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1. Motivation

The performance of MIMO transceiver depends on MIMO channel characteristics. If a transmitter with multiple antennas sends different streams through different antenna elements, the orthogonality among transmitted streams determines the performance of MIMO transceiver. The orthogonality among streams requires the independent channels between transmit and receive antennas if no other spatial processing exists. In reality, there are correlations between antenna elements because of low antenna spacing and low angle spread of signal. Fully independent channels between antenna elements will show equal magnitude of eigenvalues of channel covariance matrix. However, the eigenvalues are different from each other even when the angle spread is very large. Open loop MIMO system cannot utilize these real channel characteristics since the transmitter of open loop MIMO system transmits data streams assuming independent channels among antenna elements without knowledge of channel qualities. Without any coding in spatial domain and signal processing to separate the transmitted streams spatially, the orthogonality between antenna elements could not be guaranteed. We can take advantage of channel characteristics such as the distribution of eigenvalues and eigenvectors of channel covariance matrix. Moreover each stream can be transmitted independently through multiple antennas if the orthogonal weight vector is applied at each stream. Through these discussions, we propose a closed loop MIMO transmission and reception procedures in this paper.

2. Multi-Stream Beamforming Concept and Transceiver

The proposed method is termed as Multi Stream Beamforming (MSB) MIMO system since each stream to be transmitted is beamformed in advance. Each stream will be beamformed with the one of eigenvectors of channel covariance matrix and the modulation and code rate of each stream is determined by SINR per stream. The distribution of SINR per stream is equivalent to the distribution of eigenvalue of channel covariance matrix if each eigenvector are adopted for beamforming weight vector for each stream. The MSB MIMO system can be interpreted as an extension of conventional single stream beamforming to multi stream beamforming. Conventional beamforming methods only transmit single data stream at antenna array with small spacing multiple antennas. However, in the MSB, each antenna elements transmits an independent stream after beamforming with weight vectors from feedback information of UE. Figure 1 represents the conceptual transceiver of proposed MSB MIMO system. Figure 1 implies that each data stream is transmitted after beamforming with each eigenvector of channel covariance matrix and the modulation and code rate of each stream is dependent on the magnitude of each eigenvalue channel covariance matrix. In figure 1, λ_i $(i = 1 \cdots M)$ denotes each eigenvalue of channel covariance matrix in descending order

and $\underline{w}_i$ $(i = 1 \cdots M)$ is each weight vector for each stream.

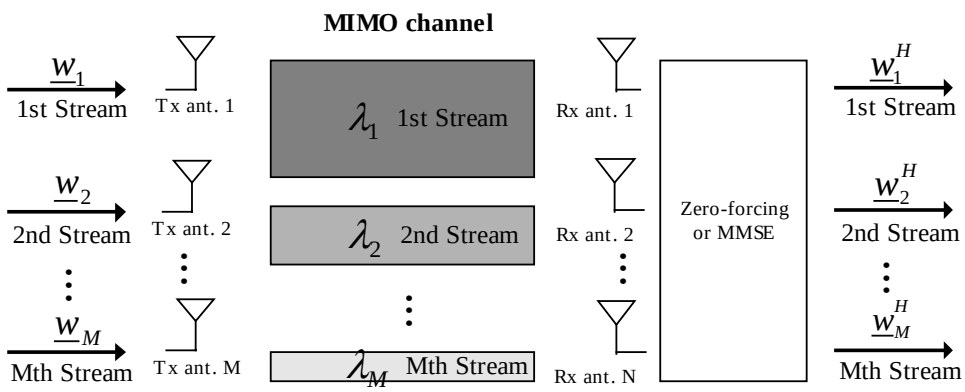

Figure 1. Conceptual block diagram of MSB MIMO transmitter and receiver

Proposed MSB can be summarized as follows. Transmitted signal with MSB is represented as,

$$\underline{S} = \underline{w}_1 s_1 + \underline{w}_2 s_2 + \cdots \underline{w}_M s_M \quad (1)$$

where $\underline{w}_i$ $(i = 1 \cdots M)$ denotes each weight vector for each symbol, s_i $(i = 1 \cdots M)$ is the symbol to be transmitted at each transmit stream. Each weight vector can be determined with eigen-decomposition of channel covariance matrix. The eigen-decomposition of channel covariance matrix is written as,

$$\underline{\underline{H}}^H \underline{\underline{H}} \Rightarrow \lambda_1 \underline{e}_1 + \lambda_2 \underline{e}_2 + \cdots + \lambda_M \underline{e}_M \quad (2)$$

where λ_i $(i = 1 \cdots M)$ is the eigenvalue of channel covariance matrix, $\underline{\underline{H}}^H \underline{\underline{H}}$ and $\underline{e}_i$ $(i = 1 \cdots M)$ represents the eigenvector corresponding to each eigenvalue, λ_i.

