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Efficient Techniques for Broadcast of System Information in mmWave Communication Systems

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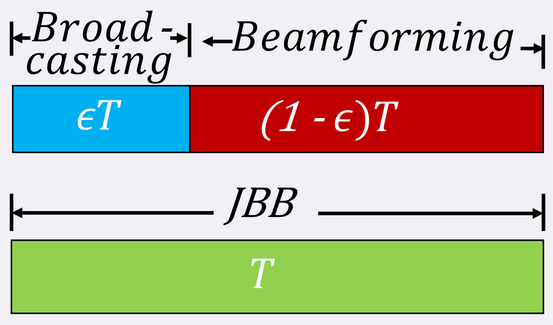
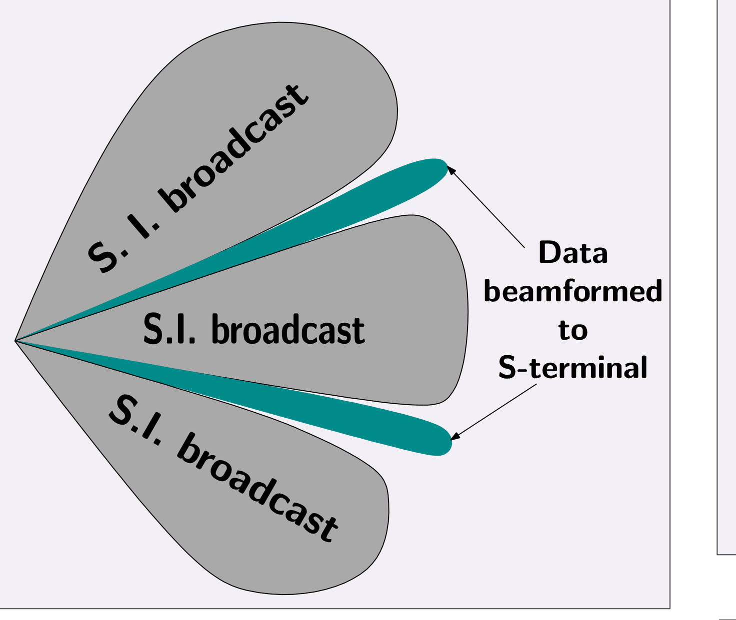
Introduction



- Traditional way of broadcasting S.I.
- S.I.: Overhead, e.g. MIB in LTE has a 3% overhead for a system b.w. of 1.08 MHz.
- Non-orthogonal Broadcast Strategy:
- Advantage of massive MIMO:

Large antenna array and a few scheduled terminals (S.T.'s) $\Rightarrow$ Broadcast S.I. in the high dimensional null space of the channel matrix to S.T.'s.



System Model

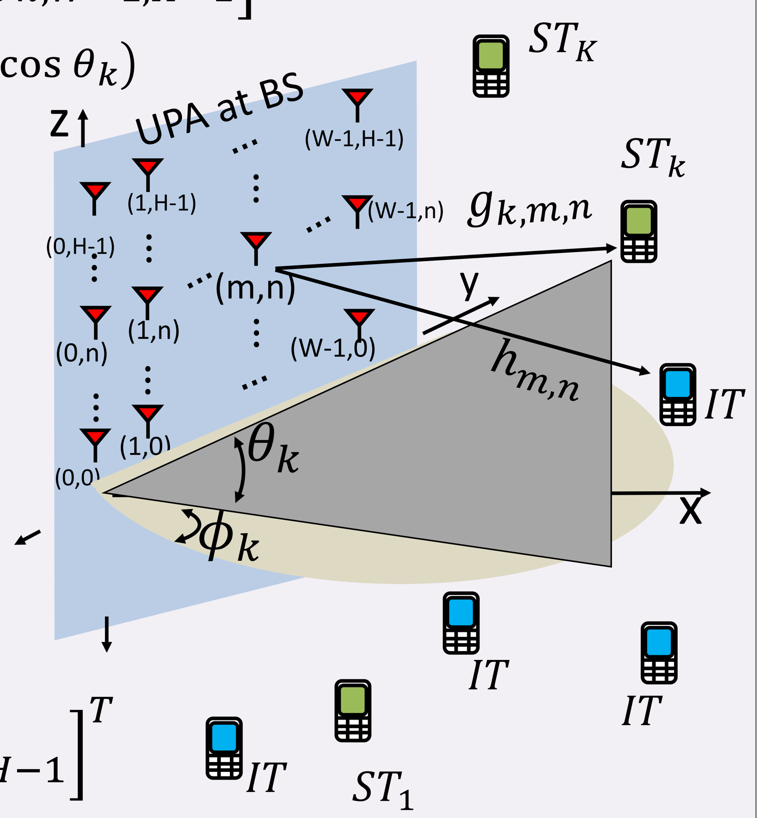
- mmWave LOS channels having only one strong path
- Channel gain from BS to k^{th} S-terminal:

