

# Supplementary Material

## Abstract

This document is the supplementary material for the article “Reconfigurable Massive MIMO: Harnessing the Power of the Electromagnetic Domain for Enhanced Information Transfer”. Two parts of the original article are presented in a more detailed form. The first part is the channel modeling of reconfigurable massive MIMO (R-mMIMO) systems. The second part is the pseudo-code of the proposed EMR domain precoding algorithm.

## I. CHANNEL MODEL FOR R-MMIMO SYSTEMS

We consider a point-to-point R-mMIMO system with  $N_r$  receive antennas and  $N_t$  transmit antennas. Assuming the  $n_t$ -th transmit antenna adopts  $\mu_{n_t}$ -th radiation pattern and the  $n_r$ -th receive antenna adopts  $\nu_{n_r}$ -th radiation pattern, respectively, then the time-delay  $(t, \tau)$  domain scalar channel between them is denoted by  $H_{n_r, n_t}(t, \tau; \nu_{n_r}, \mu_{n_t})$ , whose detailed expression is given by Table I. Furthermore, by restricting the receiver to equip a single non-reconfigurable antenna, as the original article assumes, the degraded channel model between the UE and the  $n_t$ -th antenna of the BS in the time-frequency  $(t, k)$  domain is obtained as  $h_{n_t}(t, k; \mu_{n_t})$  in Table I. Here,  $h_{n_t}(t, k; \mu_{n_t})$  refers to the same model as the Equ. (1) of the original article.

$$h_{u,k}(\mu_{n_t}) = \sum_{l=1}^L \alpha_l \mathbf{f}_{\text{rx},l}^T \mathbf{T}_l \mathbf{f}_{\text{tx},l}^{n_t} e^{j\varphi_{k,l}^{n_t}}. \quad (1)$$

## II. EMR DOMAIN PRECODING ALGORITHM

The **Algorithm 1** in the original article only gives a literal description of EMR domain precoding procedure, a more rigorous pseudo-code description of this algorithm is given below. The spectral efficiency (SE) is also calculated as Equ. (2).

$$R = \frac{1}{K} \sum_{u=1}^U \sum_{k=1}^K \log \left( 1 + \frac{|\mathbf{h}_{u,k}^H(\boldsymbol{\mu}) \mathbf{F}_{\text{RF}} \mathbf{f}_{u,k}|^2}{\sum_{j \neq u} |\mathbf{h}_{u,k}^H(\boldsymbol{\mu}) \mathbf{F}_{\text{RF}} \mathbf{f}_{j,k}|^2 + \sigma_n^2} \right), \quad (2)$$

## REFERENCES

- [1] 3GPP, “Study on channel model for frequencies from 0.5 to 100 GHz,” 3rd Generation Partnership Project (3GPP), Technical Report (TR) 38.901, 05 2017, version 14.0.0.

