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MIMO Eigen Beamforming for HSUPA of TD-SCDMA

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***Abstract*—As the evolution of the 3G standards, Multiple Input and Multiple Output (MIMO) has been adopted to enhance the performance of 3G systems for the potential of beamforming, spatial multiplexing or spatial diversity. So far, no MIMO scheme has been adopted for Time Division-Synchronous Code Division Multiple Access(TD-SCDMA). In this paper, 2x8 MIMO Eigen beamforming is proposed to improve the performance of TD-SCDMA. As size limited, the antennas at the UE or Node B are correlated, only one Eigen mode of the spatial correlation matrix is found to be useful, and only the beamforming gain and spatial diversity gain can be obtained efficiently. The simulation results of High Speed Uplink Pakcet Access (HSUPA) in the fixed reference channel show that, compared to Single Input and Mutiple Output (SIMO) 1x8, 3dB performance gain can be obtained by MIMO 2x8 Eigen beamforming; While compared to that of Single Input and Single Output (SISO), the performance gain is 8~13dB.**

Key Words: MIMO, AMC, TD-SCDMA, Eigen beamforming

I. INTRODUCTION

Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) [1] is one of the international 3G standards, proposed by Chinese Academy of Telecommunication Technology (CATT) and accepted by International Telecommunication Union (ITU) and 3G Partner Project (3GPP) as a member of Time Division Duplex (TDD) Mode. For many advanced techniques are adopted, such as smart antenna, joint detection, synchronous uplink, dynamical channel allocation, software defined Radio, etc., TD-SCDMA is a very advanced system and has very high theoretical spectrum efficiency.

However, compared to Wideband Code Division Multiple Access (WCDMA), few public researches on Multiple Input and Multiple Output (MIMO) of TD-SCDMA can be found. So far, no MIMO scheme has been adopted for TD-SCDMA in 3GPP. As the MIMO can improve the system performance by beamforming, spatial multiplexing or spatial diversity [3] [4], and the MIMO Eigen beamforming [5] can exploit the multiplexing gain and the diversity gain optimally [6], in this paper, MIMO Eigen beamforming is proposed for High Speed Uplink Packet Access (HSUPA) of TD-SCDMA firstly by configuring 8 antennas at the Node B and 2 antennas at the Mobile. As a TDD system, the channel reciprocity can be exploited to implement the Eigen beamforming easily. By adopting Adaptive Modulation and coding (AMC) and waterfilling power allocation on the Eigen mode sub-channels, the near MIMO capacity is obtained [6]. Besides MIMO, Hybrid Automatic Repeat reQuest (HARQ) is also simulated in this paper. As the HSUPA standard is still in discussion, the bit mapping of High Speed Downlink Packet Access (HSDPA) [7] is used instead for performance evaluation. The simulation results show that the throughput and the packet performance of HSUPA is improved by 8~13 dB, compared to that of Single Input and Single Output (SISO).

This paper is organized as follows. The MIMO Eigen beamforming is introduced in section II; the HSUPA simulation parameters are presented in section III; the simulation results are given in section IV and the conclusions are drawn in section V.

II. MIMO EIGEN BEAMFORMING IN TD-SCDMA

For the limited size of the terminal, 2 antennas are configured at the general User Equipment (UE). Considering the practical application and the back forwards compatibility for the released version of TD-SCDMA, the spatial interval between the antennas of the Uniform Linear Arrays (ULA) is half wavelength. So the antennas of the ULAs at both ends of the MIMO channel are correlated. From Figure 1. , only one Eigen value of the spatial correlation matrix for 2x8 MIMO channel is quite large, and no spatial multiplexing gain can be obtained. In this paper, MIMO Eigen beamforming is proposed and only the best Eigen mode of the MIMO channel is used to transmit the data

