Integrated Sensing and Communications: Signalling, Applications and Trade-offs

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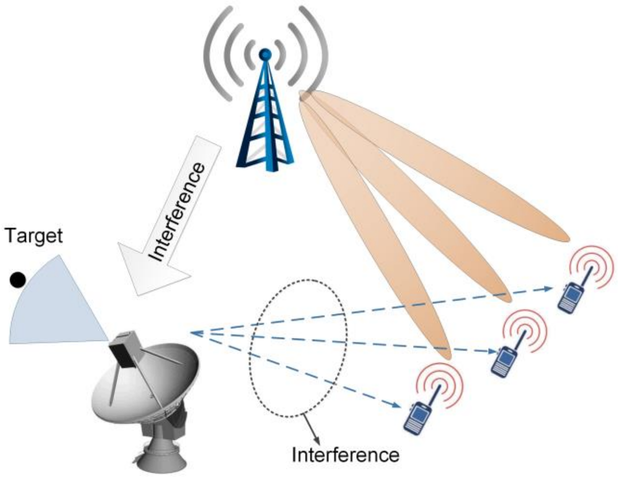
ISAC Vision and Evolution Path



Spectral Coexistence

F. Liu, Y. Cui, C. Masouros, J. Xu, T. X. Han, A. Hassanien, Y. Eldar, S. Buzzi, "Integrated Sensing and Communications: Towards Future Dual-functional Wireless Networks", IEEE Journal on Sel. Areas Comms., *in press*

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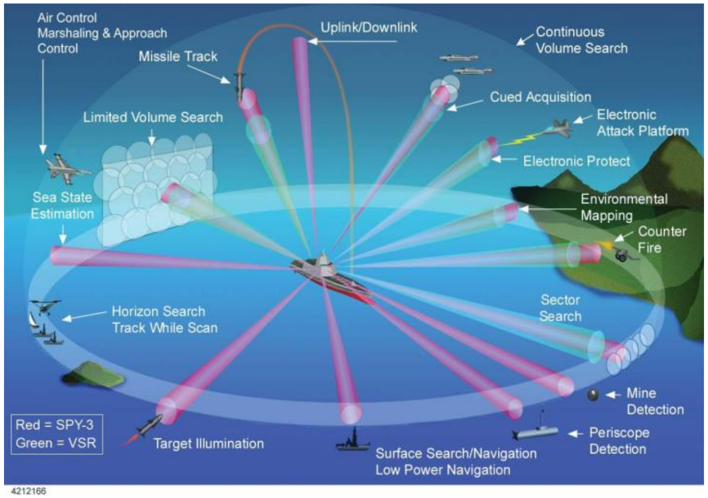

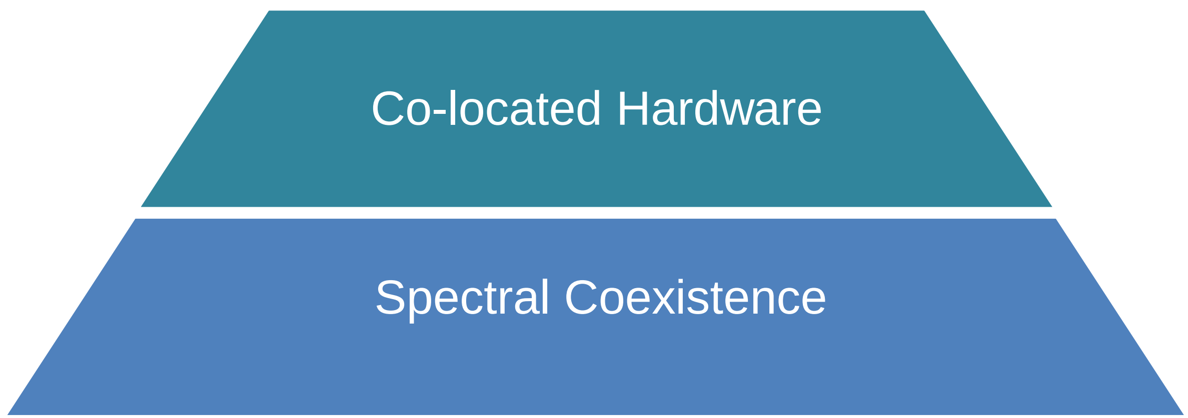

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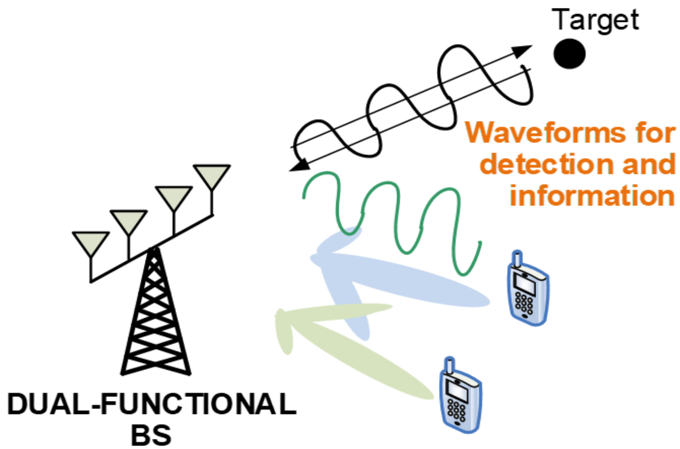

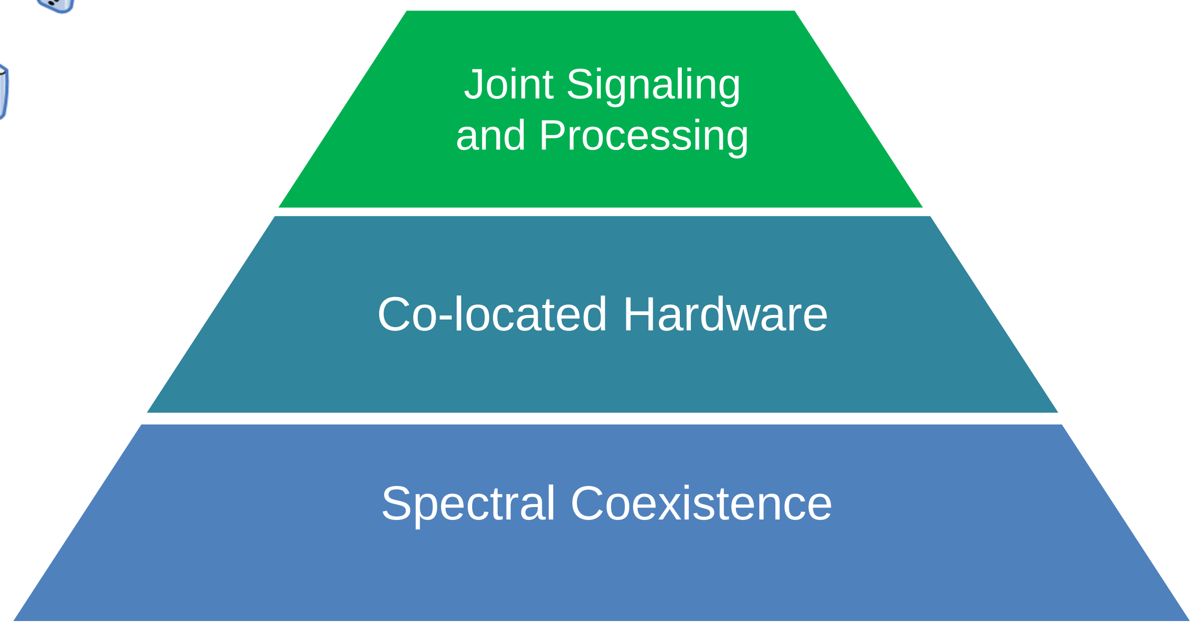

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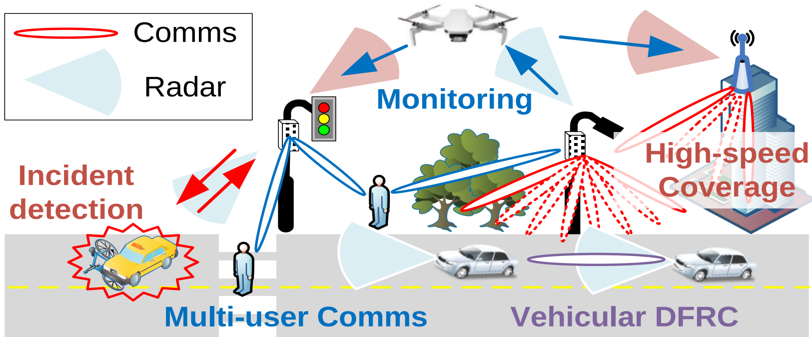

