EMF-Aware Design of Cellular Networks with Reconfigurable Intelligent Surfaces

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EMF Exposure

- Concerns about EMF exposure were raised recently due to:
  - The electromagnetic spectrum is already congested.
  - 5G Networks depends on dense deployment of base stations.
    - Although the exposure is dominated in the uplink.
  - There is no clear evidence of the EMF harness from cellular networks.
  - As a precautionary action, Cellular networks EMF is considered as Possibly carcinogenic *(Group 2B) according to* International Agency on Research on Cancer

Reconfigurable Intelligent Surface (RIS)

- What is it?
  - A surface a surface that is segmented to form a grid of discrete elements.
  - Each element can reflect the incident electromagnetic wave to a certain direction (generalized Snell's law).
  - A phase shift can be induced on the signal.
  - This surface is controlled by the base station (BS).

Applications

- Main purpose of the RIS:
  - Overcome the line of sight (LOS) problem in mm Waves.

- Other applications of the RIS include:
  - Energy efficiency maximization.
  - Sum rate maximization.
  - Localization using RIS.

- In this work, RIS is used to minimize the EMF exposure.

Our Contribution

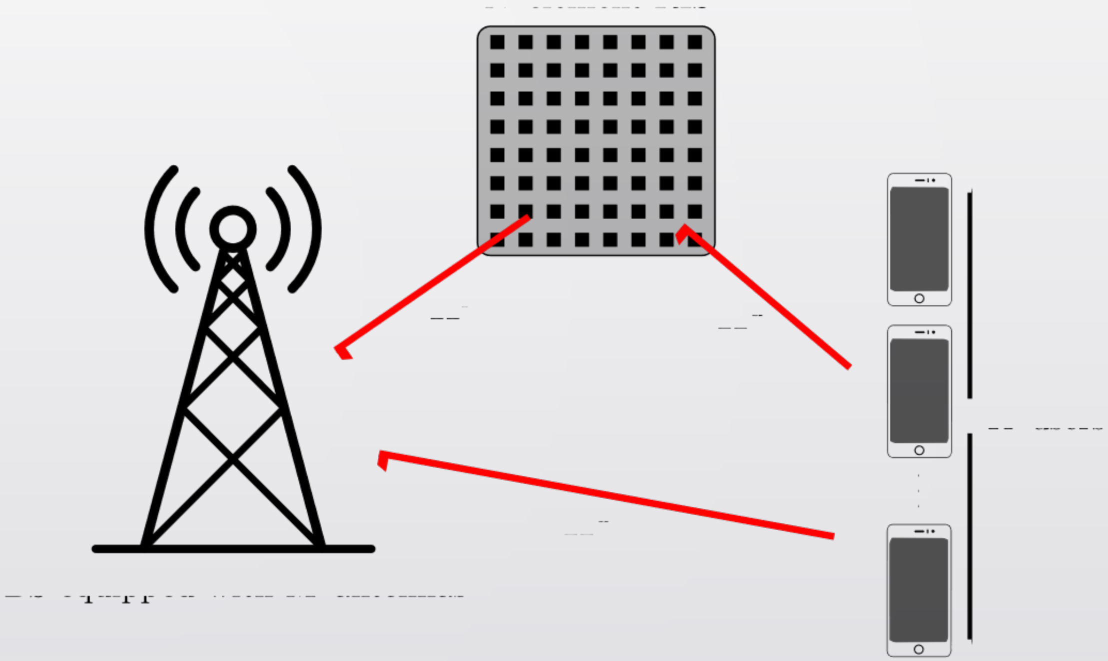
- We develop a dual gradient descent algorithm for the joint design of the RIS phases and the BS beamformer.
- We adopt a general model:
  - The direct bath is included in the model.
  - Each user may have a different reference exposure metric.
- The gradient, Hessian matrix, and the suboptimal step size are derived in closed-form.

