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# Near-field secure wireless communication with delay alignment modulation

**Key words:** Near-field; Nonuniform spherical wave (NUSW); Delay alignment modulation (DAM); Inter-symbol interference (ISI) free communication; Physical layer security; Secrecy rate



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# Motivation

- Existing artificial noise (AN) based physical layer security
  - ➢ Sacrificing part of the power for transmitting the AN
- Delay alignment modulation (DAM)
  - ➢ Inter-symbol interference (ISI) elimination at the desired receiver
  - ➢ Introducing ISI to other locations with different spatial signatures from the receiver
  - ➢ Such an ISI may play the role as the AN, without sacrificing the transmit power

# Main idea

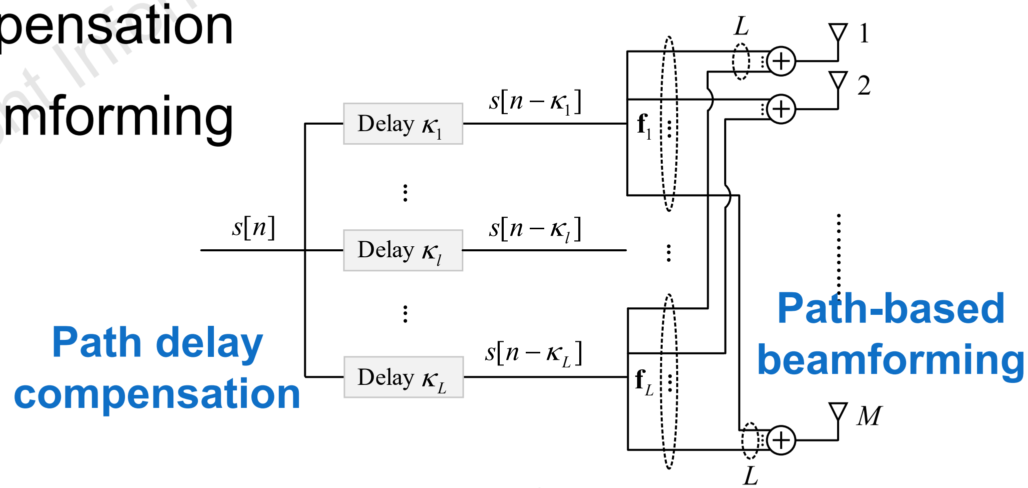
- Emerging trends for sixth-generation (6G) wireless network

  XL-MIMO: super spatial resolution

  - ➢ Millimeter wave and terahertz channels: multi-path sparsity
  - ➢ Integrated localization, sensing and communication (ILSAC): multi-path resolvability

- Key idea of DAM

  - ➢ Path delay compensation
  - ➢ Path-based beamforming




Transmitter architecture for delay alignment modulation

# Main idea

- Path-based maximal-ratio transmission (MRT) beamforming
  - Asymptotically orthogonal property for the asymptotic case
  - ISI-free and information-leakage-free communication
- Path-based zero-forcing (ZF) beamforming
  - Designing ZF beamforming to eliminate the ISI at Bob
  - ISI-free communication
- Path-based optimized beamforming
  - Maximizing the secrecy rate via the successive convex approximation (SCA) technique

# Method

When $M >> L_B$ and $M >> L_E$

$$\frac{\boldsymbol{h}_{\mathrm{B},l}^{\mathrm{H}}\boldsymbol{h}_{\mathrm{B},l'}}{\|\boldsymbol{h}_{\mathrm{B},l}\|\,\|\boldsymbol{h}_{\mathrm{B},l'}\|} \to 0,\ \forall l \neq l',$$

$$\frac{\boldsymbol{h}_{\mathrm{E},l}^{\mathrm{H}}\boldsymbol{h}_{\mathrm{E},l'}}{\|\boldsymbol{h}_{\mathrm{E},l}\|\,\|\boldsymbol{h}_{\mathrm{E},l'}\|} \to 0,\ \forall l \neq l',$$

$$\frac{\boldsymbol{h}_{\mathrm{B},l}^{\mathrm{H}}\boldsymbol{h}_{\mathrm{E},l'}}{\|\boldsymbol{h}_{\mathrm{B},l}\|\,\|\boldsymbol{h}_{\mathrm{E},l'}\|} \to 0.$$

- Near-field channel vectors tend to be asymptotically orthogonal.
- Ease the requirement that different channel vectors have distinct angles of departure (AoDs) in the far-field region.

