), frame length = 5-TS

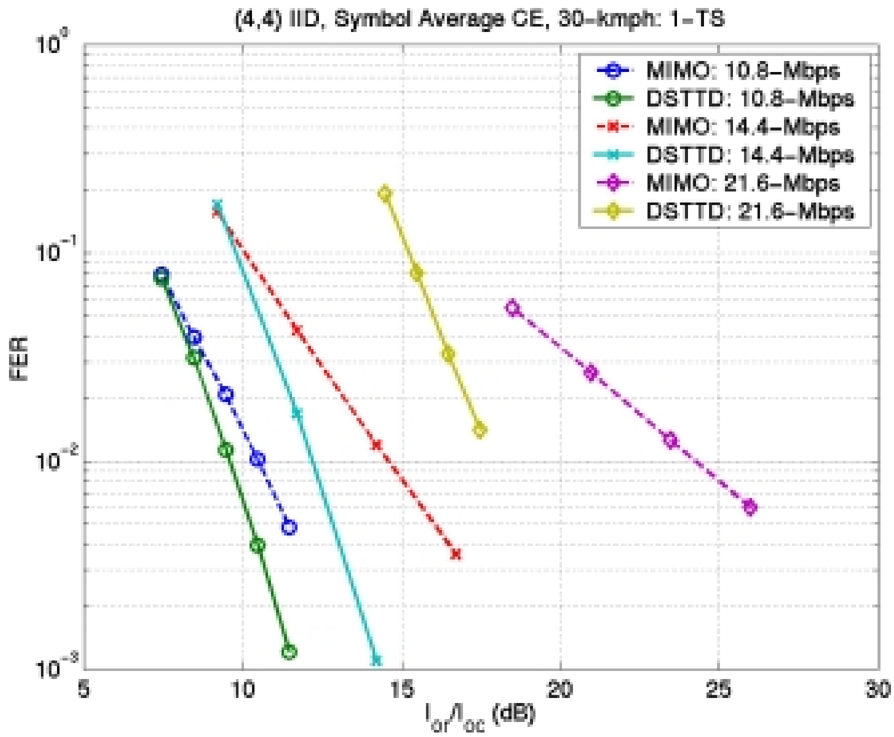

Figure 13. (4,4) MIMO vs. DSTTD with imperfect channel estimation (30-kmph), frame length = 1-TS

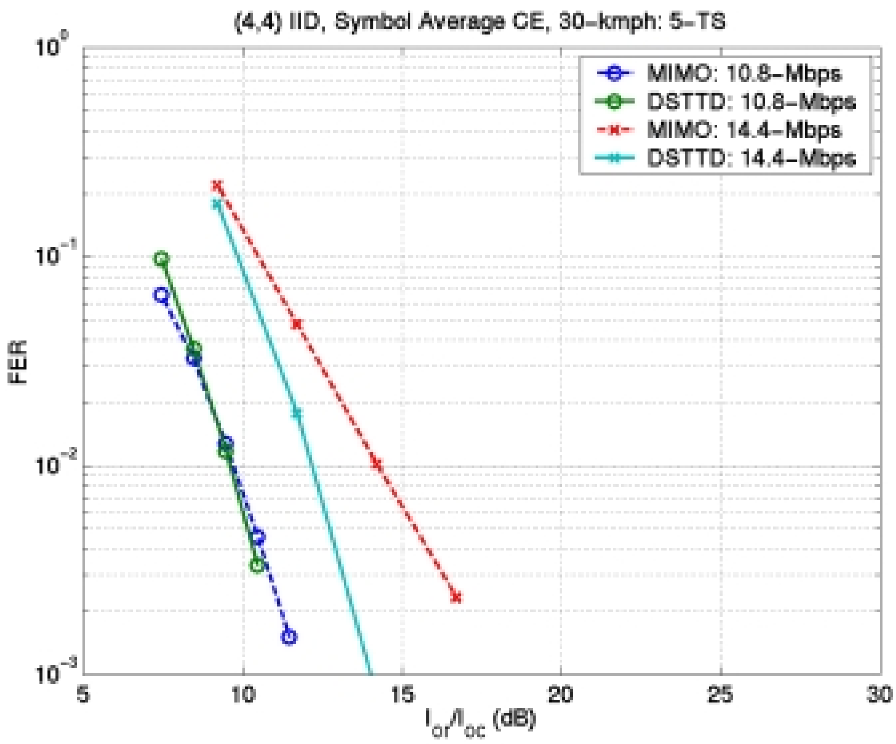

Figure 14. (4,4) MIMO vs. DSTTD with imperfect channel estimation (30-kmph), frame length = 5-TS