The received signal vector at antenna array of receiver is

$$\underline{R} = \underline{\underline{H}}\,\underline{S} + \underline{n} \quad (3)$$

where $\underline{n}$ is additive complex Gaussian noise vector.

Firstly, through zero-forcing we can estimate the transmitted signal vector, $\underline{S}$ as follow,

$$\hat{\underline{S}}_{ZF} = \left[\underline{\underline{H}}^H \underline{\underline{H}}\right]^{-1} \underline{\underline{H}}^H \underline{R} \quad (4)$$

where $\hat{\underline{S}}_{ZF}$ denotes the estimated transmitted signal vector after zero-forcing processing.

If minimum mean square error (MMSE) criterion is used the estimated transmitted signal vector can be found as,

$$\underline{\hat{S}}_{MMSE} = \left[\alpha \underline{\underline{I}} + \underline{\underline{H}}^H \underline{\underline{H}}\right]^{-1} \underline{\underline{H}}^H \underline{R} \qquad (5)$$

where α represents the signal to noise ratio at each antenna element and $\underline{\underline{I}}$ denotes the identity matrix.

Each transmitted symbol at each transmit stream can be recovered through receive beamforming from estimated transmitted signal vector with same weight vector for transmit beamforming as follows,

$$\hat{s}_1 = \underline{w}_1^H \underline{\hat{S}}, \ldots, \hat{s}_M = \underline{w}_M^H \underline{\hat{S}} \qquad (6)$$

where $\hat{s}_i \quad (i = 1 \cdots M)$ is the estimated transmitted symbol at each transmit stream and $\underline{\hat{S}}$ denotes the estimated transmitted signal vector.

3. Rate Determination for MSB

The MSB MIMO transmitter can choose suitable MCS per stream through determining SINR per stream. Note that interference cancellation is not required for the MSB MIMO since the weight vectors for data streams are orthogonal. Figure 2 and 3 represent the output SINR of proposed system with (2,2) and (4,4) antenna configuration, respectively. Figure 4 and 5 describes the eigenvalue distribution of MIMO channel. We can remark that the output SINR of the MSB MIMO system is in proportional to eigenvalue distribution of MIMO channel. If we consider the fraction data power, the number of spreading codes, IorIoc and the fractional receive power, the output SINR of each stream can be determined from the eigenvalue of each stream. It mean that MIMO channel is converted to multiple SISO channels in which each transformed SISO channel has capacity in proportion to each eigenvalue of channel covariance matrix. In other words, the MSB MIMO transmitter transforms MIMO channel to multiple SISO channels with beamforming of each stream. On the other hand PARC transmitter depends on only the instantaneous downlink channel response.

