Beyond 5G Communications

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Three Points

- Cell-free massive MIMO
- New waveforms for B5G/6G
- Intelligent Reflecting Surfaces: phase optimization

Cell-Free Massive MIMO

Joint work with Anubhab Chowdhury
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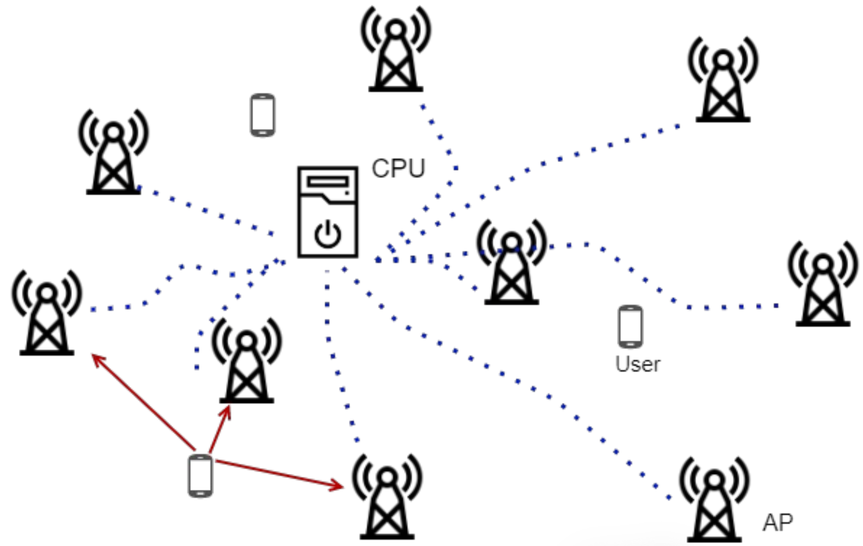
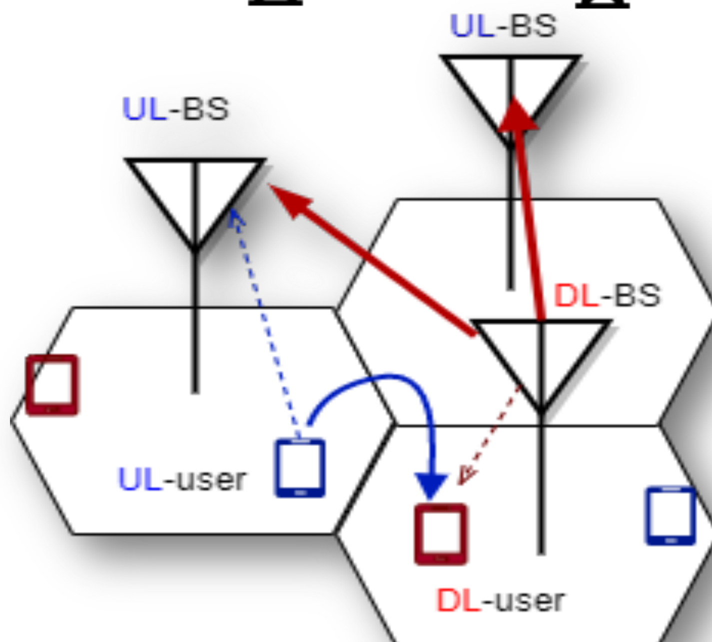
What are Cell-Free and Dynamic TDD?

- All APs (BSs) process data to/from all UEs
- Dynamic TDD: each AP can independently choose to operate in UL/DL in each slot





C1	UL	UL	UL	UL	UL	DL	DL	DL
C2	DL	DL	DL	DL	UL	UL	UL	UL
C3	UL	UL	UL	UL	DL	DL	DL	DL

Three Questions

- Cell-free with half-duplex APs and dynamic TDD vs. cell-free or cellular with full duplex APs?
  - Cell free + dynamic TDD = virtual full duplex!
- Pilot design and allocation for cell-free systems?
  - All APs are required to estimate all users' channels
- How to handle the "slowness of the speed of light"?
  - Messes up the timing across APs

