PERFORMANCE ANALYSIS OF MIMO-STBC SYSTEM IN HSDPA OVER FADING RAYLEIGH CHANNEL

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Abstract

Release 6 of 3GPP (Third Generation Partnership Project) adds HSDPA (High Speed Downlink Packet Access) in WCDMA (Wideband Code Division Multiple Access) as an effort to make system more efficient for packet data applications by increasing peak data rates and reducing packet latency. Theoretical data rate for HSDPA is approximately 14 Mbps. The actual HSDPA rate achieved is still much lower than that. Therefore the use of Multiple-antenna on transmitter and receiver, known as a Multiple-Input Multiple-Output (MIMO) technique, considered to be able to improve the system performance of physical layer by increasing the capacity and getting gain diversity.

This research simulates the physical layer model of HSDPA depicted in 3GPP standards. These include generation of transport blocks, turbo coding, rate matching, scrambling and mapping as the modulation. The MIMO Space Time Block Code (STBC) scheme with two transmitters and two receivers is integrated in physical layer of HSDPA. Some important features of HSDPA are also simulated as the test performance of STBC 2x2 which is compared by Single-Input Single-Output (SISO) HSDPA. These features are Fast Retransmission, Adaptive Modulation and Coding (AMC), the use of Hybrid Automatic-Repeat-Request (HARQ), and 2 ms Transmission Time Interval (TTI). These systems are tested in rayleigh fading channel with Gaussian noise (AWGN).

The simulation result shows that STBC 2x2 HSDPA have better performance with improvement average 2,63 dB for each transmission while SISO HSDPA only reach 0,9 dB in doppler frequency of 19,4 Hz. The STBC 2x2 also reduces the power about 4,9 dB for achieving 384 kbps HSDPA throughput compared with SISO HSDPA in 0 Hz doppler frequency.

Keywords: HSDPA, STBC, AMC, Fast Retransmission, Throughput

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1. Introduction

HSDPA (*High Speed Downlink Packet Access*) is the WCDMA (Wideband Code Division Multiple Access) evolution in downlink which often named 3.5G technology. HSDPA has more advantages than the WCDMA, such as the higher throughput and the shorter delay.

Throughput indicates the performance system in HSDPA. The HSDPA possibly achieves the throughput up to 14 Mbps with 5 MHz bandwidth. These improvement can be reached because of the new physical channel, the Adaptive Modulation and Coding (AMC) implementation, the Hybrid Automatic Repeat Request (HARQ) retransmission, the shorter (2 ms) Transmission Time Interval (TTI) than the WCDMA (10 ms), also the Fast Scheduling, and Fast Cell Selection (FCS) in WCDMA platform.

The use of MIMO (Multiple Input Multiple Output) potentially increases the received data rate with high power efficiency in HSDPA. This final thesis uses the Space Time Block Codes (STBC) method with 2 transmitter antennas and 2 receiver antennas. The purpose of this diversity method is increasing the diversity gain without channel knowledge in transmit antennas.

2. System Modeling

2.1 STBC Model in HSDPA

The design of HSDPA system is divided in two main parts: the HSDPA transmitter and the HSDPA receiver. The STBC-HSDPA modeling is simulated in MATLAB 7.1 as depicted in figure 1.

2.2 HSDPA Transmitter

a. Random Data Generator

The transmitted data of HSDPA system is in binary (0 or 1) that uniformly distributed. The data length is determined by Transport Block Size (TBS) from Channel Quality Indicator (CQI) calculation as following [15].

$$CQI = \begin{cases} 0 & SNR \leq -16 \\ \left\lfloor \frac{SNR}{1,02} + 16.62 \right. & -16 < SNR < 14 \\ 30 & SNR \geq 14 \end{cases} \quad (1)$$

The value of TBS is used in HSDPA throughput simulation. While the Bit Error Rate (BER) and Frame Error Rate (FER) simulation use fixed data length 3202 bits for each frame according to Fixed Reference Channel-5 (FRC-5) of 3GPP [1] plus 24 CRCbits.