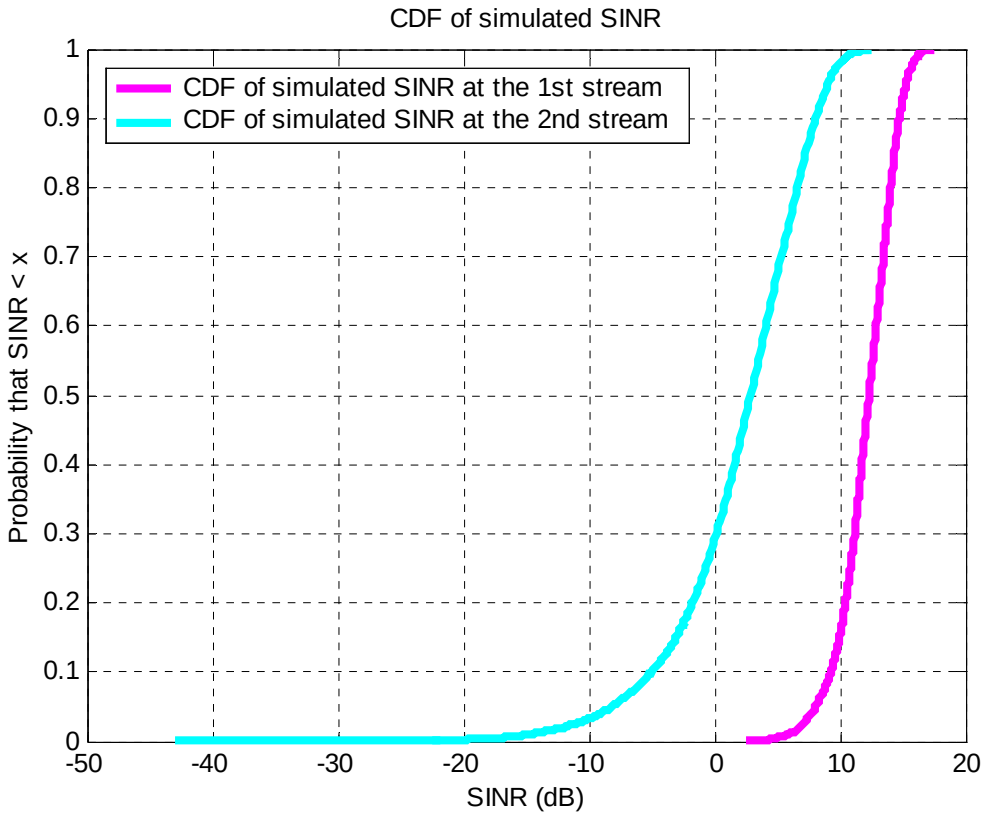

Figure 2. CDF of output SINR of MSB: (2,2) MIMO system, IorIoc = 10dB

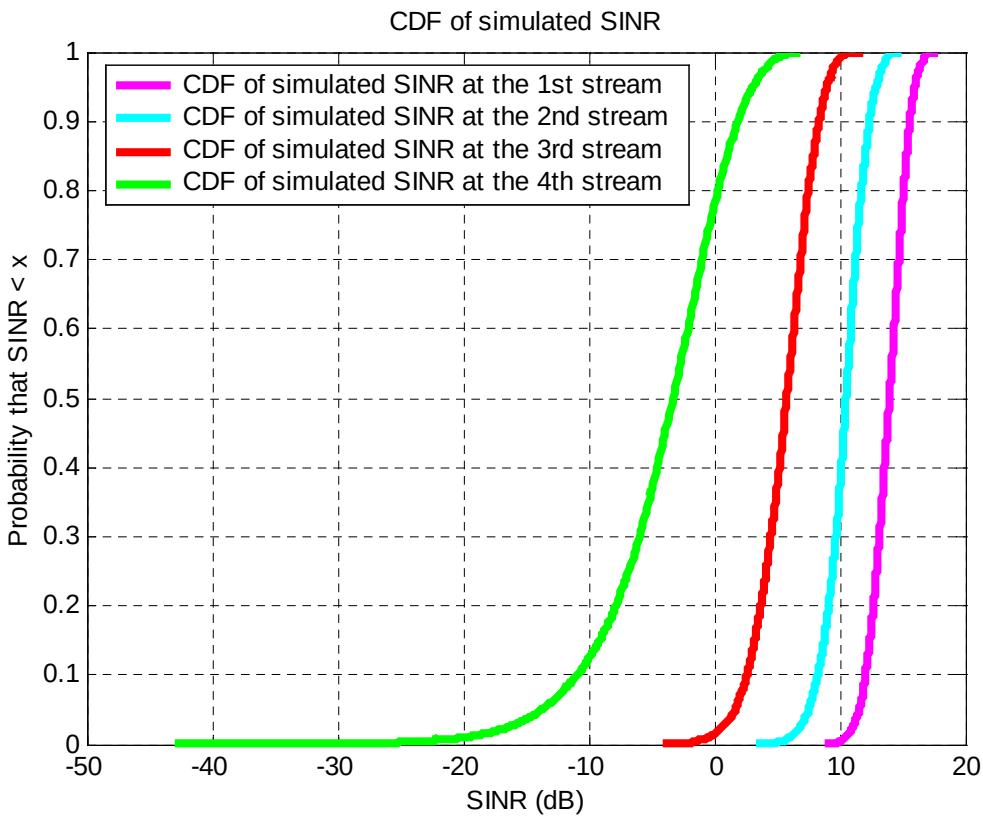

Figure 3. CDF of output SINR of MSB: (4,4) MIMO system, IorIoc = 10dB

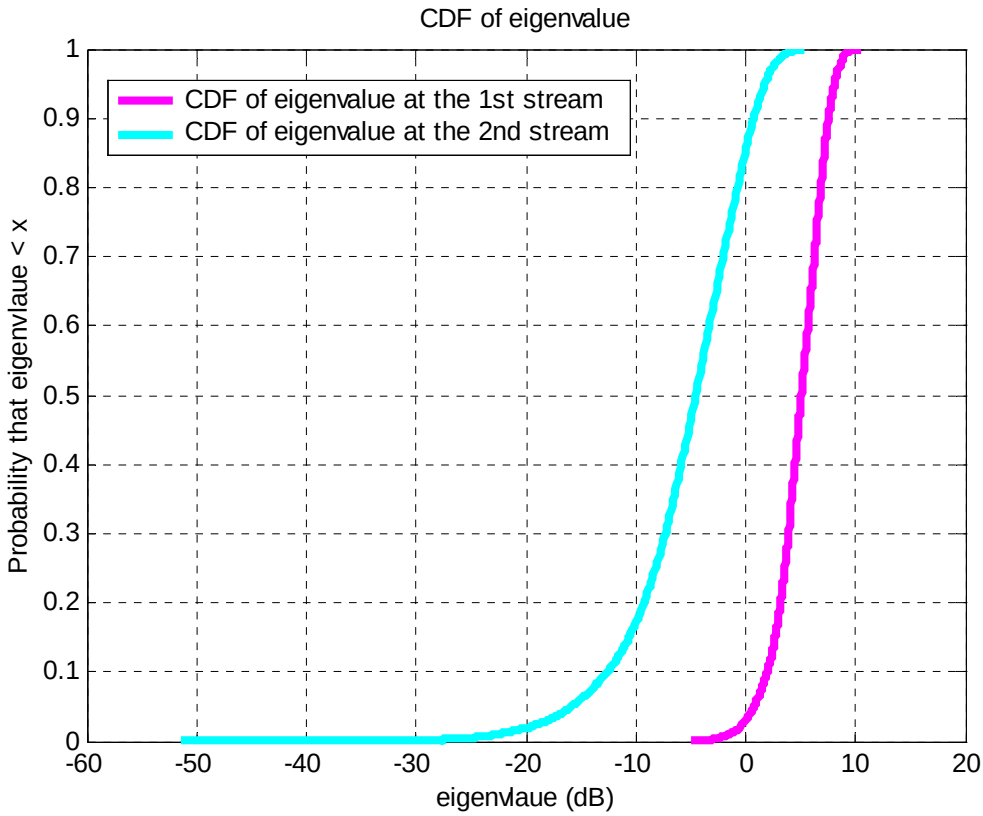

Figure 4. CDF of eigenvalue of channel: (2,2) MIMO system

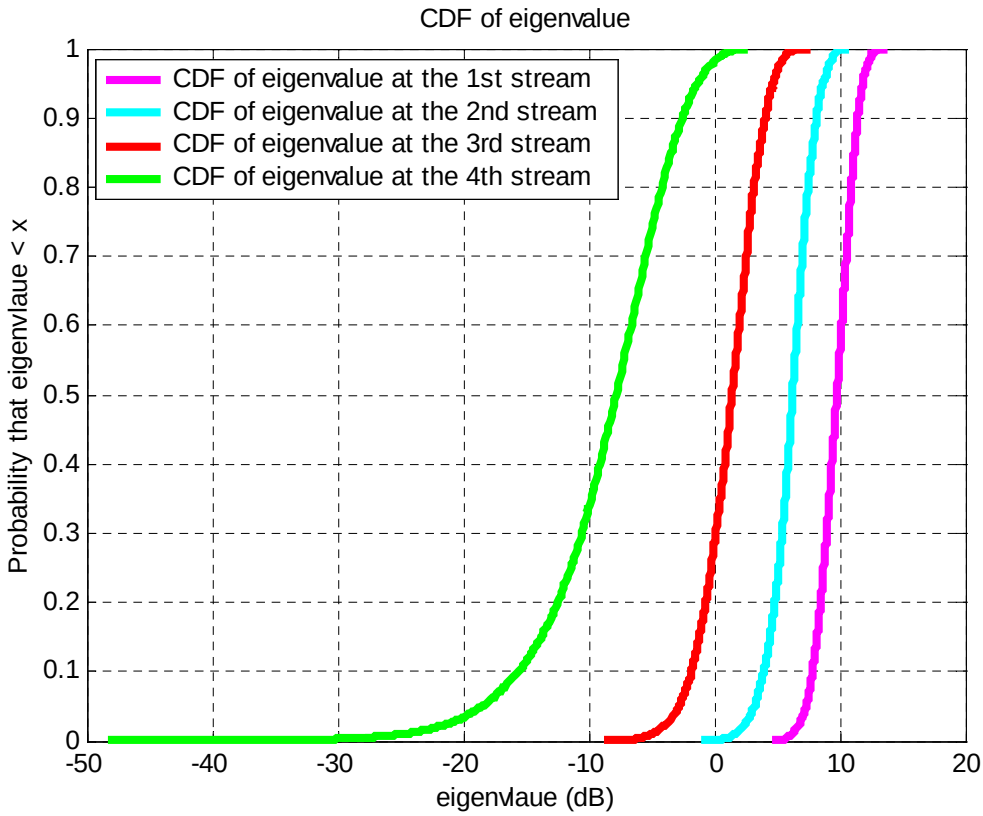

Figure 5. CDF of eigenvalue of channel: (4,4) MIMO system

4. Performances: Single User Throughput

We show the performances of the MSB MIMO system in terms of single user throughput in this section. From the simulations, we found the rate and MCS table for the MSB MIMO system. The modulation and coding schemes on each stream are one of the five options listed in Table 1. We tabulated possible rate and MCS sets for (2,2) and (4,4) MIMO antenna configurations in table 2 and 3 respectively.