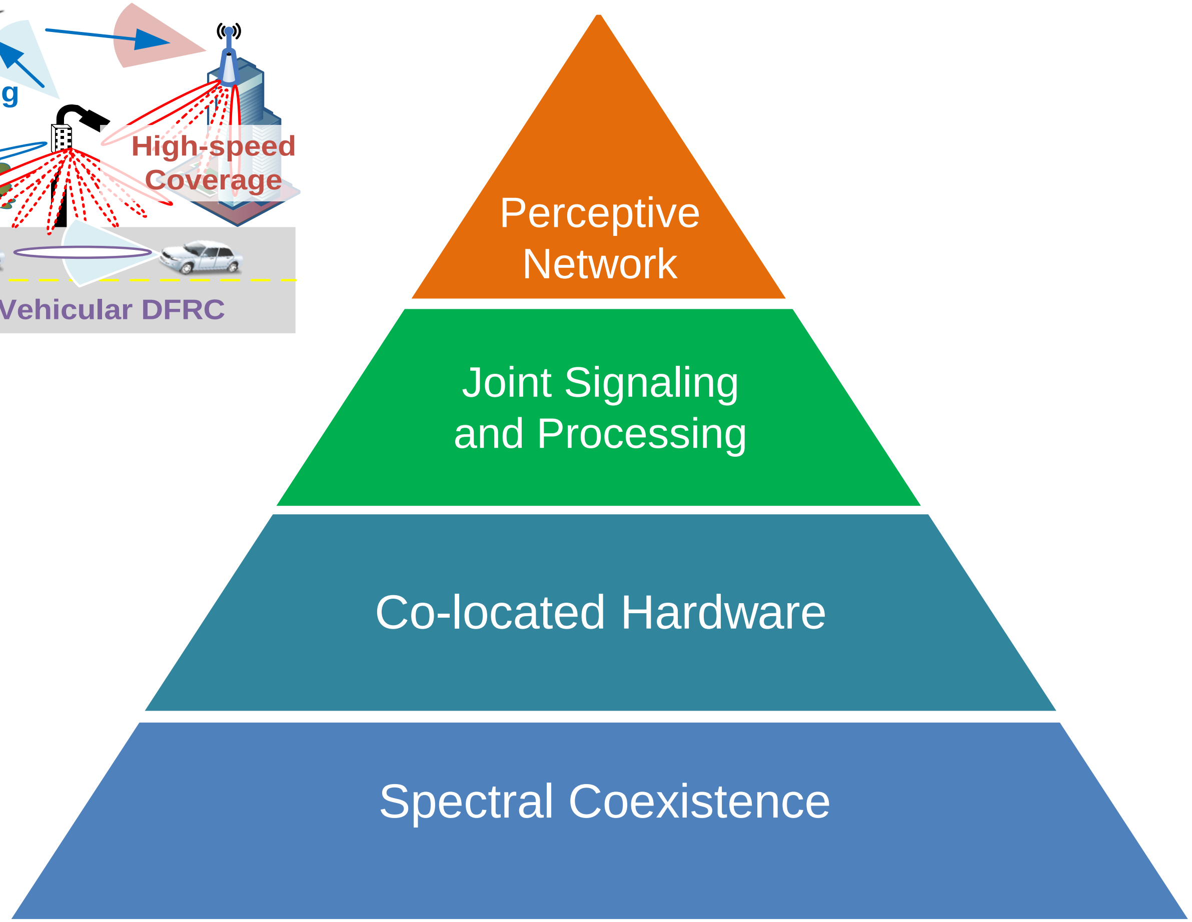

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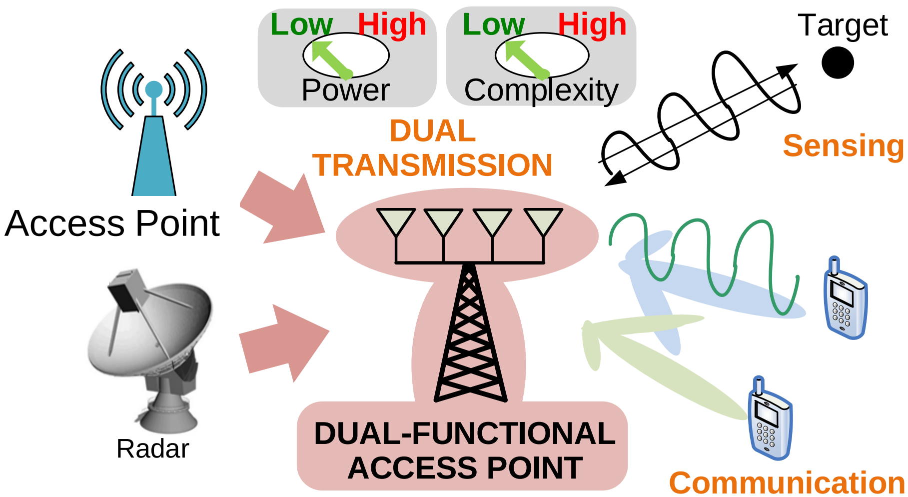
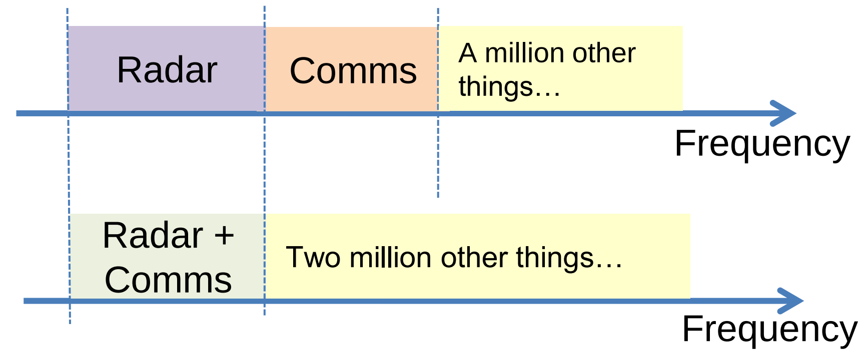
The DFRC gains

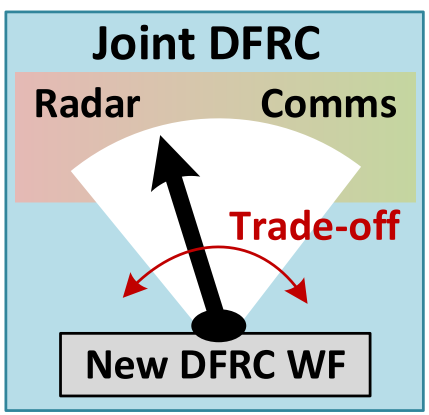
Hardware Gain



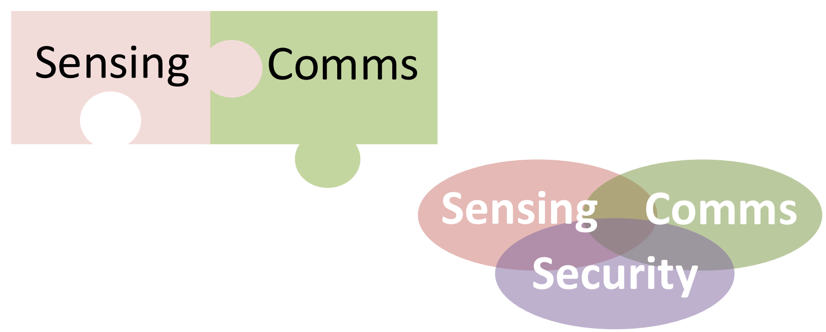
Spectrum Gain



Scalable Trade-offs

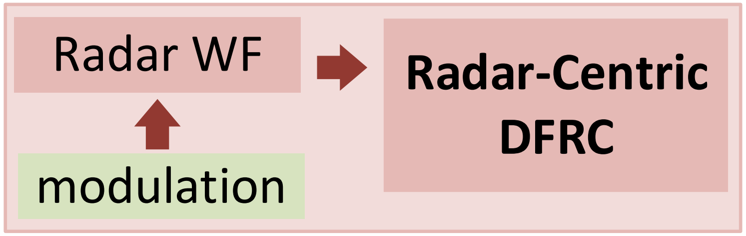


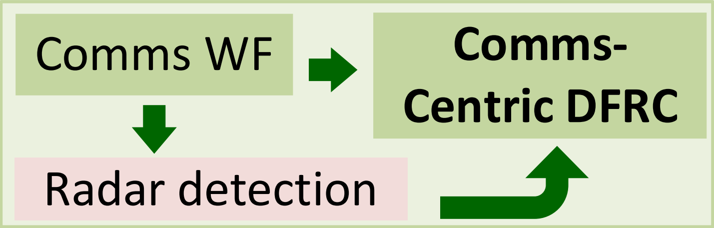
Synergies – Mutual Benefits

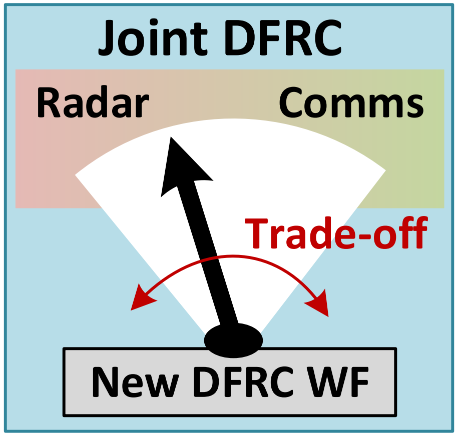


DFRC Technologies

- Radar-centric design
  - Pulse Interval Modulation (PIM)
  - Radar beampattern sidelobe signalling
  - Index Modulation (IM) using radar waveforms
  - …
- Comms-centric design
  - OFDM based DFRC
  - IEEE 802.11ad based DFRC
  - …
- Jointly optimized design
  - Radar-centric joint design
  - Weighted Comms-Radar optimization
  - …







Outline

- Motivation
- Technical highlights
  - Weighted-optimization based DFRC
  - Security for DFRC
  - Sensing-Assisted Communications

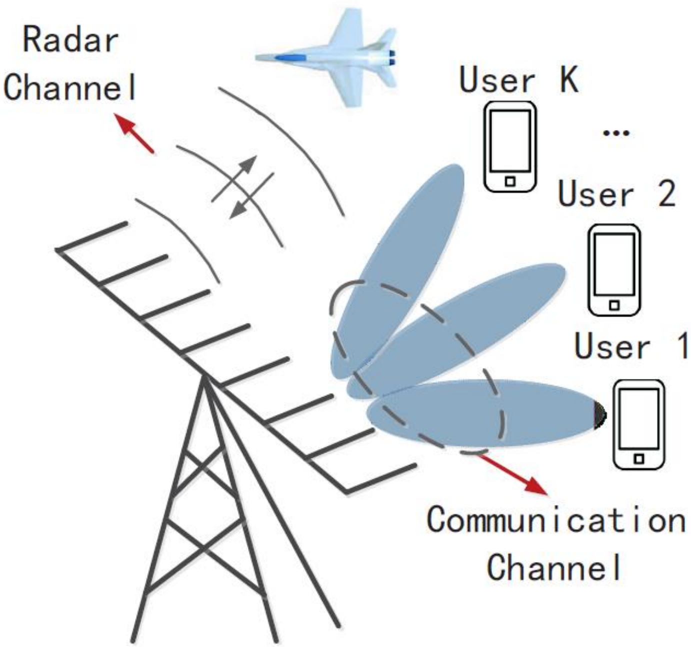
Weighted optimization

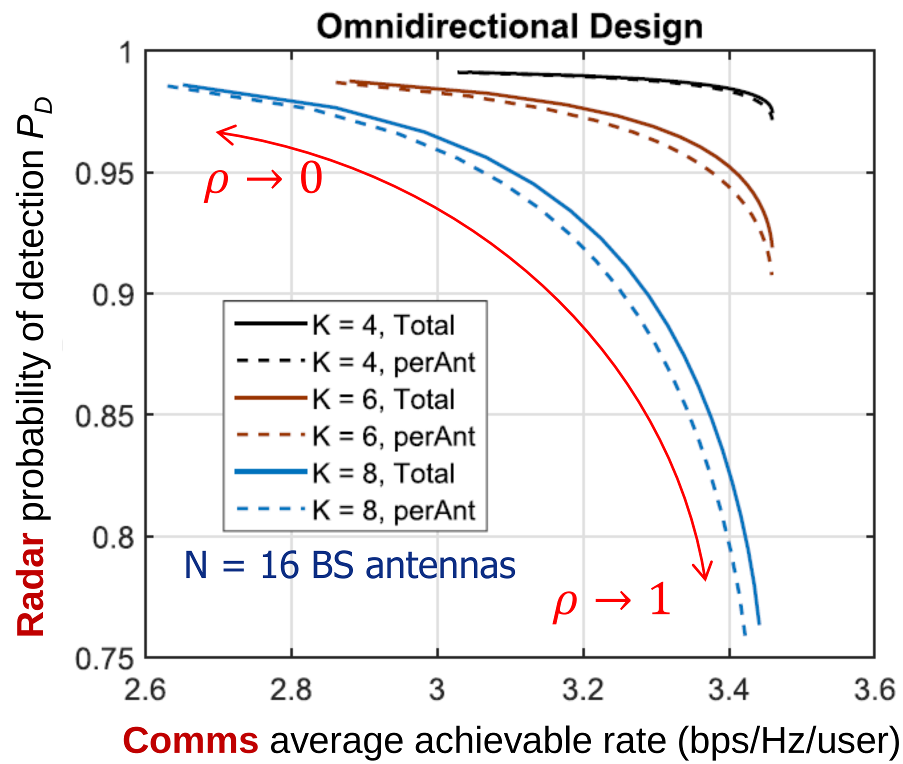
$$\mathbf{Y} = \mathbf{H}\mathbf{X} + \mathbf{Z} = \mathbf{S} + \underbrace{(\mathbf{H}\mathbf{X} - \mathbf{S})}_{\text{MUI}} + \mathbf{Z}$$

$$\min_{\mathbf{X}} \rho \left\|\mathbf{H}\mathbf{X} - \mathbf{S}\right\|_F^2 + (1-\rho)\left\|\mathbf{X} - \mathbf{X}_0\right\|_F^2$$

