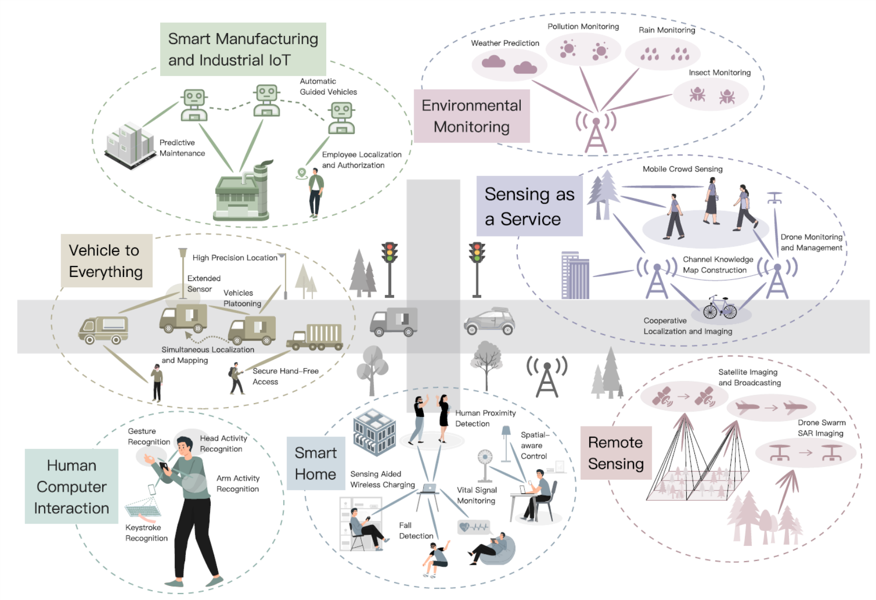
’

Addressing Eavesdropping and Sensing Line-of-Sight Blockage in Integrated Sensing and Communication

Steven Rivetti

Motivation and background

- 6G is expected to bring about an explosive growth in traffic

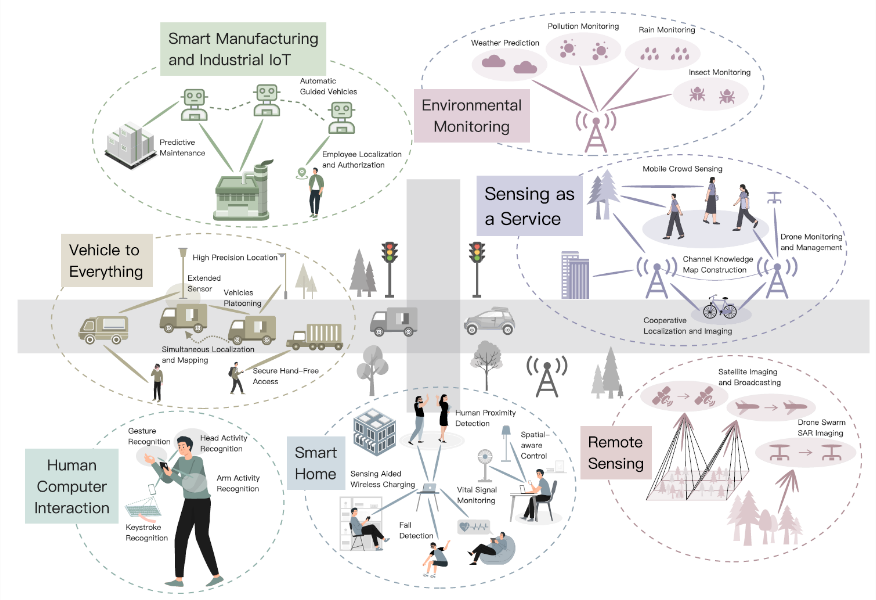


---

0 Figure from . Liu et al., “Integrated sensing and communications: Towards dual-functional wire- less networks for 6g and beyond,” IEEE journal on selected areas in communications, 2022

Motivation and background

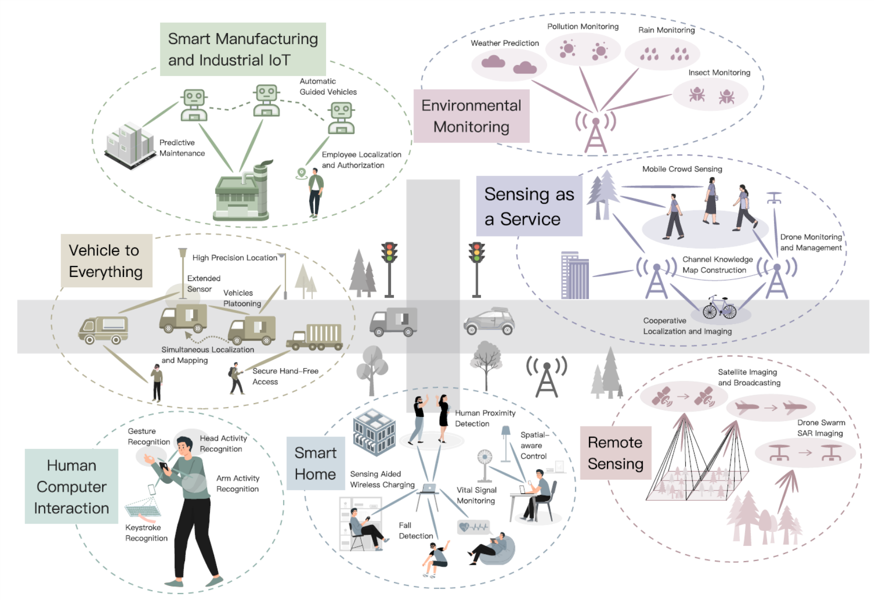
- 6G is expected to bring about an explosive growth in traffic
- higher competition for **scarce** spectrum resources



[0] Figure from . Liu et al., "Integrated sensing and communications: Towards dual-functional wire- less networks for 6g and beyond," IEEE journal on selected areas in communications, 2022

Motivation and background

- 6G is expected to bring about an explosive growth in traffic
- higher competition for **scarce** spectrum resources
- while communication at higher frequencies is being researched, We need to **orchestrate** the network entities



---

0 Figure from . Liu et al., "Integrated sensing and communications: Towards dual-functional wire- less networks for 6g and beyond," IEEE journal on selected areas in communications, 2022

How can ISAC help ?

- **ISAC**: design framework where communication and sensing tasks are **cooperate** rather than **competing** for the network resources

How can ISAC help ?