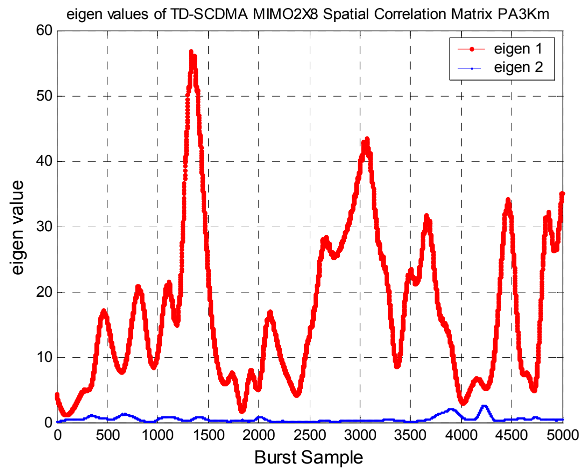

Figure 1. Eigen Values of MIMO 2x8 spatial correlation Matrix

As a TDD system, TD-SCDMA can exploit the channel reciprocity to implement the Eigen beamforming easily. In this paper, the channel impulse response (CIR) of the MIMO channel is assumed to be known to Node B by 1 subframe delay, which can be obtained by uplink

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feedback or uplink channel estimation on the associated channel. The system block of HSUPA is given in Fig 8.

The Channel Impulse Response (CIR) of the MIMO channel can be expressed as:

$$\mathbf{H} = \begin{bmatrix} \mathbf{H}_{1,1} & \mathbf{H}_{1,2} \\ \dots & \dots \\ \mathbf{H}_{8,1} & \mathbf{H}_{8,2} \end{bmatrix}_{8\times 2} \quad (1)$$

Where $\mathbf{H}_{m,n}$ is the CIR between antenna n of UE and the antenna m of Node B, which has L_m multipath.

As [4], the Eigen beamforming can be implemented as two steps. First, the transmitted data symbols are precoded with the conjunction of unitary vector $\mathbf{V}_1$, which is corresponding to the maximum Eigen value of the spatial correlation matrix at the transmitter, and then coded signals are transmitted on different antennas respectively. Second, at the receiver, the received signal vector is combined after weighted by the unitary vector $\mathbf{U}_1$ corresponding to the maximum Eigen value of the spatial correlation matrix at the receiver.

First, let's calculate the precoding vector of the Eigen beamforming.

The spatial correlation matrix at the transmitter is:

$$R_{T_M\times T_M} = \sum_{i=0}^{L_m-1} \mathbf{H}_i^H \mathbf{H}_i \quad (2)$$

Where T_M, the number of the transmitter antenna, is equal to 2, and H means the conjugative transpose of a matrix. Then calculate the Singular Value Decomposition (SVD) of the spatial correlation matrix:

$$\mathbf{R}_{T_M\times T_M} = \mathbf{VSV}^H \text{ , } \mathbf{S} = \mathbf{V}^H \mathbf{R}_{T_M\times T_M} \mathbf{V} \quad (3)$$

Where $\mathbf{S}$ is a diagonal matrix with the singular values ordered on the diagonal position. $\mathbf{V}$ is the unitary singular matrix corresponding to the singular value of $\mathbf{R}_{T_M\times T_M}$. Then $\mathbf{V}_1 = (w_1, w_2, ..w_j, .., w_{T_M})^T$ corresponding to the maximum singular value of $\mathbf{R}_{T_M\times T_M}$, is the precoding vector of the Eigen beamforming, and the operator T means the transpose.

As specified, every data field in a burst of TD-SCDMA is composed of N data symbol, the n^{th} data symbol on the code k is d_n^k, Q is the spreading factor, and code k after scrambling is expressed as:

$$c^k = [c_1^k, c_2^k, ..., c_Q^k], k = 1, ..., K \quad (4)$$

The signal after the spreading and scrambling is:

$$\underline{s}_i^k = \sum_{n=1}^{N} d_n^k \underset{\cdot}{c}_{i-(n-1)Q}^k \text{ , } \quad i = 1, ..., QN, k = 1, ..., K \quad (5)$$

And

$$\underset{\cdot}{c}_i^k = \begin{cases} c_i^k, & i \in [1, Q] \\ 0, & others \end{cases} \quad (6)$$