Table 1. Index of modulation and coding schemes and associated data rate assuming 10 out of 16 codes used.

bps/Hz	Data rate (Mbps)	Constellation	Coding rate
3	7.2	16 QAM	3/4
2	4.8	16 QAM	1/2
1.5	3.6	QPSK	3/4
1	2.4	QPSK	1/2
0.5	1.2	QPSK	1/4

Table 2 . Rate and MCS set for (2,2) MSB: (bps/Hz, symbol repetition)

Index	Rate (Mbps)	Ant 1	Ant 2	Index	Rate (Mbps)	Ant 1	Ant 2
1	14.4	3	3	17	6.0	1.5	1
2	12.0	3	2	18	4.8	1.5	0.5
3	10.8	3	1.5	19	4.2	1.5	0.5,2
4	9.6	3	1	20	3.9	1.5	0.5,4
5	8.4	3	0.5	21	3.6	1.5	0
6	7.8	3	0.5,2	22	4.8	1	1
7	7.5	3	0.5,4	23	3.6	1	0.5
8	7.2	3	0	24	3.0	1	0.5,2
9	9.6	2	2	25	2.7	1	0.5,4
10	8.4	2	1.5	26	2.4	1	0
11	7.2	2	1	27	1.8	0.5	0.5,2
12	6.0	2	0.5	28	1.5	0.5	0.5,4
13	5.4	2	0.5,2	29	1.2	0.5	0
14	5.1	2	0.5,4	30	0.9	0.5,2	0.5,4
15	4.8	2	0	31	0.6	0.5,2	0
16	7.2	1.5	1.5	32	0.3	0.5,4	0

Table 3. Rate and MCS set for (4,4) MSB: (bps/Hz)

Index	Rate (Mbps)	Ant 1	Ant 2	Ant 3	Ant 4	Index	Rate (Mbps)	Ant 1	Ant 2	Ant 3	Ant 4
1	28.8	3	3	3	3	33	12.0	3	2	0	0
2	26.4	3	3	3	2	34	15.6	3	1.5	1.5	0.5
3	25.2	3	3	3	1.5	35	14.4	3	1.5	1	0.5
4	24.0	3	3	3	1	36	13.2	3	1.5	0.5	0.5
5	22.8	3	3	3	0.5	37	12.0	3	1.5	0.5	0
6	21.6	3	3	3	0	38	10.8	3	1.5	0	0
7	24.0	3	3	2	2	39	9.6	3	1	0	0
8	22.8	3	3	2	1.5	40	12.0	2	2	0.5	0.5
9	21.6	3	3	2	1	41	10.8	2	2	0.5	0
10	20.4	3	3	2	0.5	42	9.6	2	2	0	0
11	19.2	3	3	2	0	43	12.0	2	1.5	1	0.5
12	21.6	3	3	1.5	1.5	44	10.8	2	1.5	1	0
13	20.4	3	3	1.5	1	45	10.8	2	1.5	0.5	0.5

14	19.2	3	3	1.5	0.5	46	9.6	2	1.5	0.5	0
15	18.0	3	3	1.5	0	47	8.4	2	1.5	0	0
16	19.2	3	3	1	1	48	9.6	2	1	0.5	0.5
17	18.0	3	3	1	0.5	49	8.4	2	1	0.5	0
18	16.8	3	3	1	0	50	7.2	2	1	0	0
19	15.6	3	3	0.5	0	51	6.0	2	0.5	0	0
20	14.4	3	3	0	0	52	9.6	1.5	1.5	1	0
21	18.0	3	2	2	1.5	53	8.4	1.5	1.5	0.5	0
22	19.2	3	2	1.5	1.5	54	7.2	1.5	1.5	0	0
23	21.6	3	2	2	1	55	7.2	1.5	1	0.5	0
24	18.0	3	2	2	0.5	56	6.0	1.5	0.5	0.5	0
25	16.8	3	2	2	0	57	4.8	1.5	0.5	0	0
26	18.0	3	2	1.5	1	58	6.0	1	1	0.5	0
27	16.8	3	2	1.5	0.5	59	4.8	1	1	0	0
28	15.6	3	2	1.5	0	60	4.8	1	0.5	0.5	0
29	16.8	3	2	1	1	61	3.6	1	0.5	0	0
30	15.6	3	2	1	0.5	62	2.4	1	0	0	0
31	14.4	3	2	1	0	63	2.4	0.5	0.5	0	0
32	14.4	3	2	0.5	0.5	64	1.2	0.5	0	0	0

The FER corresponding to each transmit stream decoded independently is determined using the corresponding FER vs. SINR curves. For comparison purpose, we also simulated PARC MIMO proposal [1]. To pick the optimum transmission rate, pre-computed thresholds on the SINR values of each transmit stream are utilized.