- **ISAC**: design framework where communication and sensing tasks are **cooperate** rather than **competing** for the network resources
- Massive MIMO brought about Large antenna arrays, with an exponential increase of **spatial resolution** and **beamforming capabilities**

How can ISAC help ?

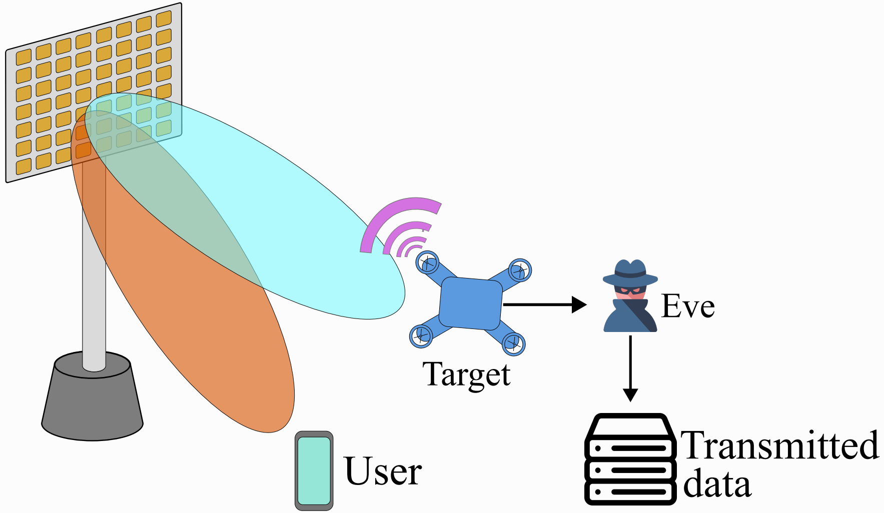
- **ISAC**: design framework where communication and sensing tasks are **cooperate** rather than **competing** for the network resources
- Massive MIMO brought about Large antenna arrays, with an exponential increase of **spatial resolution** and **beamforming capabilities**

↓

A single transceiver could in principle achieve full integration (i.e. wave-form, time, frequency, hardware) between the 2 tasks

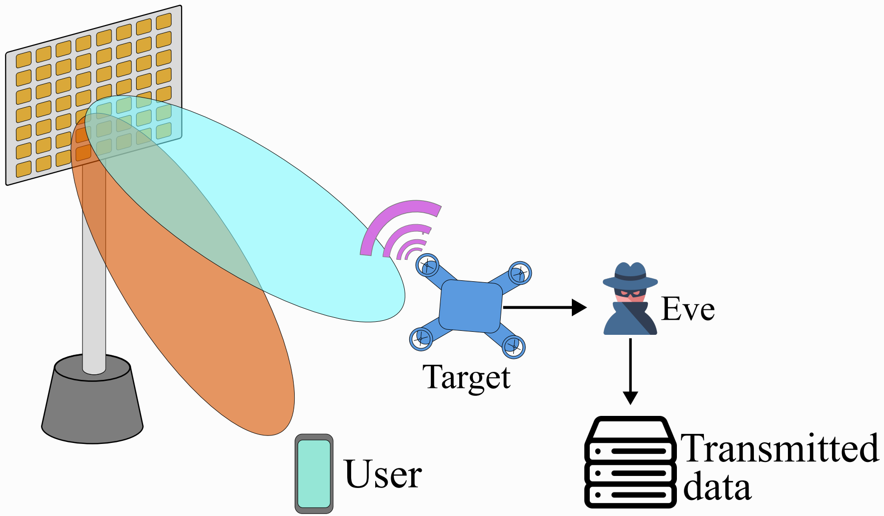
A possible security vulnerability

- Full integration increases spectral, energy and hardware efficiency



A possible security vulnerability

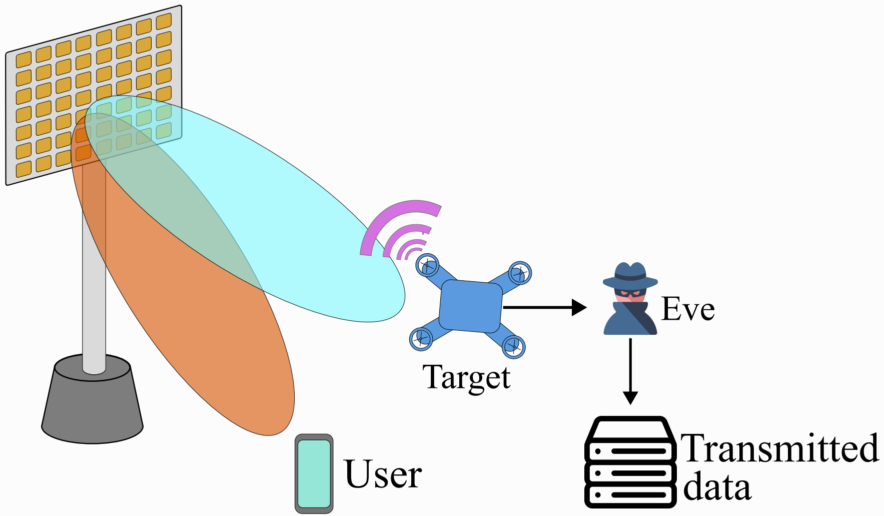
- Full integration increases spectral, energy and hardware efficiency
- However, an eavesdropping target (Eve) can acquire the transmitted Data



A possible security vulnerability

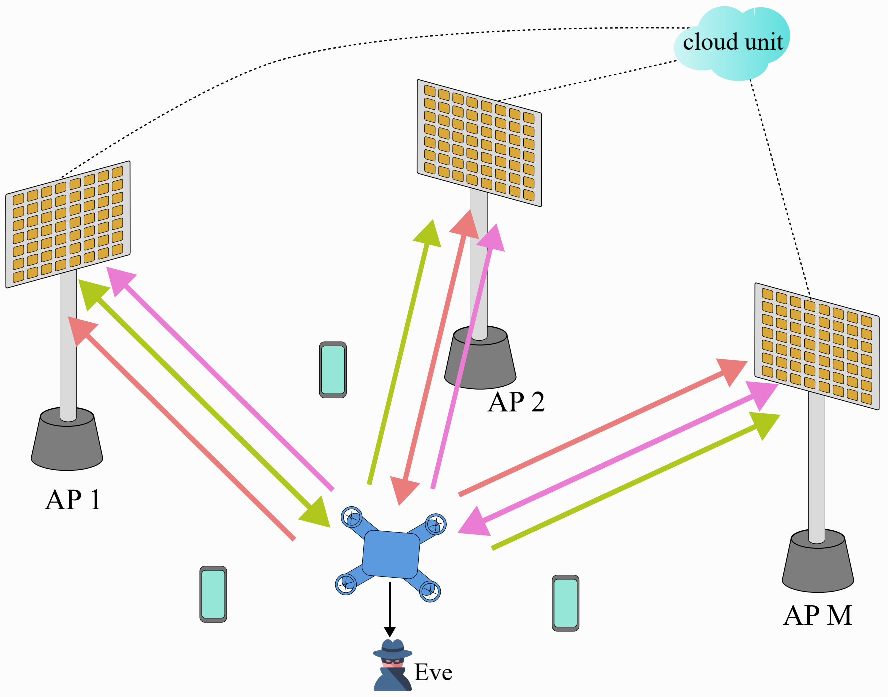
- Full integration increases spectral, energy and hardware efficiency
- However, an eavesdropping target (Eve) can acquire the transmitted Data