$$s.t.\ \frac{1}{L}\left\|\mathbf{X}\right\|_F^2 = P_T,$$

Ideal radar waveform

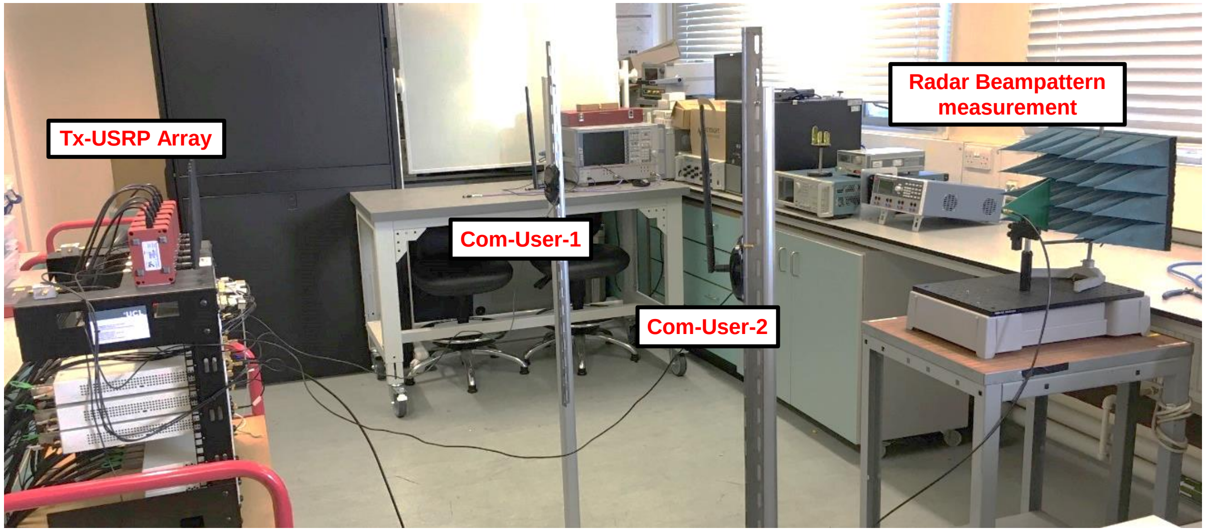




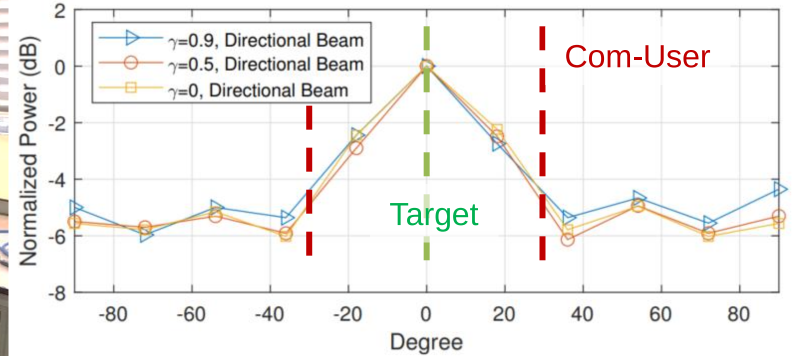
- ⬆ ρ - Comms priority
- ⬇ ρ - Radar priority

F. Liu, L. Zhou, C. Masouros, A. Li, W. Luo, and A. Petropulu, "Toward dual-functional radar-communication systems: Optimal waveform design," IEEE Trans. Signal Process., vol. 66, no. 16, pp. 4264–4279, Aug 2018.

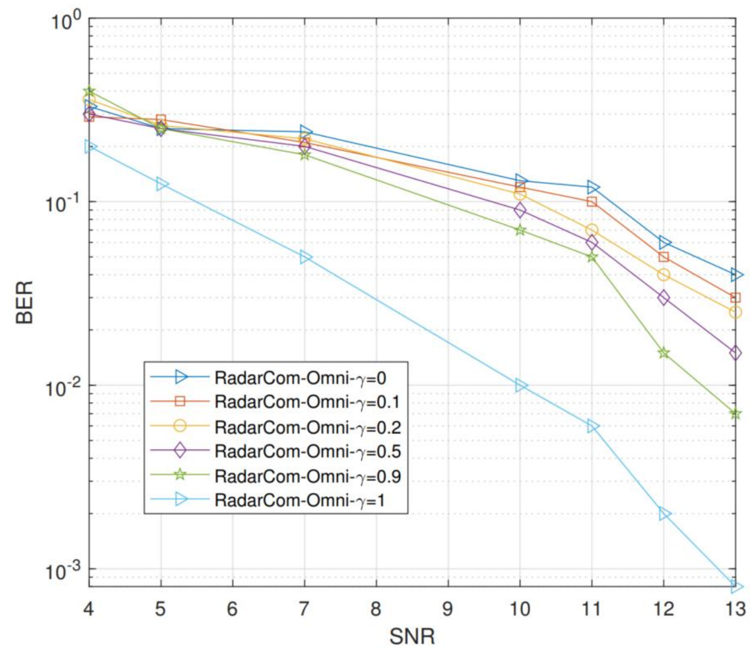
Joint DFRC – Over-the-air Proof of concept

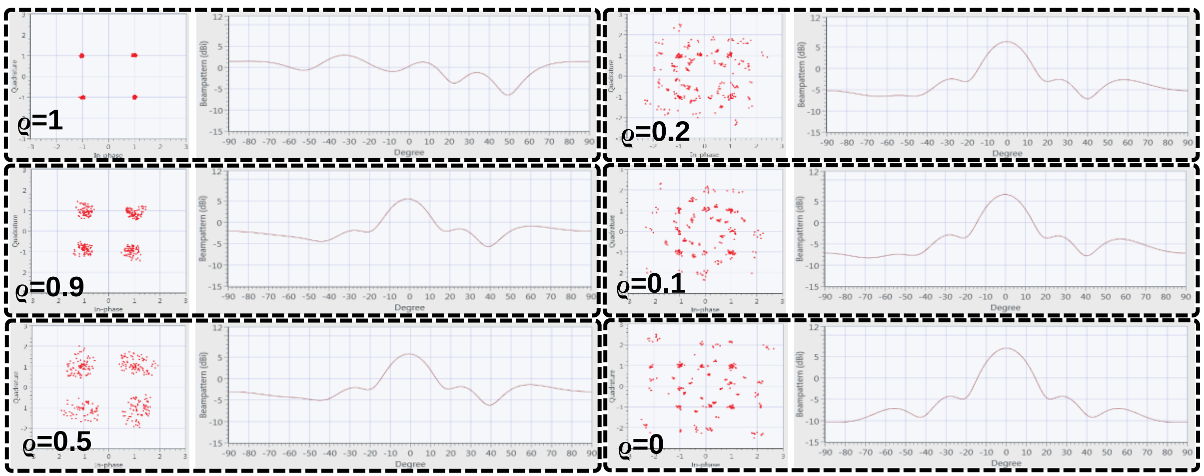


Measured Radar beampattern



Comms BER



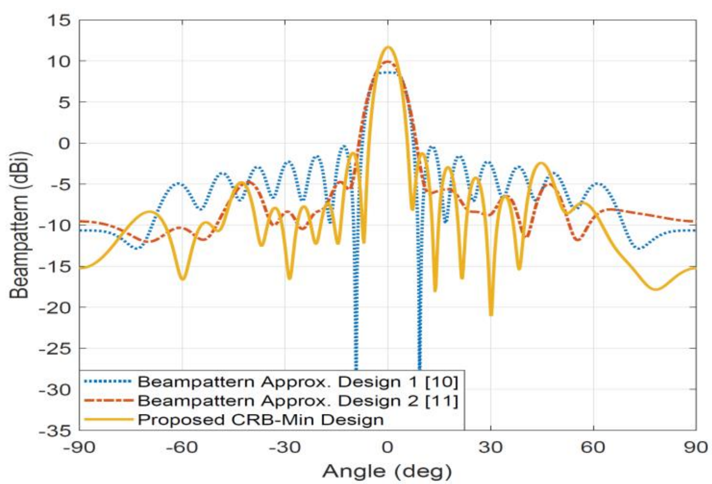


T. Xu, F. Liu, C. Masouros, I. Darwazeh, "An Experimental Proof of Concept for Integrated sensing and Communications Waveform Design", IEEE Transactions on Communications., under review - https://arxiv.org/abs/2202.04602

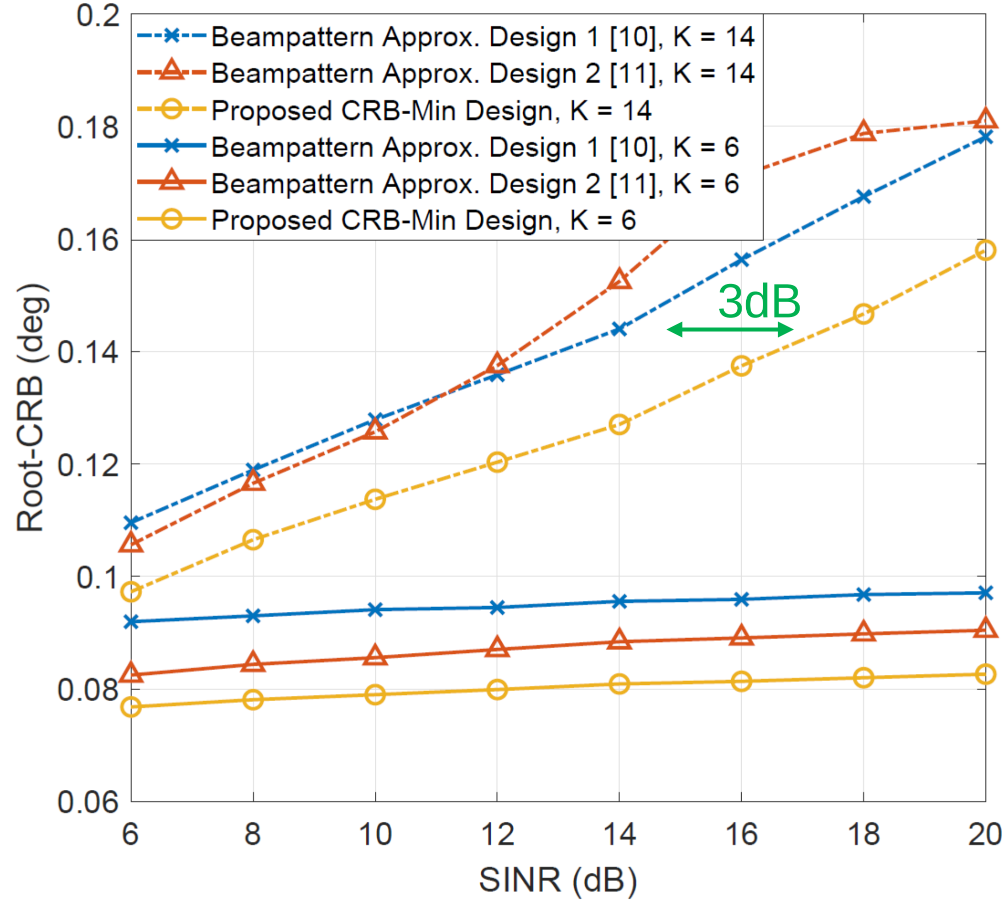
We can do better than Radar waveform approximation

Minimize CRB directly:

$$\min_{\mathbf{W}_D} \ \mathrm{CRB}(\theta)$$
$$\text{s.t.} \ \ \gamma_k \geq \Gamma_k, \forall k,$$
$$\|\mathbf{W}_D\|_F^2 \leq P_T,$$



N = 16 BS antennas



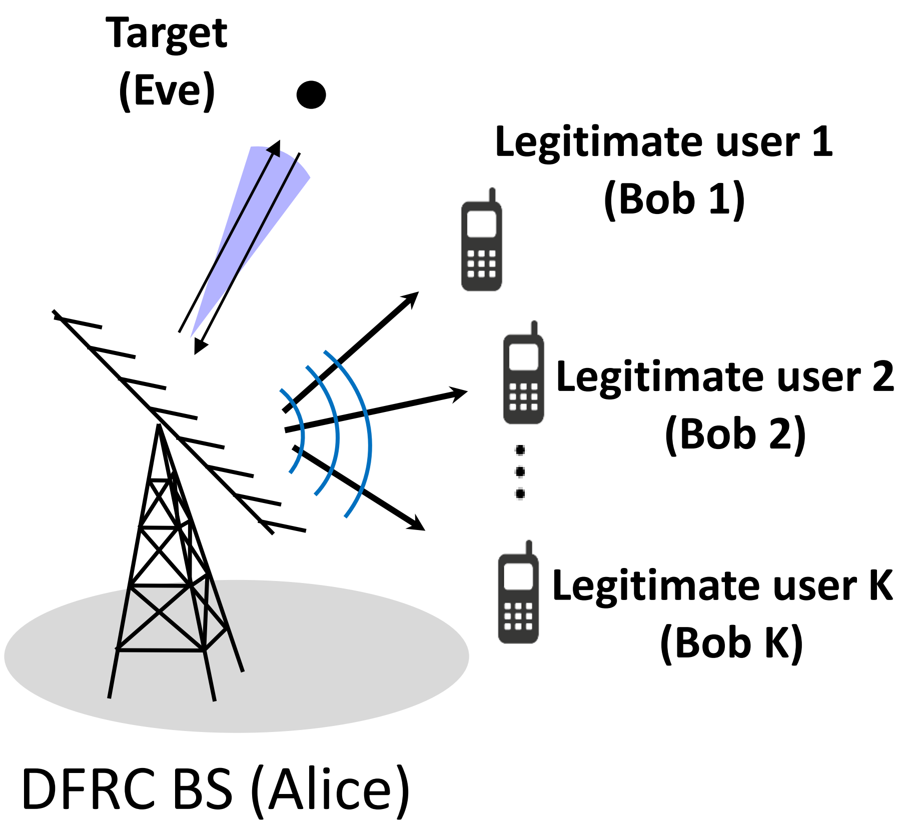
~3-4dB gains in bottom-line CRB performance

F. Liu, Y. Liu, A. Li, C. Masouros, Y. Eldar, "Cramér-Rao Bound Optimization for Joint Radar-Communication Design", IEEE Trans. Sig. Proc., *in press* - https://arxiv.org/abs/2101.12530

Dual-functional Radar-Communication

Subject to Security threats?