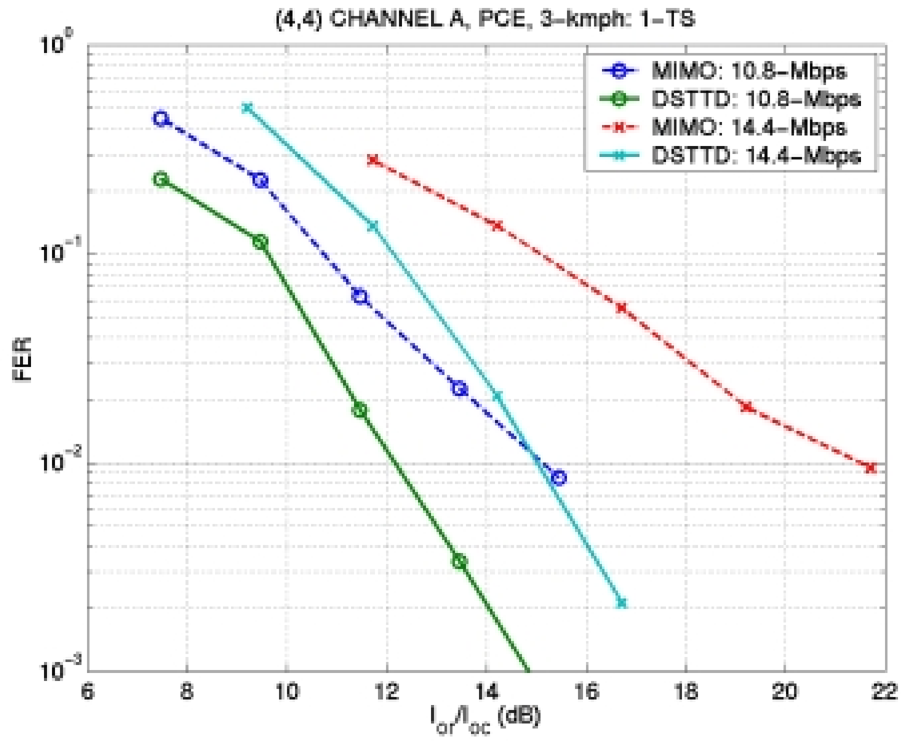

Figure 15. (4,4) MIMO vs. DSTTD in Channel A, frame length = 1-TS

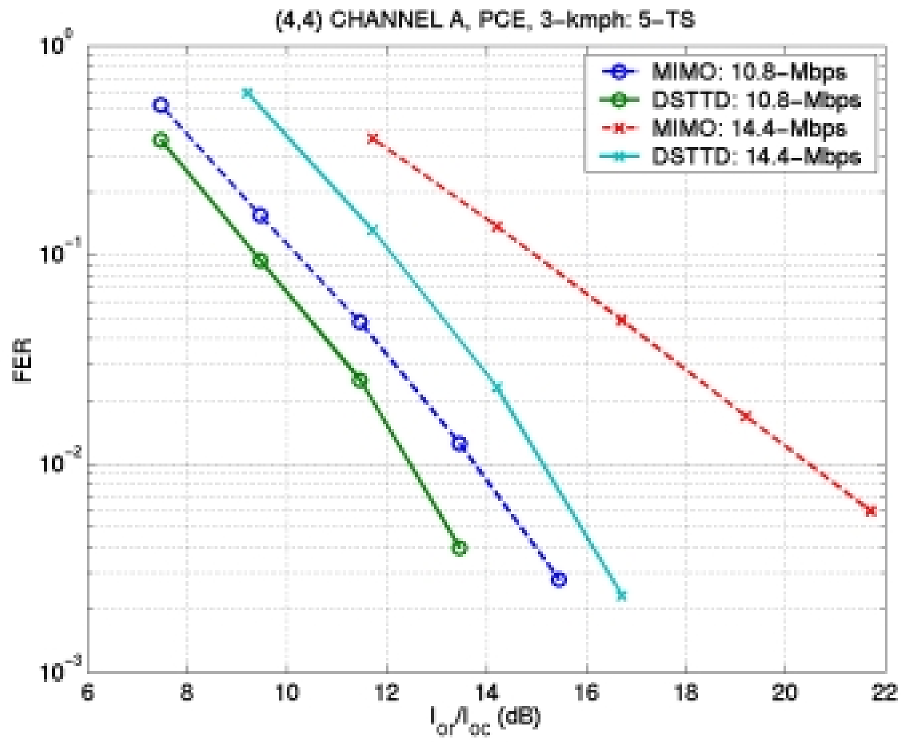

Figure 16. (4,4) MIMO vs. DSTTD in Channel A, frame length = 5-TS

