DESIGN OF SECURE AND RELIABLE MU-MIMO TRANSCEIVER SYSTEM FOR VEHICULAR NETWORKS

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ABSTRACT

MU-MIMO (Multi-User MIMO) has been a promising technique for vehicular networks to achieve faster communication. Conventional MU-MIMO transceiver is designed with One-dimensional (1-D) improper modulation schemes such as Binary Phase Shift Keying (BPSK) and Multilevel Amplitude Shift Keying (M-ASK) failed to yield standard ABER (average bit error rate). To achieve high reliability, a novel MU-MIMO uplink transceiver system is designed under PAPC (Per-Antenna Power Constraint) by assuming perfect and imperfect channel state information (CSI). MIMO communication channels are perceptible. Hence, security of the proposed system is improved by novel pseudorandom key generation technique using randomized synthetic colour image. Analytical design for proposed systems is carried and simulated for various p-norm constraints. Simulation results show higher reliability and security than the existing system. It also satisfies the linearity constraint of a power amplifier, which makes the system more suitable for practical applications.

KEYWORDS

MU-MIMO, Uplink, PAPC, 1-D improper modulation, Perfect & imperfect CSI, Colour Image, Pseudorandom key generation

1. INTRODUCTION

Vehicular networks are widely used for autonomous navigation, remotely operated vehicle, and swarm robot [1]. It utilizes cellular and wireless local area networks and demands high-speed, reliable communication without increasing channel bandwidth and power required for transmission [2-4]. To meet such requirement, MU-MIMO communication technology has been introduced in such applications [5]. Several MU-MIMO transceivers design has been reported to increase throughput and minimize total mean square error (TMSE). In all the cases a common transceiver design has been proposed for both proper and improper modulation [6-13]. The outcome revealed that the Average Bit error rate (ABER) performance of existing MU-MIMO transceiver systems was suboptimal for improper modulation. To overcome this problem, a separate MU-MIMO transceiver system had been designed for improper modulations with novel precoding strategy [14]. Joint optimal precoders and decoders were designed for improper modulation to improve the ABER performance [15-18].

Predominately the exiting MU-MIMO transceiver systems were designed under TPC (β). In TPC based power allocation techniques, linearity constraint of the individual power amplifier is not considered. This makes the system fail to meet the practical requirements and makes its challenging to be realized in real-time. An SU-MIMO transceiver has been proposed with 1-D improper modulation and PAPC [19] to meet the practical requirements in point-to-point communication. This has been extended for MU-MIMO uplink transceiver system. Additionally, to provide security, a simple and efficient novel key generation algorithm has been developed

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using randomized synthetic colour image. This makes the proposed system to have high data rate and reliability with security, which are the primary requirements for vehicular network.

The remaining sections of this article are organized as follows: Section 2 illustrates the system model used for uplink vehicular network and describes the design procedure of the proposed MU-MIMO transceiver systems and its key generation techniques. In section 3 numerical results of the proposed system are provided. Section 4 concludes the paper with future directions.

2. SYSTEM MODEL

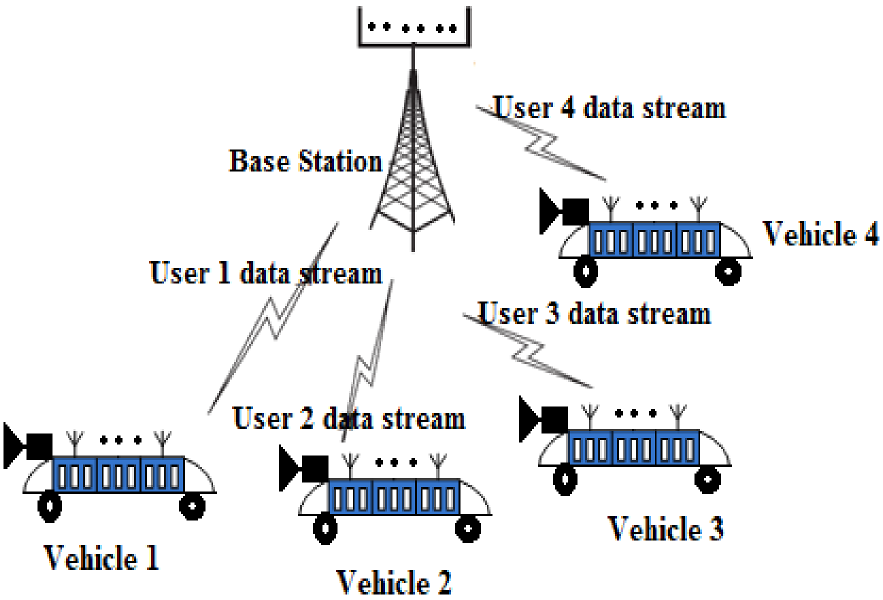

Figure 1. MU-MIMO Vehicular system models

The vehicular network provides reliable communication between the individual vehicles and the base station [1]. In the proposed work, uplink MU-MIMO transceiver is implemented in infrastructure-based vehicular networks. It consists of a single Base Station (BS) and four Vehicular Nodes (VNs) as shown in Figure 1. Both the BS and the VNs are equipped with multiple antennas. Each VNs connects to the base station with an independent uplink channel $H_m^{(UL)}$ where m = 1, 2…4. All the vehicles utilize the same frequency spectrum for signal transmission. However, they are separated in the spatial domain. Vision sensor attached at front-end of each VNs simultaneously transmits its information to BS through $H_m^{(UL)}$. After receiving the information, BS generates a command to navigate multiple vehicles on the road.

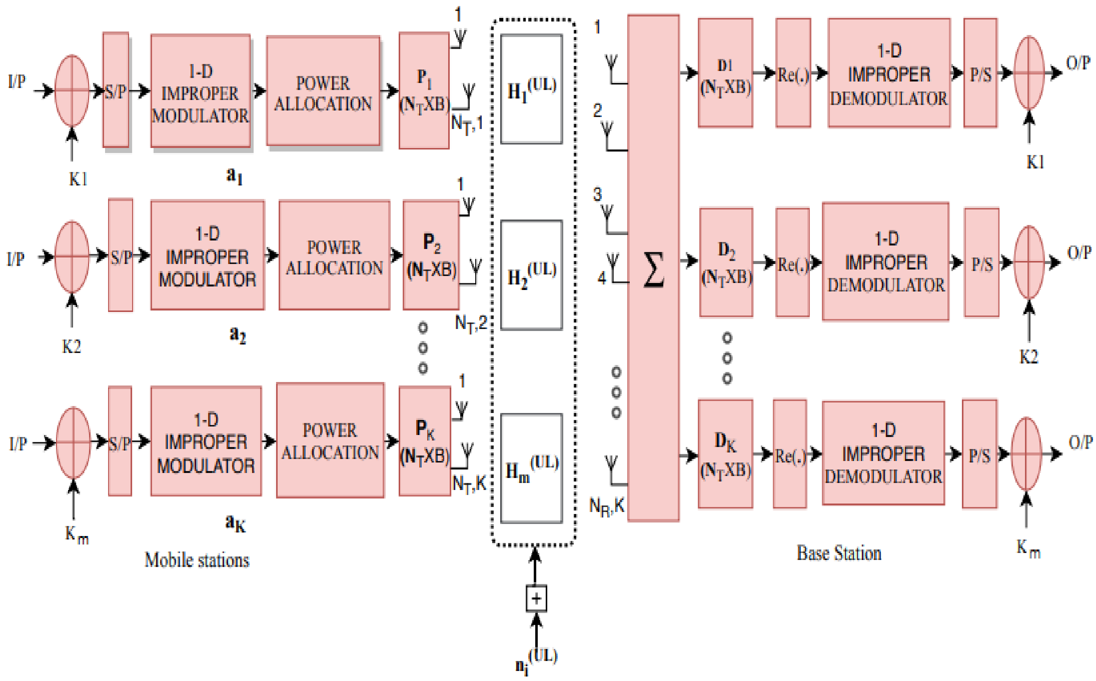

Figure 2. Proposed MU-MIMO uplink system

The block diagram of the proposed MU-MIMO uplink transceiver system with 'm' channels is shown in Figure 2. For the encryption process, the analog data obtained from the sensor is converted into binary and XORed with a key to get cipher text. This encrypted plain text is converted to parallel form and modulated using 1-D improper modulator for transmission. Digital modulation scheme yielding improper signal is called as improper modulation. In the proposed linear MIMO transceiver system improper modulation such as BPSK and M-ary ASK was implemented its pseudo-autocorrelation and cross-correlation function of complex envelope signals are assumed as nonzero [18]. A linear precoder concerning PAPC (α) is used to encode data stream of each VNs. Since the uplink channel matrices are complex, the coded data streams are multiplied by complex channel matrix ($H_m^{(UL)}$) and decoded by the linear decoders at the receiver. As the modulator outputs consist of only real components. Hence the real part of decoder output is considered for detection. The precoder and decoder matrix is updated based on the assumption of perfect and imperfect channel state information known at the BS and VN.