$$\mathbf{g}_k \triangleq \left[g_{k,0,0}, \dots, g_{k,W-1,0}, \dots, g_{k,0,H-1}, \dots, g_{k,W-1,H-1}\right]^T$$

$$g_{k,m,n} = \sqrt{\beta_k} e^{j\alpha_k} e^{j\frac{2\pi d}{\lambda}(m \sin\phi_k \sin\theta_k + n\cos\theta_k)}$$

- The channel matrix from BS to all the K S.T.'s

$$\mathbf{G} = [\mathbf{g}_1, \mathbf{g}_2, \dots, \mathbf{g}_K]^T$$



- Channel gain from BS to an I-terminal

$$\mathbf{h} \triangleq \left[h_{0,0}, \dots, h_{W-1,0}, \dots, h_{0,H-1}, \dots, h_{W-1,H-1}\right]^T$$

$$h_{m,n} = \sqrt{\beta_I} e^{j\alpha_I} e^{j\frac{2\pi d}{\lambda}(m \sin\phi_I \sin\theta_I + n\cos\theta_I)}$$

- **Assumption:** Perfect CSI at BS for the channel to S-terminals and no CSI for the channels to the I-terminals.

Non-orthogonal Broadcast Strategy (NoBS)

- The vector transmitted from the BS on the t^{th} DOF:

$$\mathbf{x}(t) = \underbrace{\sqrt{p_b}\sum_{k=1}^{K} \mathbf{v}_k^* s_k(t)}_{\text{Information beamformed to to S-terminals}} + \underbrace{\sqrt{p_I}\,\mathbf{U}\mathbf{q}(t)}_{\text{S.I. broadcast to I-terminals}}$$

- Total transmit power $P_T \triangleq p_b + p_I$
- $\mathbf{U} \in \mathbb{C}^{\mathrm{M}\times\mathrm{M}'}$ is chosen s.t. $\mathbf{G}\mathbf{U} = \mathbf{0}$ and $\mathbf{U}^H\mathbf{U} = \mathbf{I}$, $M' \le M - K$
- The signal received at the k^{th} S-terminal and an I terminal:

$$y_k(t) = \sqrt{p_b}\sum_{i=1}^{K} \mathbf{g}_k^T \mathbf{v}_i^* s_i(t) + n_k(t)$$

$$y_I(t) = \sqrt{p_I}\mathbf{h}^T\mathbf{U}\mathbf{q}(t) + \sqrt{p_b}\sum_{k=1}^{K} \mathbf{h}^T \mathbf{v}_k^* s_k(t) + w_I(t)$$

- The MR and ZF beamforming vectors:

$$\mathbf{v}_k^{MR} \triangleq \sqrt{\frac{\eta_k^{MR}}{M\beta_K}}\mathbf{g}_k, \qquad \mathbf{v}_k^{ZF} \triangleq \sqrt{\eta_k^{ZF} M\beta_K}\left[\mathbf{G}^T\left(\mathbf{G}^*\mathbf{G}^T\right)^{-1}\right]_{:,k}$$

- The per-DOF information rate to the k^{th} S-terminal and an I-terminal:

$$r_k = \log_2\left(1 + \frac{p_b\left|\mathbf{g}_k^T\mathbf{v}_k^*\right|^2}{\sigma^2 + p_b\sum_{i=1,i\neq k}^{K}\left|\mathbf{g}_k^T\mathbf{v}_i^*\right|^2}\right)$$

$$r_I \triangleq I(y_I(t);\mathbf{q}(t)) = \log_2[1 + (p_I\|\mathbf{h}^T\mathbf{U}\|^2/M'\sigma_I^2)]$$

where σ_I^2 is the variance of overall interference and noise at I-terminal.