After $\underline{s}_i^k$ of all K codes for one user has been summed together, the signal is weighted by w_j of $\mathbf{V}_1$ and transmitted on different antennas respectively. The received signal on the data field of a burst from the antenna Ka is:

$$\begin{aligned} e_i^{Ka} &= \sum_{j=1}^{T_M} \sum_{k=1}^{K} \sum_{w=1}^{W} w_j h_{Ka,j}^w s_{i-w+1}^k + n_i \\ &= \sum_{j=1}^{T_M} \sum_{k=1}^{K} \sum_{w=1}^{W} \sum_{n=1}^{N} w_j h_{Ka,j}^w d_n^k \underset{\cdot}{c}_{i-(n-1)Q-w+1}^k + n_i \end{aligned} \quad (7)$$

For Eigen beamforming, the MIMO Channel Status Information (CSI) must be known accurately at the receiver, besides at the transmitter. To estimate the CSI of MIMO, different midamble codes must be transmitted on different antennas without precoding of Eigen beamforming.

As the good autocorrelation property of the basic midamble codes in TD-SCDMA, the different shifted versions of the same basic midamble codes can be used to estimate the CSI of the different transmitter antenna simultaneously. The midamble codes for different transmitter antennas are produced as Figure 2. .

Assume that $\underline{m} = (\underline{m}_1..\underline{m}_{1+W}..\underline{m}_{1+2W}..\underline{m}_{1+3W}..\underline{m}_L)$ is the basic midamble code used for channel estimation of the user. L is the total length of the midamble code. Then the midamble code $\underline{m}^j$ for the antenna j is produced by shifting the basic midamble code by $W \cdot j$ cyclically from right to left. W is the size of the channel estimation window.

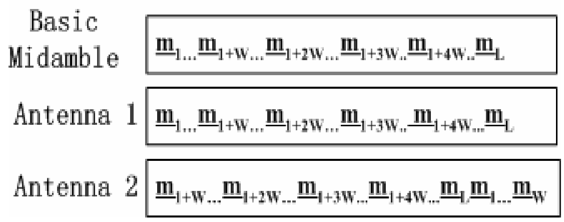

Figure 2. Midamble code selection for MIMO channel estimation

At the receiver, the received signal of the midamble part from antenna i is:

$$r^i = [r_1^i, r_2^i, ..., r_{L+W-1}^i] = \sum_{j=1}^{T_M} \left(\mathbf{H}_{i,j} * m^j \right) \sqrt{K_c / T_M} \quad (8)$$

Where the operator * means linear convolution, K_c is the code number per user, and $\sqrt{K_c / T_M}$ is used to balance the power of the data part and the midamble part. As the midamble is cyclical, only the first 128 samples are used for channel estimation:

$$\hat{r}^i = [r_1^i, r_2^i, ..., r_{128}^i] \quad (9)$$

The Fast Furrier Transform (FFT) result of $\hat{r}^i$ is expressed as:

$$\hat{r}^{i,FFT} = [\hat{r}_1^{i,FFT}, \hat{r}_2^{i,FFT}, ..., \hat{r}_{128}^{i,FFT}] \quad (10)$$

And the FFT of the first 128 sample of the basic midamble code is expressed as:

$$M = [M_1, M_2, ..., M_{128}] \quad (11)$$

Then the channel CIR between receiving antenna i and all the transmitter antennas can be estimated by Steiner's algorithm [10] as following:

$$[\hat{\mathbf{H}}_{i,1}, \hat{\mathbf{H}}_{i,2}, ...] = IDFT(\frac{\hat{r}^{i,FFT}}{M}\sqrt{T_M / K_c}) \quad (12)$$

After all the channel impulse responses between the transmitter and receiver antenna has been estimated, the CIR of the MIMO channel can be constructed as $\hat{\mathbf{H}}$:

$$\hat{\mathbf{H}} = \begin{bmatrix} \hat{\mathbf{H}}_{1,1} & \hat{\mathbf{H}}_{1,2} \\ ... & ... \\ \hat{\mathbf{H}}_{8,1} & \hat{\mathbf{H}}_{8,2} \end{bmatrix}_{8\times 2} \quad (13)$$