TABLE I  
CHANNEL MODEL FOR R-MMIMO SYSTEMS

General channel model	$H_{n_r, n_t}(t, \tau; \nu_{n_r}, \mu_{n_t}) = \sum_{l=1}^L \alpha_l \mathbf{f}_{\text{rx}, n_r}^T(\theta_{r,l}, \phi_{r,l}; \nu_{n_r}) \mathbf{T}_l \mathbf{f}_{\text{tx}, n_t}(\theta_{t,l}, \phi_{t,l}; \mu_{n_t}) \exp\left(\frac{j2\pi(\mathbf{r}_{\text{rx}, l}^T \mathbf{d}_{\text{tx}, n_r})}{\lambda}\right) \\ \times \exp\left(\frac{j2\pi(\mathbf{r}_{\text{tx}, l}^T \mathbf{d}_{\text{tx}, n_t})}{\lambda}\right) \exp\left(\frac{j2\pi(\mathbf{r}_{\text{tx}, l}^T \mathbf{v})}{\lambda} t\right) \delta(\tau - \tau_l)$		
Degraded channel model	$h_{n_t}(t, k; \mu_{n_t}) = \sum_{l=1}^L \alpha_l \mathbf{f}_{\text{rx}}^T(\theta_{r,l}, \phi_{r,l}) \mathbf{T}_l \mathbf{f}_{\text{tx}, n_t}(\theta_{t,l}, \phi_{t,l}; \mu_{n_t}) \exp\left(\frac{j2\pi(\mathbf{r}_{\text{rx}, l}^T \mathbf{d}_{\text{rx}})}{\lambda}\right) \\ \times \exp\left(\frac{j2\pi(\mathbf{r}_{\text{tx}, l}^T \mathbf{d}_{\text{tx}, n_t})}{\lambda}\right) \exp\left(\frac{j2\pi(\mathbf{r}_{\text{tx}, l}^T \mathbf{v})}{\lambda} t\right) \exp(j2\pi\tau_l(-\frac{B_w}{2} + \frac{B_w k}{K}))$		
Parameter	Definition	Parameter	Definition
$\alpha_l$	Channel gain for $l$ -th path	$\lambda$	Wavelength
$L$	Total number of paths	$\tau_l$	Channel delay for $l$ -th path
$\mathbf{T}_l$	Polarization coupling matrix for $l$ -th path	$\mathbf{v}$	UE velocity vector
$(\theta_{r,l}, \phi_{r,l})$	Elevation/azimuth angle for $l$ -th arrival path	$(\theta_{t,l}, \phi_{t,l})$	Elevation/azimuth angle for $l$ -th departure path
$\nu_{n_r}$	Pattern type for $n_r$ -th receive antenna	$\mu_{n_t}$	Pattern type for $n_t$ -th transmit antenna
$\mathbf{f}_{\text{rx}, n_r}(\theta_{r,l}, \phi_{r,l}; \nu_{n_r})$	Radiation pattern of $n_r$ -th receive antenna	$\mathbf{f}_{\text{tx}, n_t}(\theta_{t,l}, \phi_{t,l}; \mu_{n_t})$	Radiation pattern of $n_t$ -th transmit antenna
$\mathbf{r}_{\text{rx}, l}$	Spherical unit vector for $l$ -th arrival path	$\mathbf{r}_{\text{tx}, l}$	Spherical unit vector for $l$ -th departure path
$\mathbf{d}_{\text{rx}, n_r}$	Location vector of $n_r$ -th receive antenna	$\mathbf{d}_{\text{tx}, n_t}$	Location vector of $n_t$ -th transmit antenna
$B_w$	System bandwidth	$K$	Total number of subcarriers

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**Algorithm 1:** EMR domain precoding algorithm

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**Input:** CSI  $\mathbf{h}_{u,k}(\boldsymbol{\mu})$ ,  $\forall u, k, \boldsymbol{\mu}$ ;

**Output:** EMR domain precoding vector  $\boldsymbol{\mu}^*$ ;

1 **Initialization:**  $\boldsymbol{\mu}^0 = \mathbf{0}_{N_t}$ ;

2 **for**  $i = 1 : T_{\text{iter}}$  **do**

3     **for**  $n_t = 1 : N_t$  **do**

4         **for**  $p = 0 : P - 1$  **do**

5              $\tilde{\boldsymbol{\mu}} = \{\mu_l = \mu_l^i, l < n_t, \mu_{n_t} = \bar{\mu}_p, \mu_m = \mu_m^{i-1}, m > n_t\}$ ;

6             Apply HP to CSI  $\mathbf{h}_{u,k}(\tilde{\boldsymbol{\mu}})$ ,  $\forall u, k$ , and calculate SE value

$R_p = R(\mathbf{h}_{u,k}(\tilde{\boldsymbol{\mu}}), \forall u, k)$  according to Equ. (2);

7             **end**

8              $p^* = \arg \max_{0 \leq p \leq P-1} R_p$ ;

9              $\mu_{n_t}^i = \bar{\mu}_{p^*}$ ;

10         **end**

11 **end**

12 **return**  $\boldsymbol{\mu}^* = \boldsymbol{\mu}^{T_{\text{iter}}}$ .

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