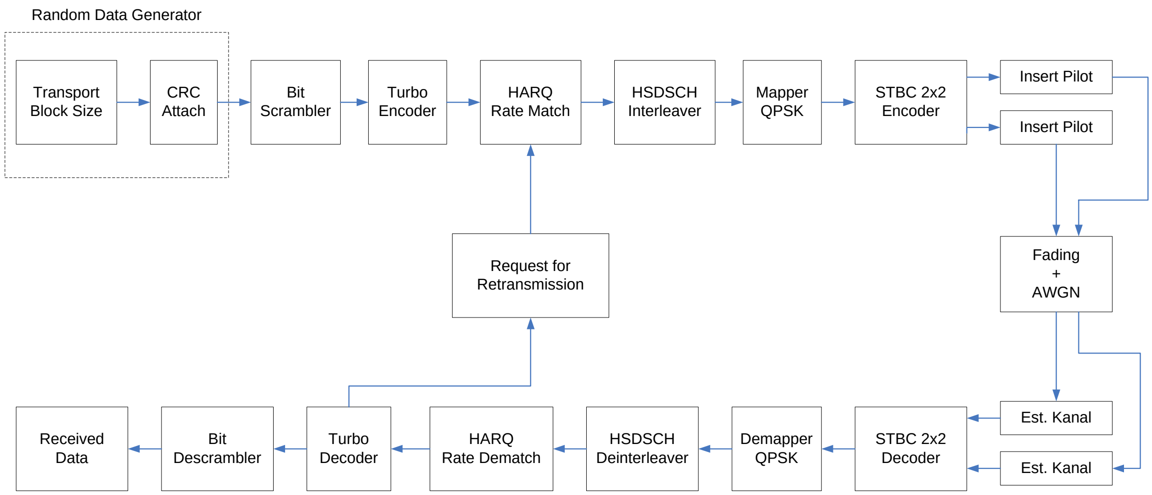

Figure 1 STBC-HSDPA Model

b. Bit Scrambler

The output bits from data generator are scrambled using bit scrambler. The output bits of scrambling process are denoted as $d_{im,k}$ which is defined by the following relation [3].

$$d_{im,k} = \left(b_{im,k} + y_k\right) \bmod 2 \qquad k = 1,2,\ldots,B \tag{2}$$

$$y_\gamma = \left(\sum_{x=1}^{16} g_x \cdot y'_{\gamma-x}\right) \bmod 2 \quad 1 < \gamma \le B \tag{3}$$

Where $b_{im,k}$ is the input bits from scrambler with y_k as the scrambling sequence in k number bits and g = {g_1,g_2,..., g_x} = {0,0,0,0,0,0,0,0,0,0,1,0,1,1,0,1}.

c. Turbo Encoder

The Structure of turbo encoder is a Parallel Concatenated Convolutional Code (PCCC) with two 8-state constituent encoder and one internal interleaver. The coding rate of turbo encoder is 1/3 with turbo polynomial generator $g0(D) = 1 + D2 + D3$ dan $g1(D) = 1 + D + D3$ as depicted in figure 2.

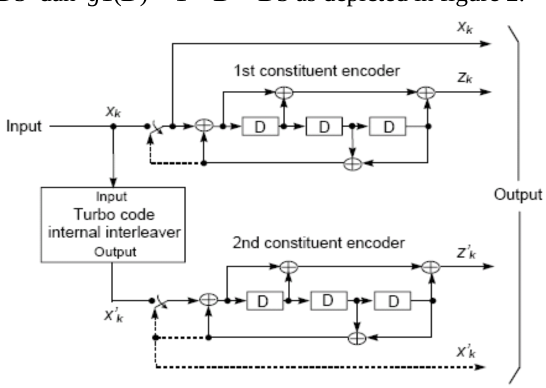

Figure 2 Structure of turbo encoder [3]

d. HARQ Rate Match

The HARQ rate match is used to matches the output bits from turbo encoder to the number of bits in physical channel (HS-PDSCH). HARQ functionality is controlled by Redundancy Version (RV) parameters within two rate match stages as shown in figure below [3].