Orthogonal Broadcast Strategy (OBS)

- In OBS a fraction $0 < \epsilon < 1$ of total DOF's is reserved for broadcast of S.I.
- The per-DoF information rate to the k^{th} S-terminal and an I-terminal:

$$r_k' = (1-\epsilon)\log_2\left(1 + \frac{p_b'\left|\mathbf{g}_k^T\mathbf{v}_k^*\right|^2}{\sigma^2 + p_b'\sum_{i=1,i\neq k}^{K}\left|\mathbf{g}_k^T\mathbf{v}_i^*\right|^2}\right)$$

$$r_I' = \epsilon\log_2\left(1 + p_I'\|\mathbf{h}^T\mathbf{U}\|^2/M'\sigma^2\right)$$

- Total average transmit power in OBS: $P_T' \triangleq \epsilon p_I' + (1-\epsilon)p_b'$.

Asymptotic Performance Analysis $(\mathbf{W} \to \infty, \mathbf{H} \to \infty)$

- **Theorem 1:** For fixed $0 < \epsilon < 1$, a fixed per-DOF information rate $r_k = R^\infty$, $k = 1, \dots, K$ to each S-terminal and a fixed rate R_I^∞ to an I-terminal, the ratio of the required total transmit power for OBS to that for NoBS is asymptotically ($(W,H) \to \infty$) given by

$$\mu(\epsilon, R_I^\infty) \triangleq \lim_{(W,H)\to\infty}\frac{P_T'}{P_T} = \epsilon\left(2^{R_I^\infty/\epsilon} - 1\right)/\left(2^{R_I^\infty} - 1\right)$$

- Further, the asymptotic expression is a good approximation for this ratio for sufficiently large M, i.e.

$$M \gg \sum_{i=1}^{K}\frac{\beta_I}{\beta_i}\max\left[\frac{2^{R^\infty} - 1}{2^{R_I^\infty} - 1}, \frac{(1-\epsilon)\left(2^{R^\infty/(1-\epsilon)} - 1\right)}{\epsilon\left(2^{R_I^\infty/\epsilon} - 1\right)}\right]$$

- **Corollary 1:** For any $R_I^\infty > 0$ and $0 < \epsilon < 1$, the asymptotic ratio $\mu(\epsilon, R_I^\infty)$ is always greater than one, i.e.,

$$\mu(\epsilon, R_I^\infty) > 1$$

- Further, for a fixed $R_I^\infty > 0$, $\mu(\epsilon, R_I^\infty)$ increases monotonically with decreasing ϵ, i.e.,