Some Findings

- HD-CF with many distributed APs and fewer antennas/AP is better than FD-massive MIMO cellular (& even FD CF!!)
  - Overall, HD-CF has
    - Better rate-region
    - Better resilience to interference
    - Better 90%ile rate, better fairness
- "Cell-edge" users' performance improves
  - More uniform quality of service across the cell
- Mutually unbiased orthogonal pilots far outperform orthogonal pilot reuse
- New timing advance and cyclic prefix duration optimization is needed for cell-free communications

HD-CF + DTDD vs. FD-Cellular: TCOM 2022: https://arxiv.org/abs/2110.09968

Cell-free under channel aging: https://arxiv.org/abs/2209.02777, https://arxiv.org/abs/2104.10404

New Waveforms for B5G/6G

Joint work with Arunkumar K. P. and Niladri Halder
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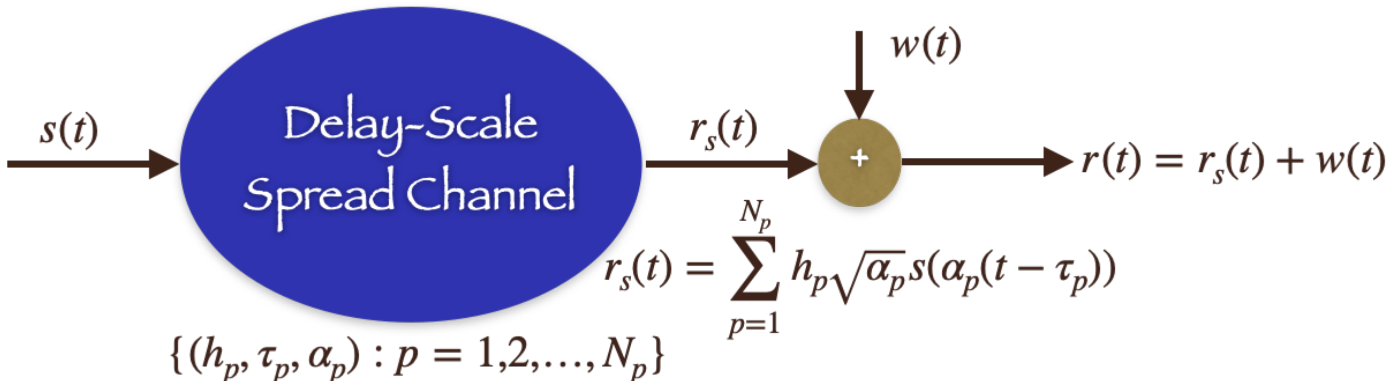
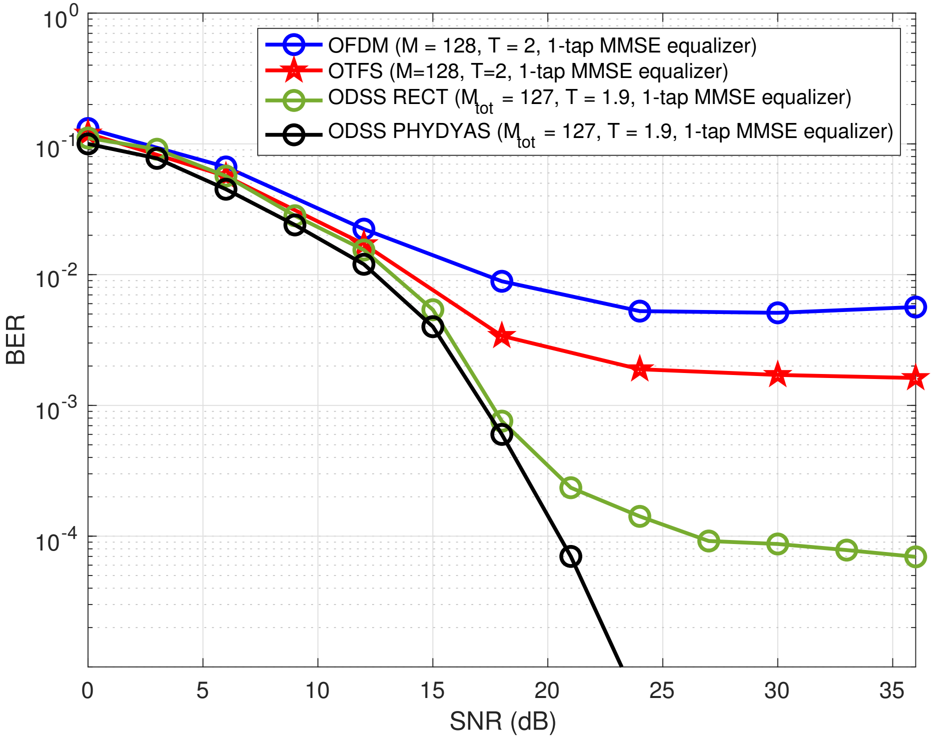
New Use-Cases