System Model

- The received signal at the BS for a MISO system can be represented as:

$$\boldsymbol{y} = (\mathbf{H}^{\mathrm{r}}\boldsymbol{\Phi}(\boldsymbol{\theta})\mathbf{H}^{\mathrm{u}} + \mathbf{H}^{\mathbf{d}})\,\mathbf{x} + \mathbf{n},$$

where $\mathbf{x}\,\epsilon\,\mathbb{C}^{k\times 1}$ represents users' transmitted signal, $\mathbf{H}^{\mathrm{u}}\,\epsilon\,\mathbb{C}^{N\times k}$, $\mathbf{H}^{\mathrm{r}}\epsilon\,\mathbb{C}^{M\times N}$ and $\mathbf{H}^{\mathbf{d}}\,\epsilon\,\mathbb{C}^{K\times M}$ represent the channel between (users and the RIS), (RIS and BS) and (users and the BS), respectively. $\boldsymbol{\Phi}(\boldsymbol{\theta})$ is a diagonal matrix where $\Phi_{i,i} \triangleq e^{j\theta_i}$ represents the phase shift induced by the i^{th} element. Finally, $\mathbf{n}\,\epsilon\,\mathbb{C}^{M\times 1}$ is the AWGN noise at the BS with zero mean and σ^2 varience.



Exposure Index (EI)

- The EMF exposure can be quantified using the exposure index which is defined as

$$EI(\boldsymbol{\theta}) \triangleq \sum_{k=1}^{K} SAR_k = \sum_{k=1}^{K} SAR_k^{\mathrm{ref}} p_k \; [W/Kg].$$

Specific Absorption Rate (SAR) represents the absorbed power for a unit of mass.

- SAR_k^{ref} is user k’s SAR when the transmitted power is unity.

Optimization Problem

$$\underset{\boldsymbol{p},\boldsymbol{\theta},\boldsymbol{G}}{\text{minimize}}\ EI(\boldsymbol{p}),$$

s.t.

$$r_k(\boldsymbol{\theta},\mathbf{G},\boldsymbol{p})\ \triangleq \log_2(1+SNIR_k) \geq r_k^{\text{th}} \qquad \forall\ k$$

$$p_k < p_{max} \quad \forall\ k$$

where $r_k(\boldsymbol{\theta},\mathbf{G})$ in bits/Hz is the actual spectral efficiency for user k and r_k^{th} is the minimum spectral efficiency required by user k.

Problem Reduction

- First, we design the receiver beamformer in such a way that it eliminates the cross interference (Zero Forcing beamformer) which is represented as

$$\mathbf{G}(\boldsymbol{\theta}) = \left(\mathbf{H}^{\mathrm{r}}\boldsymbol{\Phi}(\boldsymbol{\theta})\mathbf{H}^{\mathrm{u}} + \mathbf{H}^{\mathbf{d}}\right)^{+}.$$

- Since the objective function is monotonically increasing in the users' power, the optimal power allocation strategy is such that the data rate constraint holds with equality. p_k can be represented as

$$p_k(\boldsymbol{\theta}) = \left(2^{r_k^{\mathrm{th}}} - 1\right)\sigma^2\left\|g_{(k)}\right\|^2.$$

The Reduced Optimization Problem

After making $\mathbf{G}$ and $\boldsymbol{p}$ as variables of $\boldsymbol{\theta}$, $\boldsymbol{\theta}$ becomes the only optimization variable to consider. Therefore, we can rewrite our problem as

$$\underset{\boldsymbol{\theta}}{\text{minimize}} \sum_{k=1}^{K} SAR_k^{\text{ref}}\, p_k(\boldsymbol{\theta}),$$

s.t.

$$p_k(\boldsymbol{\theta}) < p_{max}.$$

The Lagrangian

- The Lagrangian of our problem can be written as

$$\mathcal{L}(\boldsymbol{\theta}, \boldsymbol{\lambda}) = EI(\boldsymbol{\theta}) + \lambda^T(\boldsymbol{p}(\boldsymbol{\theta}) - p_{max}),$$

where $\boldsymbol{\lambda} \in \mathbb{R}^{K\times 1}$ represents the KKT multipliers of the Lagrangian

- The optimal point must be a saddle point within the Lagrangian according to the KKT conditions.

