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Source:	**LSI Corporation (formerly Agere Systems)**
Title:	**DL Transmit Diversity with Spatial Multiplexing for 4 TX Antennas**
Agenda Item:	**7.2.6**
Document for:	**Discussion and Decision**

I INTRODUCTION

SFBC-FSTD was adopted at the RAN1#49 meeting [1] as the working assumption for open loop downlink transmit diversity with 4 transmit antennas. In this contribution, we compare the performance of SFBC-FSTD with SFBC-SM (where SM is an abbreviation for spatial multiplexing). We show that SFBC-FSTD performs better at low SNRs, whereas SFBC-SM performs better at high SNRs. To achieve maximal capacity in an LTE network while operating in open loop, we suggest that SFBC-FSTD should be used at low SNRs, and SFBC-SM at high SNRs.

II CODE DESCRIPTIONS

The code matrix (antenna index x subcarrier index) for SFBC-FSTD is given by [1]:

$$\begin{bmatrix} s_1 & s_2 & 0 & 0 \\ 0 & 0 & s_3 & s_4 \\ -s_2^* & s_1^* & 0 & 0 \\ 0 & 0 & -s_4^* & s_3^* \end{bmatrix} \tag{1}$$

Note that the structure in (1) achieves better averaging of channel estimates (since RS on antennas 3 and 4 are weaker than those on antennas 1 and 2). The code matrix for SFBC-SM is given by:

$$\begin{bmatrix} s_1 & s_2 \\ s_3 & s_4 \\ -s_2^* & s_1^* \\ -s_4^* & s_3^* \end{bmatrix} \tag{2}$$

For the same modulation and coding scheme, it can be readily seen that the transmission rate of SFBC-SM is twice that of SFBC-FSTD.

III PERFORMANCE COMPARISON

From an information theory perspective, a useful criterion for benchmarking the performance of a coding scheme is to compute its mutual information, which is a measure of the maximum data rate the code will support at an arbitrarily low BER. By this measure, good codes are those whose mutual information is as close as possible to the capacity of the channel. Figure 1 plots the mutual information as a function of SNR in an i.i.d. Rayleigh fading channel for three TxD[1] codes — SFBC-FSTD, SFBC-SM, and QO-SFBC-CR[2] (which was presented in an earlier contribution [2]).

[1] TxD is an abbreviation for transmit diversity.
[2] QO-SFBC-CR is an abbreviation for quasi-orthogonal SFBC with constellation rotation.

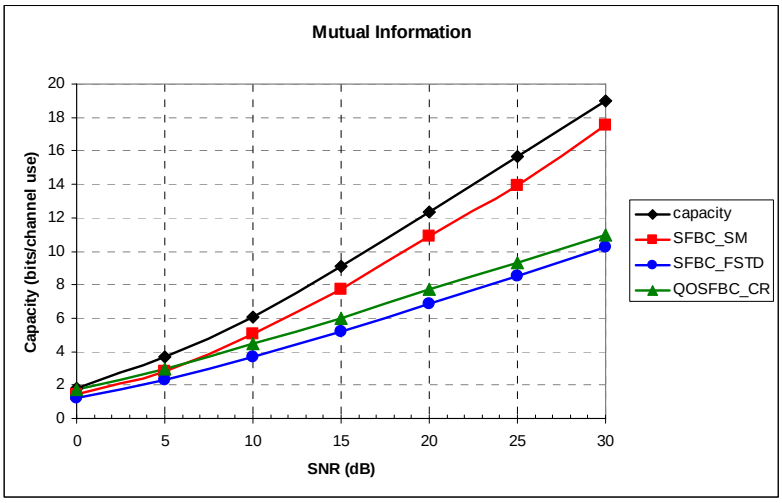

Figure 1: Mutual information for Open Loop Space-Time Codes in 4x2 i.i.d. Rayleigh

The capacity of a 4x2 i.i.d. Rayleigh fading channel is shown by the black curve. It can be seen that SFBC-SM nearly achieves the capacity of the channel, whereas both SFBC-FSTD and QO-SFBC-CR are well below capacity at high SNRs. This suggests to us that at high SNRs, SFBC-SM has the potential to offer better performance than SFBC-FSTD. To explore this possibility further, we simulated the FER performance of SFBC-FSTD and SFBC-SM using the simulation setup outlined in Table 1.