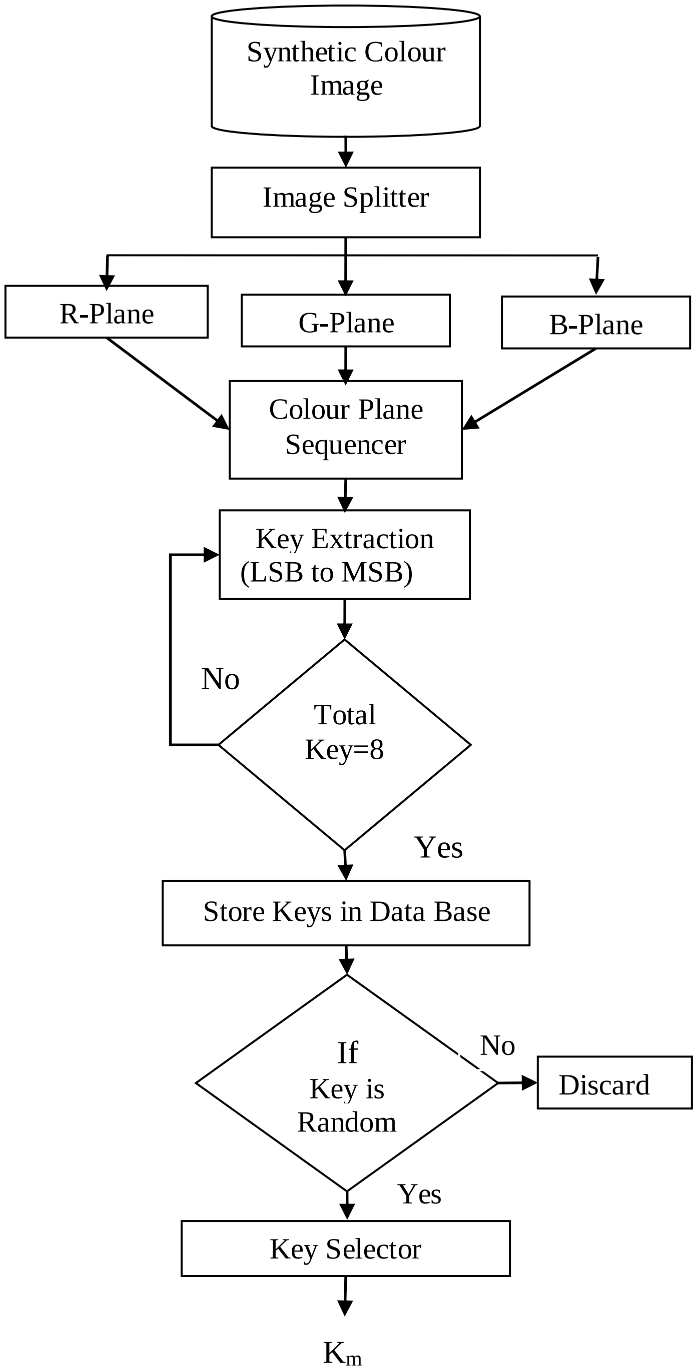

Figure.3. Flow Chart for key generation algorithm

A novel image-based key generation technique proposed for the stream cipher encryption and decryption algorithm is described in Figure.3. A 256×256 random pixel synthetic colour image is chosen as shown in Figure. 4. The colour image is made up of three layers namely red, green and blue. The pixel values in each layer vary from 0 to 255 representing the intensity level. Therefore, 8 bits are required to represent the value of one pixel. This facilitates the generation of 8 separate keys with a size of 65536 bits by extracting one bit at a time from LSB to MSB as shown in Figure.5.

The key generation process is repeated for all the three layers, and a total of 24 keys are generated. The keys fulfill the randomness property are used for encryption process, and others are discarded. To get better protection against brute force attacker, a key selection process for encryption and decryption also performed randomly.

Figure. 4 Random pixel synthetic colour image

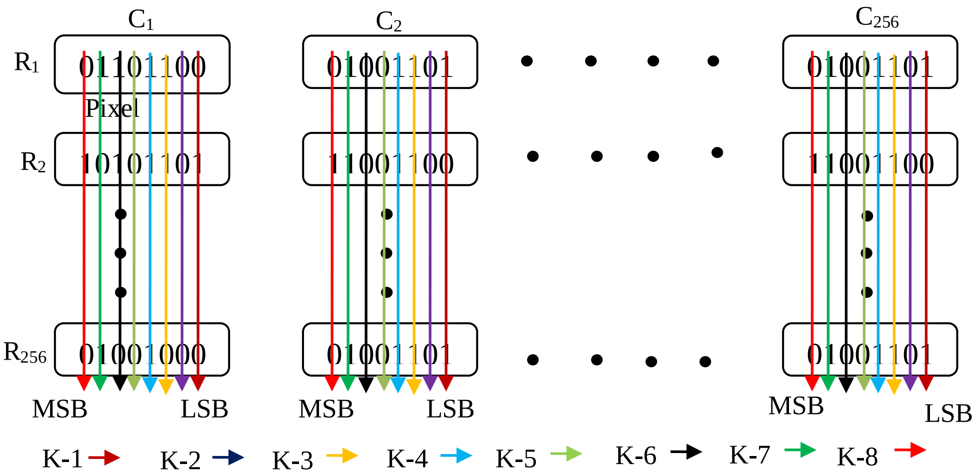

Figure. 5 Method for Key Generation

2.1. Problem formulation for minimum TMSE design with perfect CSI

The mathematical model for uplink MU-MIMO system by assuming channel matrix H is perfectly known to both transmitter and receiver is derived as follows. This model is used to minimize the TMSE for the detected symbol. The notations and their meanings used in this paper are given in Table 1.

Table 1. Notations and their meanings used in the system model

Notation	Meaning
K_m	K_m is a randomly chosen key from the finite set of possible keys
$\mathbf{d}_l^{\wedge(UL)}$	Output data vectors form the l^{th} decoder
$\mathbf{a}_l$	Input data vectors to the l^{th} precoder
$\mathbf{H}_m^{\wedge(UL)}$	Uplink MIMO channel matrices of m^{th} vehicle
$\mathbf{n}_l^{(UL)}$	Additive White Gaussian Noise (AWGN) vector with zero-mean and variance $(\sigma_n^{(UL)})^2$.whose entries are spatially, temporally and independent and identically distributed (i.i.d)
$\mathbf{P}_m$	Precoding matrix for the m^{th} Vehicle
$\mathbf{D}_l$	Decoding matrix for the l^{th} Vehicle
B	TPC
A	PAPC
$\lVert . \rVert$	p-norm norm
$E(\cdot)$	Expectation
$R(\cdot)$	Real part of a complex-valued vector
$(\cdot)^{-1}$	Matrix inverse
$(\cdot)^{T}$	Matrix transpose
$(\cdot)^{*}$	Matrix complex conjugate
$(\cdot)^{H}$	Matrix Hermitian
$Tr(\cdot)$	Trace of a matrix
$\mathbf{I}_B$	Identity matrix,
N_T	Number of transmit antennas
N_R	Number of receive antennas
B_m	Data stream for the m^{th} Vehicle