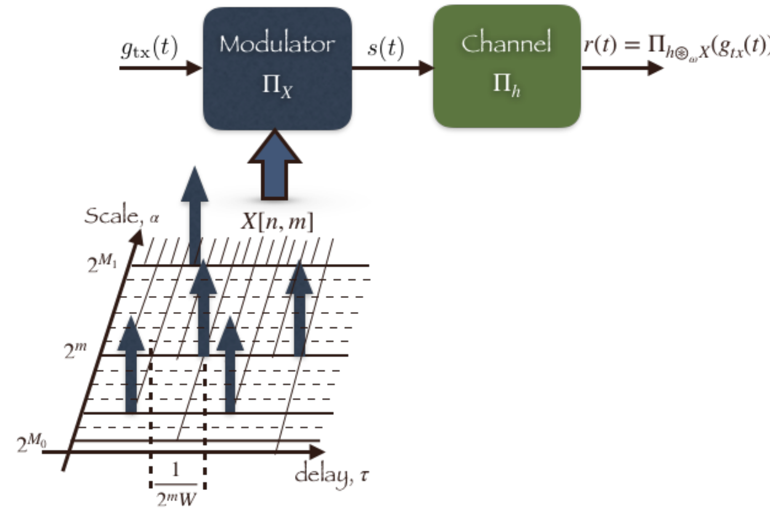
- Broadband rural communications
  - Sub GHz center frequency: wide coverage
  - High bandwidth, high velocity support
- The effect of Doppler can be approximated as a frequency shift only if $B/f_c \ll 1$ and $v \ll \frac{c}{2BT}$
- Otherwise, delay-scale channel:



Orthogonal Delay Scale Space Modulation

- Uses the Mellin Transform
- Mount symbols in the delay-scale domain





$$X[n,m] = \frac{q^{-n/2}}{N}\sum_{k=0}^{N-1}\frac{\sum_{l=0}^{M(k)-1} x[k,l]e^{j2\pi\left(\frac{ml}{M(k)}-\frac{nk}{N}\right)}}{M(k)}$$

$$s(t) = \sum_{n=0}^{N-1}\sum_{m=0}^{M(n)-1} X[n,m]q^{n/2}g_{\text{tx}}\left(q^n\left(t-\frac{m}{q^nW}\right)\right)$$

$P = 20, \tau_{max} = 10ms, \alpha_{max} = 1.001$

$\tau_{max}\delta f_{max} = 0.2 < 0.25$

https://ece.iisc.ac.in/~cmurthy/Papers/Journal_ODSS_Final_Arun_main.pdf, TSP 2022