Table 1: Simulation setup

antenna configuration	4 transmit (at eNodeB) and 2 receive (at UE)
FFT size	512 tones across 5 MHz BW
channel model	SCM-C, 30km/hr Doppler
encoding scheme	3GPP Turbo encoder/decoder
Modulation	QPSK, 16-QAM, and 64-QAM
number of RBs	1 (12 subcarriers) and 4 (48 subcarriers)
frame	1ms (14 OFDM symbols)
channel estimation	realistic (time averaging with frequency interpolation)
receiver	maximum likelihood (spherical decoder [3] for SFBC-SM, linear for SFBC-FSTD)

To conduct an equitable comparison between SFBC-SM and SFBC-FSTD, their respective modulation and coding schemes were chosen such that their data rate (or spectral efficiency) was identical, as shown in Table 2 and Table 3. The results presented in Table 2 are for 1RB, and those in Table 3 are for 4RB. Comparing the performance of the two TxD codes at 1% FER, we observe that except for case # 1, SFBC-SM outperforms SFBC-FSTD. The most dramatic performance improvement is seen in cases #4 and #8, whereby SFBC-SM exhibits a 5dB gain over SFBC-FSTD. All the performance curves corresponding to the eight simulation cases can be found in section IV.

Based on the results show in Table 2 and Table 3, we can make the following observations:

- High spectral efficiency is better achieved via spatial multiplexing gain rather than diversity gain.
- Performance advantage of SFBC-SM over SFBC-FSTD either improves or stays the same in going from 1RB to 4RB. Presumably, the larger block length (in the turbo coder) helps SFBC-SM more so than SFBC-FSTD.
- For 4RB, we see a monotonic improvement in the performance advantage of SFBC-SM over SFBC-FSTD as function of spectral efficiency. This result is consistent with the capacity curve shown in Figure 1, whereby the mutual information of SFBC-SM is much higher than SFBC-FSTD at higher SNRs.
- At low SNRs and with inadequate frequency diversity (such as in case # 1), the diversity advantage of SFBC-FSTD leads to its better performance.

Therefore, our results establish that we should take advantage of spatial multiplexing gain at higher SNRs by using SFBC-SM to achieve higher spectral efficiencies. At low SNRs with inadequate frequency diversity (such as in case # 1), SFBC-FSTD should be used to exploit the diversity gain.

Table 2: Performance comparison between SFBC-SM and SFBC-FSTD for 1RB

Case	Figure number	SFBC-SM	SFBC-FSTD	Spectral Efficiency	Performance advantage of SFBC-SM at 1% FER
1	2	4/5-QPSK	4/5-16QAM	3.2 bps/Hz	-0.8 dB
2	3	9/10-QPSK	9/10-16QAM	3.6 bps/Hz	+2.0 dB
3	4	3/5-16QAM	4/5-64QAM	4.8 bps/Hz	+1.6 dB
4	5	2/3-16QAM	8/9-64QAM	5.33 bps/Hz	+5.0 dB

Table 3: Performance comparison between SFBC-SM and SFBC-FSTD for 4 RB

Case	Figure number	SFBC-SM	SFBC-FSTD	Spectral Efficiency	Performance advantage of SFBC-SM at 1% FER
5	6	4/5-QPSK	4/5-16QAM	3.2 bps/Hz	+1.2 dB
6	7	9/10-QPSK	9/10-16QAM	3.6 bps/Hz	+2.0 dB
7	8	3/5-16QAM	4/5-64QAM	4.8 bps/Hz	+2.4 dB
8	9	2/3-16QAM	8/9-64QAM	5.33 bps/Hz	+5.0 dB