How can we counteract such attacks ?

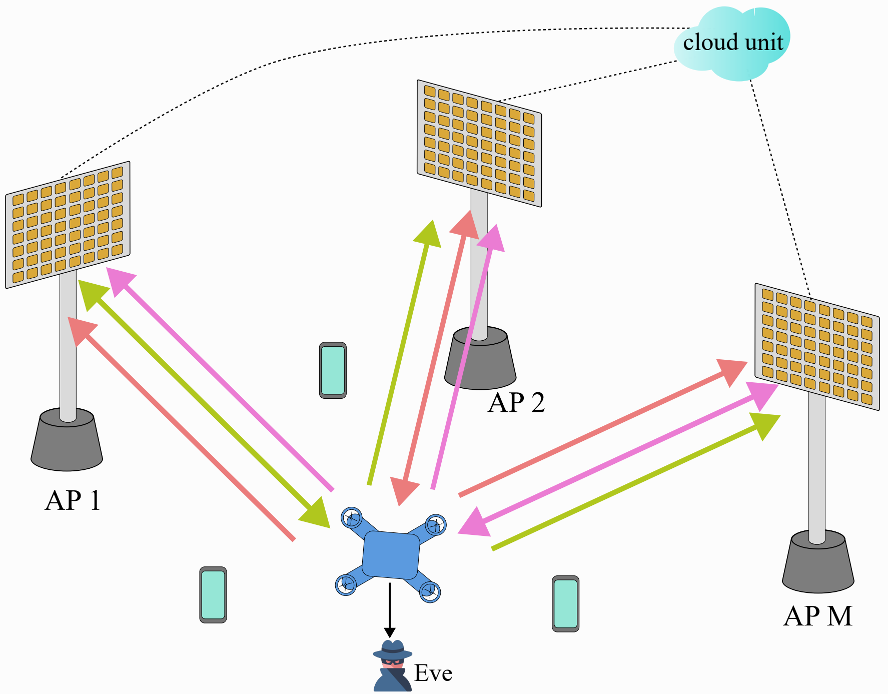


Eve aware signal design [1]

- **Cell-Free MIMO**: distributed access points (APs) cooperating to realize network functions → almost uniform quality of service

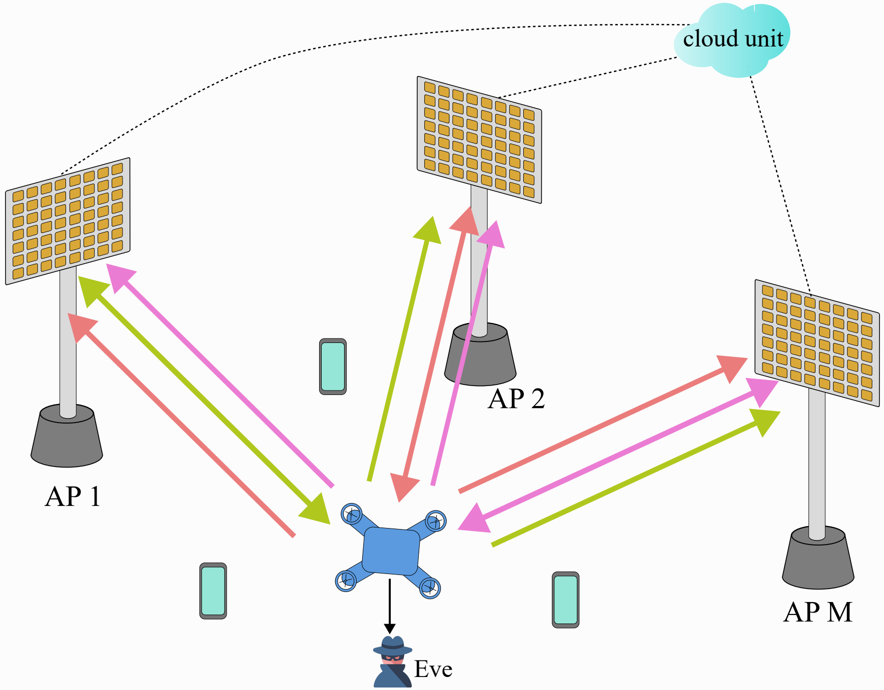


- **Cell-Free MIMO**: distributed access points (APs) cooperating to realize network functions $\longrightarrow$ almost uniform quality of service
- How can we sense eve while preventing Eavesdropping ?



- **Cell-Free MIMO**: distributed access points (APs) cooperating to realize network functions → almost uniform quality of service
- How can we sense eve while preventing Eavesdropping ?

Artificial noise (AN) !