The TMSE matrix for uplink can be formulated as,

$$E[\lVert \mathbf{e}^{(UL)} \rVert^2] = E[\lVert \mathbf{d}_l^{\wedge(UL)} - \mathbf{a}_l \rVert^2] \tag{1}$$

where $\mathbf{d}_l^{\wedge(UL)} = R(\mathbf{D}_l[\sum_{m=1}^{K} \mathbf{H}_m^{(UL)} \mathbf{P}_m \mathbf{a}_m] + \mathbf{D}_l \mathbf{n}_l^{(UL)})$

Substituting the value of $\mathbf{d}_l^{\wedge(UL)}$ in (1), we obtain

$$E[\lVert \mathbf{e}^{(UL)} \rVert^2] = E[\left\lVert R(\mathbf{D}_l[\sum_{m=1}^{K} \mathbf{H}_m^{(UL)} \mathbf{P}_m \mathbf{a}_m] + \mathbf{D}_l \mathbf{n}_l^{(UL)}) - \mathbf{a}_l \right\rVert^2] \tag{2}$$

The TMSE calculation is expanded as follows:

$$E[\|\mathbf{e}^{(UL)}\|^2] = Tr\{E(0.5(\mathbf{D}_l \sum_{m=1}^{K} \mathbf{H}_m^{(UL)} \mathbf{P}_m \mathbf{a}_m + \mathbf{D}_l^* \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^* \mathbf{P}_m^* \mathbf{a}_m^*) + 0.5(\mathbf{D}_l \mathbf{n}_l^{(UL)} + \mathbf{D}_l^* (\mathbf{n}_l^{(UL)})^*) - \sum_{m=1}^{K} \mathbf{a}_m)(0.5(\mathbf{D}_l^{\mathsf{H}} \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^{\mathsf{H}} \mathbf{P}_m^{\mathsf{H}} \mathbf{a}_m^{\mathsf{H}} + \mathbf{D}_l^{\mathsf{T}} \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^{\mathsf{T}} \mathbf{P}_m^{\mathsf{T}} \mathbf{a}_m^{\mathsf{T}} + 0.5(\mathbf{D}_l^{\mathsf{H}} (\mathbf{n}_l^{(UL)})^{\mathsf{H}} + \mathbf{D}_l^{\mathsf{T}} (\mathbf{n}_l^{(UL)})^{\mathsf{T}}) - \sum_{m=1}^{K} \mathbf{a}_m^{\mathsf{H}})\} \tag{3}$$

Using assumptions made in [15-18], equation (3) is simplified for calculation of TMSE

$$E[\|\mathbf{e}^{(UL)}\|^2] = Tr\{0.25\mathbf{D}_l \sum_{m=1}^{K} \mathbf{H}_m^{(UL)} (\mathbf{H}_m^{(UL)})^{\mathsf{T}} \mathbf{P}_m \mathbf{P}_m^{\mathsf{T}} \mathbf{D}_l^{\mathsf{T}} + 0.25\mathbf{D}_l \sum_{m=1}^{K} \mathbf{H}_m^{(UL)} (\mathbf{H}_m^{(UL)})^{\mathsf{H}} \mathbf{P}_m \mathbf{P}_m^{\mathsf{H}} \mathbf{D}_l^{\mathsf{H}} + 0.25\mathbf{D}_l^* \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^* (\mathbf{H}_m^{(UL)})^{\mathsf{T}} \mathbf{P}_m^* \mathbf{P}_m^{\mathsf{T}} \mathbf{D}_l^{\mathsf{T}} + 0.25\mathbf{D}_l^* \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^* (\mathbf{H}_m^{(UL)})^{\mathsf{H}} \mathbf{P}_m^* \mathbf{P}_m^{\mathsf{H}} \mathbf{D}_l^{\mathsf{H}} - 0.5\mathbf{D}_l \sum_{m=1}^{K} \mathbf{H}_m^{(UL)} \mathbf{P}_m - 0.5\mathbf{D}_l^* \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^* \mathbf{P}_m^* - 0.5\mathbf{D}_l^{\mathsf{T}} \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^{\mathsf{T}} \mathbf{P}_m^{\mathsf{T}} - 0.5\mathbf{D}_l^{\mathsf{H}} \sum_{m=1}^{K} (\mathbf{H}_m^{(UL)})^{\mathsf{H}} \mathbf{P}_m^{\mathsf{H}} + 0.25(\sigma_{n,l}^{(UL)})^2 \mathbf{D}_l \mathbf{D}_l^{\mathsf{H}} + 0.25(\sigma_{n,l}^{(UL)})^2 \mathbf{D}_l^* \mathbf{D}_l^{\mathsf{T}} + \mathbf{I}_{B_l}\} \tag{4}$$

To minimize the TMSE subject to PAPC,

$$\min_{\mathbf{P_m},\mathbf{D_m}} tr(E[\|\mathbf{e}^{(UL)}\|^2]) \ s.t. \sum_{m=1}^{K} (Tr(\mathbf{P}_m \mathbf{P}_m^{\mathsf{H}})^p)^{1/p} \le \alpha \tag{5}$$

Where α is the PAPC.

Using Lagrangian to get the solution for the defined problem

$$\eta^{(UL)} = E[\|\mathbf{e}^{(UL)}\|^2] + \mu^{(UL)}([\sum_{m=1}^{K} (Tr(\mathbf{P}_m \mathbf{P}_m^{\mathsf{H}})^p)^{1/p}] - \alpha) \tag{6}$$

where $\mu^{(UL)}$ is the Lagrange multiplier.

Substitute equation (4) in (6) to get an expanded version of (6). The uplink one-dimensional improper modulation based transceiver design problem in (5) is non-convex and also continuously differentiable. Therefore by taking the derivatives of $\eta^{(UL)}$ with respect to $\mathbf{D}_l$ and $\mathbf{P}_l$, Then the related Karush-Kuhn-Tucker(KKT) conditions can be obtained and given in the following

$$\frac{\partial \eta^{(UL)}}{\partial \mathbf{D}_l} = 0$$

$$\mathbf{D}_z \{\sum_{z=1}^{K} \mathbf{H}_Z^{(UL)} \mathbf{P}_z \mathbf{P}_z^{\mathsf{H}} \mathbf{H}_z^{(UL)^{\mathsf{H}}} + (\sigma_n^{(UL)})^2\} + \mathbf{D}_z^* \{\sum_{z=1}^{K} (\mathbf{H}_Z^{(UL)})^* \mathbf{P}_z^* \mathbf{P}_z^{\mathsf{H}} (\mathbf{H}_Z^{(UL)})^{\mathsf{H}}\} = 2\mathbf{P}_z^{\mathsf{H}} (\mathbf{H}_Z^{(UL)})^{\mathsf{H}} \tag{7}$$

$$\frac{\partial \eta^{(UL)}}{\partial \mathbf{P}_l} = 0$$

$$\mathbf{D}_z^*\mathbf{D}_z^{\mathsf{H}}\{\sum_{z=1}^{K}(\mathbf{H}_z^{(UL)})^*(\mathbf{H}_Z^{(UL)})^{\mathsf{H}}\mathbf{P}_z^*\}+\mathbf{D}_z\mathbf{D}_z^{\mathsf{H}}\{\sum_{z=1}^{K}\mathbf{H}_Z^{(UL)}(\mathbf{H}_Z^{(UL)})^{\mathsf{H}}\mathbf{P}_z\}+2\mu^{(UL)}k\sum_{z=1}^{K}\mathbf{P}_z = 2(\mathbf{H}_Z^{(UL)})^{\mathsf{H}}\mathbf{D}_z^{\mathsf{H}} \tag{8}$$

where $k = [Tr(\Sigma_{z=1}^{K}\mathbf{P}_z\mathbf{P}_z^{\mathsf{H}})^p\,]^{(1/p)-1}[\Sigma_{z=1}^{K}\mathbf{P}_z^{\mathsf{T}}\mathbf{P}_z^*\,]^{p-1}$