Radar + Information: Subject to Security Threats



Target can be:

- Enemy aircraft
- Malicious UAV
- Non-cooperative car
- …

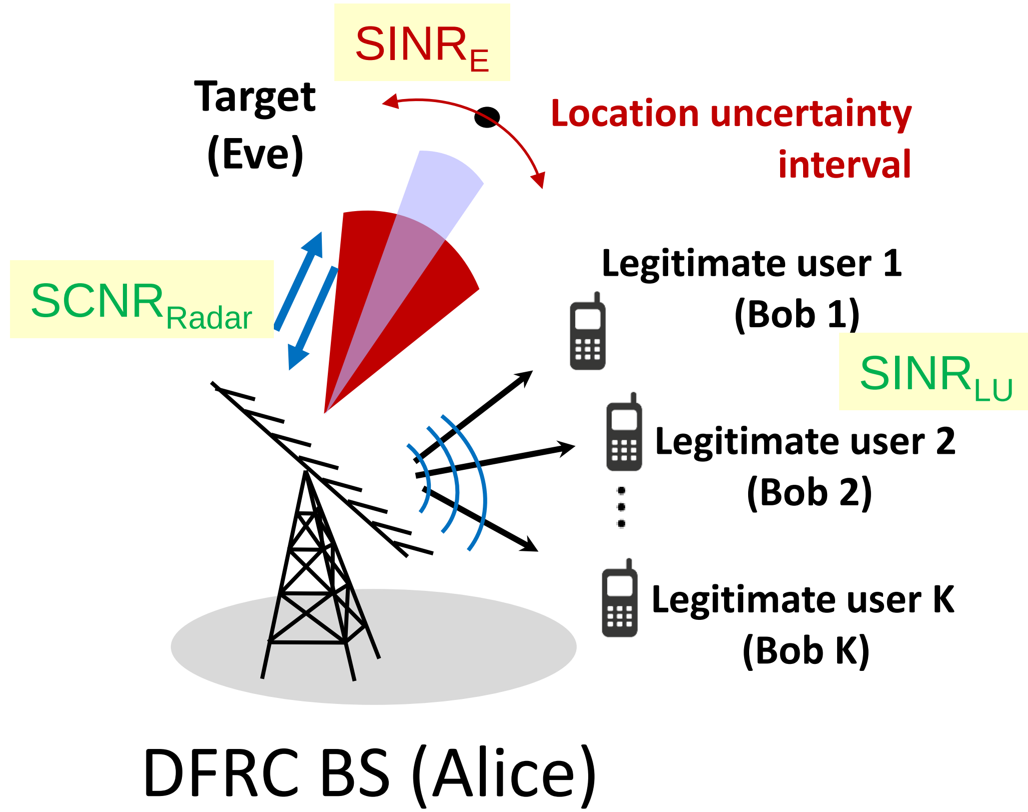
Malicious target can:

- Detect Data intended for LUs – unique to DFRC
- Infer critical radar info (location, ID, …, …)

- Need for PHY security guarantees over the Radar beamwidth
- Secure Beamforming / Artificial Noise

Unique Sensing Performance vs Security Trade-offs

- ↑ Power towards the direction of target
- ↓ Useful signal power ($SINR_E$) towards the target
- ↑ $SINR_{LU}$ towards the users



Apply PHY Sec approaches

- Secure BF
- AN, Jamming
- Cooperative Security
- …

Z. Wei, F. Liu, C. Masouros, N. Su, A. Petropulu, "Towards Multi-Functional 6G Wireless Networks: Integrating Sensing, Communication and Security" IEEE Comms Mag., under review

Secure DFRC BF - Perfect CSI, Target Uncertainty

Secure Beamformer

$$\min_{\mathbf{W}_i,\mathbf{R}_X} \sum_{\theta_m\in\Phi} \frac{|\alpha|^2 \mathbf{a}^H(\theta_m)\sum_{i=1}^{K}\mathbf{W}_i\mathbf{a}(\theta_m)}{|\alpha|^2\mathbf{a}^H(\theta_m)\mathbf{R}_N\mathbf{a}(\theta_m)+\sigma^2}$$

$$s.t.\ \mathbf{a}^H(\theta_0)\mathbf{R}_X\mathbf{a}(\theta_0) - \mathbf{a}^H(\theta_m)\mathbf{R}_X\mathbf{a}(\theta_m) \geq \gamma_s, \quad \forall\theta_m \in \Omega$$

$$\mathbf{a}^H(\theta_k)\mathbf{R}_X\mathbf{a}(\theta_k) \leq (1+\alpha)\,\mathbf{a}^H(\theta_0)\mathbf{R}_X\mathbf{a}(\theta_0), \quad \forall\theta_k \in \Phi$$

$$(1-\alpha)\,\mathbf{a}^H(\theta_0)\mathbf{R}_X\mathbf{a}(\theta_0) \leq \mathbf{a}^H(\theta_k)\mathbf{R}_X\mathbf{a}(\theta_k), \quad \forall\theta_k \in \Phi$$

$$\mathrm{SINR}_i \geq \gamma_b, \forall i,$$

$$\mathrm{tr}(\mathbf{R}_X) = P_0,$$

$$\mathbf{W}_i = \mathbf{W}_i^H,\ \mathbf{W}_i \succeq 0, \forall i,$$

$$\mathrm{rank}(\mathbf{W}_i) = 1, \forall i,$$

$$\mathbf{R}_N = \mathbf{R}_N^H,\ \mathbf{R}_N \succeq 0,$$

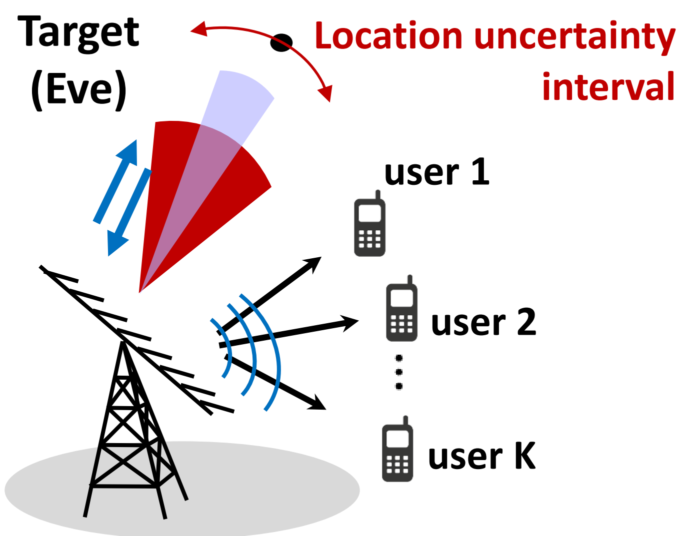
Fractional Programming + SDR

Tx signal

$$\mathbf{x} = \mathbf{Ws} + \mathbf{n} \qquad \mathbf{R}_X = \mathrm{E}\left[\mathbf{xx}^H\right] = \sum_{i=1}^{K}\mathbf{W}_i + \mathbf{R}_N$$

PSRL greater than γ_s

Main beam region within angle spread ϕ, within $\pm\alpha$ of θ_0

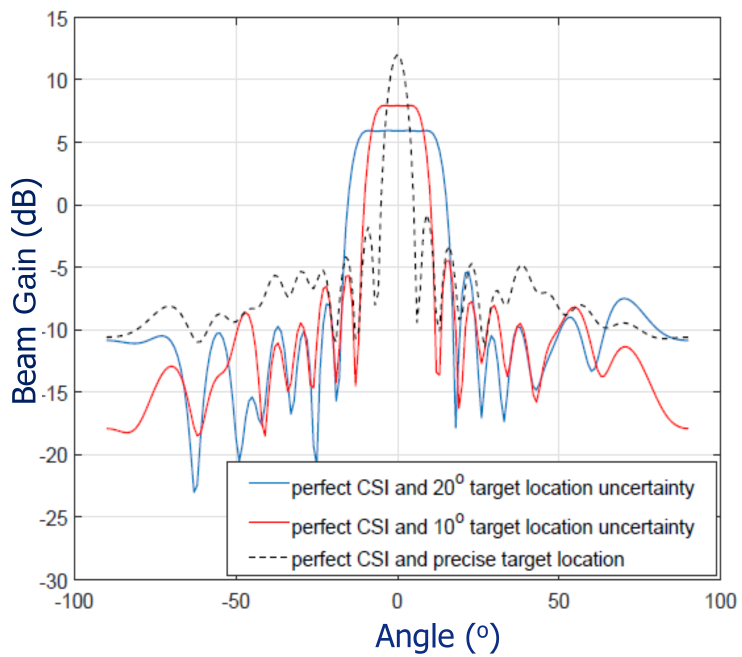


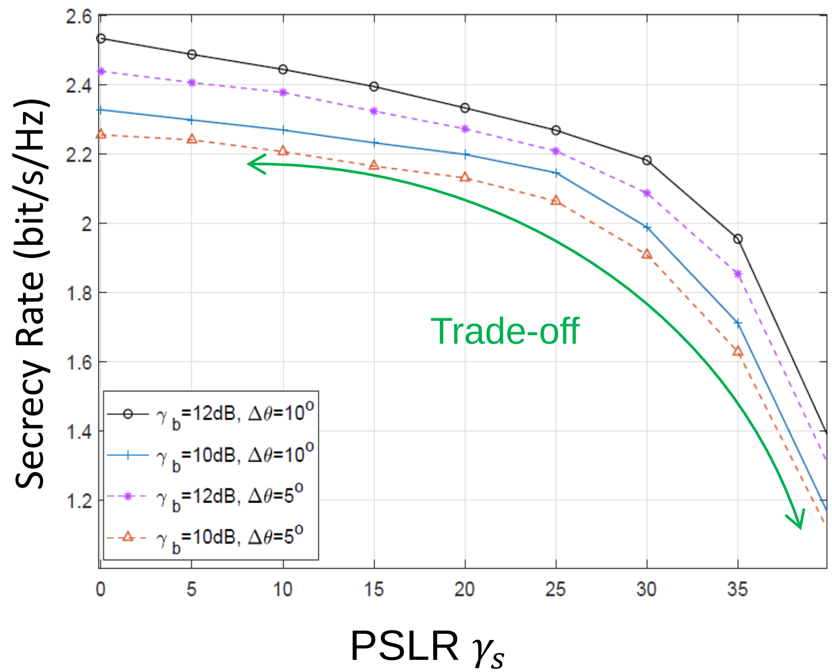
DFRC BS (Alice)

N. Su, F. Liu, C. Masouros, "Secure Radar-Communication Systems with Malicious Targets: Integrating Radar, Communications and Jamming Functionalities", IEEE Trans. Wireless Comms., vol. 20, no. 1, pp. 83-95, Jan. 2021

Numerical Results

N = 18 antennas, K = 4 legitimate users, one target – LU SNR $\gamma_b = 10\text{dB}$.