- The waveform transmitted by the m-th AP is defined as

$$\phi_m = \mathbf{F}_m \mathbf{x}_m + \xi_m$$

- precoding matrix $\mathbf{F}_m = [\mathbf{f}_{m,1} \dots \mathbf{f}_{m,S}]$
- transmit symbols $\mathbf{x}_m = [x^t_{m,1} \dots x^t_{m,S}]^\top$
- Artificial noise $\xi_m \sim \mathcal{CN}(0, \mathbf{R}_{\Xi_m})$

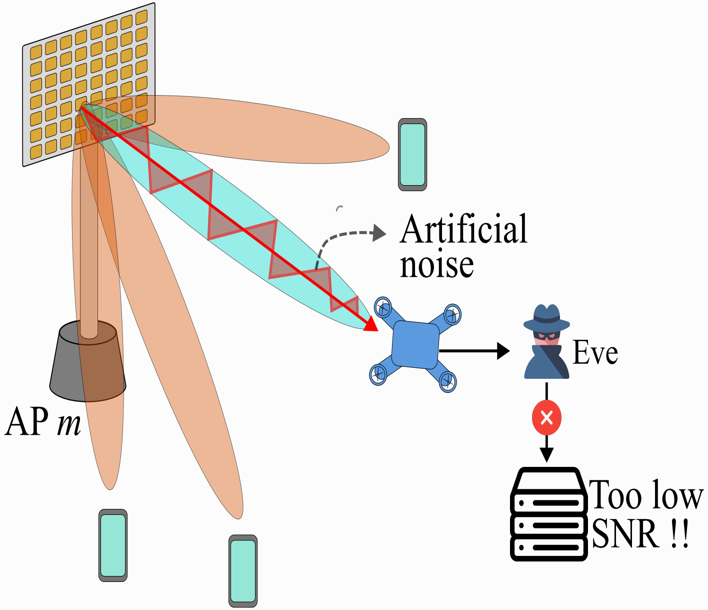
- We optimize $\{\mathbf{F}_m, \mathbf{R}_{\Xi_m}\}$ as follows

$$\min_{\{\mathbf{F}_m,\mathbf{R}_{\Xi_m}\}} \mathrm{CRB}_{\theta_1,\ldots,\theta_M}$$

$$\text{s.t. } \frac{\text{desired signal}}{\mathrm{MUI} + \sum_{m=1}^{M} |\mathbf{h}_{m,k}^{\mathsf{H}} \mathbf{R}_{\Xi_m} \mathbf{h}_{m,k}| + \sigma_{\mathrm{c}}^2} \geq \gamma_k,\ \forall k$$

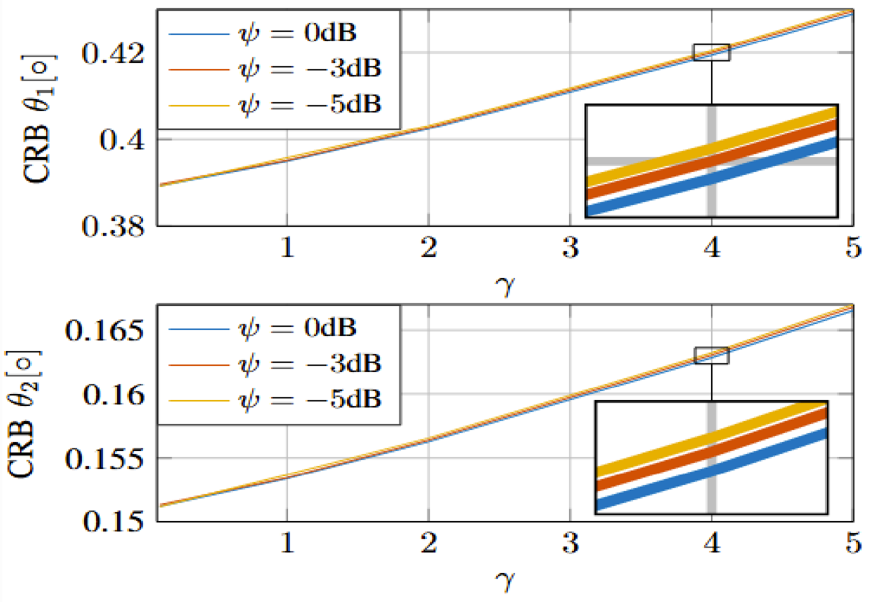
$$\frac{\text{desired signal}}{\sum_{m=1}^{M} (\delta_m^m)^2 |\mathbf{a}(\theta_m)^{\mathsf{H}} \mathbf{R}_{\Xi_m} \mathbf{a}(\theta_m)| + \sigma_{\mathrm{s}}^2} \leq \psi$$

$$\|\phi_m\|^2 \leq P,\ \forall m$$

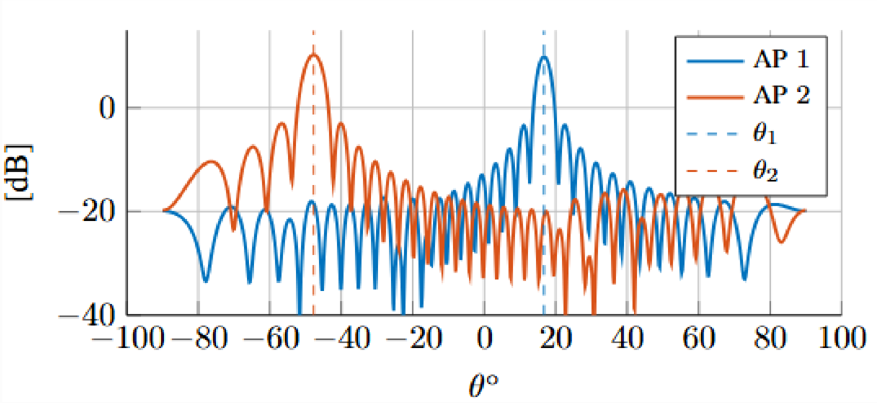


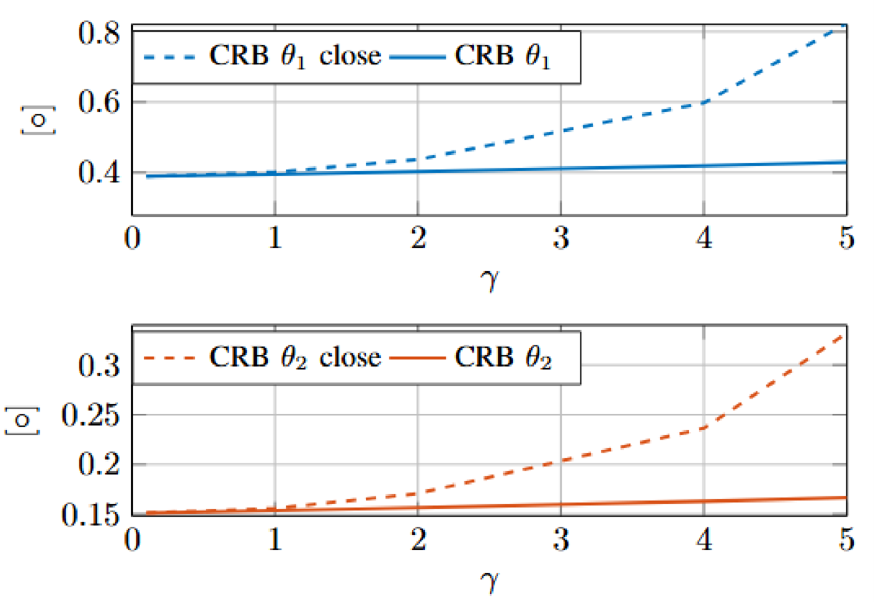
Eve aware signal design [1]