The expression of Lagrange multiplier is obtained by equating the equations (7) and (8).

$$\mu^{(UL)} = \frac{(\sigma_n^{(UL)})^2}{2\alpha}[\sum_{z=1}^{K}Tr(\mathbf{D}_z\mathbf{D}_z^{\mathsf{H}})] \tag{9}$$

An iterative procedure shown in Figure 2 is used to find the optimum solution for $\mathbf{D}_z$ and $\mathbf{P}_z$

$$\mathbf{D}_z = \mathbf{D}_{z,Re} + j\mathbf{D}_{z,Im},$$
$$\mathbf{E}_{z,Re}^{(UL)} + j\mathbf{E}_{z,Im}^{(UL)} = \mathbf{D}_z\{\sum_{z=1}^{K}\mathbf{H}_Z^{(UL)}\mathbf{P}_z\mathbf{P}_z^{\mathsf{H}}\mathbf{H}_z^{(UL)\mathsf{H}}\},$$
$$\mathbf{F}_{z,Re}^{(UL)} + j\mathbf{F}_{z,Im}^{(UL)} = \{\sum_{z=1}^{K}(\mathbf{H}_Z^{(UL)})^*\mathbf{P}_z^*\mathbf{P}_z^{\mathsf{H}}(\mathbf{H}_Z^{(UL)})^{\mathsf{H}}\},$$
$$\mathbf{G}_{z,Re}^{(UL)} + j\mathbf{G}_{z,Im}^{(UL)} = 2\mathbf{P}_z^{\mathsf{H}}(\mathbf{H}_Z^{(UL)})^{\mathsf{H}}.$$

Then $\mathbf{D}_{z,Re}$ and $\mathbf{D}_{z,Im}$ can be expressed as

$$\begin{bmatrix}\mathbf{D}_{z,Re} & \mathbf{D}_{z,Im}\end{bmatrix} = \begin{bmatrix}\mathbf{G}_{z,Re}^{(UL)} & \mathbf{G}_{z,Im}^{(UL)}\end{bmatrix}\begin{bmatrix}\mathbf{E}_{z,Re}^{(UL)}+\mathbf{F}_{z,Re}^{(UL)}+(\sigma_n^{(UL)})^2\mathbf{I}_{N_R} & \mathbf{E}_{z,Im}^{(UL)}+\mathbf{F}_{z,Im}^{(UL)} \\ \mathbf{F}_{z,Im}^{(UL)}-\mathbf{E}_{z,Im}^{(UL)} & \mathbf{E}_{z,Re}^{(UL)}-\mathbf{F}_{z,Re}^{(UL)}+(\sigma_n^{(UL)})^2\mathbf{I}_{N_R}\end{bmatrix}^{-1} \tag{10}$$

Likewise, define

$$\mathbf{P}_z = \mathbf{P}_{z,Re} + j\mathbf{P}_{z,Im},$$
$$\mathbf{R}_{z,Re}^{(UL)} + j\mathbf{R}_{z,Im}^{(UL)} = \mathbf{D}_z\mathbf{D}_z^{\mathsf{H}}\{\sum_{z=1}^{K}\mathbf{H}_Z^{(UL)}(\mathbf{H}_Z^{(UL)})^{\mathsf{H}}\},$$
$$\mathbf{S}_{z,Re}^{(UL)} + j\mathbf{S}_{z,Im}^{(UL)} = \Sigma_{m=1}^{K}(\mathbf{H}_Z^{(UL)})^{\mathsf{H}}\mathbf{D}_z^*\mathbf{D}_z^{\mathsf{H}}(\mathbf{H}_z^{(UL)})^*$$
$$\mathbf{T}_{z,Re}^{(UL)} + j\mathbf{T}_{z,Im}^{(UL)} = 2(\mathbf{H}_z^{(UL)})^{\mathsf{H}}\mathbf{D}_z^{\mathsf{H}}.$$

Then $\mathbf{P}_{z,Re}$ and $\mathbf{P}_{z,Im}$ can be expressed as

$$\begin{bmatrix}\mathbf{P}_{z,Re} \\ \mathbf{P}_{z,Im}\end{bmatrix} = \begin{bmatrix}(\mathbf{R}_{z,Re}^{(UL)}+\mathbf{S}_{z,Re}^{(UL)}+2\mu^{(UL)}k\mathbf{I}_{N,T} & \mathbf{S}_{z,Im}^{(UL)}-\mathbf{R}_{z,Im}^{(UL)} \\ \mathbf{R}_{z,Im}^{(UL)}+\mathbf{S}_{z,Im}^{(UL)} & \mathbf{R}_{z,Re}^{(UL)}-\mathbf{S}_{z,Re}^{(UL)}+2\mu^{(UL)}k\mathbf{I}_{N,T}\end{bmatrix}^{-1}\begin{bmatrix}\mathbf{T}_{z,Re}^{(UL)} \\ \mathbf{T}_{z,Im}^{(UL)}\end{bmatrix} \tag{11}$$

2.2. Problem formulation for minimum TMSE design with imperfect CSI

For imperfect case, the m^{th} user channel is modeled as

$$\mathbf{H}_m^{(UL)} = \mathbf{H}_m^{\wedge(UL)} + \mathbf{E}_m^{(UL)} \tag{12}$$

To estimate the channel matrix, training sequences were used.

$$\mathbf{H}_m^{\wedge(UL)} = \mathbf{R}_{R,m}^{1/2}\mathbf{H}_{wm}^{\wedge(UL)}\mathbf{R}_T^{1/2} \text{ and } \mathbf{E}_m^{(UL)} = \mathbf{R}_{e,R,m}^{1/2}\mathbf{E}_{w,m}^{(UL)}\mathbf{R}_T^{1/2}, \text{ m=1...K} \tag{13}$$

where $\mathbf{R}_T^{1/2}$ & $\mathbf{R}_{R,m}^{1/2}$ are the correlation matrices and $\mathbf{E}_m^{(UL)}$ is the error model. The entries of $\mathbf{H}_{wm}^{\wedge(UL)}$ and $\mathbf{E}_{w,m}^{(UL)}$ are independent and identically distributed.

Substitute equation (13) in (12) to get an expanded version of (12).

$$\mathbf{H}_m^{(UL)} = \mathbf{R}_{R,m}^{1/2}\mathbf{H}_{wm}^{\wedge(UL)}\mathbf{R}_T^{1/2} + \mathbf{R}_{e,R,m}^{1/2}\mathbf{E}_{w,m}^{(UL)}\mathbf{R}_T^{1/2} \tag{14}$$

where $\mathbf{R}_{e,R,m} = [\mathbf{I}_{N_{R,m}} + \sigma_{ce,m}^2\mathbf{R}_{R,m}^{-1}]^{-1}$ and $\sigma_{ce,m}^2 = Tr(\mathbf{R}_T^{-1})\sigma_n^2/\mathbf{P}_{tr,m}$. In $\mathbf{R}_{e,R,m}$, $\sigma_{ce,m}^2$ is a channel estimation error variance and in $\sigma_{ce,m}^2$, σ_n^2 is a noise variance and $\mathbf{P}_{tr,m}$ is a training power of the user m.