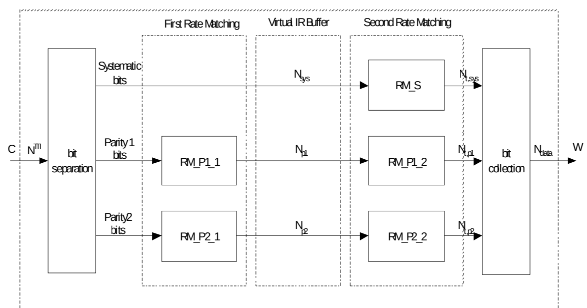

Figure 3 HARQ functionality in HSDPA

e. HSDSCH Interleaver

The interleaving process is done by divides the HARQ rate match outputs into 32x30 (R2=32 rows, C2=30 columns) matrix with performing inter-column permutation pattern as defined in table below.

Table 1. Inter-Column-Permutation pattern of HSDSCH Interleaver [3]

Number of columns C2	Inter-column permutation pattern < P2(0), P2(1), …, P2(C2-1) >
30	<0, 20, 10, 5, 15, 25, 3, 13, 23, 8, 18, 28, 1, 11, 21, 6, 16, 26, 4, 14, 24, 19, 9, 29, 12, 2, 7, 22, 27, 17>

f QPSK Mapper

The QPSK mapper is used to maps each two bits data into one modulated symbol. There are four symbol levels to represent the combination of two bits as stated below.

s_{QPSK} = 0.7071+0.7071i = 1∠45°; for bits of '00'
s_{QPSK} = 0.7071-0.7071i = 1∠135°; for bits of '01'
s_{QPSK} = -0.7071+0.7071i = 1∠225°; for bits of'10'
s_{QPSK} = -0.7071-0.7071i = 1∠315°; for bits of '11'

g STBC Encoder 2x2

The output symbols from QPSK mapper is then transmitted with STBC method for two transmitter and two receiver antennas as described in [13]. At a given symbol period, two signals are simultaneously transmitted from the two antennas. The signal transmitted from antenna Tx-1 is denoted by S_0 and from antenna Tx-2 by S_1. During the next symbol period signal $-(S_1)^*$ is transmitted from antenna Tx-1, and $(S_0)^*$ signal is transmitted from antenna Tx-2 where ( )* is the complex conjugate operation.

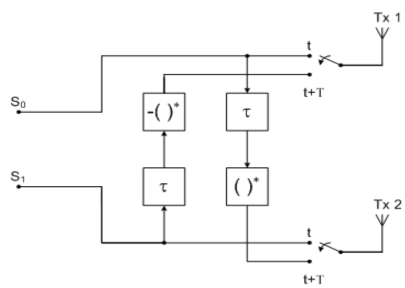

Figure 4 STBC transmission method

3.3 HSDPA Receiver

a. Channel Estimation

By comparing the transmitted pilot wih the receive pilot, the receiver can estimate the channel effect by utilizing the STBC orthogonality as following matrix relation.

$$\begin{bmatrix}\tilde{h}_0\\ \tilde{h}_1\end{bmatrix} = \frac{1}{|p|^2+|p|^2}\begin{bmatrix}p & p\\ -p & p\end{bmatrix}^H \begin{bmatrix}r_0\\ r_1\end{bmatrix}$$

$$= \frac{1}{2p^2}\begin{bmatrix}p & -p\\ p & p\end{bmatrix}\begin{bmatrix}r_0\\ r_1\end{bmatrix} \quad (11)$$

b. STBC Decoder

Figure 7 shows the signal receiving between two receiver antennas.

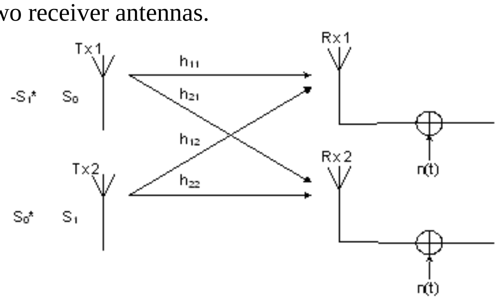

Figure 5 The STBC Receiver

At the t time, Rx 1 and Rx 2 will receive the incoming signal from Tx 1 and Tx 2 through the different paths. The received signal for Rx 1 at the t time is stated as following equation:

$$y_{11} = h_{11}.s_0 + h_{12}.s_1 + n_{11} \quad (12)$$

While the received signal for Rx 2 is stated as:

$$y_{21} = h_{21}.s_0 + h_{22}.s_1 + n_{21} \quad (13)$$

At the $t+T$, the received signal for Rx 1 is stated as the following equation:

$$y_{12} = -h_{11}.s_1^* + h_{12}.s_0^* + n_{12} \quad (14)$$

While the received signal for Rx 2 At the $t+T$ is stated as:

$$y_{22} = -h_{21}.s_1^* + h_{22}.s_0^* + n_{22} \quad (15)$$

The channel response h_{11}, h_{12}, h_{21}, h_{22} is got after the channel eatimation process. Then it will be combined with the received signal at time of t and $t+T$ according to the following equation:

$$\tilde{s}_0 = h_{11}^*.y_{11} + h_{12}.y_{12}^* + h_{21}^*.y_{21} + h_{22}.y_{22}^* \quad (16)$$

$$\tilde{s}_1 = h_{12}^*.y_{11} - h_{11}.y_{12}^* + h_{22}^*.y_{21} - h_{21}.y_{22}^* \quad (17)$$

c. QPSK Demapper

The received signal from STBC Decoder is transformed into log-likelihood QPSK symbols by this soft demapper.

d. HSDSCH Deinterleaver

This block will rearrange the data output from QPSK demapper into the same data sequence in interleaver input at the transmitter side.

e. Rate Dematch

The function of Rate Dematch is to conduct the rearrangement of codewords from turbo encoder which have been matched with the bit amount in HS-PDSCH (expressed in U). The valuable U is 960 bits for QPSK modulation. Parameter used in Rate Dematch is identical with the parameter used in the Rate Match.

***f.* Turbo Decoder**

The turbo decoder is used to decodee the sequence of received Parallel Concatenated Convolutional Code (PCCC). The decoder used in this final thesis is constant log-MAP with the input is in form of log-likelihood ratio (LLR).

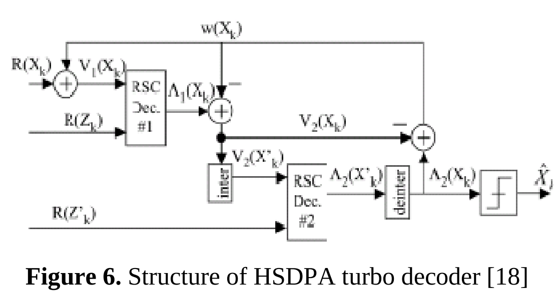

Figure 6. Structure of HSDPA turbo decoder [18]

g. *Bit Descrambler*

To get the unscrambled data hence the bit output from turbo decoder is passed to the Bit Descrambler. The descrambling process is conducted with the same method at Bit Scrambler as following relation:

$$\text{Unscramble data} = (\hat{X}_k + y_k) \bmod 2 \qquad (18)$$
$$k=1,2,..,B$$

Where $\hat{X}_k$ is the output from turbo decoder and y_k is the scrambling sequence generated in Bit Scrambler.

3.4 Simulation Parameter

Table 2. Simulation Parameter

Parameter	Nilai
User equipment class	UE category 12 (QPSK Only)
Number bit per frame	3202 bits
Number transmitted frame	1000 frames
Transmission Time Interval (TTI)	2 ms
Inter-TTI Distance	1 TTI
BER Target	10^{-5}
Sperading factor	16
Carrier Frequency	2.1 GHz
Chip rate	3,84 Mcps
Channel coding	Turbo Code; Rate = 1/3
Packet Retransmission	HARQ with *Increment Redundancy*
Relative Mean Power	[0 -10] dB
Relative Path Delay	[0 976] ns
User Velocity	0 kmph, 3 kmph, 10 kmph
Doppler Frequency	0 Hz 5.8 Hz 19.4 Hz
UE delay	25 ms
Node B delay	15 ms
Iub delay	10 ms
RNC delay	10 ms
Iu-Core delay	3 ms

4. Simulation Result Analysis

4.1 SISO performance in HSDPA retransmission

Figure 7 shows the SISO HSDPA performance using 4 times transmission. Retransmission in HSDPA is possible if there is wrong received data packet at the User Equpment (UE) side. This simulation uses only maximum 4 times transmission for each data frame.