- Simulation results obtained with $M = 2$ APs
- We notice a trade-off between sensing and communication
- a lower maximum SNR for the EVE corresponds to a lightly higher CRB



Eve aware signal design [1]

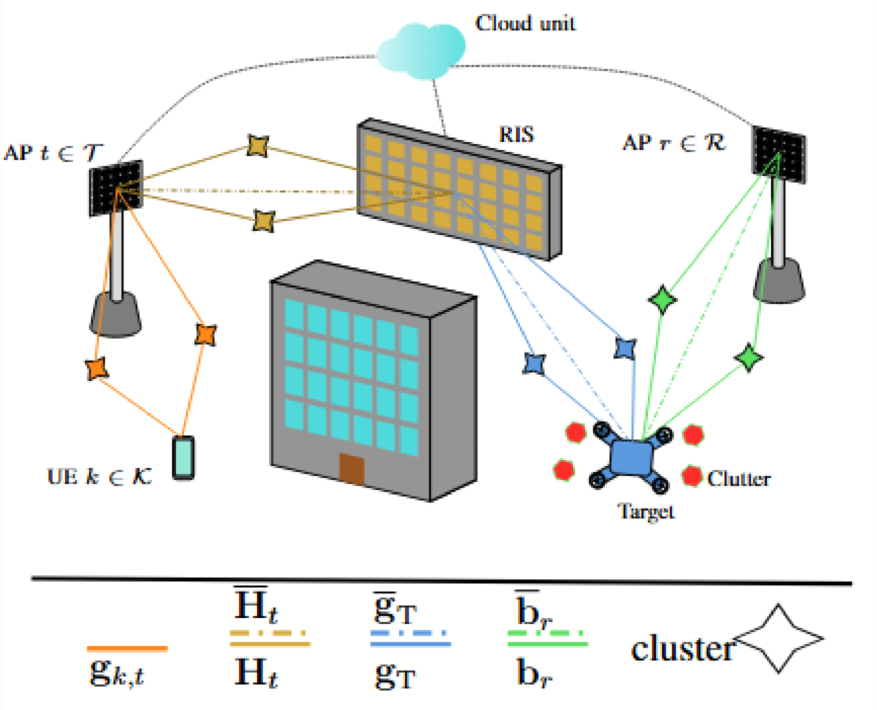




- Angular proximity between target and UEs causes serious performance degradations

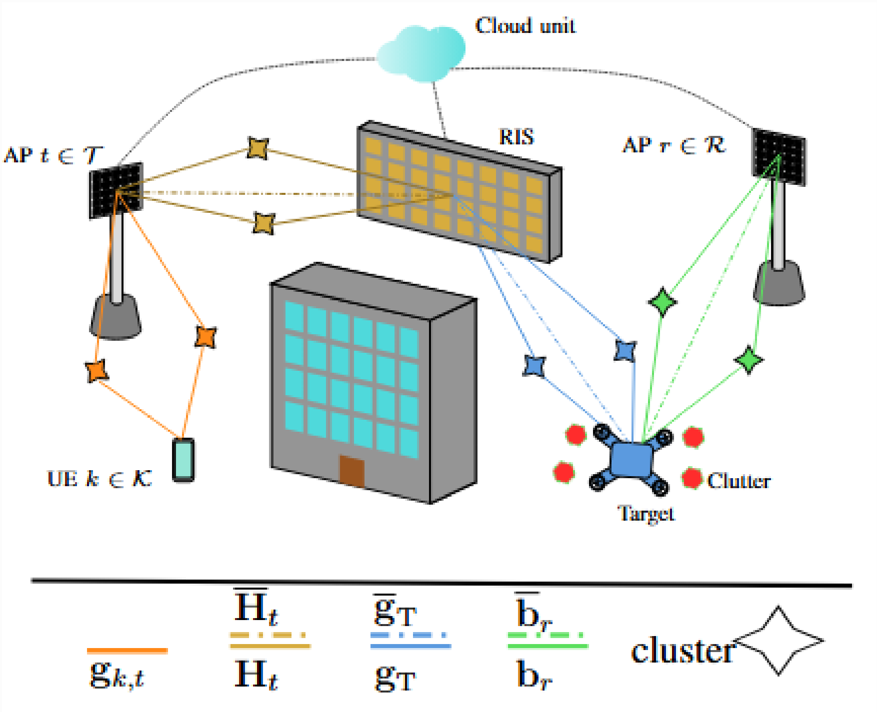
Addressing Line of sight blockage [2]

- Line of sight (LOS) blockage between transmitting APs and target



- Line of sight (LOS) blockage between transmitting APs and target

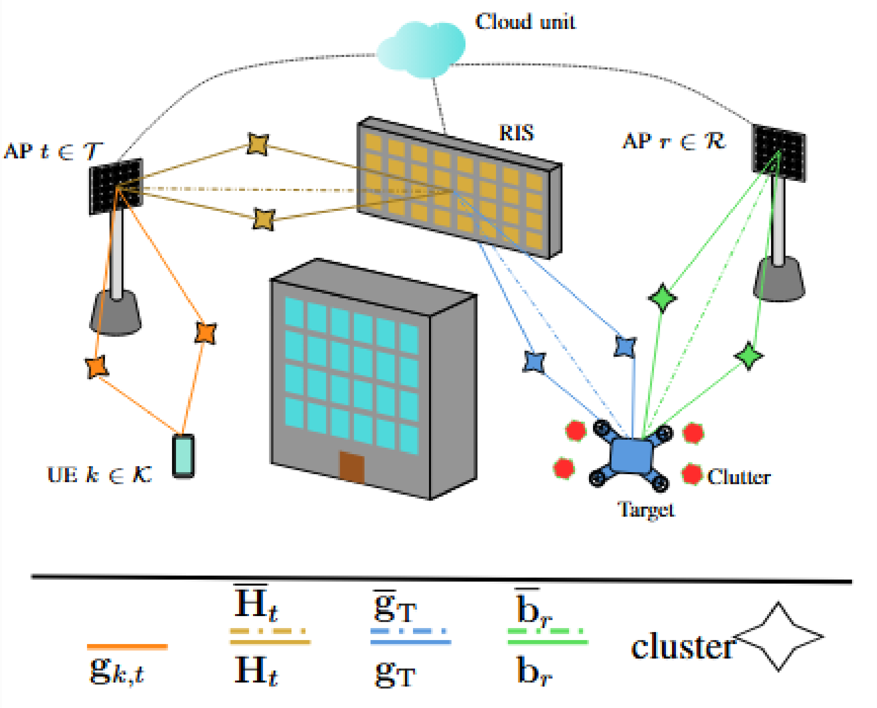
deploy a RIS !