The TMSE calculation for the improper modulation based uplink MU-MIMO system for imperfect case defined as follows:

$$E[\left\|\mathbf{e}^{(UL)}\right\|^2] = E[\left\|\mathbf{d}_l^{\wedge(UL)} - \mathbf{a}_l\right\|^2] \tag{15}$$

where $\mathbf{d}_l^{\wedge(UL)} = R(\mathbf{D}_l[\Sigma_{m=1}^K(\mathbf{H}_m^{\wedge(UL)} + \mathbf{E}_m^{(UL)})\mathbf{P}_m\mathbf{a}_m] + \mathbf{D}_l\mathbf{n}_l^{(UL)})$ is the vector after decoder. Substituting the value of $\mathbf{d}_l^{\wedge(UL)}$ in (15), we obtain

$$E[\left\|\mathbf{e}^{(UL)}\right\|^2] = E[\left\|R(\mathbf{D}_l[\sum_{m=1}^{K}(\mathbf{H}_m^{\wedge(UL)} + \mathbf{E}_m^{(UL)})\mathbf{P}_m\mathbf{a}_m] + \mathbf{D}_l\mathbf{n}_l^{(UL)}) - \mathbf{a}_l\right\|^2] \tag{16}$$

The TMSE calculation is expanded as follows:

$$\begin{aligned} E[\left\|\mathbf{e}^{(UL)}\right\|^2] &= Tr\{E(0.5(\mathbf{D}_l\Sigma_{m=1}^K\mathbf{H}_m^{\wedge(UL)}\mathbf{P}_m\mathbf{a}_m + \mathbf{D}_l^*\Sigma_{m=1}^K(\mathbf{H}_m^{\wedge(UL)})^*\mathbf{P}_m^*\mathbf{a}_m^*) \\ &+ 0.5(\mathbf{D}_l\mathbf{E}_l^{(UL)}\Sigma_{m=1}^K\mathbf{P}_m\mathbf{a}_m + \mathbf{D}_l^*(\mathbf{E}_l^{(UL)})^*\Sigma_{m=1}^K\mathbf{P}_m^*\mathbf{a}_m^*) + 0.5(\mathbf{D}_l\mathbf{n}_l^{(UL)} + \mathbf{D}_l^*(\mathbf{n}_l^{(UL)})^*) - \Sigma_{m=1}^K\mathbf{a}_m) \\ &(0.5(\mathbf{D}_l^{\mathsf{H}}\Sigma_{m=1}^K(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{H}}\mathbf{P}_m^{\mathsf{H}}\mathbf{a}_m^{\mathsf{H}} + \mathbf{D}_l^{\mathsf{T}}\Sigma_{m=1}^K(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{T}}\mathbf{P}_m^{\mathsf{T}}\mathbf{a}_m^{\mathsf{T}}) + 0.5(\mathbf{D}_l^{\mathsf{H}}(\mathbf{E}_l^{(UL)})^{\mathsf{H}}\Sigma_{m=1}^K\mathbf{P}_m^{\mathsf{H}}\mathbf{a}_m^{\mathsf{H}} \\ &+ \mathbf{D}_l^{\mathsf{T}}(\mathbf{E}_l^{(UL)})^{\mathsf{T}}\Sigma_{m=1}^K\mathbf{P}_m^{\mathsf{T}}\mathbf{a}_m^{\mathsf{T}}) + 0.5(\mathbf{D}_l^{\mathsf{H}}(\mathbf{n}_l^{(UL))^{\mathsf{H}}} + \mathbf{D}_l^{\mathsf{T}}(\mathbf{n}_l^{(UL)})^{\mathsf{T}}) - \Sigma_{m=1}^K\mathbf{a}_m^{\mathsf{H}})\} \end{aligned} \tag{17}$$

Using the following assumptions made in [15-18] simplifies the equation (17). Then TMSE is calculated as

$$E[\|\mathbf{e}^{(UL)}\|^2] = Tr\{\, 0.25\mathbf{D}_l[\sum_{m=1}^{K}\mathbf{H}_m^{\wedge(UL)}\mathbf{P}_m\mathbf{P}_m^{\mathsf{H}}(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{H}}]\mathbf{D}_l^{\mathsf{H}} - 0.5\mathbf{D}_l^{*}\sum_{m=1}^{K}(\mathbf{H}_m^{\wedge(UL)})^{*}\mathbf{P}_m^{*}$$
$$+0.25\mathbf{D}_l[\sum_{m=1}^{K}\mathbf{H}_m^{\wedge(UL)}\mathbf{P}_m\mathbf{P}_m^{\mathsf{T}}(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{T}}]\mathbf{D}_l^{\mathsf{T}} - 0.5\mathbf{D}_l^{\mathsf{H}}\sum_{m=1}^{K}(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{H}}\mathbf{P}_l^{\mathsf{H}}$$
$$+0.25\mathbf{D}_l\mathbf{R}_{e,R,l}\mathbf{D}_l^{\mathsf{H}}[\sum_{m=1}^{K}Tr(\mathbf{R}_T\mathbf{P}_m\mathbf{P}_m^{\mathsf{H}})]\sigma_{ce,l}^2 - 0.5\mathbf{D}_l\sum_{m=1}^{K}\mathbf{H}_m^{\wedge(UL)}\mathbf{P}_m + 0.25\mathbf{D}_l\mathbf{D}_l^{\mathsf{H}}(\sigma_n^{(UL)})^2 \tag{18}$$
$$-0.5\mathbf{D}_l^{\mathsf{T}}\sum_{m=1}^{K}(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{T}}\mathbf{P}_l^{\mathsf{T}} + \mathbf{I}_{B_l} + 0.25\mathbf{D}_l^{*}[\sum_{m=1}^{K}(\mathbf{H}_m^{\wedge(UL)})^{*}\mathbf{P}_m^{*}\mathbf{P}_m^{\mathsf{H}}(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{H}}]\mathbf{D}_l^{\mathsf{H}}$$
$$+0.25\mathbf{D}_l^{*}[\sum_{m=1}^{K}(\mathbf{H}_m^{\wedge(UL)})^{*}\mathbf{P}_m^{*}\mathbf{P}_m^{\mathsf{T}}(\mathbf{H}_m^{\wedge(UL)})^{\mathsf{T}}]\mathbf{D}_l^{\mathsf{T}} + 0.25\mathbf{D}_l^{*}\mathbf{R}_{e,R,l}^{*}\mathbf{D}_l^{\mathsf{T}}[\sum_{m=1}^{K}Tr(\mathbf{R}_T\mathbf{P}_m\mathbf{P}_m^{\mathsf{H}})]^{*}\sigma_{ce,l}^2$$
$$+0.25\mathbf{D}_l^{*}\mathbf{D}_l^{\mathsf{T}}(\sigma_n^{(UL)})^2$$

To minimize the TMSE subject to PAPC, hence

$$\min_{\mathbf{P_m},\mathbf{D_m}} \; tr(E[\|\mathbf{e}^{(UL)}\|^2]) \;\; s.t.\Sigma_{m=1}^{K}(Tr(\mathbf{P}_m\mathbf{P}_m^{\mathsf{H}})^{p})^{1/p} \le \alpha \tag{19}$$

Where α is the PAPC.

Using Lagrangian to arrive at the solution for the defined problem

$$\eta^{(UL)} = E[\|\mathbf{e}^{(UL)}\|^2] + \mu^{(UL)}([\sum_{m=1}^{K}(Tr(\mathbf{P}_m\mathbf{P}_m^{\mathsf{H}})^{p})^{1/p}] - \alpha) \tag{20}$$

where $\mu^{(UL)}$ is the Lagrange multiplier.