Table 4 summarizes the simulation assumptions. Unless otherwise remarked, the assumptions in table 4 are maintained in the single-user throughput simulations. The criterion for choosing the sets was to maximize the throughput for a given geometry such that the frame error rate was no more than 10%.

Table 4. Simulation assumptions

UE speed	3 km/hr
Fraction data power	0.7
Number of spreading codes	10 out of 16
TTI length	3 slots
Channel estimation	perfect
Channel model	i.i.d. flat fading
Frame error rate target	< 10%
Feedback error rate	0
Feedback delay	7 slots
Fractional receive power	0.98

We compare single user throughput of MSB MIMO system to that of PARC MIMO system. Figure 6 and 7 depict the comparison of single user throughput results of proposed MSB and conventional PARC in (2,2) and in (4,4) antenna configuration respectively. It can be noted that MSB shows better performance than those of PARC with perfect interference cancellation. If we consider the perfect interference cancellation is not realistic and requires heavy computations in the receiver, the MSB shows remarkable performance compared to PARC with no interference cancellation.

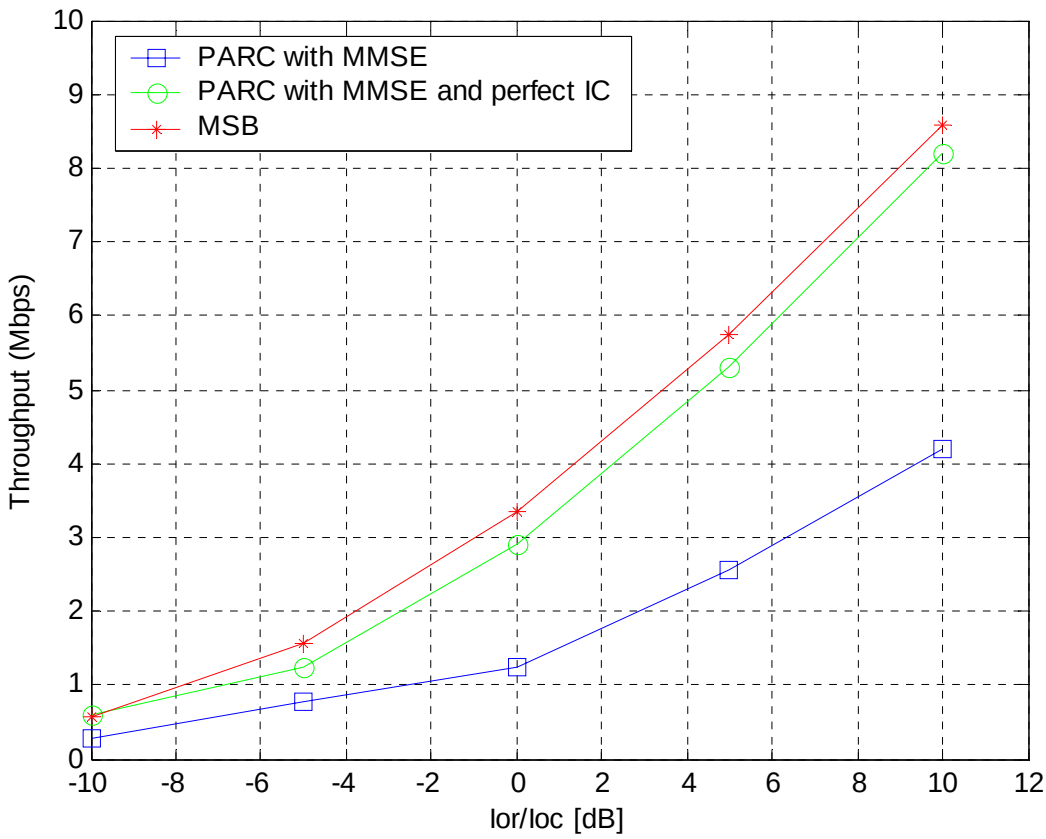

Figure 6. Comparisons of single user throughput results: (2,2) MIMO system.