- Line of sight (LOS) blockage between transmitting APs and target

deploy a RIS !

- millimeter Waves frequency band → sparse channel



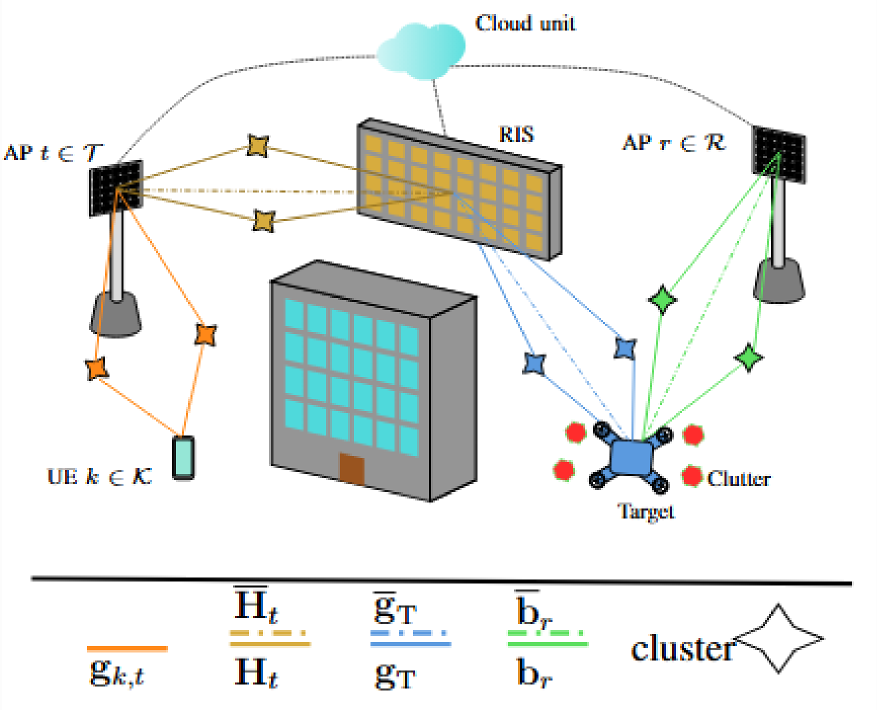
Addressing Line of sight blockage [2]

- Line of sight (LOS) blockage between transmitting APs and target

↓

deploy a RIS !

- millimeter Waves frequency band → sparse channel
- We want ot maximize the **probability of detection** in presence of **clutter**

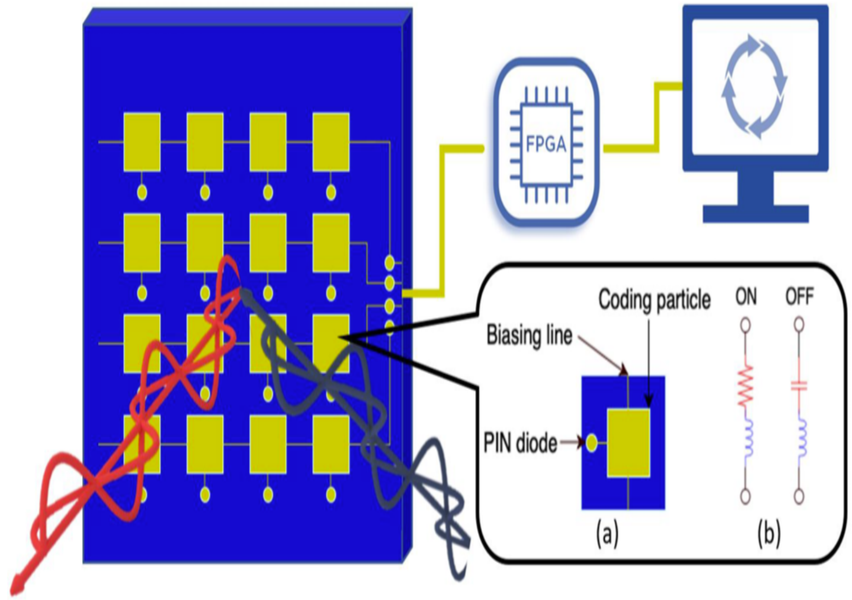


- **clutter**: set of unwanted radar echos generated by objects near the target
- Radar echo at AP r during timeslot τ

$$\mathbf{y}_r[\tau] = \sum_{t\in\mathcal{T}} c_{t,r}\mathbf{b}_r\left(\mathbf{H}_t^{\mathsf{H}}\Theta\mathbf{g}_t\right)^{\mathsf{H}}\mathbf{F}_t\mathbf{X}[\tau]\rho + \mathbf{z}_r[\tau] + \mathbf{n}_r[\tau]$$

- 2-way radar channel
- transmit waveform
- clutter $\mathbf{z}_r[\tau] \sim \mathcal{CN}(0, \delta_{\mathbf{z}}^2\mathbf{R}_r)$
- noise

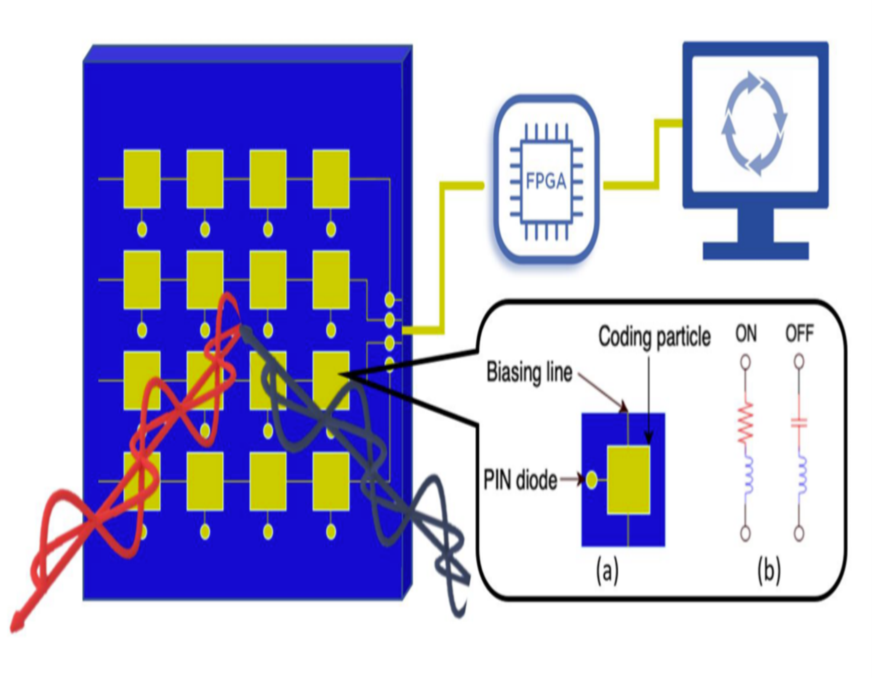
- **Reconfigurable intelligent surface**: array of passive reflecting elements imposing a phase shift onto the signal