By taking the derivatives of η with respect to $\mathbf{D}_l$ & $\mathbf{P}_l$, it can be shown that the Lagrangian can be derived.

$$\frac{\partial\eta^{(UL)}}{\partial\mathbf{D}_l} = 0$$

$$\mathbf{D}_z(\sum_{z=1}^{K}\mathbf{H}_Z^{\wedge(UL)}\mathbf{P}_z\mathbf{P}_z^{\mathsf{H}}(\mathbf{H}_z^{\wedge(UL)})^{\mathsf{H}} + \mathbf{R}_{e,R,z}\sigma_{ce,z}^2\mathbf{R}_T\sum_{z=1}^{K}Tr(\mathbf{P}_z\mathbf{P}_z^{H})) + \mathbf{D}_z^{*}\sum_{z=1}^{K}(\mathbf{H}_Z^{\wedge(UL)})^{*}\mathbf{P}_z^{*}\mathbf{P}_z^{\mathsf{H}}(\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}}$$
$$+(\sigma_n^{(UL)})^2\mathbf{D}_z = 2\mathbf{P}_z^{\mathsf{H}}(\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}} \tag{21}$$

$$\frac{\partial\eta^{(UL)}}{\partial\mathbf{P}_l} = 0$$

$$\mathbf{P}_z((\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}}\sum_{z=1}^{K}\mathbf{D}_z\mathbf{D}_z^{\mathsf{H}}\mathbf{H}_Z^{\wedge(UL)} + \mathbf{R}_T\sigma_{ce,z}^2\mathbf{R}_{e,R,z}\sum_{z=1}^{K}Tr(\mathbf{D}_z\mathbf{D}_z^{H}))\mathbf{P}_z + \mathbf{P}_z^{*}(\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}}\sum_{z=1}^{K}\mathbf{D}_z^{*}\mathbf{D}_z^{\mathsf{H}}(\mathbf{H}_z^{\wedge(UL)})^{*}$$
$$+2k\,\mu^{(UL)}\sum_{z=1}^{K}\mathbf{P}_z = 2(\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}}\mathbf{D}_z \tag{22}$$

where $k = [Tr(\Sigma_{z=1}^{K}\mathbf{P}_z\mathbf{P}_z^{\mathsf{H}})^{p}]^{(1/p)-1}[\Sigma_{z=1}^{K}\mathbf{P}_z^{\mathsf{T}}\mathbf{P}_z^{*}]^{p-1}$

The expression of Lagrange multiplier is obtained by equating the equations (21) and (22).

$$\mu^{(UL)} = \frac{(\sigma_n^{(UL)})^2}{2\alpha}[\sum_{z=1}^{K} Tr(\mathbf{D}_z \mathbf{D}_z^{\mathsf{H}})] \tag{23}$$

An iterative procedure is shown in Figure.6. is used to find the optimum solution for $\mathbf{D}_z$ and $\mathbf{P}_z$

$$\begin{aligned}
&\mathbf{D}_z = \mathbf{D}_{z,Re} + j\mathbf{D}_{z,Im},\\
&\mathbf{E}_{z,Re}^{(UL)} + j\mathbf{E}_{z,Im}^{(UL)} = \mathbf{H}_Z^{\wedge(UL)} \Sigma_{z=1}^{K} \mathbf{P}_z \mathbf{P}_z^{\mathsf{H}} (\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}} + \mathbf{R}_{e,R,z} \sigma_{ce,z}^2 \mathbf{R}_T \Sigma_{z=1}^{K} Tr(\mathbf{P}_z \mathbf{P}_z^{\mathsf{H}}),\\
&\mathbf{F}_{z,Re}^{(UL)} + j\mathbf{F}_{z,Im}^{(UL)} = (\mathbf{H}_Z^{\wedge(UL)})^* \Sigma_{z=1}^{K} \mathbf{P}_z^* \mathbf{P}_z^{\mathsf{H}} (\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}},\\
&\mathbf{G}_{z,Re}^{(UL)} + j\mathbf{G}_{z,Im}^{(UL)} = 2\mathbf{P}_z^{\mathsf{H}} (\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}}.
\end{aligned}$$

Then $\mathbf{D}_{z,Re}$ and $\mathbf{D}_{z,Im}$ can be expressed as

$$\begin{bmatrix} \mathbf{D}_{z,Re} & \mathbf{D}_{z,Im} \end{bmatrix} = \begin{bmatrix} \mathbf{G}_{z,Re}^{(UL)} & \mathbf{G}_{z,Im}^{(UL)} \end{bmatrix} \begin{bmatrix} \mathbf{E}_{z,Re}^{(UL)} + \mathbf{F}_{z,Re}^{(UL)} + (\sigma_n^{(UL)})^2 \mathbf{I}_{N_R} & \mathbf{E}_{z,Im}^{(UL)} + \mathbf{F}_{z,Im}^{(UL)} \\ \mathbf{F}_{z,Im}^{(UL)} - \mathbf{E}_{z,Im}^{(UL)} & \mathbf{E}_{z,Re}^{(UL)} - \mathbf{F}_{z,Re}^{(UL)} + (\sigma_n^{(UL)})^2 \mathbf{I}_{N_R} \end{bmatrix}^{-1} \tag{24}$$

Likewise, define

$$\begin{aligned}
&\mathbf{P}_z = \mathbf{P}_{z,Re} + j\mathbf{P}_{z,Im},\\
&\mathbf{R}_{z,Re}^{(UL)} + j\mathbf{R}_{z,Im}^{(UL)} = \Sigma_{z=1}^{K} (\mathbf{H}_z^{\wedge(UL)})^{\mathsf{H}} \mathbf{D}_z \mathbf{D}_z^{\mathsf{H}} \mathbf{H}\wedge_z^{(UL)} + \mathbf{R}_T \sigma_{ce,z}^2 \mathbf{R}_{e,R,z} \Sigma_{z=1}^{K} Tr(\mathbf{D}_z \mathbf{D}_z^{\mathsf{H}}),\\
&\mathbf{S}_{z,Re}^{(UL)} + j\mathbf{S}_{z,Im}^{(UL)} = \Sigma_{m=1}^{K} (\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}} \mathbf{D}_m^* \mathbf{D}_m^{\mathsf{H}} (\mathbf{H}_Z^{\wedge(UL)})^*,\\
&\mathbf{T}_{z,Re}^{(UL)} + j\mathbf{T}_{z,Im}^{(UL)} = 2(\mathbf{H}_Z^{\wedge(UL)})^{\mathsf{H}} \mathbf{D}_z.
\end{aligned}$$

Then $\mathbf{P}_{z,Re}$ and $\mathbf{P}_{z,Im}$ can be expressed as

$$\begin{bmatrix} \mathbf{P}_{z,Re} \\ \mathbf{P}_{z,Im} \end{bmatrix} = \begin{bmatrix} (\mathbf{R}_{z,Re}^{(UL)} + \mathbf{S}_{z,Re}^{(UL)} + 2\mu^{(UL)} k \mathbf{I}_{N,T} & \mathbf{S}_{z,Im}^{(UL)} - \mathbf{R}_{z,Im}^{(UL)} \\ \mathbf{R}_{z,Im}^{(UL)} + \mathbf{S}_{z,Im}^{(UL)} & \mathbf{R}_{z,Re}^{(UL)} - \mathbf{S}_{z,Re}^{(UL)} + 2\mu^{(UL)} k \mathbf{I}_{N,T} \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{T}_{z,Re}^{(UL)} \\ \mathbf{T}_{z,Im}^{(UL)} \end{bmatrix} \tag{25}$$

With the help of duality theory, the above design of the Uplink MU-MIMO transceiver system can be implemented for the downlink design.