Based on $\hat{\mathbf{H}}$, the interference signal, which is created by the midamble passed through the time disperse MIMO channel, can be reconstructed and eliminated from the received signal on the data field. For the signal from the antenna Ka at the receiver, the interference reconstructed is:

$$I^{Ka} = \sum_{j=1}^{2}\left(\underline{m}^j * \hat{\mathbf{H}}_{Ka,j}\right)\sqrt{K_c / T_M} \quad (14)$$

The received signal after the interference eliminated is:

$$[\hat{e}_{NQ+1}^{Ka}, ..., \hat{e}_{NQ+L+W-1}^{Ka}] = [e_{NQ+1}^{Ka}, ..., e_{NQ+L+W-1}^{Ka}] - I^{Ka} \quad (13)$$

As [4], the post beamforming vector should be calculated for the detection. The spatial correlation matrix at the transmitter and receiver can be estimated respectively as:

$$\hat{R}_{T_M \times T_M} = \sum_{i=0}^{L_m-1}\hat{\mathbf{H}}_i^H \hat{\mathbf{H}}_i, \hat{R}_{R_M \times R_M} = \sum_{i=0}^{L_m-1}\hat{\mathbf{H}}_i \hat{\mathbf{H}}_i^H \quad (15)$$

Where $\hat{\mathbf{H}}_i$ is the i^{th} multipath of the MIMO CIR $\hat{\mathbf{H}}$, L_m is the number of the multipath. Then the singular Value decomposition (SVD) of spatial correlation matrix at the transmitter and receiver are respectively as following [4]:

$$\hat{\mathbf{R}}_{T_M \times T_M} = \hat{\mathbf{V}}\hat{\mathbf{S}}\hat{\mathbf{V}}^H, \hat{\mathbf{S}} = \hat{\mathbf{V}}^H \hat{\mathbf{R}}_{T_M \times T_M}\hat{\mathbf{V}} \quad (16)$$

$$\hat{\mathbf{R}}_{R_M \times R_M} = \hat{\mathbf{U}}\hat{\mathbf{S}}'\hat{\mathbf{U}}^H, \hat{\mathbf{S}}' = \hat{\mathbf{U}}^H \hat{\mathbf{R}}_{R_M \times R_M}\hat{\mathbf{U}} \quad (17)$$

Where the unitary vector $\hat{\mathbf{V}}_1$ is corresponding to the maximum Eigen value of the spatial correlation matrix of the transmit antenna array. The unitary vector $\hat{\mathbf{U}}_1$ is corresponding to the maximum Eigen value of the spatial correlation matrix of the reception antenna array. Then the received signal on the Eigen mode channel can be expressed as:

$$\underline{\hat{e}}_i = \hat{\mathbf{U}}_1^H \cdot (\hat{e}_i^1, \hat{e}_i^2) \quad (18)$$

While the virtual channel impulse response on the MIMO Eigen mode channel selected can be expressed as:

$$\hat{\mathbf{h}} = \hat{\mathbf{U}}_1^H \hat{\mathbf{H}}\hat{\mathbf{V}}_1 \quad (19)$$

$\hat{\mathbf{h}}$ and $\underline{\hat{e}}$ after the Eigen beamforming and midamble interference canceled are sent to joint detection, then data symbols on the best Eigen mode channel are detected out and the inter-symbol interference and multiple access interference is eliminated. After the demodulation, de-interleaving and decoding, the data stream is recovered.

Eigen beamforming above can be applied in both Single Input and Multiple Output (SIMO) and MIMO system. For SIMO, the precoding vector is 1.

III. HSUPA SIMULATION PARAMETERS FOR FIXED REFERENCE CHANNEL

For the HSUPA standards are still not available, in this paper, the bit mapping and HARQ scheme of High Speed Downlink Packet Access (HSDPA) from the category 1 (1.4Mbps) is simulated for fixed reference channel [7]. The bit mapping of referred HSDPA is adopted as TABLE I. . The information data rate is kept constant, the modulation type fixed, the UE channel quality indicator (CQI) error and the signaling error is not simulated and therefore Acknowledge/Non-Acknowledge (ACK/NACK) reports are considered error free. The system model of the HSUPA link is as Figure 8. . In every TTI, only one user is scheduled to transmit in the uplink.