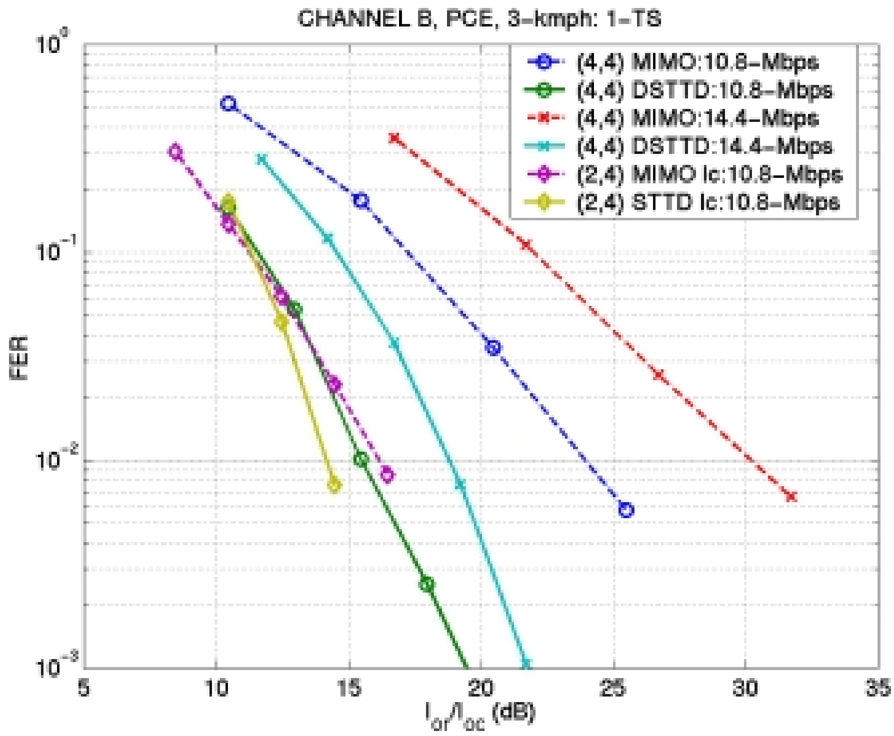

Figure 17. (4,4) MIMO vs. DSTTD in Channel B, frame length = 1-TS

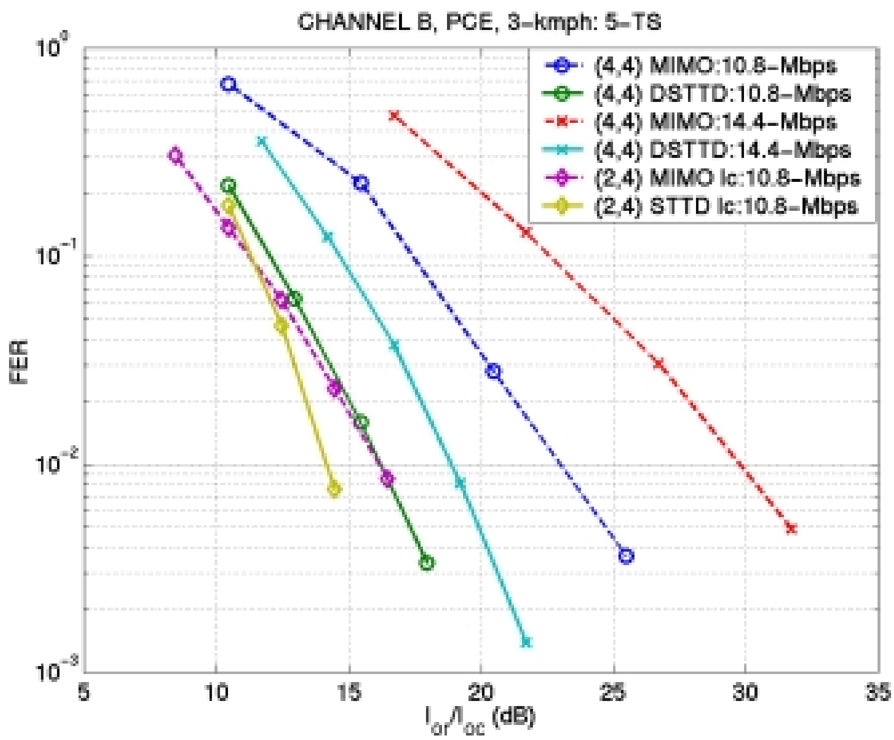

Figure 18. (4,4) MIMO vs. DSTTD in