- ↑ location uncertainty angular interval → ↓ power gain of mainbeam.
- CSI imperfections deteriorate the radar PSLR
- ↑ PSLR → ↓ Secrecy Rate (more power spent on radar PSLR fulfilment)

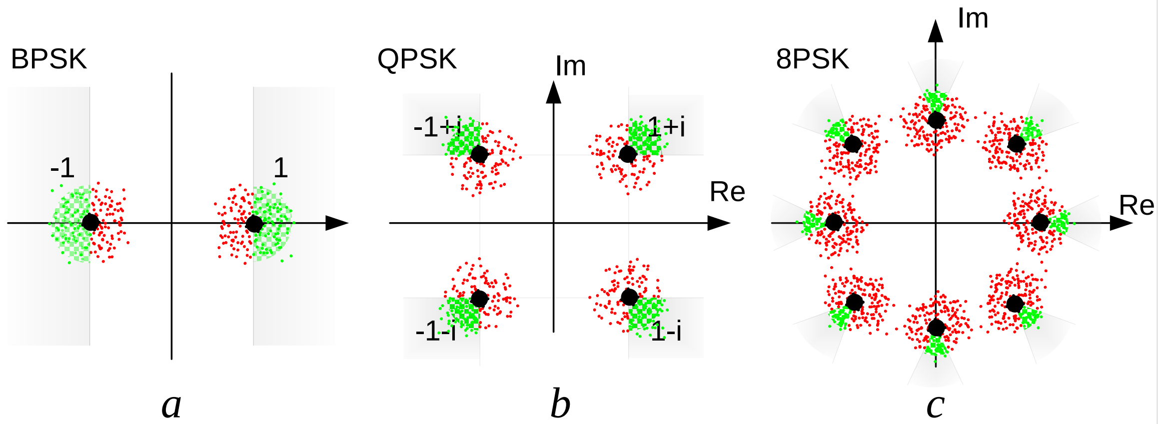
N. Su, F. Liu, C. Masouros, "Secure Radar-Communication Systems with Malicious Targets: Integrating Radar, Communications and Jamming Functionalities", IEEE Trans. Wireless Comms., vol. 20, no. 1, pp. 83-95, Jan. 2021

Secure Dual-functional Radar-Communication

Exploiting Constructive / Destructive Interference

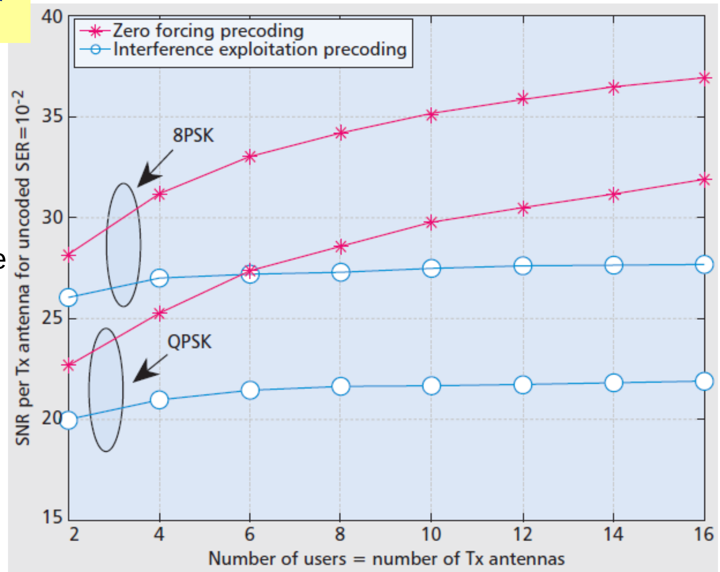
Basics of Constructive Interference (CI)

Key Concept: Exploitation of green interference power



PSK constellations and constructive – destructive interference sectors

Up to 10x Power Reduction



Early Works:

C. Masouros and E. Alsusa, "A Novel Transmitter-Based Selective-Precoding Technique for DS/CDMA systems", IEEE Signal Processing letters, vol. 14, no. 9, pp. 637-640, Sept. 2007

C. Masouros, "Correlation Rotation Linear Precoding for MIMO Broadcast Communications", *IEEE Trans. on Sig. Proc., vol 59, issue 1, pp. 252-262, Jan 2011*

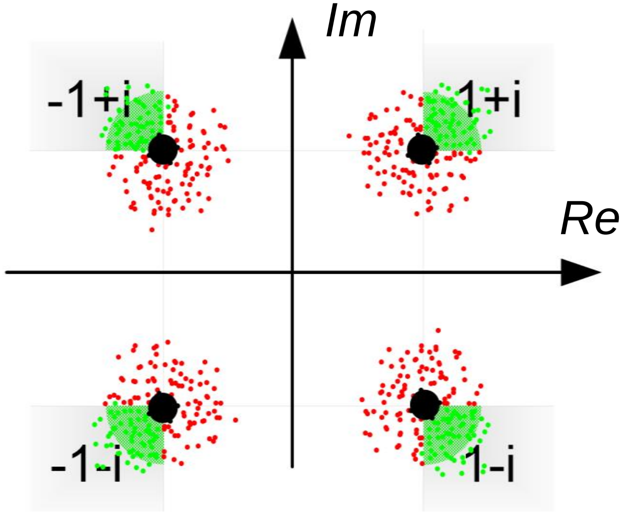
C. Masouros, T. Ratnarajah, M. Sellathurai, C. Papadias, A. Shukla, "Known Interference in Wireless Communications: A Limiting factor or a Potential Source of Green Signal Power?", IEEE Comms. Mag., vol. 51, no. 10, pp. 162-171, Oct. 2013

C. Masouros, M. Sellathurai, T. Ratnarajah, "Interference Optimization for Transmit Power Reduction in Tomlinson-Harashima Precoded MIMO Downlinks", IEEE Trans. Sig. Proc., vol. 60, no. 5, pp. 2470-2481, May 2012

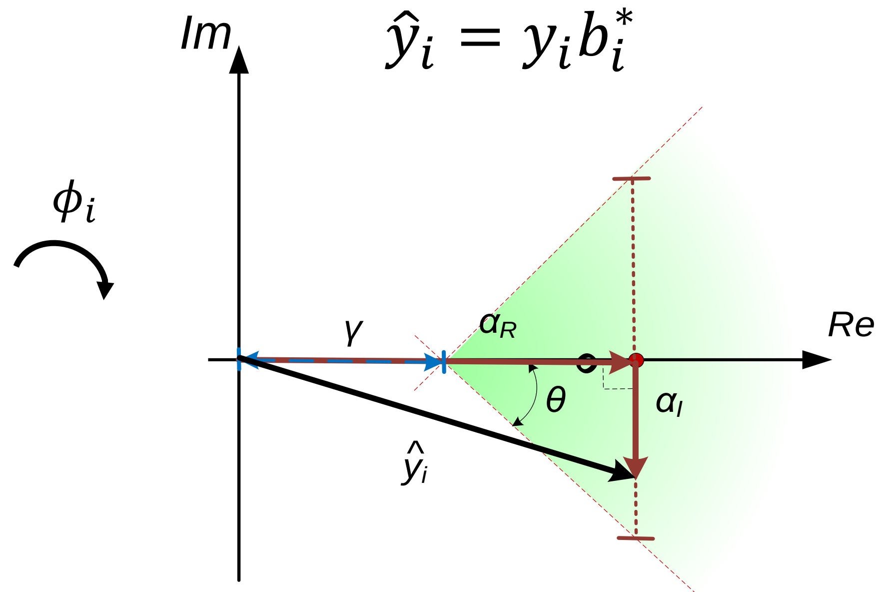
Optimization based Interference Exploitation first introduced in the context of Vector Perturbation:

C. Masouros, M. Sellathurai, T. Ratnarajah, "Vector Perturbation Based on Symbol Scaling for Limited Feedback MIMO Downlinks", IEEE Trans. Sig. Proc., vol. 62, no. 3, pp. 562-571, Feb.1, 2014

Constructive Interference for M-PSK



$$b_i = e^{j\phi_i}$$



$$\hat{y}_i = y_i b_i^*$$

<u>Constructive Interference:</u>

1. $\alpha_R \geq \gamma$
2. $|\alpha_I| \leq (\alpha_R - \gamma)\tan\theta$

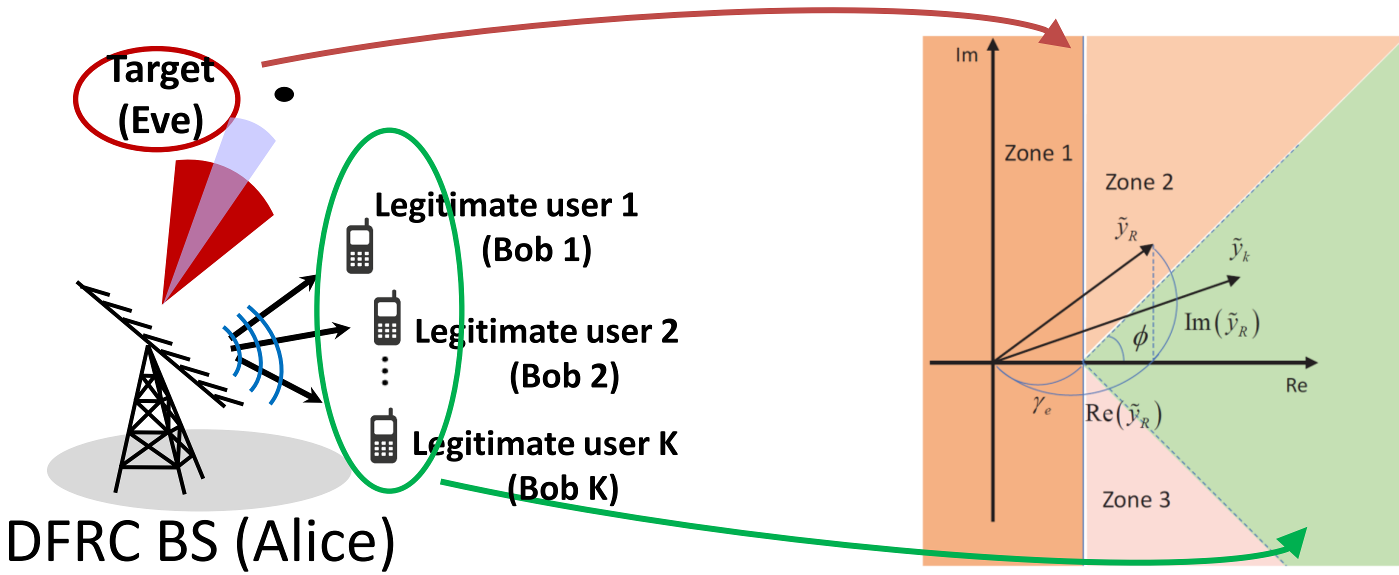
$$\alpha_R = Re(\hat{y}_i),\ \alpha_I = Im(\hat{y}_i)$$

$$\theta = \frac{\pi}{M}, \gamma = \sqrt{\Gamma_i N_0}$$

C. Masouros and G. Zheng, "Exploiting Known Interference as Green Signal Power for Downlink Beamforming Optimization", IEEE Trans. Sig. Proc., vol.63, no.14, pp.3668-3680, July, 2015

A. Li, *et. al*, "A Tutorial on Interference Exploitation via Symbol-Level Precoding: Overview, State-of-the-Art and Future Directions", IEEE Comms. Surveys and tutorials., vol. 22, no. 2, pp. 796-839, 2020

Exploiting Interference for Secure DFRC



$$\max_{\mathbf{x}} \quad \min_{\theta_p \in \mathrm{card}(\Psi)} \frac{\mu \left| \mathbf{w}^H \mathbf{U}\left(\theta_p\right) \mathbf{x} \right|^2}{\mathbf{w}^H \left(\boldsymbol{\Sigma}\left(\mathbf{x}\right) + \mathbf{I}_{N_R} \right) \mathbf{w}} \tag{38a}$$