A. *Time slot allocation*

The time slot allocation scheme adopted for HSUPA is as Figure 3. . TS0 of every subframe must be used for downlink broadcasting information and TS1 must be used as UL TS to access the users, report the CQI and transmit other signaling. TS2~TS5 can be combined together for data transmission in UL, and TS6 is used for downlink control information. In every data TS, 10 codes with length 16 are used for QPSK transmission, or 9 codes with length 16 are used for 16QAM transmission.

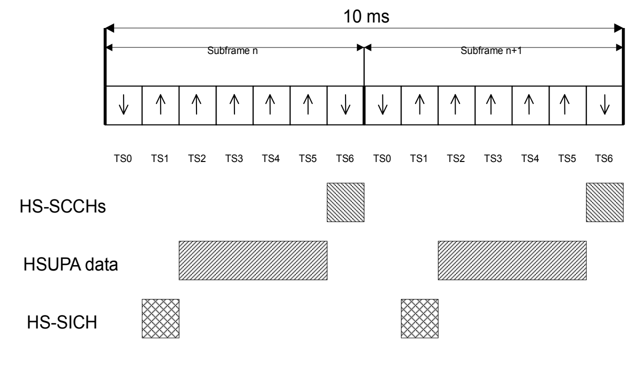

Figure 3. timeslot allocation for HSUPA simulation

TABLE I.
HS-DSCH FIXED REFERENCE CHANNEL – CATEGORY 1

Parameter	Unit	Value	
Modulation		QPSK	16QAM
Maximum information bit rate	Kbps	528	750
Number of HARQ Processes		4	4
Information Bit Payload (N_{INF})	Bits	2640	3750
Number Code Blocks	Blocks	1	1
Total Available of Soft Channel bits	Bits	28160	28160

in UE			
Number of Soft Channel bit per HARQ Proc.	Bits	7040	7040
Number of coded bits per TTI	Bits	3520	6336
Coding Rate		0.75	0.59
Number of HS-USCH Timeslots	Slots	4	4
Number of HS-USCH codes per TS	Codes	10	9
Spreading factor	SF	16	16

B. HARQ

HARQ scheme of HSDPA is adopted here to guarantee the reliable data transmission, which is specified in [9]. If the retransmission exceeds 4, the data block is dropped.

C. Performance metric

The performance metric is the information bit throughput at the Node B. In the simulation, parameter $\hat{I}_{or}/I_{oc}$ is used to get throughput plots. $\hat{I}_{or}/I_{oc}$ is introduced by the 3GPP in [11], where $\hat{I}_{or}$ is the post-channel transmitted power density by a transmitter, i.e. UE here. I_{oc} is the sum of interference from other cells and thermal noise.

According to [11], throughput is described as equation (20) with the assumption that ARQ is used.

$$R = R_b\left(\frac{1 - FER_r}{\bar{N}}\right) \quad (20)$$

Where R is throughput measured in term of bits per second; R_b is the transmitted information bit rate. FER_r is the residual Frame Error Rate beyond the maximum number of transmissions; $\bar{N}$ is the average number of transmission attempts.

D. Other General Simulation parameters

The other general simulation parameter is as TABLE II. .

TABLE II.
GENERAL SIMULATION PARAMETERS FOR HSUPA SIMULATION

Parameter	Assumption
Carrier Frequency	2 GHz
Chip rate	1.28 Mcps
Fast fading model	Jakes spectrum
Channel ray mapping	Shifted to nearest multiple of the sampling rate
RRC filter	Off
Receiver	Joint Detection (MMSE-BLE)
Midamble	One basic midamble is used for one user
Turbo decoding	MaxLogMap 4 iterations
Input to turbo decoder	Soft
HARQ	As 3GPP TR25.222
Propagation model	Pedestrian A at 3km/h

IV. SIMULATION RESULTS

As the limited size, 2 antennas are configured at the UE, and the antenna spatial interval is set as half of the wavelength, so the antennas at the both UE and Node B are highly correlated, little spatial multiplexing can be obtained. Only the best Eigen mode is used for data transmission. For the reference, the throughput and average packet delay performance of the SISO antenna and SIMO 1x8 Eigen beamforming are simulated.