Channel B, frame length = 5-TS

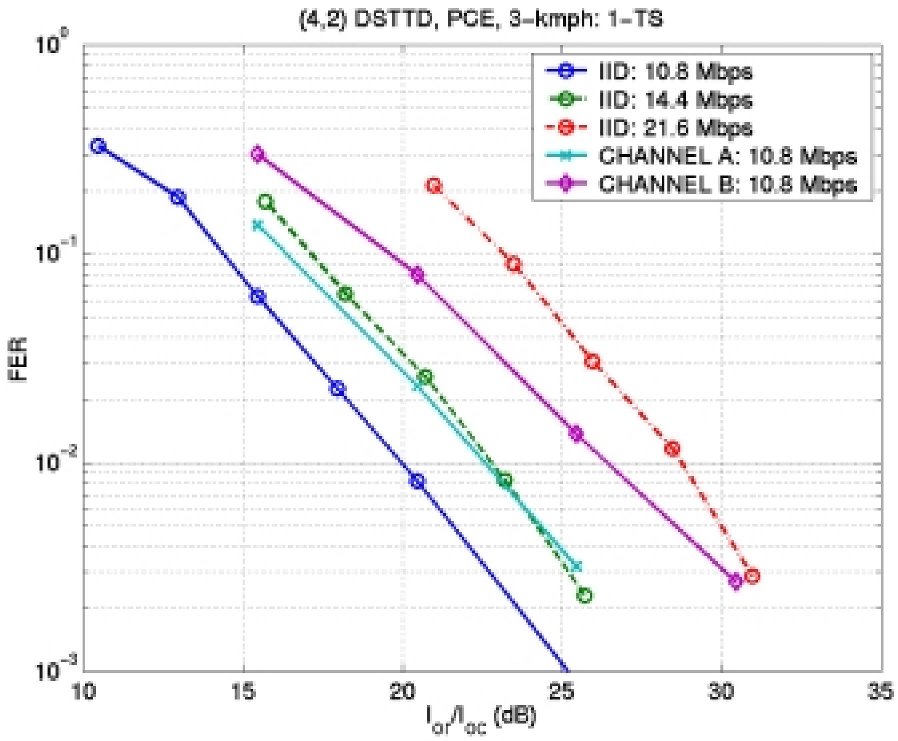

Figure 19. (4,2) DSTTD, frame length = 1-TS

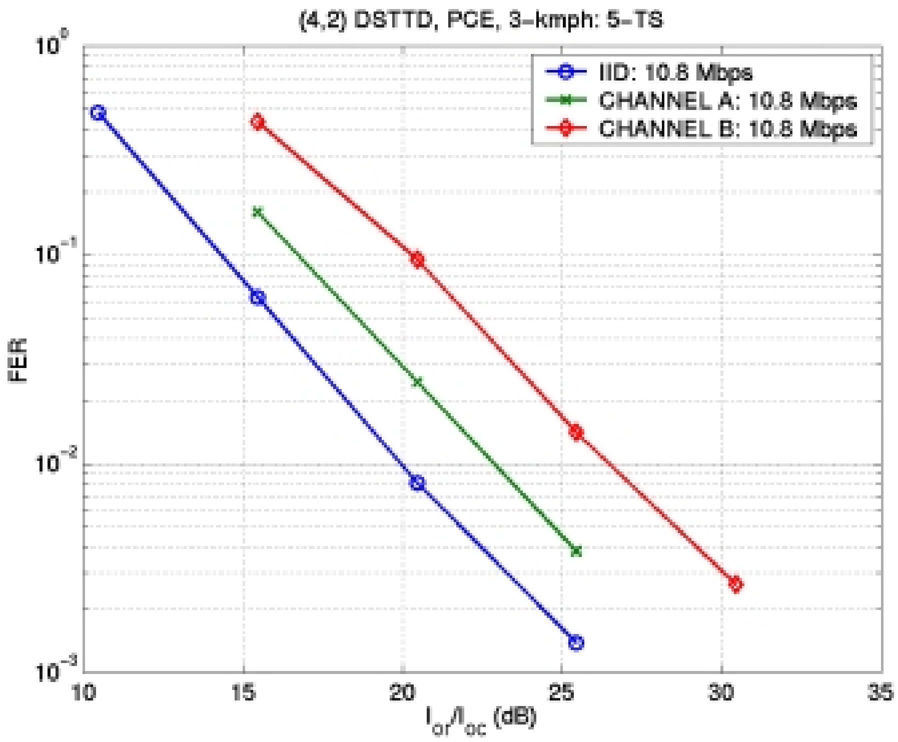

Figure 20. (4,2) DSTTD, frame length = 5-TS