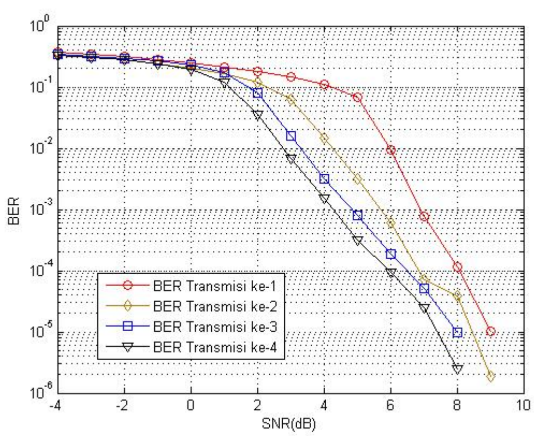

Figure 7 (a) SISO BER retransmission in fd = 0 Hz

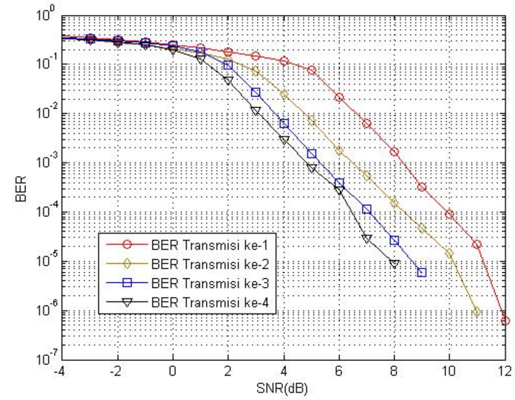

Figure 7 (b) SISO BER retransmission in fd = 5.8 Hz

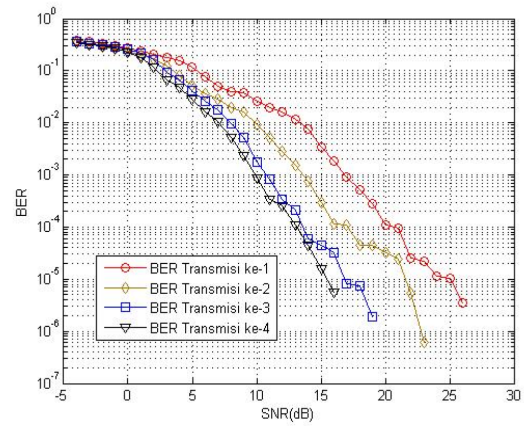

Figure 7 (c) SISO BER retransmission in fd = 19.4 Hz

From the BER to SNR graphs above can be seen that the use of retransmission in HSDPA system gives the SNR improvement in each channel condition. It is possible because the HARQ retransmission controlled by RV (Redundancy Version) may increase the probability of decoding data packet correctly in turbo decoder. The delivered data packet after the first transmission will get the redundant bits, so for the next transmission. The more retransmission take palace, the more delay between UE and Node B. Table 3 shows the SNR comparison for each transmission in SISO HSDPA.

Table 3. SNR for BER 10^{-5} in SISO HSDPA

Doppler Frequency	SISO HSDPA SNR for BER 10^{-5} (dB)			
	1st Trans	2nd Trans	3rd Trans	4th Trans
fd = 0 Hz	9,2	8,5	8	7,4
fd = 5,8 Hz	11,4	10,2	8,8	8
fd = 19,4 Hz	24	21,5	16,9	15,5

4.2 STBC 2x2 Performance in HSDPA Retransmission

Figure 8 shows the graphs of STBC 2x2 performance using 4 times transmission. The STBC 2x2 HSDPA is conducted in selective fading channel with independent and identically Rayleigh distributed (i.i.d).