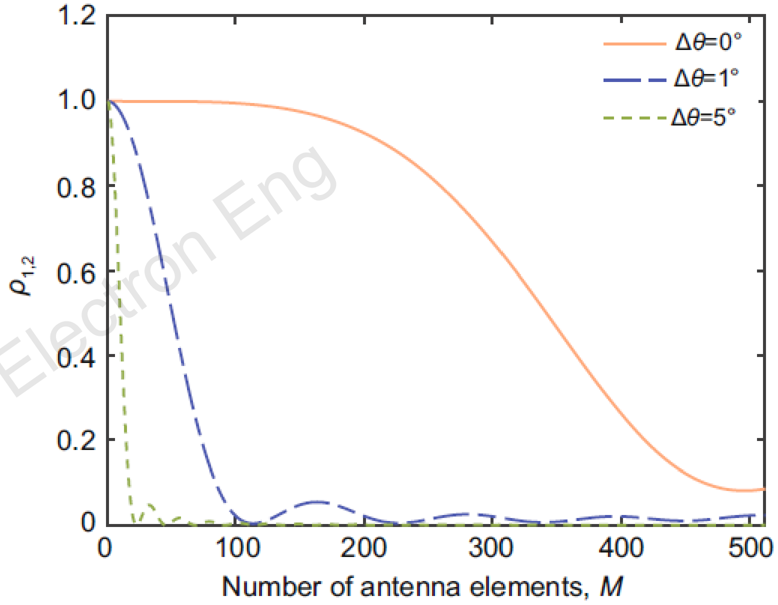



**Fig. 2** Absolute square of the normalized inner product for two near-field channel vectors, where $(r_1, \theta_1) = (30\ \mathrm{m}, 0^\circ)$ and $(r_2, \theta_2) = (45\ \mathrm{m}, \theta_1 + \Delta\theta)$

$$y_{\mathrm{B}}[n] \to \left(\sum_{l=1}^{L_{\mathrm{B}}} \sqrt{p_l}\,\|\boldsymbol{h}_{\mathrm{B},l}\|\right) s[n - n_{\mathrm{B,max}}] + z_{\mathrm{B}}[n]$$

$$y_{\mathrm{E}}[n] \to z_{\mathrm{E}}[n]$$

**ISI-free and information-leakage-free communication**

# Method

- **Path-based ZF beamforming toward ISI-free communication**

$$y_{\mathrm{B}}[n] = \underbrace{\left(\sum_{l=1}^{L_{\mathrm{B}}} \boldsymbol{h}_{\mathrm{B},l}^{\mathrm{H}} \boldsymbol{f}_l\right) s\left[n - n_{\mathrm{B,max}}\right]}_{\text{desired signal}} + \underbrace{\sum_{l=1}^{L_{\mathrm{B}}} \sum_{l'=1, l' \neq l}^{L_{\mathrm{B}}} \boxed{\boldsymbol{h}_{\mathrm{B},l}^{\mathrm{H}} \boldsymbol{f}_{l'}} s\left[n - n_{\mathrm{B,max}} + \Delta_{\mathrm{B}l',\mathrm{B}l}\right]}_{\text{ISI}} + z_{\mathrm{B}}[n],$$

$$\boldsymbol{h}_{\mathrm{B},l}^{\mathrm{H}} \boldsymbol{f}_{l'} = 0, \forall l \neq l'$$

$$y_{\mathrm{B}}[n] = \left(\sum_{l=1}^{L_{\mathrm{B}}} \boldsymbol{h}_{\mathrm{B},l}^{\mathrm{H}} \boldsymbol{H}_{\mathrm{B},l}^{\perp} \boldsymbol{b}_l\right) s\left[n - n_{\mathrm{B,max}}\right] + z_{\mathrm{B}}[n]$$

**An ISI-free AWGN channel**

- **Path-based optimized DAM beamforming**

$$\gamma_{\mathrm{B}} = \frac{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{A} \bar{\boldsymbol{f}}}{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{B} \bar{\boldsymbol{f}} + 1}$$

$$\gamma_{\mathrm{E}} = \frac{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{C} \bar{\boldsymbol{f}}}{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{D} \bar{\boldsymbol{f}} + 1}$$

$$\max_{\bar{\boldsymbol{f}}} \left(\log_2\left(1 + \frac{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{A} \bar{\boldsymbol{f}}}{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{B} \bar{\boldsymbol{f}} + 1}\right) - \log_2\left(1 + \frac{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{C} \bar{\boldsymbol{f}}}{\bar{\boldsymbol{f}}^{\mathrm{H}} \boldsymbol{D} \bar{\boldsymbol{f}} + 1}\right)\right)$$
$$\text{s.t. } \left\|\bar{\boldsymbol{f}}\right\|^2 \leq P.$$