IV PERFORMANCE CURVES

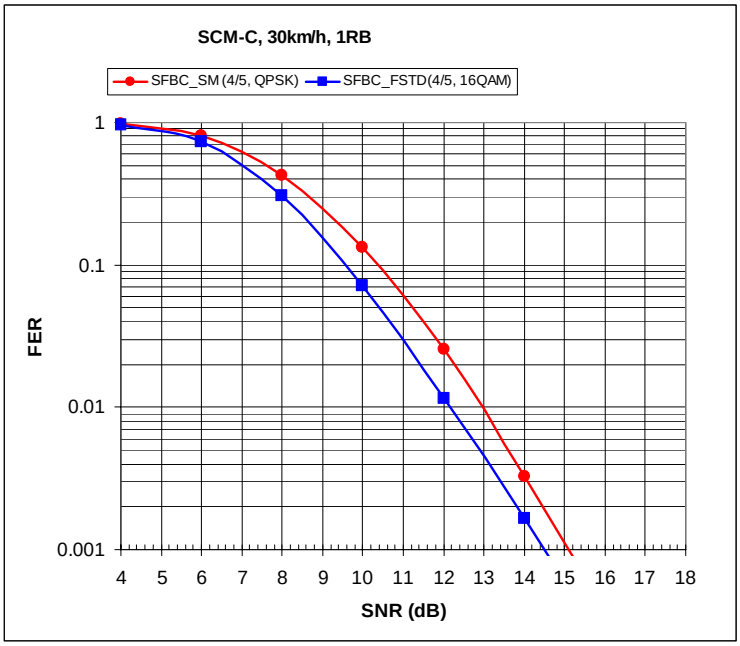

Figure 2: Case 1 – comparison of SFBC-SM with SFBC-FSTD at 3.2 bps/Hz

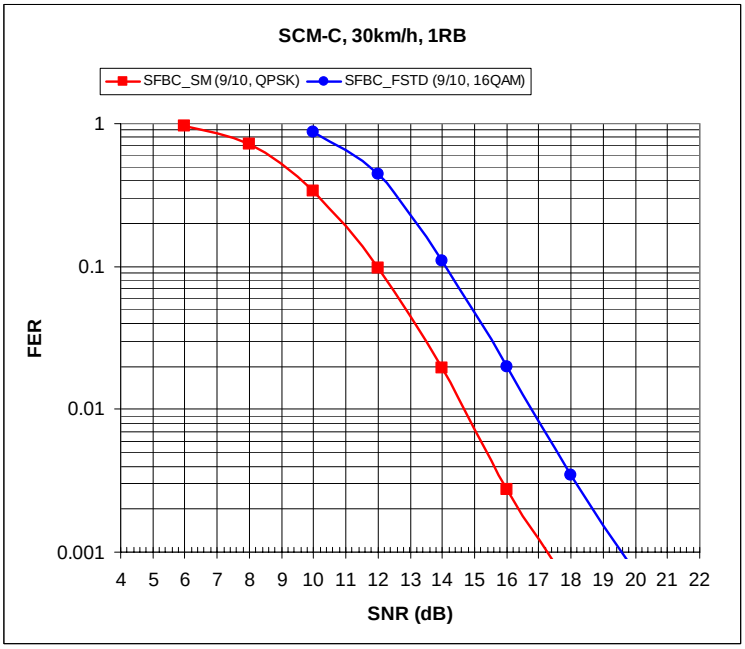

Figure 3: Case 2 – comparison of SFBC-SM with SFBC-FSTD at 3.6 bps/Hz

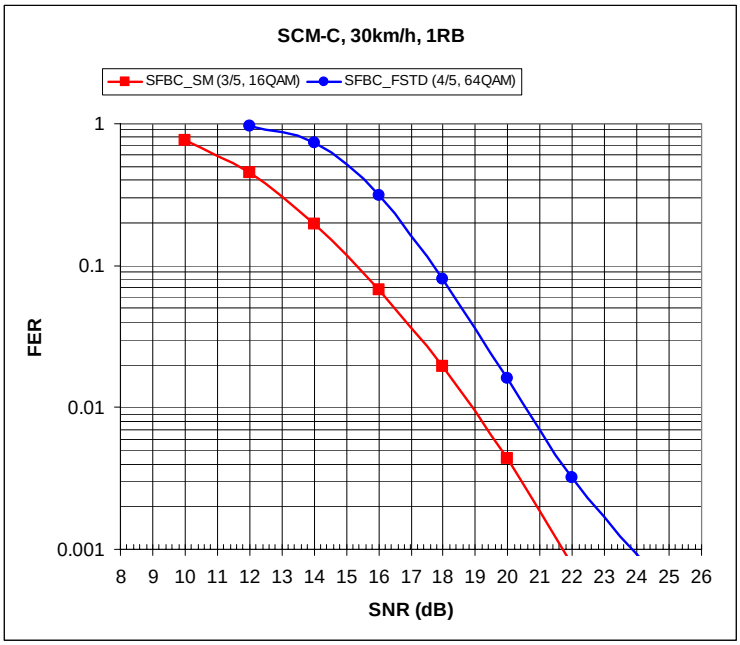

Figure 4: Case 3 – comparison of SFBC-SM with SFBC-FSTD at 4.8 bps/Hz