$$\partial\mu(\epsilon, R_I^\infty)/\partial\epsilon < 0$$

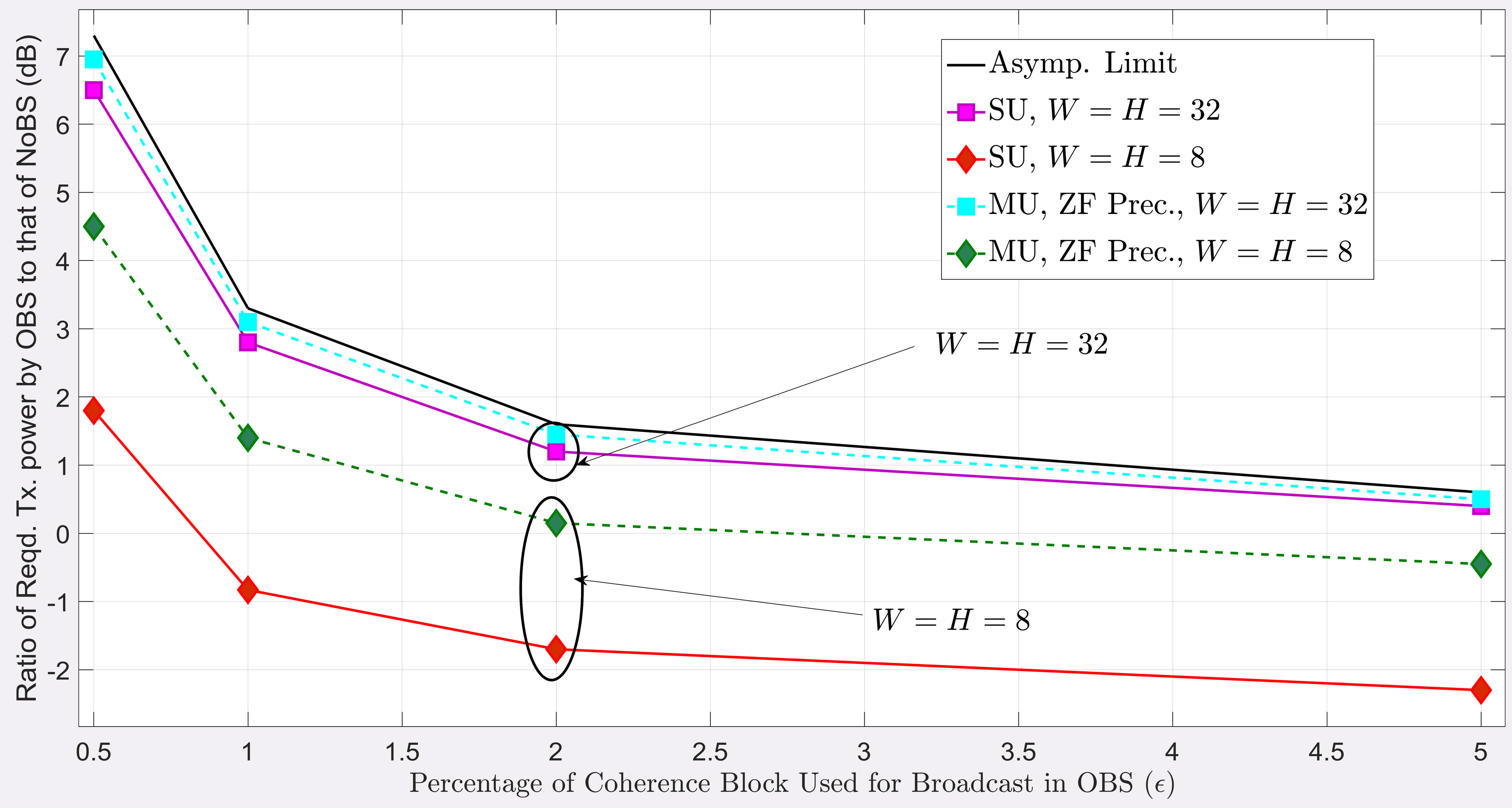
Simulation Parameters

- Antenna spacing in the BS, $d = \lambda/2$, $M' = 8$.
- I-terminal: $\beta_I = 1$ and $(\phi_I, \theta_I) = (85°, 40°)$, $r_I^{des} = 0.02$ bits/DOF.

Single User:
- $\beta_1 = 1$
- $(\phi_1, \theta_1) = (90°, 45°)$
- $r_1^{des} = 2$ bits/DOF.

Multi User:
- $\beta_k = 1, k = 1, \dots, 4$
- $(\phi_1, \theta_1) = (90°, 45°)$, $(\phi_2, \theta_2) = (60°, 30°)$, $(\phi_3, \theta_3) = (22.5°, 60°)$, $(\phi_4, \theta_4) = (15°, 15°)$
- $r_k^{des} = 0.5$ bits/DOF for each k.

Simulation Results



Future Work

- Effect of channel estimation error.
- Consideration of NLOS scenario.

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