**Maximizing the secrecy rate**

# Results

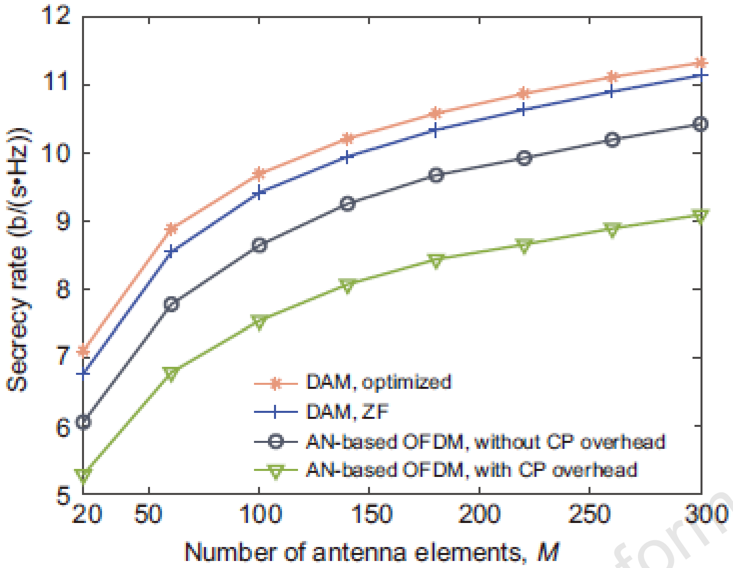



**Fig. 3** Secrecy rate versus the number of antenna elements at Alice

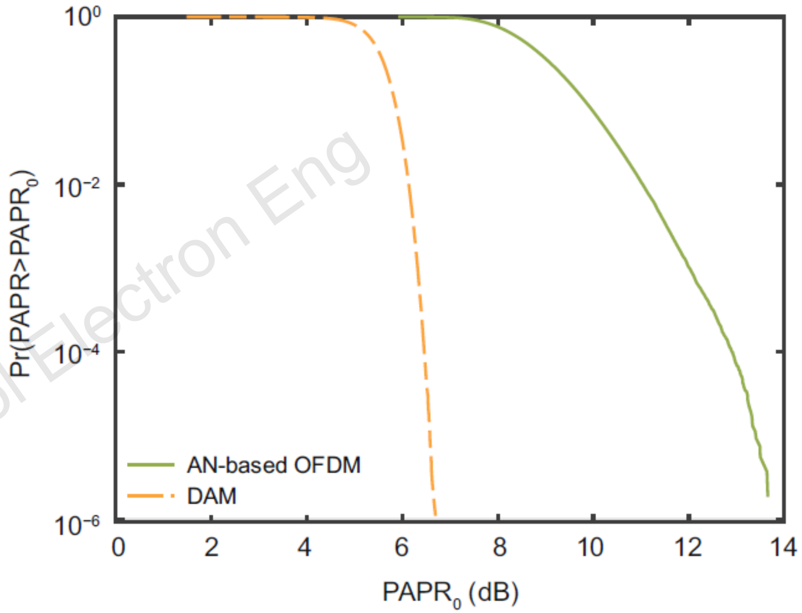



**Fig. 5** Comparison of PAPR for DAM and AN-based OFDM



**Secrecy rate**: DAM outperforms the AN-based OFDM due to the saving of cyclic prefix (CP) overhead and power allocating to the AN.

**PAPR**: Single-carrier DAM achieves a lower PAPR than the AN-based OFDM.

# Conclusions

- We proposed a novel near-field secure communication via DAM.
- By considering the near-field NUSW model, the path-based MRT, ZF, and optimized beamforming schemes were designed.
- Simulation results showed that the proposed DAM yields a better secrecy rate and PAPR performance than the AN-based OFDM scheme.

Haiquan LU received his PhD degree from Southeast University, Nanjing, China, in 2024. His main research interests include intelligent reflecting surface-aided communications and extremely large-scale multiple-input multiple-output (XL-MIMO) communications.

Yong ZENG is a full professor with the National Mobile Communications Research Laboratory, Southeast University, China, and also with the Purple Mountain Laboratories, Nanjing, China. He was listed as Highly Cited Researcher by Clarivate Analytics for six consecutive years (2019–2024). He is the recipient of the Australia Research Council (ARC) Discovery Early Career Researcher Award (DECRA), 2020 & 2024 IEEE Marconi Prize Paper Award in Wireless Communications, 2018 IEEE Communications Society Asia-Pacific Outstanding Young Researcher Award, 2020 & 2017 IEEE Communications Society Heinrich Hertz Prize Paper Award, 2021 IEEE ICC Best Paper Award, and 2021 China Communications Best Paper Award. He has published more than 200 papers, which have been cited more than 29 000 times.