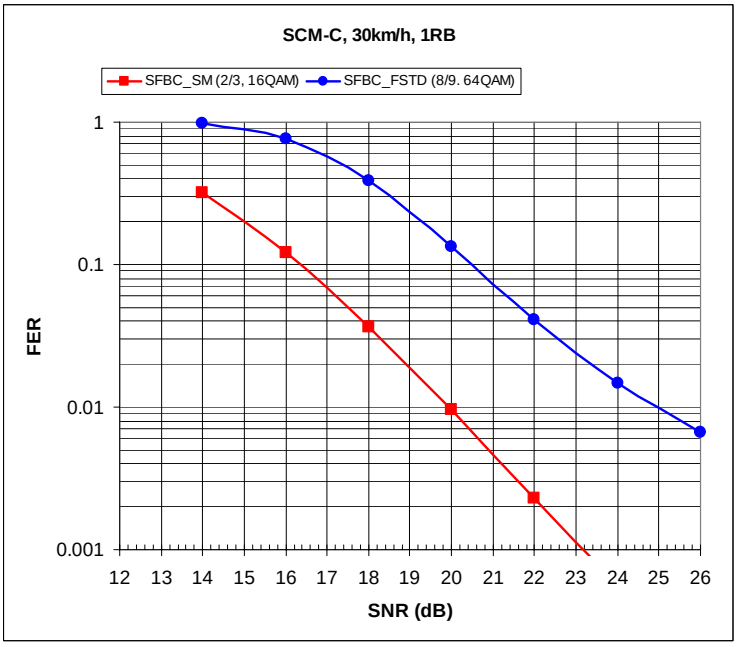

Figure 5: Case 4 – performance comparison of SFBC-SM with SFBC-FSTD for 5.33 bps/Hz

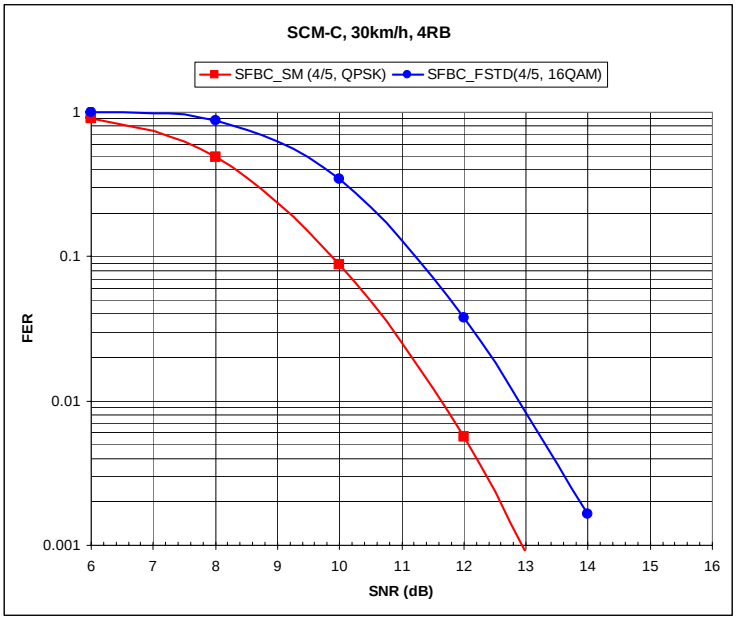

Figure 6: Case 5 – performance comparison between SFBC-SM and SFBC-FSTD for 3.2bps/Hz

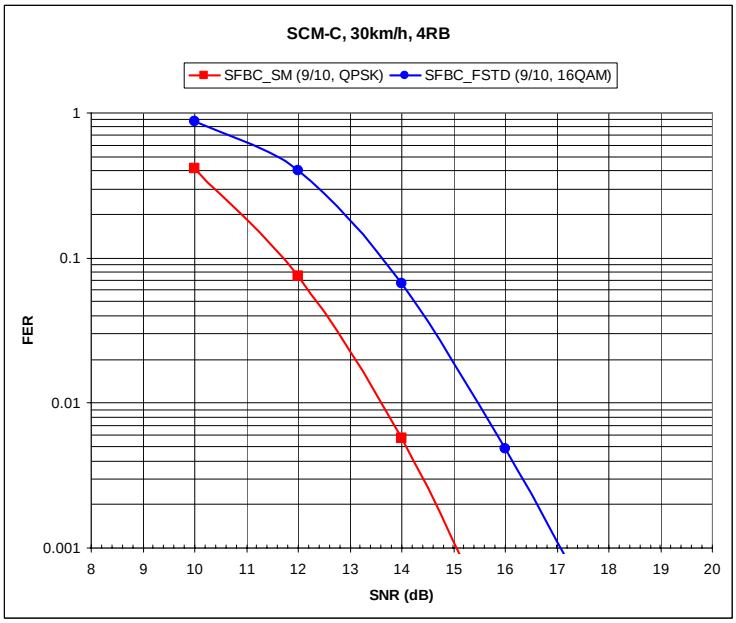

Figure 7: Case 6 – performance comparison between SFBC-SM and SFBC-FSTD for 3.6bps/Hz