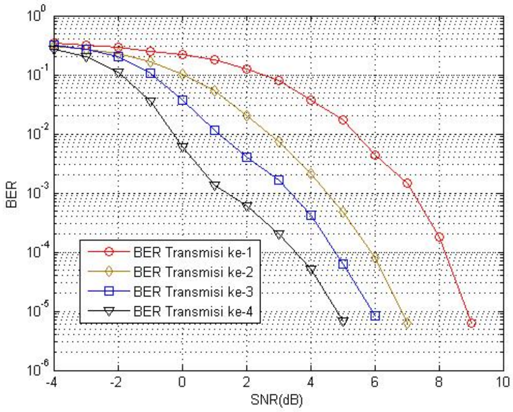

Fig 8 (a) STBC 2x2 BER retransmission in fd = 0 Hz

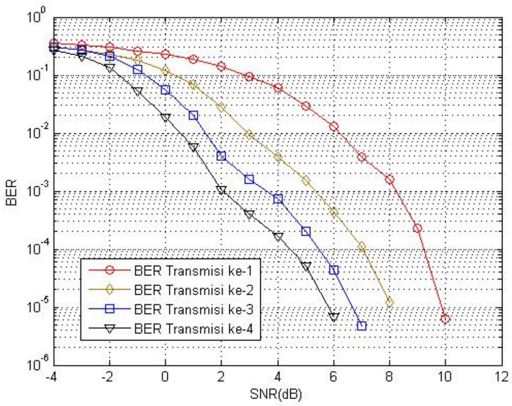

Fig 8 (b) STBC 2x2 BER retransmission in fd = 5.8 Hz

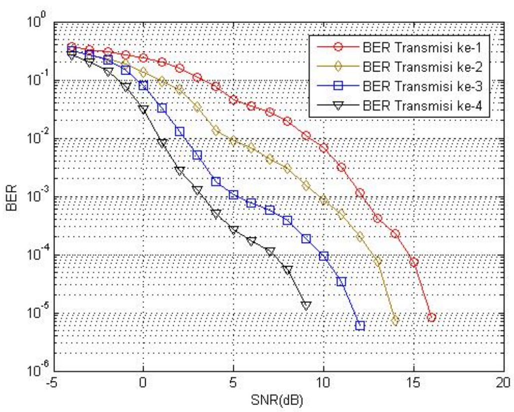

Fig 8 (c) STBC 2x2 BER retransmission in fd = 19.4 Hz

From the graphs BER to SNR in figure 8 can be seen that the use of MIMO STBC 2x2 in HSDPA retransmission gives the SNR improvement to the SISO (figure 7) for each transmission. It is possible because MIMO STBC 2x2 offers gain diversity as the improvement in transmitter side depend on the number of used antennas at transmitter and receiver. This simulation uses only 2 transmitter antennas and 2 receiver antennas which is integrated with HSDPA system. Table 4 shows the SNR comparison for each transmission in STBC 2x2 HSDPA and table 5 shows the SNR improvement for STBC 2x2 HSDPA to the SISO HSDPA.

Table 4. SNR for BER 10^{-5} in STBC 2x2 HSDPA

Doppler Frequency	STBC 2x2 HSDPA SNR for BER 10^{-5} (dB)			
	1st Trans	2nd Trans	3rd Trans	4th Trans
fd = 0 Hz	8,9	6.9	5,9	4.9
fd = 5,8 Hz	9,9	8	6,8	5,8
fd = 19,4 Hz	16	13,9	11,7	9

Table 5. SNR improvement for STBC 2x2 to SISO

Doppler Frequency	SNR improvement for each Transmission (dB)				Average Improvement (dB)
	1st Trans	2nd Trans	3rd Trans	4th Trans	
fd = 0 Hz	0,3	1,6	2,1	2,5	1,625
fd = 5,8 Hz	1,5	2,2	2	2,2	1,975
fd = 19,4 Hz	8	7,6	5,2	6,5	6,825

4.3 AMC performance in Throughput SISO HSDPA and STBC 2x2 HSDPA

Throughput in this simulation is defined as the number of correct received bits from the transmitted frames divided by the number of Transmission Time Interval (TTI) from the transmitted frames including TTI from retransmitted frames. The Adaptive Modulation and Coding (AMC) is expressed by changing the length of Tranport Block Size (TBS) in one frame based on the SNR and RV parameter in HARQ rate match for retransmitting packet. The TBS and RV parameter will determine the effective code rate of HSDPA. This simulation is conducted in selective Rayleigh fading channel with the Doppler frequency 0 Hz.