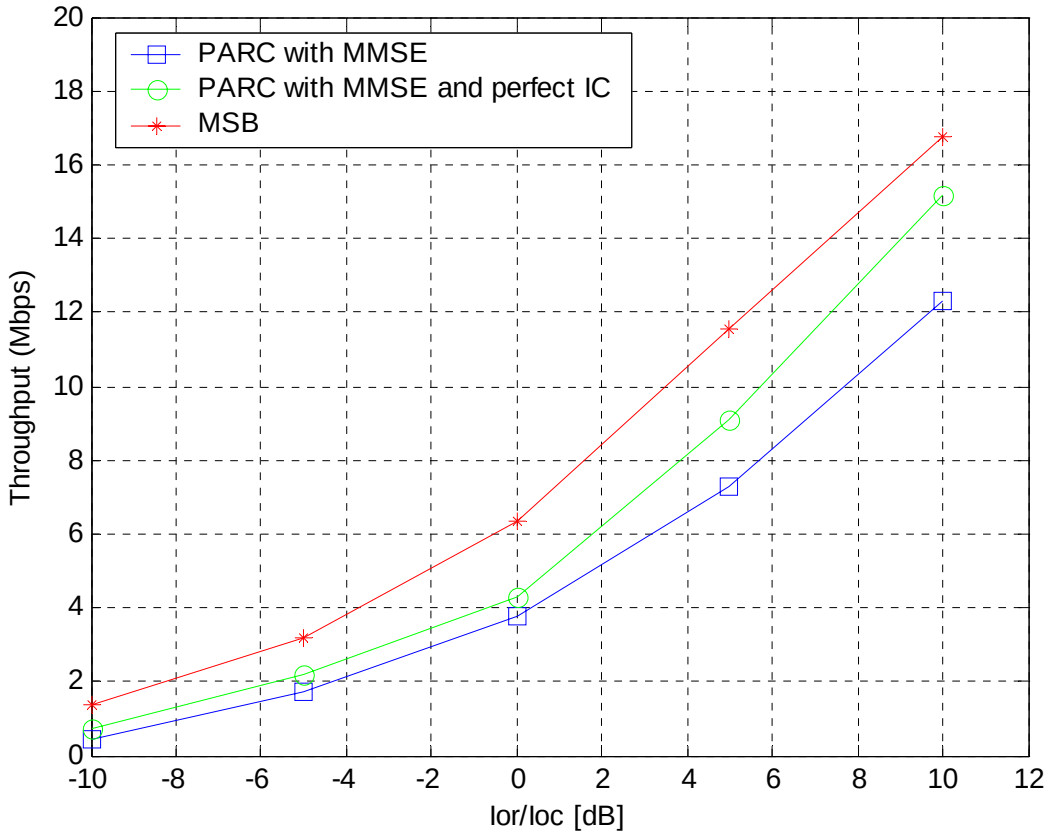

Figure 7. Comparisons of single user throughput results: (4,4) MIMO system.

When 15 codes are fully utilized out of 16 codes, the single user throughput can be further enhanced. Figure 8 compares single user throughput results of various MIMO proposals with same simulation environments given in table 4 except the number of codes used.