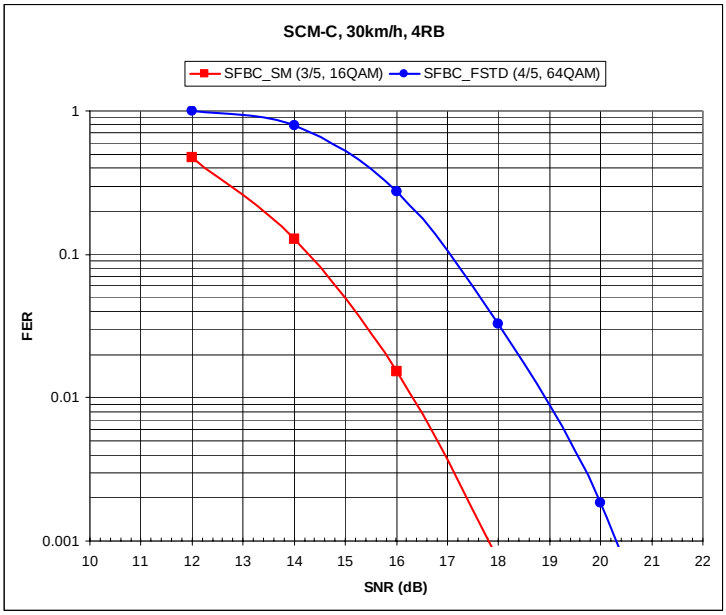

Figure 8: Case 7 – performance comparison between SFBC-SM and SFBC-FSTD for 4.8bps/Hz

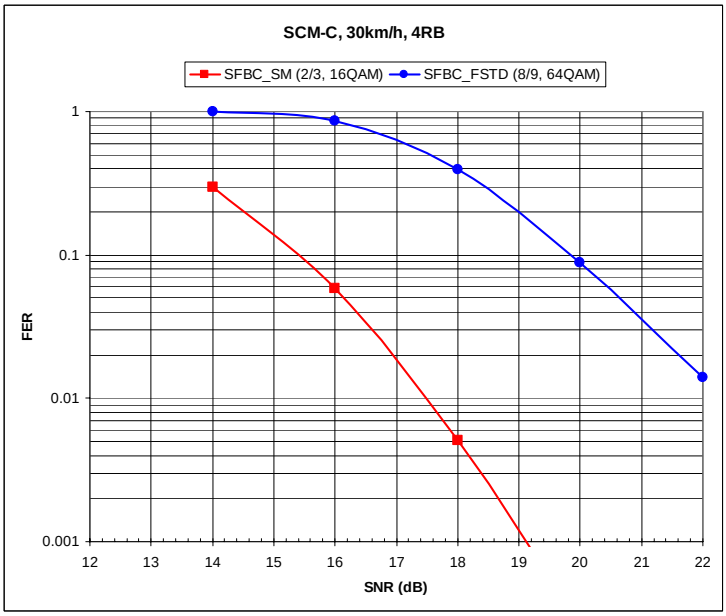

Figure 9: Case 8 – performance comparison between SFBC-SM and SFBC-FSTD for 5.33bps/Hz

V CONCLUSION

In this contribution, we compared the performance of SFBC-SM[3] with SFBC-FSTD (which is currently the working assumption for DL TxD) for the 4x2 antenna configuration. We showed through simulations that, at higher SNRs, significantly better performance (on the order of several dBs) is achieved by exploiting spatial multiplexing gain rather than diversity gain. Conversely, at low SNRs, diversity plays a more important role. Hence, to achieve optimal capacity in an LTE network, SFBC-FSTD should be used at lower SNRs and SFBC-SM at higher SNRs. Therefore, we recommend that both SFBC-SM and SFBC-FSTD should be adopted as techniques for downlink TxD in open loop 4x2 operation.

VI REFERENCES

[1] R1-072620, MIMO Ad Hoc summary, 3GPP RAN1#49, Kobe, Japan, May 2007.

[2] R1-071801, Agere Systems, "Performance Comparison of Downlink Tx Diversity schemes with 4 Tx antennas for the Shared Data Channel," 3GPP RAN1 #48bis, St. Julians, Malta, March 2007.

[3] R1-072047, LSI Corporation, "Further results on QO-SFBC as a TxD scheme for 4 transmit antennas," 3GPP RAN1 #49, Kobe, Japan, May 2007.

[3] SM is an abbreviation for spatial multiplexing.