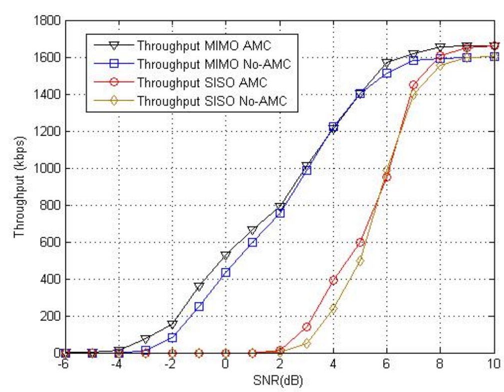

Figure 9 Throughput comparisons of SISO HSDPA and STBC 2x2 HSDPA

From figure 9 can be seen that the use of AMC in HSDPA may increase the efficiency for transmitting data packet. It means that the delivery packet in less ideal channel condition (low SNR) is preffered to send small frame length with low code rate (high addition redundancy). Figure 10 shows that 384 kbps throughput in SISO-AMC is achieved in 3.7 dB SNR but the SISO-Non AMC achieves the 384 throughput at SNR of 4.7 dB. The use of MIMO STBC 2x2 in HSDPA is reducing the tranmit power compared with SISO in achieving the same throughput. In this case there is 3 dB differences between the SISO and STBC 2x2 HSDPA when achieving throughput of 1000 kbps.

4.4 AMC performance in RTT SISO and STBC 2x2 HSDPA

Round Trip Time (RTT) in this simulation is defined as the delay of packet traveling from the receiver terminal (UE) through entire network elements to the application server and back to the receiver. The delay assumptions from network elements are the UE delay (25 ms), Node B delay (15 ms), air interface delay (10 ms), Iu + Core Network delay (3 ms). This simulation is conducted in selective Rayleigh fading channel with 0 Hz Doppler frequency.

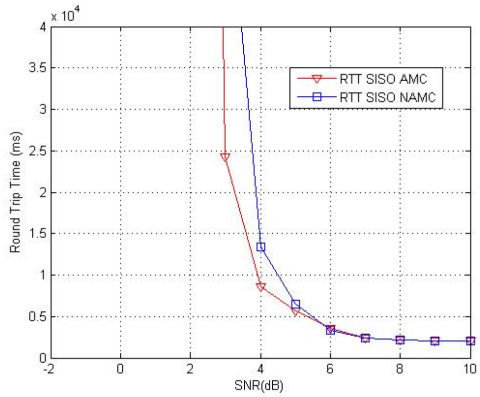

Figure 10 (a) RTT Comparison in SISO HSDPA

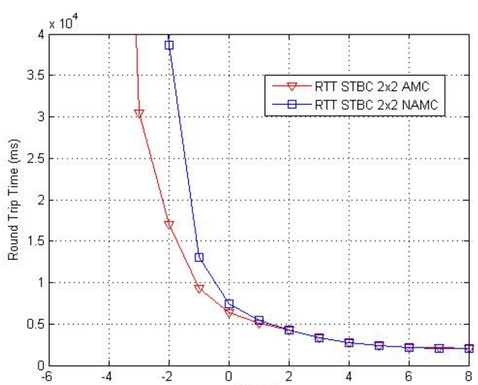

Figure 10 (b) RTT Comparison in STBC 2x2 HSDPA

From figure 10 can be seen that the RTT a packet is determined by the throughput at the certain SNR. The SISO-Non AMC RTT with SNR less than -2 dB is towards infinity. The STBC 2x2 Non AMC also achieves the RTT towards infinity at SNR below -4 dB. It possibly happened because the reached throughput at that SNR is 0 kbps. The increasing throughput because of the AMC gives the better performance than the Non-AMC system. The use of diversity which is represented by STBC 2x2 also gives better performance than the SISO. It means that the order of RTT for the HSDPA system using MIMO and AMC will be more lower compared to which only use one of the AMC and MIMO or not at all.

4.5 STBC 2x2 and SISO performance in Multi User HSDPA

Multi user in this simulation mean that there are 'n' numbers of user in a HSDPA cell but only a user which is be investigated for the test performance. The (n-1) users will act as the interferer for the investigated user. This simulation uses maximum 4 times transmissions. Figure 11 shows the BER comparison for each transmission with n = 4 users and n = 16 users. This simulation is conducted in selective Rayleigh fading channel with the Doppler frequency 0 Hz.