← Radar SNR

$$\text{s.t.} \quad \left\|\mathbf{x}\right\|^2 \leq P_0 \tag{38b}$$

$$\left| \mathrm{Im}\left(\tilde{\mathbf{h}}_k^H \mathbf{x} \right) \right| \leq \left(\mathrm{Re}\left(\tilde{\mathbf{h}}_k^H \mathbf{x} \right) - \sqrt{\sigma_{C_k}^2 \Gamma_k} \right) \tan\phi, \forall k \tag{38c}$$

← Constructive interference to users

$$\left| \mathrm{Im}\left(\alpha_0 \tilde{\mathbf{a}}_t^H \left(\beta_p\right) \mathbf{x} \right) \right| \geq \left(\mathrm{Re}\left(\alpha_0 \tilde{\mathbf{a}}_t^H \left(\beta_p\right) \mathbf{x} \right) - \sqrt{\sigma_T^2 \Gamma_T} \right) \tan\phi, \forall p, \tag{38d}$$

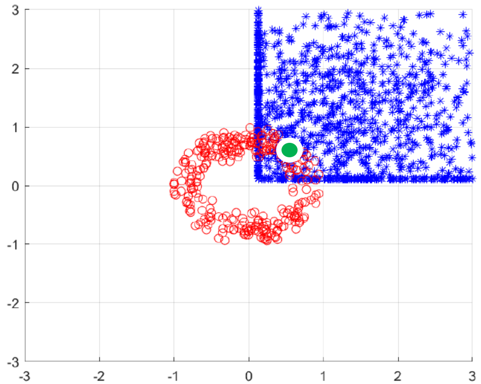
← Destructive interference to target (Eve)

N. Su, F. Liu, Z. Wei, Y. Liu, C. Masouros, "Secure Dual-Functional Radar-Communication Transmission: Exploiting Interference for Resilience Against Target Eavesdropping", IEEE Trans. Wireless Comms. *In press*

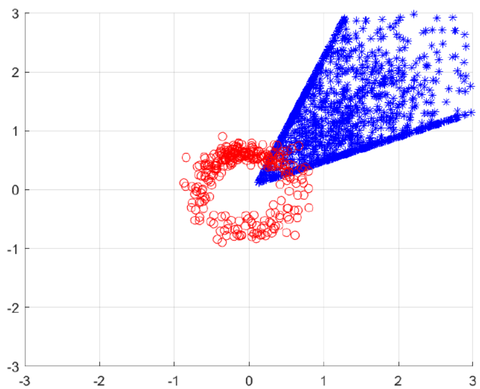
N = 10 antennas, *K* = 5 legitimate users, one target.

Signal Constellations at users / target

Constructive interference

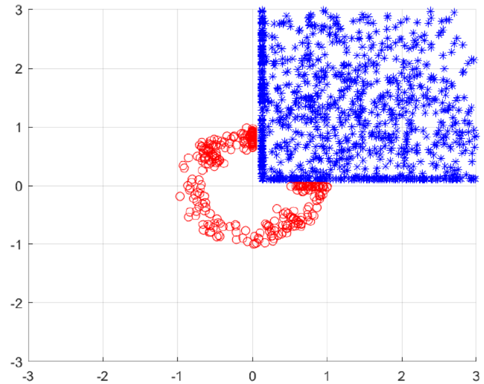


(a) QPSK, CI

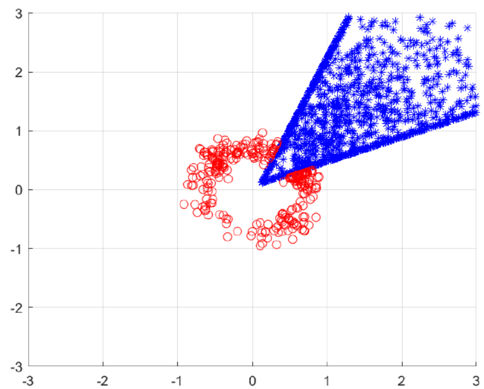


(c) 8PSK, CI

Constructive - Destructive interference

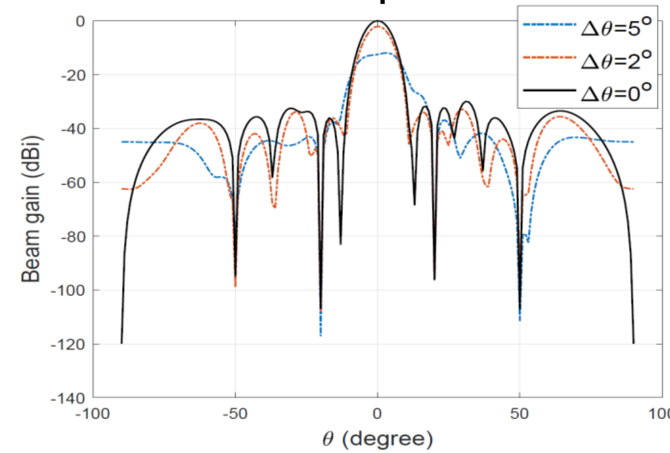


(b) QPSK, CI-DI

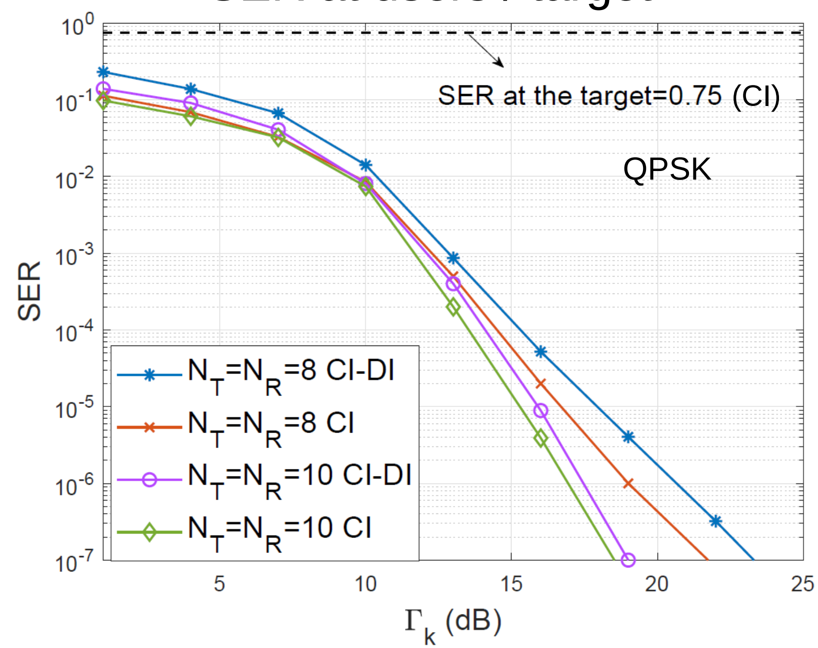


(d) 8PSK, CI-DI

Radar beampattern



SER at users / target



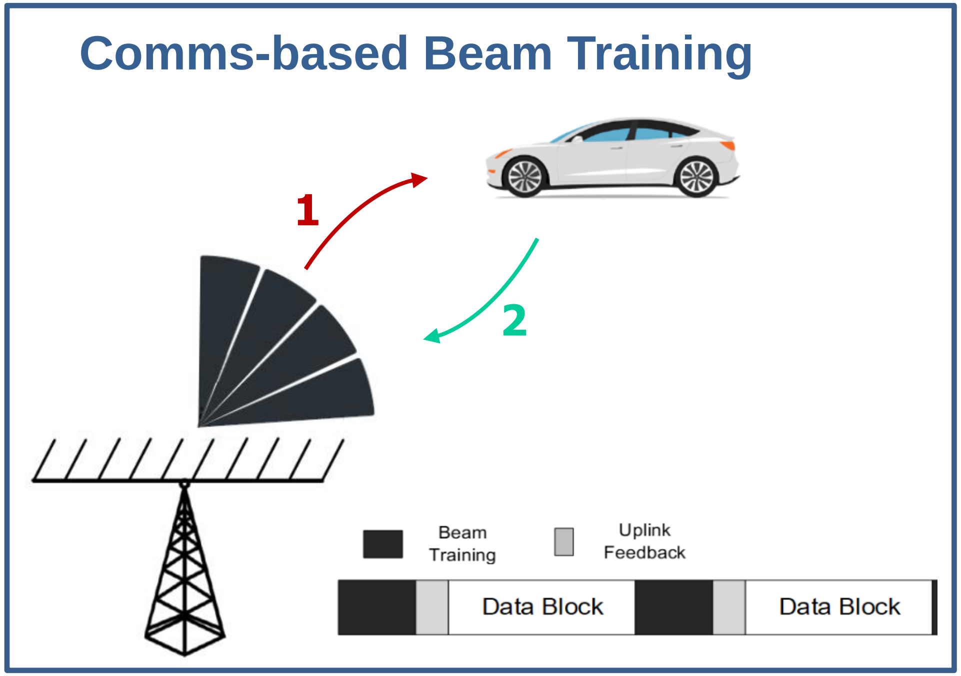
N. Su, F. Liu, Z. Wei, Y. Liu, C. Masouros, "Secure Dual-Functional Radar-Communication Transmission: Exploiting Interference for Resilience Against Target Eavesdropping", IEEE Trans. Wireless Comms. *In press*

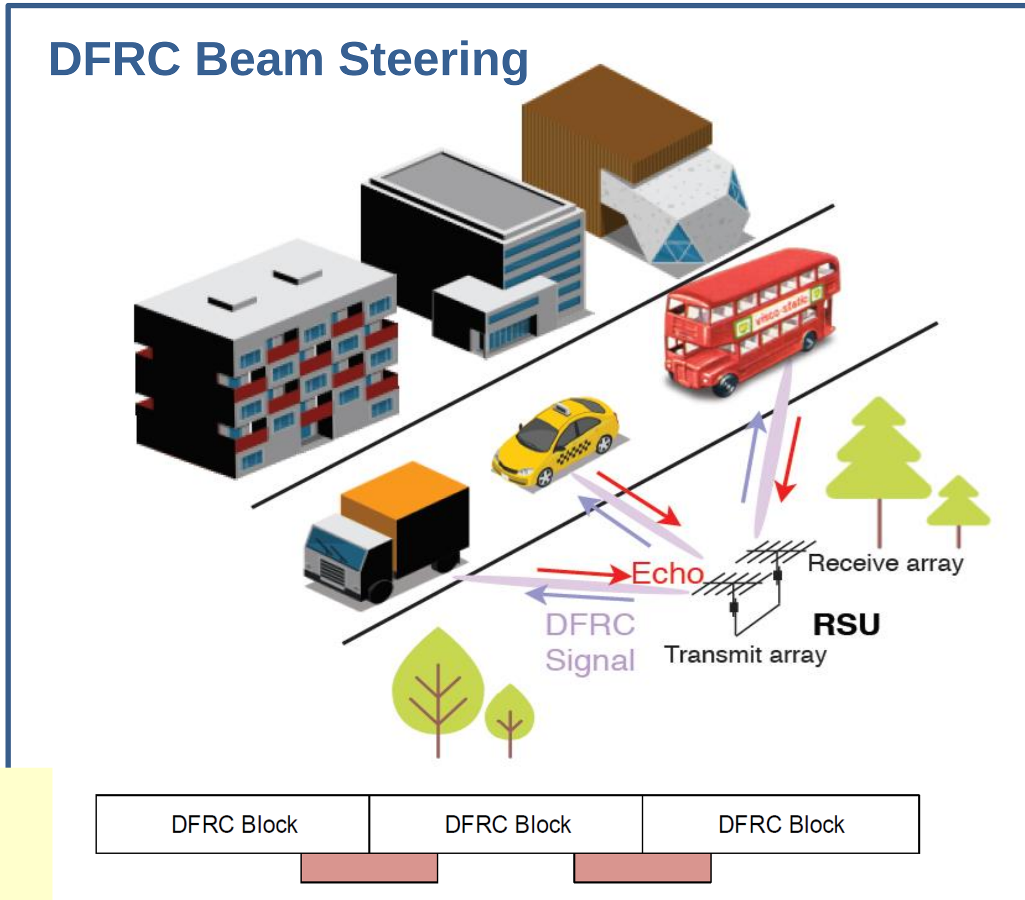
Radar-assisted Vehicular Network

Communication Served by Sensing

Radar-assisted Vehicular Network:

Comms served by Sensing: Radar tracking for Comms beam-steering

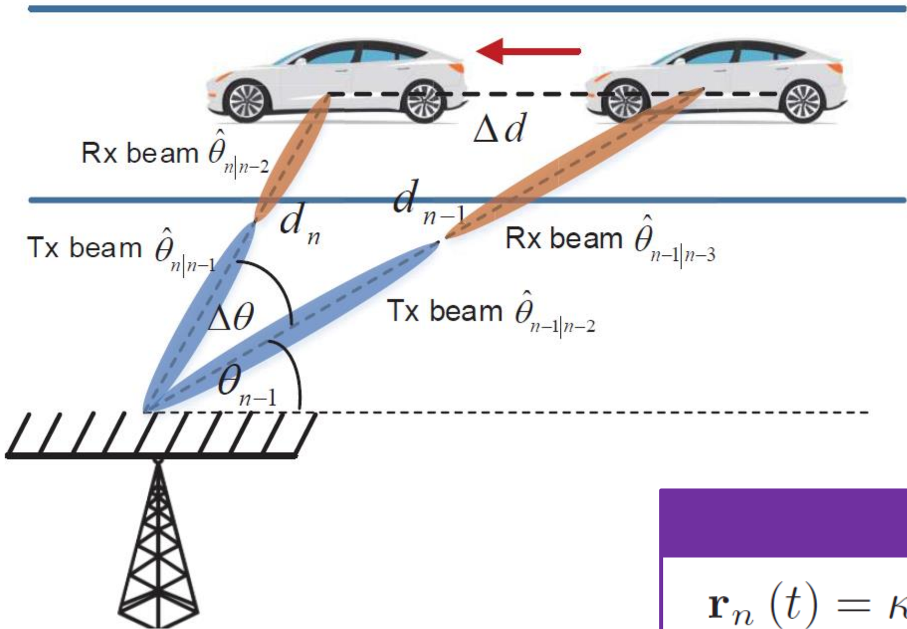




Advantages of DFRC Signalling:

- No dedicated downlink pilots are needed;
- No uplink feedback is needed;
  - No feedback overhead/errors
  - No quantization errors
- The whole downlink frame can be used for tracking → Significant matched-filtering gain

System Model - Signal Model



State transition model

$$\mathbf{x}_n = \mathbf{g}(\mathbf{x}_{n-1}) + \boldsymbol{\omega}_n$$

$$= \begin{cases} \theta_n = \theta_{n-1} + d_{n-1}^{-1} v_{n-1} \Delta T \sin\theta_{n-1} + \omega_{\theta,n}, \\ d_n = d_{n-1} - v_{n-1}\Delta T \cos\theta_{n-1} + \omega_{d.n}, \\ v_n = v_{n-1} + \omega_{v,n}, \\ \beta_n = \beta_{n-1}\left(1 + d_{n-1}^{-1} v_{n-1}\Delta T \cos\theta_{n-1}\right) + \omega_{\beta,n}, \end{cases}$$

Radar measurement model

$$\mathbf{r}_n(t) = \kappa\sqrt{p_n}\beta_n e^{j2\pi\mu_n t}\mathbf{b}(\theta_n)\mathbf{a}^H(\theta_n)\mathbf{f}_n s_n(t-\tau_n) + \mathbf{z}_n(t)$$

matched filtering

$$\mathbf{y}_n = \mathbf{h}(\mathbf{x}_n) + \tilde{\mathbf{z}}_n$$

$$= \begin{cases} \tilde{\mathbf{r}}_n = \beta_n\sqrt{Gp}\kappa\mathbf{b}(\theta_n)\mathbf{a}^H(\theta_n)\mathbf{f}_n + \mathbf{z}_{\theta,n} \\ \hat{\tau}_n = \dfrac{2d_n}{c} + z_{\tau,n} \quad \text{Round-trip delay} \\ \hat{f}_{D,n} = \dfrac{2v_n\cos\theta_n f_c}{c} + z_{f,n} \quad \text{Doppler offset} \end{cases}$$

Communication model

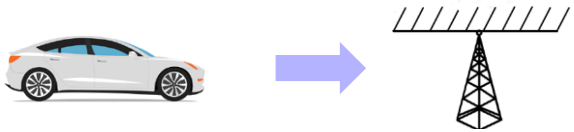
$$c_n(t) = \tilde{\kappa}\sqrt{p_n}\alpha_n\mathbf{w}_n^H\mathbf{u}(\theta_n)\mathbf{a}^H(\theta_n)\mathbf{f}_n s_n(t) + z_c(t),$$

Predictive Beamformers

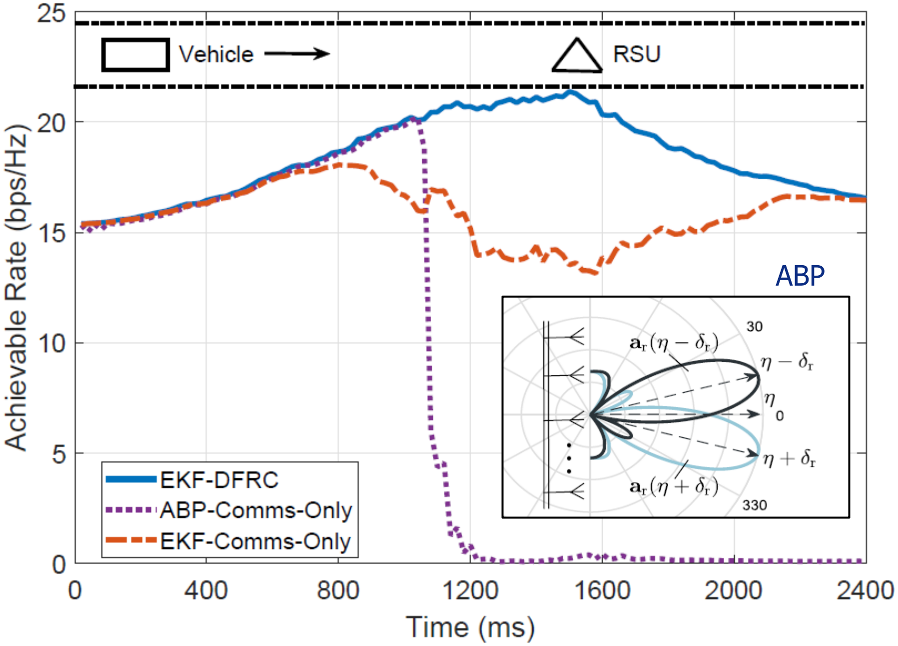
Tx: $\mathbf{f}_n = \mathbf{a}\left(\hat{\theta}_{n|n-1}\right)$ Rx: $\mathbf{w}_n = \mathbf{u}\left(\hat{\theta}_{n|n-2}\right)$

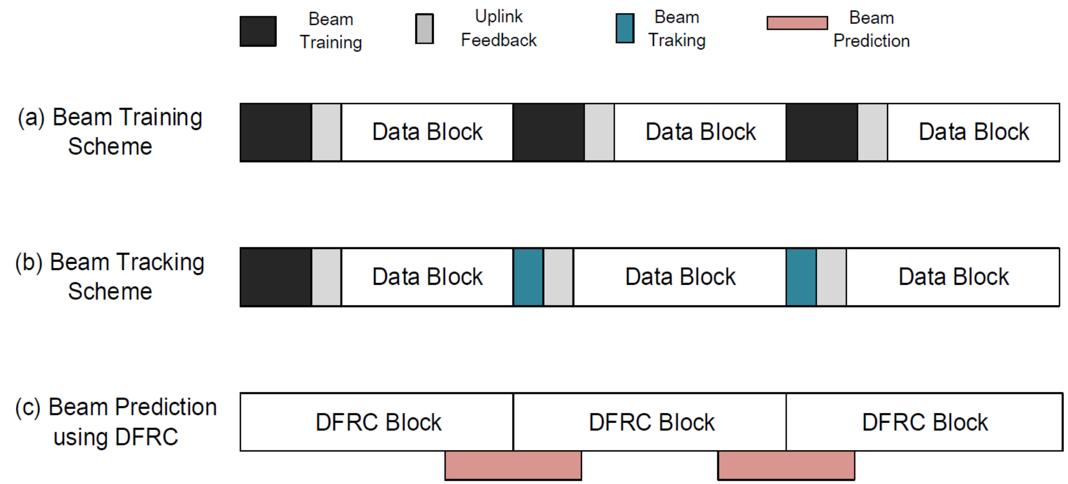
F. Liu, W. Yuan, C. Masouros and J. Yuan, "Radar-Assisted Predictive Beamforming for Vehicular Links: Communication Served by Sensing", IEEE Trans. Wireless Commun., vol. 19, no 11, pp. 7704-7719, Nov. 2020

Numerical Results - DFRC vs Comms only



N = 64, v_0 = 18m/s (65 km/hour), beamwidth: π/64





- EKF-Comms-only: poor angle estimation at RSU crossing point – suffering data rate
- Auxiliary Beam Pair (ABP) tracking: at RSU crossing point the correct beam will unlikely fall into angle search interval – beam goes beyond the search space and is not recovered
- EKF-DFRC: Minimal disruption in the rate

F. Liu, W. Yuan, C. Masouros and J. Yuan, "Radar-Assisted Predictive Beamforming for Vehicular Links: Communication Served by Sensing", IEEE Trans. Wireless Commun., vol. 19, no 11, pp. 7704-7719, Nov. 2020

Z. Du, F. Liu, W. Yuan, C. Masouros, Z. Zhang, S. Xia, and G. Caire, "Integrated Sensing and Communications for V2I Networks: Dynamic Predictive Beamforming for Extended Vehicle Targets," IEEE Trans. on Wireless Comms., under review

Future outlook - Cellular as a Sensor

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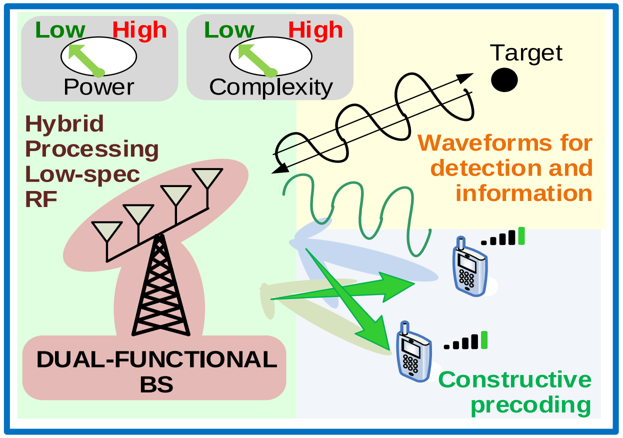
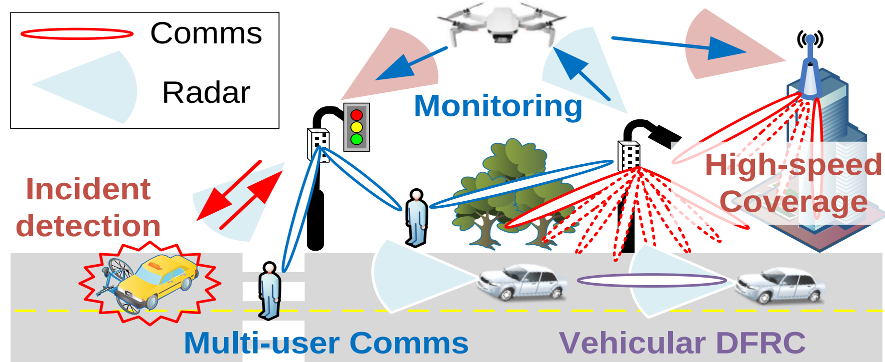
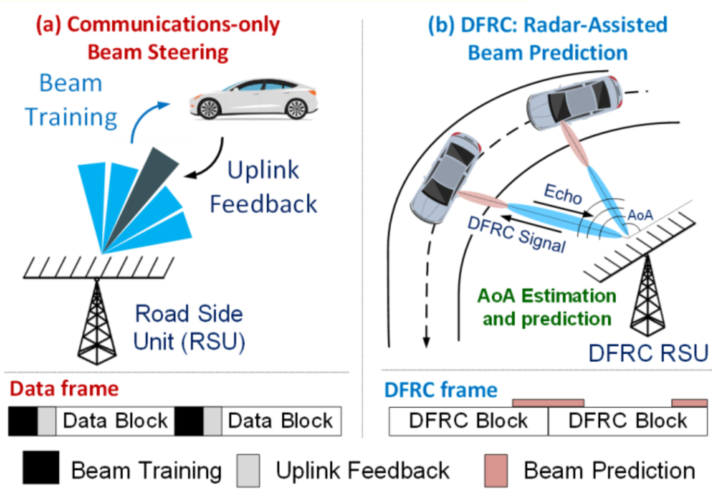
Hardware-Efficient DFRC