[0] Figure from Pan, Cunhua, et al. "Reconfigurable intelligent surfaces for 6G systems: Principles, applications, and research directions." IEEE Communications Magazine 59.6 (2021): 14-20.

Addressing Line of sight blockage [2]

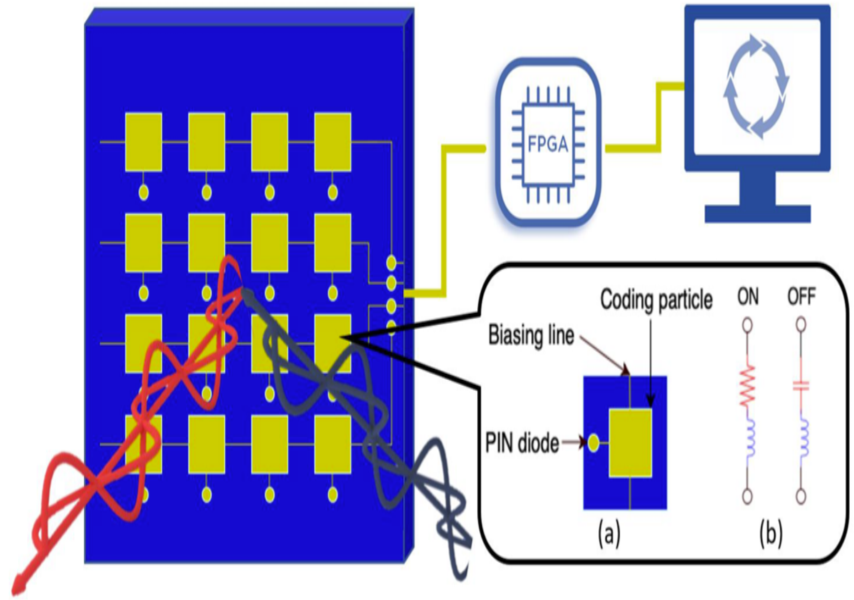
- **Reconfigurable intelligent surface**: array of passive reflecting elements imposing a phase shift onto the signal
- **standard configuration**: each element is connected to ground via tunable impedance$\longrightarrow$ elements are independent from each other



---

[0] Figure from Pan, Cunhua, et al. "Reconfigurable intelligent surfaces for 6G systems: Principles, applications, and research directions." IEEE Communications Magazine 59.6 (2021): 14-20.

- **Reconfigurable intelligent surface**: array of passive reflecting elements imposing a phase shift onto the signal
- **standard configuration**: each element is connected to ground via tunable impedance$\rightarrow$ elements are independent from each other
- diagonal matrix $\Theta = \text{diag}(\theta)$, where $\theta = [e^{j\psi_1}, \ldots, e^{j\psi_N}]$



[0] Figure from Pan, Cunhua, et al. "Reconfigurable intelligent surfaces for 6G systems: Principles, applications, and research directions." IEEE Communications Magazine 59.6 (2021): 14-20.

- **Assuming a LoS structure for the sensing links**, We optimize the power allocation of the transmit waveform and the RIS phaseshifts as follows

- **Assuming a LoS structure for the sensing links**, We optimize the power allocation of the transmit waveform and the RIS phaseshifts as follows

$$\underset{\theta,\rho}{\text{maximize}} \quad \boxed{\frac{\sum_{\tau=1}^{U}\sum_{r\in\mathcal{R}}\sum_{a\in\mathcal{T}}\delta_{a,r}^{2}\left\|\bar{\mathbf{b}}_{r}\left(\bar{\mathbf{H}}_{a}^{\mathsf{H}}\Theta\bar{\mathbf{g}}_{\mathrm{t}}\right)^{\mathsf{H}}\mathbf{F}_{a}\mathbf{X}[\tau]\rho\right\|^{2}}{RUM\left(\sigma^{2}+\delta_{\mathbf{z}}^{2}\right)}} \rightarrow \text{SCNR}$$

- **Assuming a LoS structure for the sensing links**, We optimize the power allocation of the transmit waveform and the RIS phaseshifts as follows

$$\underset{\theta,\rho}{\text{maximize}} \quad \boxed{\frac{\sum_{\tau=1}^{U}\sum_{r\in\mathscr{R}}\sum_{a\in\mathscr{T}} \delta_{a,r}^2 \left\|\bar{\mathbf{b}}_r \left(\bar{\mathbf{H}}_a^{\mathsf{H}}\Theta\bar{\mathbf{g}}_{\mathsf{t}}\right)^{\mathsf{H}} \mathbf{F}_a\mathbf{X}[\tau]\rho\right\|^2}{RUM\left(\sigma^2+\delta_{\mathbf{z}}^2\right)}} \rightarrow \text{SCNR}$$

$$\text{subject to} \quad \boxed{\text{SINR}_k \geq \gamma_k, \quad \forall k \in \mathscr{K}} \rightarrow \text{SINR}$$

- **Assuming a LoS structure for the sensing links**, We optimize the power allocation of the transmit waveform and the RIS phaseshifts as follows

$$\underset{\theta,\rho}{\text{maximize}} \quad \boxed{\frac{\sum_{\tau=1}^{U}\sum_{r\in\mathcal{R}}\sum_{a\in\mathcal{T}}\delta_{a,r}^{2}\left\|\bar{\mathbf{b}}_{r}\left(\bar{\mathbf{H}}_{a}^{\mathrm{H}}\Theta\bar{\mathbf{g}}_{\mathrm{t}}\right)^{\mathrm{H}}\mathbf{F}_{a}\mathbf{X}[\tau]\rho\right\|^{2}}{RUM\left(\sigma^{2}+\delta_{\mathbf{z}}^{2}\right)}} \rightarrow \text{SCNR}$$

$$\text{subject to} \quad \boxed{\text{SINR}_{k}\geq\gamma_{k},\quad \forall k\in\mathcal{K}} \rightarrow \text{SINR}$$

$$\boxed{\mathbb{E}\left\{\|\mathbf{F}_{t}\mathbf{X}[\tau]\rho\|^{2}\right\}\leq P_{t},\ \forall t\in\mathcal{T}} \rightarrow \text{Power consumption}$$