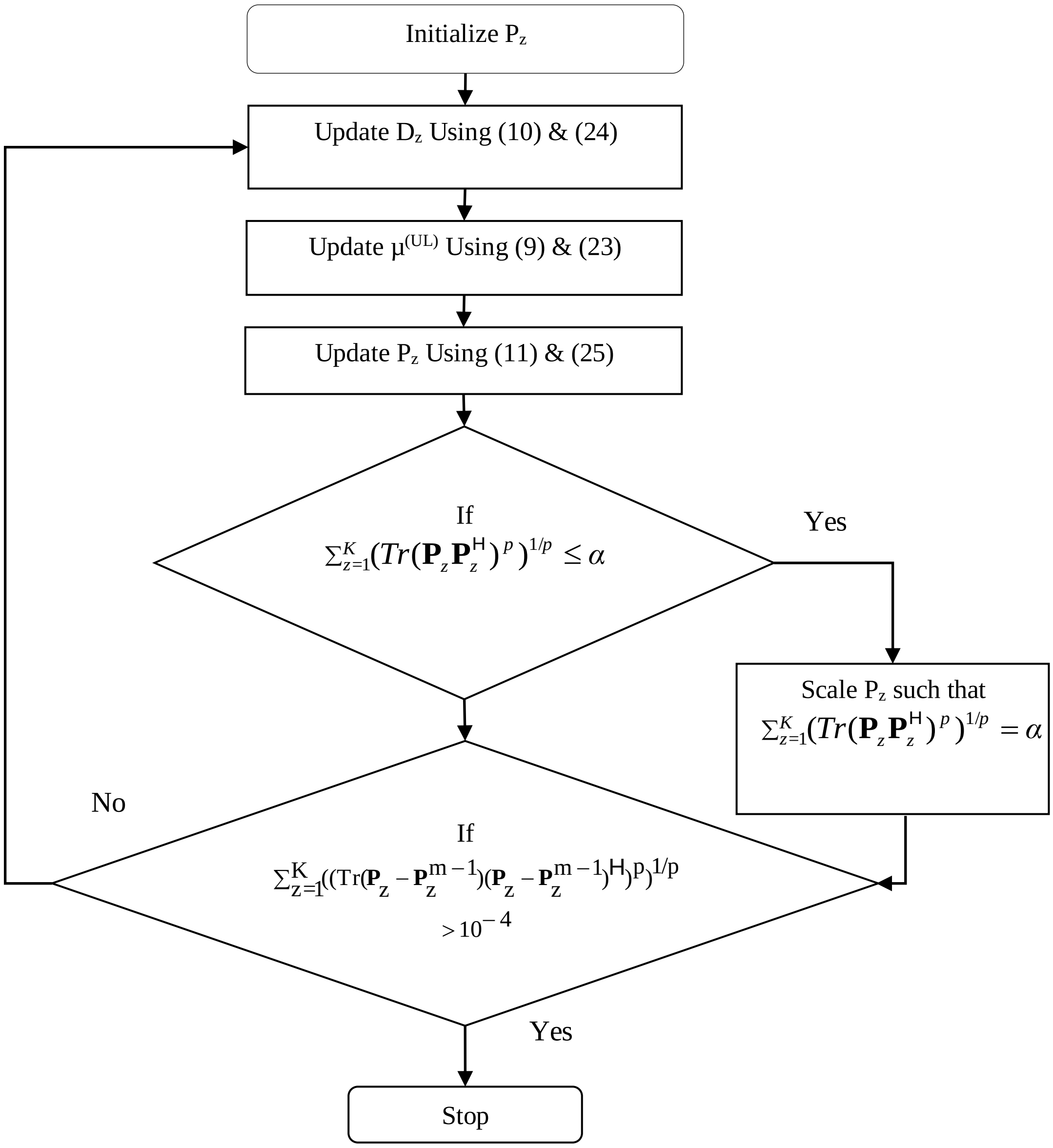

Figure 6. Iterative procedure to get optimum precoder and decoder

3. RESULTS &DISCUSSION

The proposed work aims to improve the security and reliability of MU-MIMO transceiver system. The security of the systems is evaluated by using randomness test, and the reliability of the system is tested in terms of ABER. The proposed cryptographic key generation technique used for security is validated using the National Institute of Standards and Technology (NIST) test suite, and its probability values of the tests are given in Table.2. It is observed that the probability values resulting from all the tests are greater than 0.01. [20] These results show that the generated keys are random in nature. Similarly, the reliability of the proposed MU-MIMO uplink system mathematical model is tested by evaluating the ABER concerning SNR using MATLAB in a simulation environment with parameters described in Table. 3.

Table.2 NIST Parameter analysis

Test	P-Key$_1$	P- Key$_2$	P- Key$_3$	P- Key$_4$	P- Key$_5$	Result
Frequency	0.534146	0.122325	0.035174	0.350485	0.911413	Pass
Block Frequency	0.534146	0.213309	0.739918	0.739918	0.739918	Pass
Cumulative Sums	0.739918	0.122325	0.213309	0.213309	0.534146	Pass
Runs	0.911413	0.122325	0.350485	0.350485	0.350485	Pass
Longest Run	0.350485	0.739918	0.017912	0.534146	0.739918	Pass
Rank	0.066882	0.213309	0.534146	0.213309	0.739918	Pass
FFT	0.739918	0.350485	0.534146	0.534146	0.911413	Pass
Non-Overlapping Template	0.991468	0.911413	0.739918	0.911413	0.911413	Pass
Approximate Entropy	0.122325	0.122325	0.035174	0.739918	0.739918	Pass
Serial	0.350485	0.534146	0.017912	0.350485	0.739918	Pass
Linear Complexity	0.350485	0.534146	0.534146	0.534146	0.066882	Pass

Table. 3. Simulation parameters and its values

Parameter	Values					
Vehicular stations	4					
Base station	1					
No of transmitting antennas(N_T) at each vehicle	4					
No of receiving antennas(N_R) at base station	16					
No of the data stream (B) from each vehicle	4					
p-values	4.12		2.36		1.76	
	α	β	α	β	α	β
	1.1W	3.16W	2.8W	6.31W	5.5W	10W

The ABER is compared for both proposed and conventional transceiver system, at the output of decryption algorithm by concerning proposed key generation technique. Two improper modulation techniques namely BPSK and 4-ASK modulation are used for evaluation. Standard p-values such as 4.12, 2.36, and 1.76 are also considered and simulated for both perfect and imperfect CSI condition.

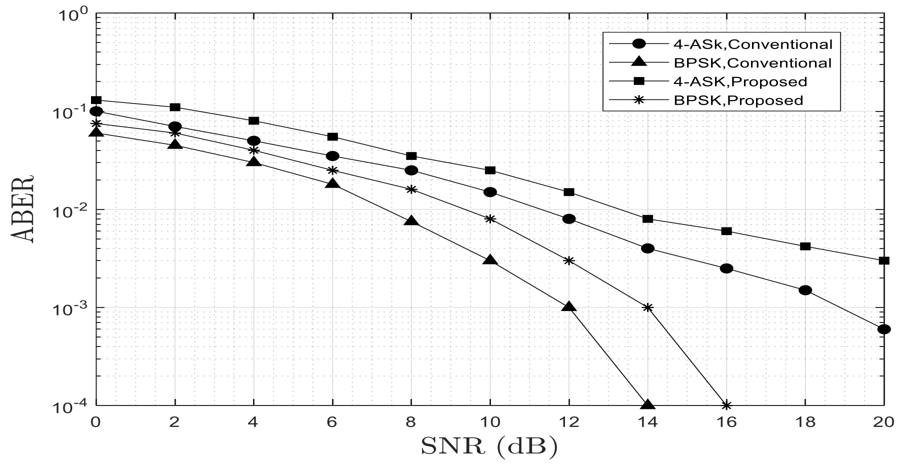

Figure 7. Performance comparison results of MU-MIMO uplink system with respect to perfect CSI for p=4.12

Figure 7 shows the performance of the proposed MU-MIMO systems for BPSK and 4-ASK modulation for the p-value of 4.12 with a perfect CSI at the transmitter and receiver. It is observed that SNR is increased from 7.5dB to 9.5dB for BPSK and from 11.5dB to 13.5dB in the case of 4-ASK. This indicates that the proposed system demand an additional 2 dB of SNR at the ABER level of 10^{-2}. This notifying increase in SNR is worth as the design is more realistic.

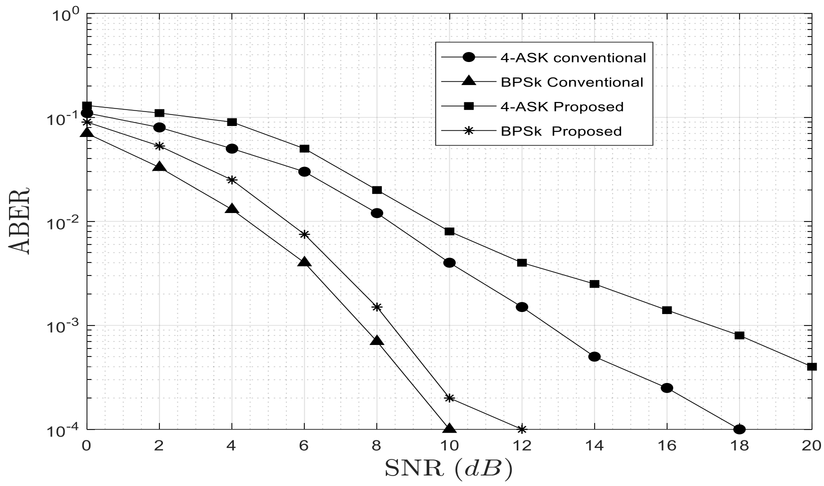

Figure 8. Performance comparison results of MU-MIMO uplink system with respect to perfect CSI for p=2.36

The p-value is decreased and simulated for p=2.36 as illustrated in Figure 8. The SNR is increased from 4.5dB to5.5dB for BPSK and from 8.5dB to 9.5dB in the case of 4-ASK. Here an SNR increase of 1 dB is observed at the same ABER level of 10^{-2} for both the improper modulation schemes. A lesser increase in SNR showcases that the system is nearing optimal as the p-value is reduced from 4.12 to 2.36.