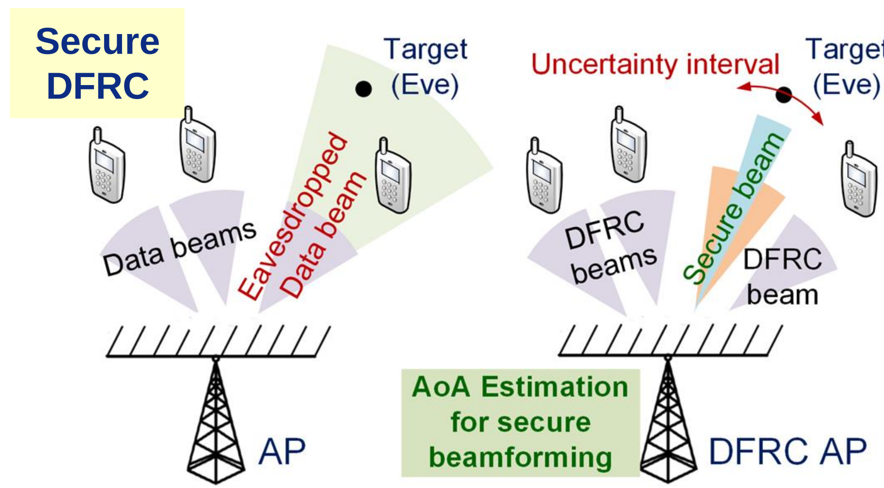
Pervasive sensing through dense cellular infrastructure



Sensing-Assisted Comms



Multicell / multi-static DFRC



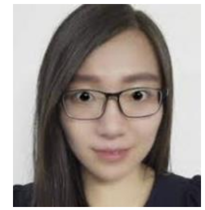
Thank you


Fan Liu

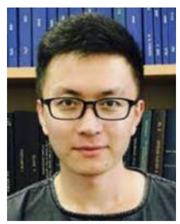

Iman Vailulahi


Xiaoye Jing


Abdel Salem


Xiaoyan Hu


Nanchi Su


Tongyang Xu


Ang Li


Murat Temiz


Nial Peters

UKRI [dstl] UDRC Project
Mar 2019 – Dec 2021 (£1m)

Marie Curie Fellowship
Nov 2018 – Oct 2020 (£160k)

GOV.UK Defence and Security Accelerator MoD DASA Project
Jul 2021 – Mar 2022 (£100k)

EPSRC CI-PHY Project
Apr 2018 – Jul 2021 (£1.1m)

EPSRC LeanCom Project
Oct 2019 – Nov 2023 (£860k)

PAINLESS Project
Oct 2018 – Sep 2022 (€4.2m)

References

Overviews

1. F. Liu, Y. Cui, C. Masouros, J. Xu, T. X. Han, A. Hassanien, Y. Eldar, S. Buzzi, “Integrated Sensing and Communications: Towards Future Dual-functional Wireless Networks”, IEEE Journal on Sel. Areas Comms., in press
2. Z. Wei, F. Liu, C. Masouros, N. Su, A. Petropulu, “Towards Multi-Functional 6G Wireless Networks: Integrating Sensing, Communication and Security” IEEE Wireless Comms Mag., in press
3. J. A. Zhang, F. Liu, C. Masouros, R. W. Heath, Z. Feng, L. Zheng, A. Petropulu, “An Overview of Signal Processing Techniques for Joint Communication and Radar Sensing” IEEE Jour. Selected Topics Sig Proc, vol. 15, no. 6, pp. 1295-1315, Nov. 2021
4. F. Liu and C. Masouros, "A Tutorial on Joint Radar and Communication Transmission for Vehicular Networks - *Parts I - III*", IEEE Commun. Lett., vol. 25, no. 2, pp. 322-336, Feb. 2021 *- EiC Invited Paper*
5. F. Liu, C. Masouros, H. Griffiths, A. Petropulu, and L. Hanzo, “Joint Radar and Communication Design: Applications, State-of-the-art, and the Road Ahead”, IEEE Trans Commun., vol. 68, no. 6, pp. 3834-3862, June 2020. *– EiC invited paper*

Book Chapter

6. F. Liu, C. Masouros, “Communication and Radar systems: Spectral Co-existence and Beyond”, published by the Wiley Press book “Spectrum Sharing: The Next Frontier in Wireless Networks”, Edited by: Constantinos Papadias, Tharm Ratnarajah, Dirk Slock, 2020 edition Wiley Press *– Invited*

Radar-Comms Coexistence

7. F. Liu, A. Garcia, C. Masouros, and G. Geraci, “Interfering Channel Estimation in Radar-Cellular Coexistence: How Much Information Do We Need?”, IEEE Trans. Wireless Comm., vol. 18, no. 9, pp. 4238-4253, Sept. 2019
8. F. Liu, C. Masouros, A. Li, T. Ratnarajah and J. Zhou, “MIMO Radar and Cellular Coexistence: A Power-Efficient Approach Enabled by Interference Exploitation”, IEEE Trans. Sig Proc, vol. 66, no. 14, pp. 3681-3695, July 2018,
9. F. Liu, C. Masouros, A. Li, and T. Ratnarajah, "Robust MIMO Beamforming for Cellular and Radar Coexistence," IEEE Wireless Commun. Lett., vol. 6, no. 3, pp. 374-377, June 2017.
10. F. Liu, L. Zhou, C. Masouros, A. Li, A. Petropulu, “Dual-functional cellular and radar transmission: Beyond co-existence”, IEEE SPAWC 2018

References

Dual-functional Radar-Communication

11. F. Liu, Y. Liu, A. Li, C. Masouros, Y. Eldar, “Cramér-Rao Bound Optimization for Joint Radar-Communication Design”, IEEE Trans. Sig. Proc., vol. 70, pp. 240-253, 2022
12. L. Chen, F. Liu, W. Wang, and C. Masouros, "Joint Radar-Communication Transmission: A Generalized Pareto Optimization Framework", IEEE Trans. Signal Process., vol. 69, pp. 2752-2765, 2021.
13. F. Liu, C. Masouros, T. Ratnarajah, and A. Petropulu, “On Range Sidelobe Reduction for Dual-functional Radar-Communication Waveforms”, IEEE Wireless Commun. Lett., 2020.
14. F. Liu, C. Masouros, A. Li, H. Sun, and L. Hanzo, “MU-MIMO Communications and MIMO Radar: From Co-existence to Joint Transmission”, IEEE Trans. Wireless Commun., vol. 17, no. 4, pp. 2755-2770, April 2018
15. F. Liu, L. Zhou, C. Masouros, A. Li, W. Luo, and A. Petropulu, "Toward Dual-functional Radar-Communication Systems: Optimal Waveform Design," IEEE Trans Signal Process., vol. 66, no. 16, pp. 4264-4279, Aug. 2018.
16. F. Liu and C. Masouros, “Jont Beamforming Design for Extended Target Estimation and Multiuser Communication”, IEEE RadarConf 2020 - Special Session on Coexistence of Radar and Communication Systems – *Invited paper*
17. F. Liu, L. Zhou, C. Masouros, A. Li, and A. Petropulu, “Dual-functional cellular and radar transmission: Beyond co-existence”, IEEE SPAWC 2018 – Special Session on Spectrum Sharing and Co-Existence - *Invited paper*
18. F. Liu, C. Masouros, A. Li, J. Zhou, and L. Hanzo, "Simultaneous Target Detection and Multi-user Communications Enabled by Joint Beamforming," IEEE RadarConf 2018.
19. L. Zhou, F. Liu, C. Tian, C. Masouros, A. Li, W. Jiang, and W. Luo, "Optimal Waveform Design for Dual-functional MIMO Radar-Communication Systems," IEEE/CIC ICCC 2018

Hardware-efficient DFRC Transmission

20. I. Valiulahi, A. Salem, C. Masouros, F. Liu “Antenna Selection for Energy-Efficient Dual-Functional Radar-Communication Systems”, IEEE Wireless Comms. Let., in press
21. X. Hu, C. Masouros, F. Liu, R. Nissel, “MIMO-OFDM Dual-Functional Radar-Communication Systems: Low-PAPR Waveform Design”, IEEE Trans. Comms, in press
22. O. Dizdar, A. Kaushik, B. Clerckx, C. Masouros, “Rate-Splitting Multiple Access for Joint Radar-Communications with Low-Resolution DACs”, IEEE Trans. Coms., in press
23. F. Liu and C. Masouros, "Hybrid Beamforming With Sub-arrayed MIMO Radar: Enabling Joint Sensing and Communication at mmWave Band," IEEE ICASSP 2019.

References

Secure DFRC Transmission

24. N. Su, F. Liu, Z. Wei, Y. Liu, C. Masouros, “Secure Dual-Functional Radar-Communication Transmission: Exploiting Interference for Resilience Against Target Eavesdropping”, IEEE Trans. Wireless Comms., in press
25. N. Su, F. Liu, and C. Masouros, “Secure Radar-Communication Systems with Malicious Targets: Integrating Radar, Communications and Jamming Functionalities”, IEEE Trans. Wireless Comm., *vol. 20, no. 1, Jan. 2021*
26. N. Su, F. Liu, and C. Masouros, “Enhancing the Physical Layer Security of Dual-functional Radar-Communication Systems”, IEEE GLOBECOM 2019

Vehicular DFRC Transmission

27. Z. Du, F. Liu, W. Yuan, C. Masouros, Z. Zhang, G. Caire, “Integrated Sensing and Communications for V2I Networks: Dynamic Predictive Beamforming for Extended Vehicle Targets”, IEEE Trans. Wireless Comms., under review
28. W. Yuan, F. Liu, C. Masouros, J. Yuan, D. W. K. Ng, and N. G. Prelcic, "Bayesian Predictive Beamforming for Vehicular Networks: A Low-Overhead Joint Radar-Communication Approach", IEEE Trans. Wireless Commun., vol. 20, no. 3, pp. 1442-1456, March 2021
29. F. Liu, W. Yuan, C. Masouros, and J. Yuan, “Radar-assisted Predictive Beam-forming for Vehicular Links: Communication Served by Sensing”, IEEE Trans. Wireless Commun., vol. 19, no 11, pp. 7704-7719, Nov. 2020
30. W. Yuan, F. Liu, C. Masouros, J. Yuan, and D. W. K. Ng, "Joint Radar-Communication Based Bayesian Predictive Beamforming for Vehicular Networks", IEEE RadarConf 2020, Special Session on Multi-Function Spectral System Co-Design – *Invited paper*
31. C. Aydogdu, F. Liu, C. Masouros, H. Wymeersch, and M. Rydström, "Distributed Radar-aided Vehicle-to-Vehicle Communication", IEEE RadarConf 2020.
32. F. Liu, W. Yuan, C. Masouros, and J. Yuan, “Radar-assisted Predictive Beamforming for Vehicle-to-Infrastructure Links”, IEEE ICC 2020, Workshop on Communication and Radar Spectrum Sharing

DFRC expreiments

33. T. Xu, F. Liu, C. Masouros, I. Darwazeh, “An Experimental Proof of Concept for Integrated Sensing and Communications Waveform Design”, IEEE Transactions on Communications, in press