From Figure 4. Figure 5. Figure 6. Figure 7. , the performance of SIMO and MIMO Eigen beamforming are much better than that of SISO; the performance gain is about 5dB for SIMO case, and about 3dB more performance gain is obtained by MIMO for 2 antennas are configured at the UE, diversity gain can be obtained for the same transmission power at the Node B. From Fig 6 and Fig 7, the performance gain for SIMO is about 10dB, and about 3dB more gain for MIMO Eigen beamforming. Comparing the results of QPSK and 16QAM, more gain is obtained in 16QAM, because 16QAM is more sensitive to the noise and channel estimation error.

V. CONCLUSION

In this paper, MIMO Eigen beamforming is proposed to improve the performance of TD-SCDMA HSUPA for the channel reciprocity can be exploited easily in TDD system. As the limited size, 2 antennas are configured at the UE. As the antennas at the both UE and Node B are highly correlated, little spatial multiplexing can be obtained. Only the best Eigen mode is used for data transmission. Compared to SISO, the performance gain of SIMO 1x8 Eigen beamforming is about 10dB for 16QAM, and 5dB for QPSK; 3dB more gain can be obtained by MIMO 2x8 Eigen beamforming for reception diversity at the UE. Higher order modulation, such as 64QAM may be applied for MIMO Eigen beamforming for higher throughput.

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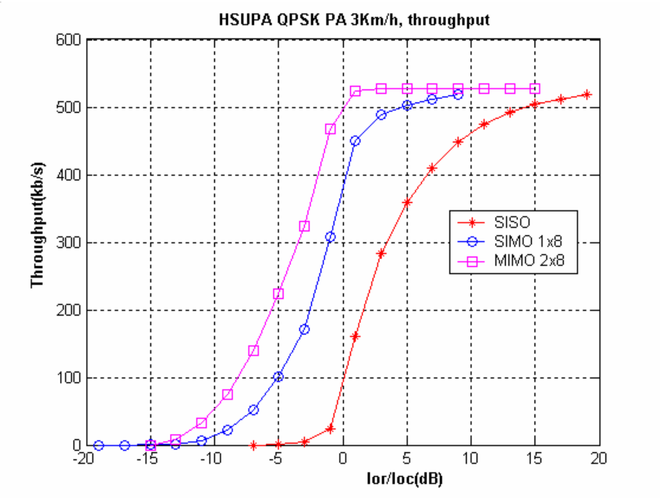