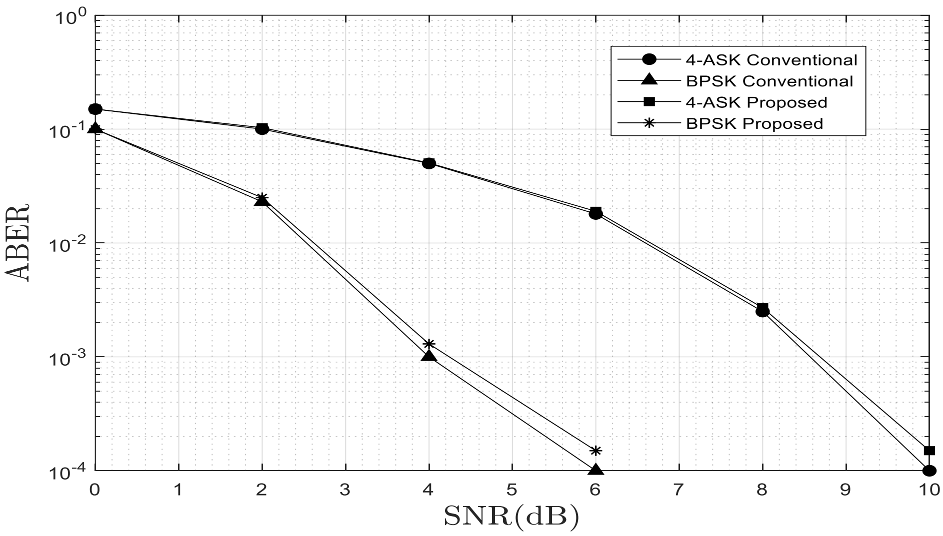

Figure 9. Performance comparison results of MU-MIMO uplink system with respect to perfect CSI for p=1.76

The p-value is further reduced close to unity (p=1.76), and its ABER is evaluated as in Figure 9. It is observed that for BPSK modulation, both TPC and PAPC require an SNR value of 2.5dB and 4-ASK modulation requires an SNR of 6.5dB at 10^{-2} ABER. This makes the SNR requirement for PAPC is same as TPC. From these results, the proposed system found to be optimal for practical realization.

The proposed system is also tested for imperfect CS condition for various p-values (p=4.12 and p=2.36). The values of transmitting and receive correlation matrices are set to be ρ_T=0.5, ρ_R=0.5 respectively and the channel estimation error is set as σ_{ce}^2=0.015 to simulate the imperfect channel state condition.

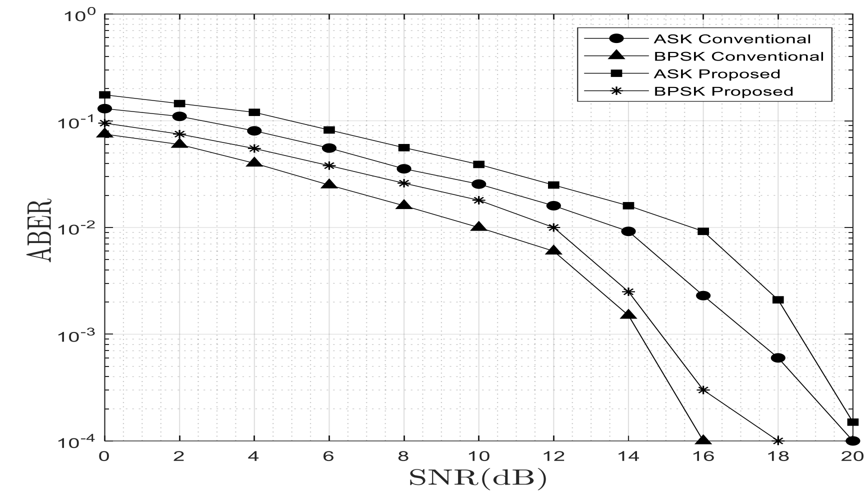

Figure 10a. Performance comparison results of MU-MIMO uplink system with respect to imperfect CSI for p=4.12.

Figure.10a&10b.shows the comparisons of MU-MIMO uplink system with TPC and PAPC for the imperfect CSI. It illustrates BPSK and 4-ASK requires an increase of 2 dB (BPSK: 10dB to12 dB & 4-ASK: 14dB to 16dB) and 1 dB (BPSK: 7 to8dB & 4-AKS: 11dB to 12dB) for p-value of 4.12 and 2.36 respectively at 10^{-2} ABER level. A difference of 2.5dB in the SNR is observed between the perfect and imperfect case, which makes the system suitable for realization.

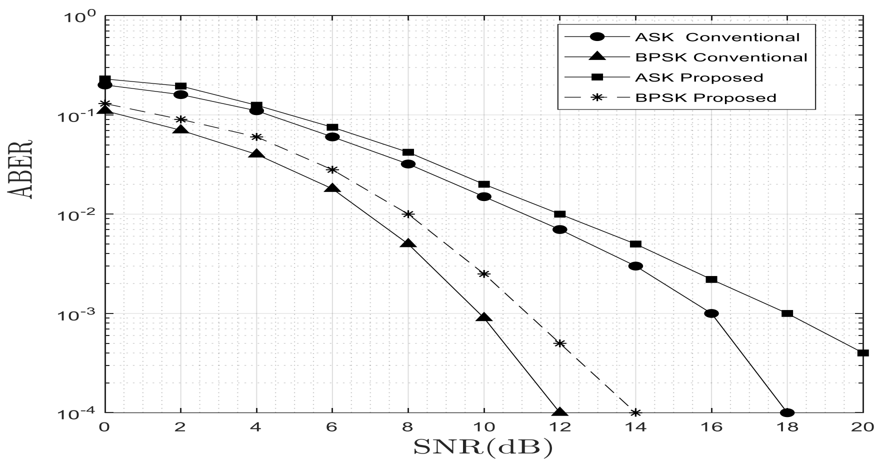

Figure 10b. Performance comparison results of MU-MIMO uplink system with respect to imperfect CSI for p=2.36.

4. CONCLUSIONS

In this paper, 1-D improper modulation based uplink MU-MIMO transceiver employing PAPC with TMSE criterion is proposed for the vehicular network to achieve reliability. In addition to that to achieve security, a novel pseudo-random key generation technique was proposed for its stream cipher technique. The proposed key generation technique uses random pixel value based synthetic colour image to generate keys. Five out of 24 generated keys satisfy the randomness test, and its probability value is found to be greater than 0.01. The proposed key generation techniques make the RF-based vehicular network secure and also the overall transceiver design to be less complex.

Reliability is improved by jointly optimizing the precoder and decoder of the transceiver system using the iterative algorithm. It uses the inverse water-filling technique with respect to PAPC for power allocation, which satisfies the linearity constraint of the power amplifier and makes the system realizable. Simulation studies of the proposed system are carried out for various p-values in the range $1<p<\infty$ for both perfect and imperfect CS condition. An optimum solution is obtained when the value of p approaches unity (p=1.76). Hence the proposed mathematical model for MU-MIMO transceiver system meets the practical requirement of a vehicular network design. It can also be implemented for other RF-MIMO & visual MIMO communication networks which required low ABER and high security.

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