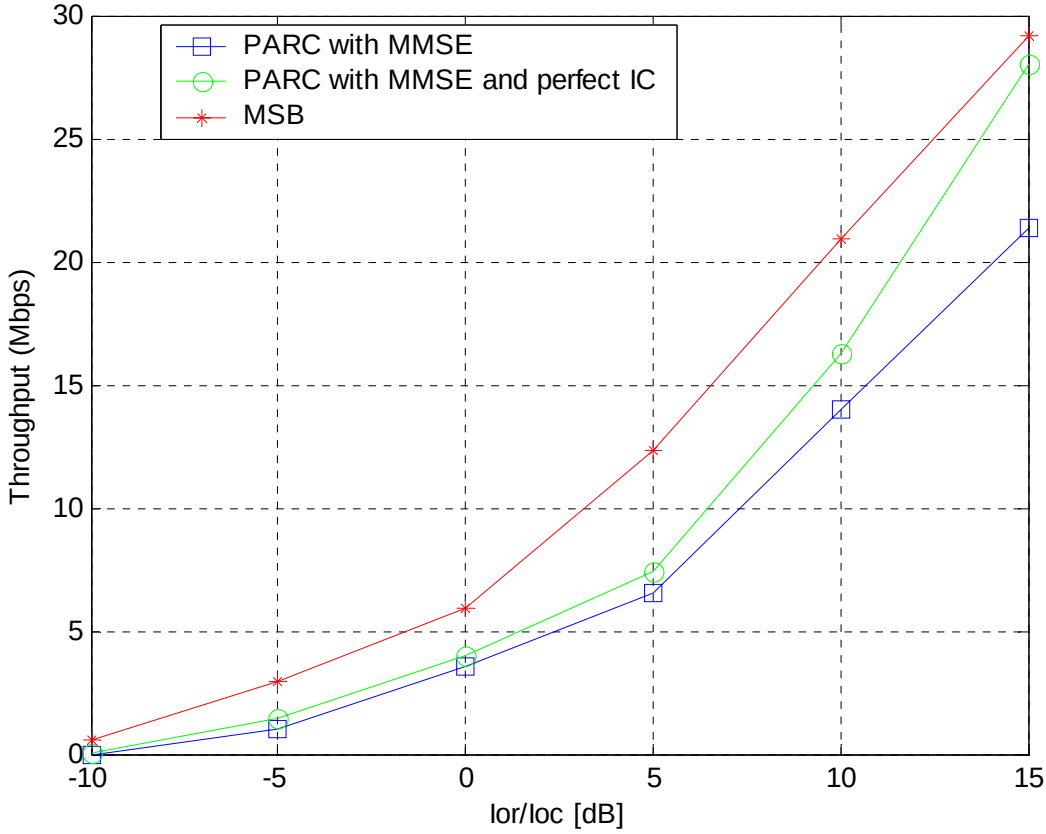

Figure 8. Comparisons of single user throughput results: 15 out of 16 codes, (4,4) MIMO system.

5. Multi-user Scheduling with Space Division Multiplexing

We also should investigate the impact of multi-user scheduling on system throughput since MIMO work item has been considered under HSDPA system environment. When several users are serviced at the same time, conventional HSDPA assumes code division multiplexing among users. In proposed MSB MIMO system, space division multiplexing can be also applied for multi-user scheduling through the use of beamforming. If the cross-correlations between weight vectors of different users are reasonably low, different streams belong to different users can be serviced simultaneously with space division multiplexing.

Space division multiplexing allows MIMO system to utilize code resources efficiently. Low cross-correlation between weight vectors of one user and those of other user gives the possibility of simultaneous services of two users with same codes. It means that multiple users can be serviced at the same time with the help of spatial division even when available orthogonal code is not sufficient. Figure 9 depicts the overall system proposal of the MSB MIMO system considering multi-user spatial multiplexing and scheduling.

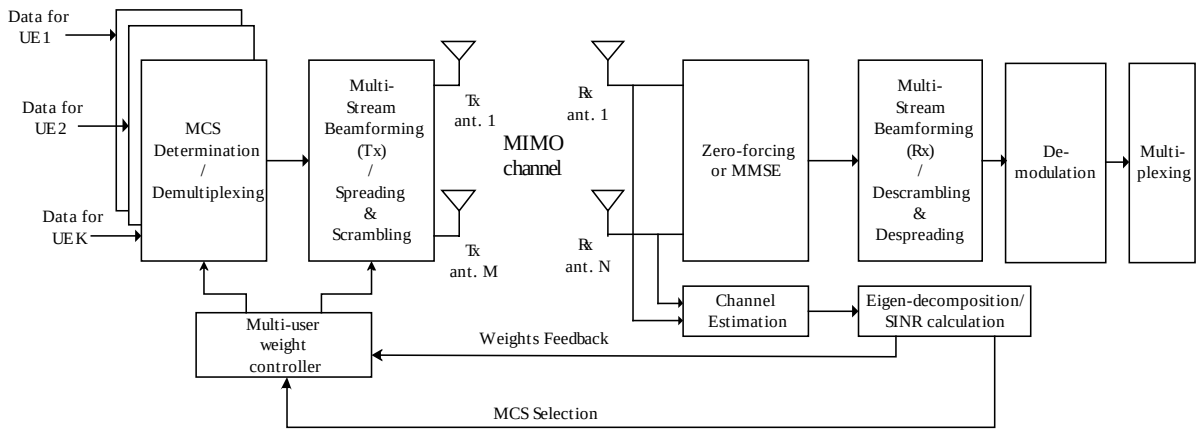

Figure 9. The MSB MIMO System with multi-user spatial multiplexing and scheduling

6. Feedback Semantics

Since proposed MSB MIMO system is a closed loop MIMO system, the efficient feedback of required information should be considered. As can be seen in Figure 9, the MSB receiver feeds back the information for MCS selection and the weight values for beamforming at transmitter. The information of MCS selection for rate determination can be considered as a kind of CQI in conventional HSDPA.

We also should take into account which channel could convey required feedback information. For CQI-like information, we could utilize the existing HS-DPCCH with some modification. However, details of feedback for rate determination need more considerations. For weight values, the feedback signalling structure should also be studied considering the amount of feedback. One of possible method of feedback of weights is the introduction of the new uplink channel. Details of weights feedback need more studies considering the impact of feedback delay and quantization error of weights on performance of MSB.

7. Conclusion

We proposed a closed loop MIMO system termed as MSB which beamforms each stream with each eigenvector of channel covariance matrix. We showed the remarkable performances of proposed MSB MIMO system through single user throughput simulations. From above discussions, the MSB MIMO system would be considered for MIMO TR for one of MIMO transceiver.

8. References

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