- **Assuming a LoS structure for the sensing links**, We optimize the power allocation of the transmit waveform and the RIS phaseshifts as follows

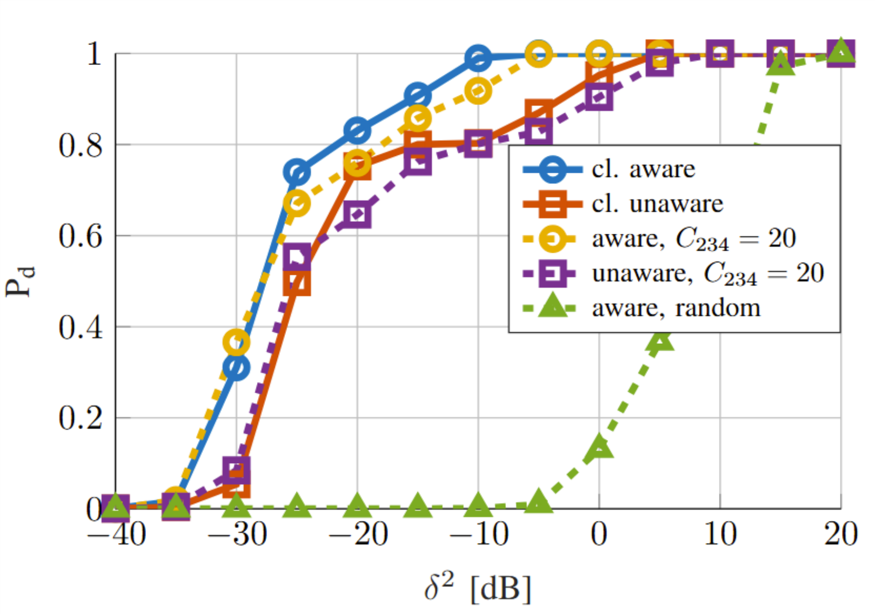
$$\underset{\theta,\rho}{\text{maximize}} \quad \frac{\sum_{\tau=1}^{U}\sum_{r\in\mathcal{R}}\sum_{a\in\mathcal{T}} \delta_{a,r}^{2} \left\| \bar{\mathbf{b}}_{r} \left(\bar{\mathbf{H}}_{a}^{\mathsf{H}} \Theta \bar{\mathbf{g}}_{\mathrm{t}} \right)^{\mathsf{H}} \mathbf{F}_{a}\mathbf{X}[\tau]\rho \right\|^{2}}{RUM\left(\sigma^{2}+\delta_{\mathbf{z}}^{2}\right)} \rightarrow \text{SCNR}$$

$$\text{subject to} \quad \text{SINR}_{k} \geq \gamma_{k}, \quad \forall k \in \mathcal{K} \rightarrow \text{SINR}$$

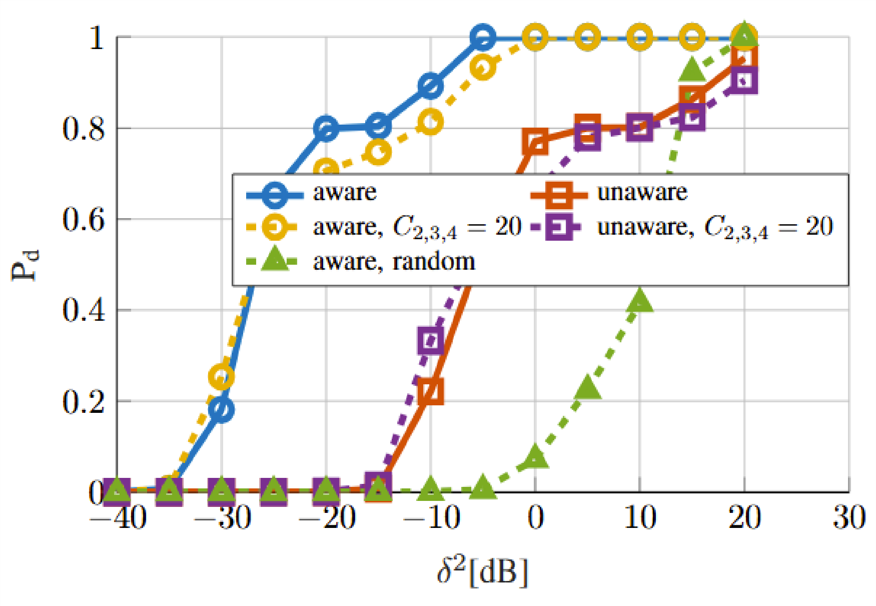
$$\mathbb{E}\left\{ \left\| \mathbf{F}_{t}\mathbf{X}[\tau]\rho \right\|^{2} \right\} \leq P_{t}, \ \forall t \in \mathcal{T} \rightarrow \text{Power consumption}$$

$$|\theta_{n}| = 1, \quad n = 1, \ldots, N \rightarrow \text{RIS reflectivity}$$

Cutter to noise ratio= 20[dB]



Cutter to noise ratio= 40[dB]



- the probability of detection is obtained trough a generalized likelihood ratio test

Conclusions

Conclusions

- ISAC proposes itself as a solution to the spectrum resource scarcity problems in beyond 5G networks
- Network functionalities are now integrated to various extents, increasing the network effeciency
- in this presentation I have presented possible solutions to two challenges that such network can face.
- the main challenge toward commercial ISAC implementation lies in understading the fundamental trade-offs between network functions

References

[1] Rivetti Steven, Emil Björnson, and Mikael Skoglund. "**Secure spatial signal design for ISAC in a cell-free MIMO network**." 2024 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2024.

[2] Rivetti Steven, Ozlem Tugfe Demir, Emil Björnson, and Mikael Skoglund. "**Clutter-Aware Target Detection for ISAC in a Millimeter-Wave Cell-Free Massive MIMO System**." arXiv preprint arXiv:2411.08759 (2024).

KTH

VETENSKAP
OCH KONST