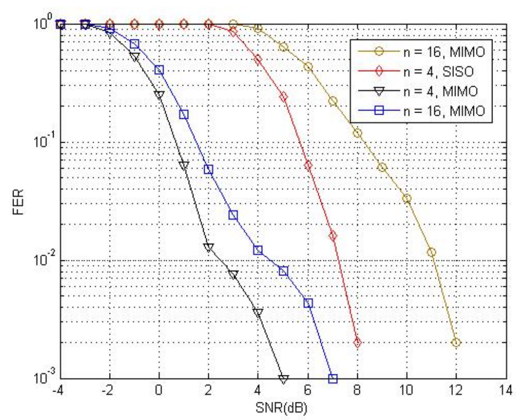

Figure 11 (a) SISO BER in Multi user HSDPA

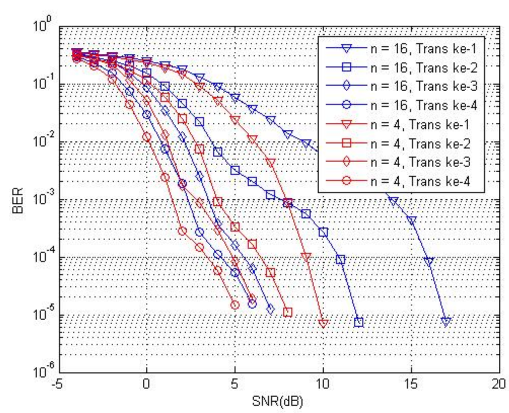

Figure 11 (b) STBC 2x2 BER in Multi user HSDPA

From figure 11 can be seen that the addition of number users will result the dedradation of system performance. It is possible because the increasing number of users will cause the SNR shifting to achieve the same target BER as in the single user system. It means that the interferences are becoming tha additive noise in received SNR. The SNR comparison in SISO multi user and STBC 2x2 multi user. The SNR improvement of multi user STBC 2x2 HSDPA to multi user SISO HSDPA is shown in table 6.

Table 6. SNR improvemnet of STBC 2x2 to SISO in multi user HSDPA

Number of User (n)	Perbaikan SNR per Transmisi (dB)				Improvement Average (dB)
	1st Trans	2nd Trans	3rd Trans	4th Trans	
n = 4	0,1	0,5	1,8	2,3	1,175
N = 16	1,1	3,5	6,4	5,4	4,1

4.6 Throughput comparison for STBC 2x2 and SISO in multi user HSDPA

The throughput calculation for multi user HSDPA system is done with assumption that the existence of entire users is ruled is Round Robin (RR) scheduling. This scheduling distributes the same physical resources to entire users in a cell. Figure 12 shows the throughput comparison for n = 4 users and n = 16 users. This simulation is conducted in selective Rayleigh fading channel with the Doppler frequency 0 Hz.

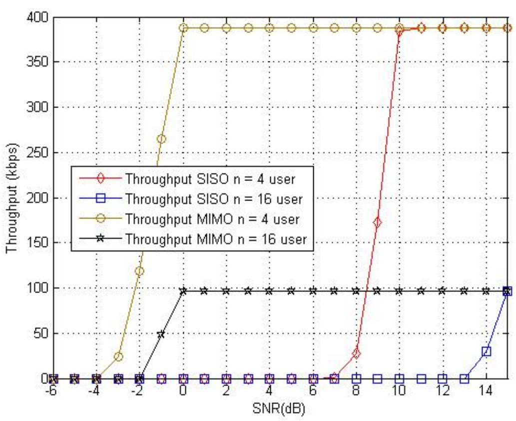

Figure 12 Throughput comparisons in multi user HSDPA

From figure 12 can be seen that by dividing physical resources to the entire user causes the throughput degradation significantly compared to the single user system. The achieved maximum throughput for n = 4 users is less than 1660/4 kbps by assuming that the maximum cell throughput is the maximum throughput for single user system (1660 kbps). For n =16, the maximum achieved throughput is less than 1660/ 16 kbps. However the use of MIMO STBC 2x2 in HSDPA reducing the power needs to get the same throughput as in SISO system.

5. Conclution

1. STBC 2x2 HSDPA have better performance with improvement average 2,63 dB for each transmission while SISO HSDPA only reach 0,9 dB in doppler frequency of 19,4 Hz.
2. The STBC 2x2 also reduces the power about 4,9 dB for achieving 384 kbps HSDPA throughput compared with SISO HSDPA in 0 Hz doppler frequency

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