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 μ_{n_t}-th radiation pattern and the n_r-th receive antenna adopts ν_{n_r}-th radiation pattern, respectively, then the time-delay (t,τ) domain 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 [1]. 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 $h_{n_t}\left(t,k;\mu_{n_t}\right)$ in Table I.

II. EMR domain precoding algorithm

The **EMR domain precoding algorithm** in the original article only gives a literal description, a more rigorous pseudo-code description of this algorithm is given below. The spectral efficiency (SE) is calculated as Equ. (1). Here, u and k are indexes for UE and subcarrier, respectively. $\boldsymbol{F}_{RF} \in \mathbb{C}^{N_t \times M_t}$ is the analog precoder, and $\boldsymbol{f}_{u,k} \in \mathbb{C}^{M_t}$ is the digital precoder. Besides, the n_t-th element of $\boldsymbol{h}_u^{\mathrm{H}}\left(t,k;\boldsymbol{\mu}\right)$ is generated by $h\left(t,k;\mu_{n_t}\right)$ from Table I.

$$R=\frac{1}{K}\sum_{u=1}^{U}\sum_{k=1}^{K}\log\left(1+\frac{|\boldsymbol{h}_u^{\mathrm{H}}\left(t,k;\boldsymbol{\mu}\right)\boldsymbol{F}_{\mathrm{RF}}\boldsymbol{f}_{u,k}|^2}{\sum\limits_{j\neq u}^{U}|\boldsymbol{h}_u^{H}\left(t,k;\boldsymbol{\mu}\right)\boldsymbol{F}_{\mathrm{RF}}\boldsymbol{f}_{j,k}|^2+\sigma_n^2}\right), \tag{1}$$

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	$H_{n_r,n_t}(t,\tau;\nu_{n_r},\mu_{n_t}) = \sum_{l=1}^{L} \alpha_l \boldsymbol{f}_{\mathrm{rx},n_r}^{\mathrm{T}}(\theta_{r,l},\phi_{r,l};\nu_{n_r}) \boldsymbol{T}_l \boldsymbol{f}_{\mathrm{tx},n_t}(\theta_{t,l},\phi_{t,l};\mu_{n_t}) \exp\left(\frac{\mathrm{j}2\pi\left(\boldsymbol{r}_{\mathrm{rx},l}^{\mathrm{T}}\boldsymbol{d}_{\mathrm{rx},n_r}\right)}{\lambda}\right)$ $\times \exp\left(\frac{\mathrm{j}2\pi\left(\boldsymbol{r}_{\mathrm{tx},l}^{\mathrm{T}}\boldsymbol{d}_{\mathrm{tx},n_t}\right)}{\lambda}\right) \exp\left(\frac{\mathrm{j}2\pi\left(\boldsymbol{r}_{\mathrm{rx},l}^{\mathrm{T}}\boldsymbol{v}\right)}{\lambda}t\right) \delta\left(\tau-\tau_l\right)$
Degraded channel model	$h_{n_t}(t,k;\mu_{n_t}) = \sum_{l=1}^{L} \alpha_l \boldsymbol{f}_{\mathrm{rx}}^{\mathrm{T}}(\theta_{r,l},\phi_{r,l}) \boldsymbol{T}_l \boldsymbol{f}_{\mathrm{tx},n_t}(\theta_{t,l},\phi_{t,l};\mu_{n_t}) \exp\left(\frac{\mathrm{j}2\pi\left(\boldsymbol{r}_{\mathrm{rx},l}^{\mathrm{T}}\boldsymbol{d}_{\mathrm{rx}}\right)}{\lambda}\right)$ $\times \exp\left(\frac{\mathrm{j}2\pi\left(\boldsymbol{r}_{\mathrm{tx},l}^{\mathrm{T}}\boldsymbol{d}_{\mathrm{tx},n_t}\right)}{\lambda}\right) \exp\left(\frac{\mathrm{j}2\pi\left(\boldsymbol{r}_{\mathrm{rx},l}^{\mathrm{T}}\boldsymbol{v}\right)}{\lambda}t\right) \exp\left(\mathrm{j}2\pi\tau_l\left(-\frac{B_w}{2}+\frac{B_w k}{K}\right)\right)$

Parameter	Definition	Parameter	Definition
α_l	Channel gain for l-th path	λ	Wavelength
L	Total number of paths	τ_l	Channel delay for l-th path
$\boldsymbol{T}_l$	Polarization coupling matrix for l-th path	$\boldsymbol{v}$	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
ν_{n_r}	Pattern type for n_r-th receive antenna	μ_{n_t}	Pattern type for n_t-th transmit antenna
$\boldsymbol{f}_{\mathrm{rx},n_r}(\theta_{r,l},\phi_{r,l};\nu_{n_r})$	Radiation pattern of n_r-th receive antenna	$\boldsymbol{f}_{\mathrm{tx},n_t}(\theta_{t,l},\phi_{t,l};\mu_{n_t})$	Radiation pattern of n_t-th transmit antenna
$\boldsymbol{r}_{\mathrm{rx},l}$	Spherical unit vector for l-th arrival path	$\boldsymbol{r}_{\mathrm{tx},l}$	Spherical unit vector for l-th departure path
$\boldsymbol{d}_{\mathrm{rx},n_r}$	Location vector of n_r-th receive antenna	$\boldsymbol{d}_{\mathrm{tx},n_t}$	Location vector of n_t-th transmit antenna
B_w	System bandwidth	K	Total number of subcarriers

Algorithm 1: EMR domain precoding algorithm

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

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

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

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

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

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

      $\widetilde{\boldsymbol{\mu}} = \left\{\mu_l = \mu_l^i, l < n_t, \mu_{n_t} = \bar{\mu}_p, \quad \mu_m = \mu_m^{i-1}, m > n_t\right\}$;

      Apply HP to CSI $\boldsymbol{h}_{u,k}\left(\widetilde{\boldsymbol{\mu}}\right), \forall u,k$, and calculate SE value $R_p = R\left(\boldsymbol{h}_{u,k}\left(\widetilde{\boldsymbol{\mu}}\right), \forall u,k\right)$ according to Equ. (2);

    end

    $p^{\star} = \arg\max_{0\le p\le P-1} R_p$;

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

  end

end

return $\boldsymbol{\mu}^{\star} = \boldsymbol{\mu}^{T_{iter}}$.