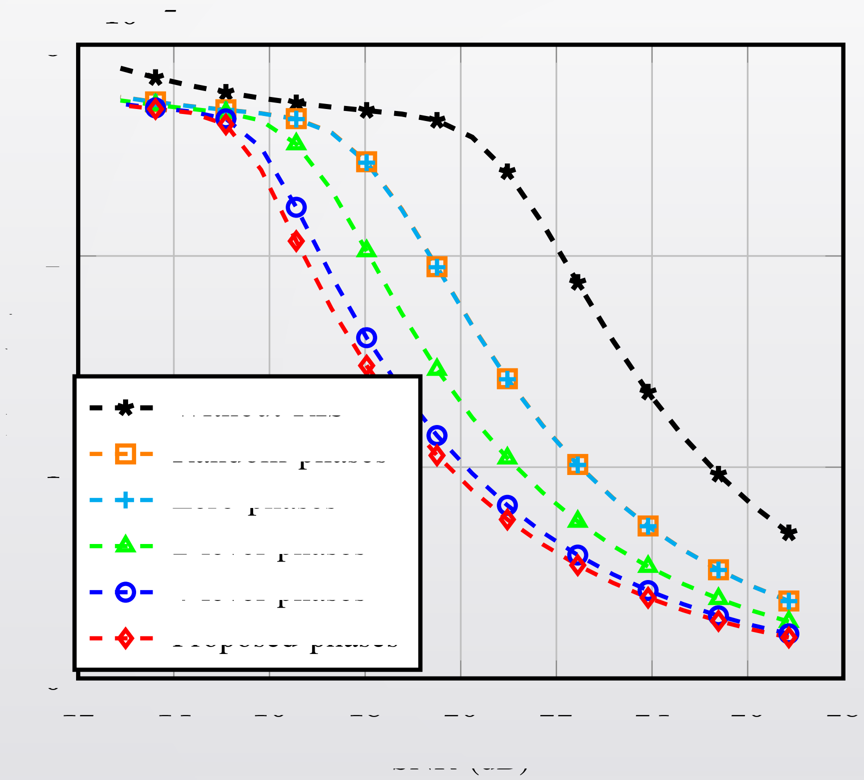
Dual Gradient Descent Algorithm

- One way to find the saddle point in the Lagrangian we apply the dual gradient descent algorithm as follows

$$\boldsymbol{\theta}^{(t)} \leftarrow \boldsymbol{\theta}^{(t-1)} - \alpha_\theta \nabla_{\boldsymbol{\theta}} \mathcal{L}\left(\boldsymbol{\theta}^{(t-1)}, \boldsymbol{\lambda}^{(t-1)}\right),$$

$$\boldsymbol{\lambda}^{(t)} \leftarrow \boldsymbol{\lambda}^{(t-1)} + \alpha_\lambda \nabla_{\boldsymbol{\lambda}} \mathcal{L}\left(\boldsymbol{\theta}^{(t)}, \boldsymbol{\lambda}^{(t-1)}\right).$$

Proposed Algorithm Performance



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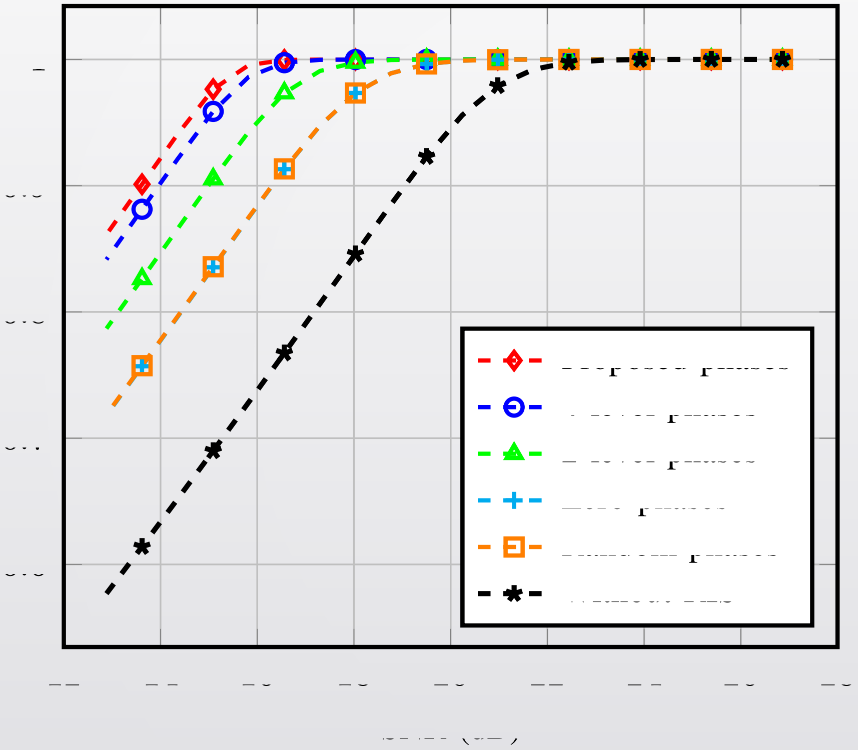

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Thank you