Figure 4. Throughput of QPSK in Pedestrian A 3km/h

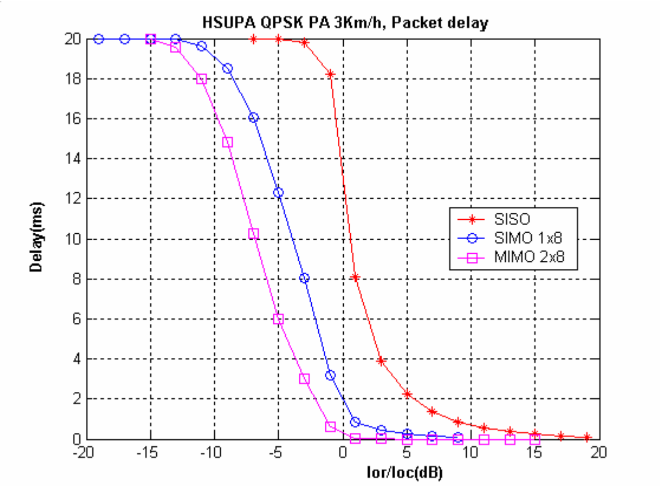

Figure 5. packet delay of QPSK in Pedestrian A at 3km/h

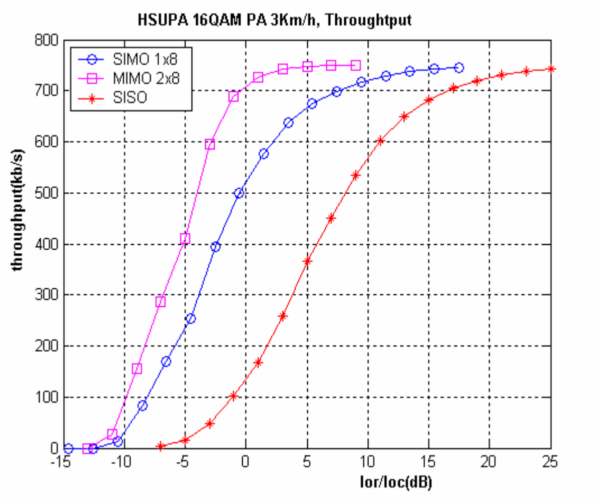

Figure 6. Throughput of 16QAM in Pedestrian A 3km/h

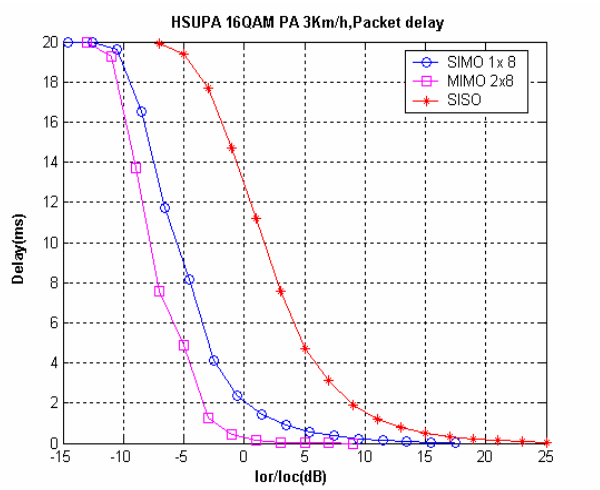

Figure 7. packet delay of16QAM in Pedestrian A 3km/h

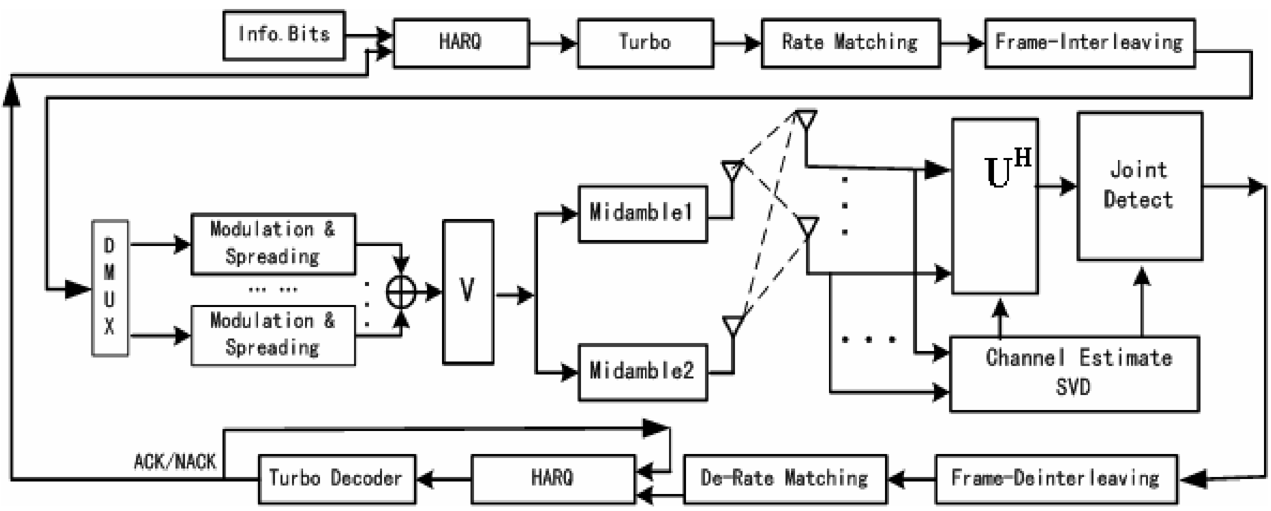

Figure 8. Theoretical Block of the MIMO Eigen Beamforming