IRS Phase Optimization

Joint work with Yashvanth L., QINF 2021, 2022
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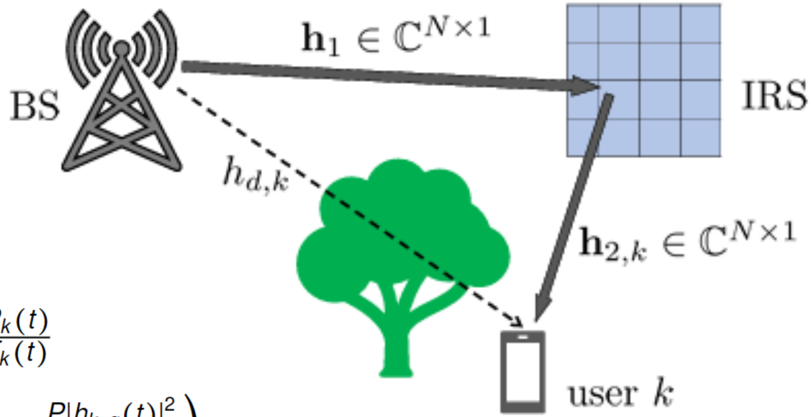
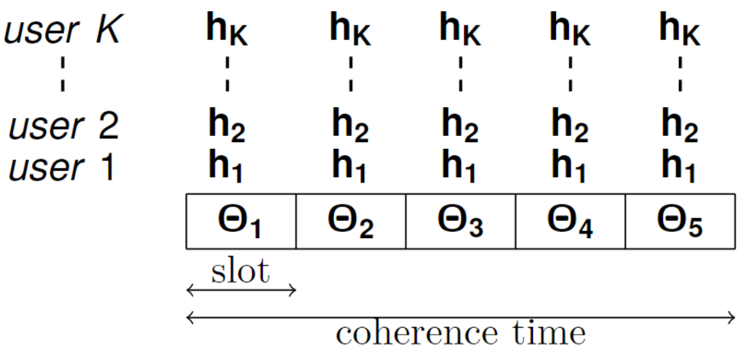
IRS Assisted Opportunistic User Scheduling*

Channel model:

$$h_{k,q}(t) = \sqrt{\beta_{r,k}}\mathbf{h}_{2,k}^H \mathbf{\Theta}_q(t)\mathbf{h}_1 + \sqrt{\beta_{d,k}} h_{d,k}.$$



Randomly configure the IRS phase angles in every time slot, and schedule the user with *highest PF metric* for transmission



$$k^* = \arg\max \frac{R_k(t)}{T_k(t)}$$

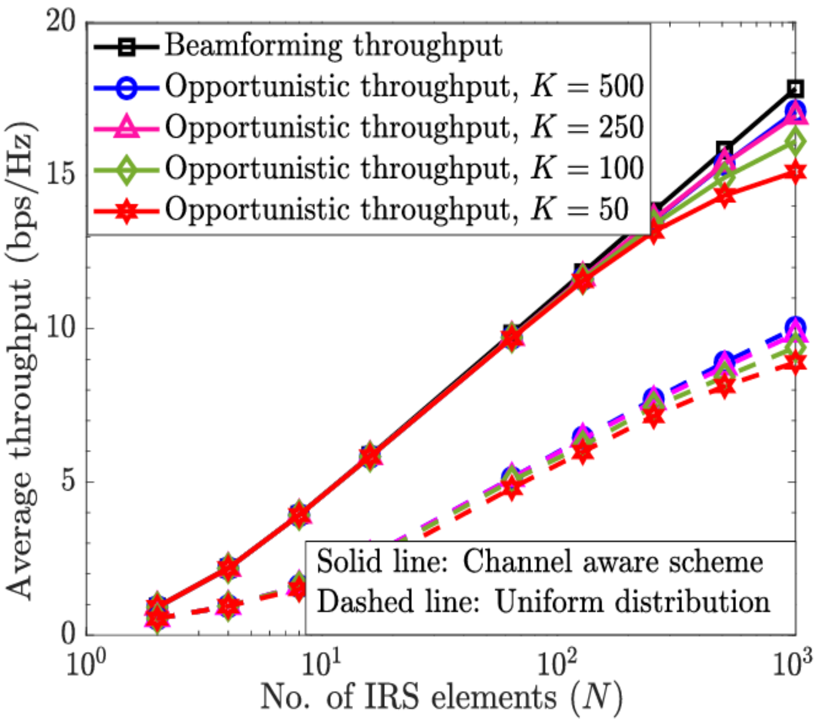
$$R_k(t) = \log_2\left(1 + \frac{P|h_{k,q}(t)|^2}{\sigma^2}\right)$$

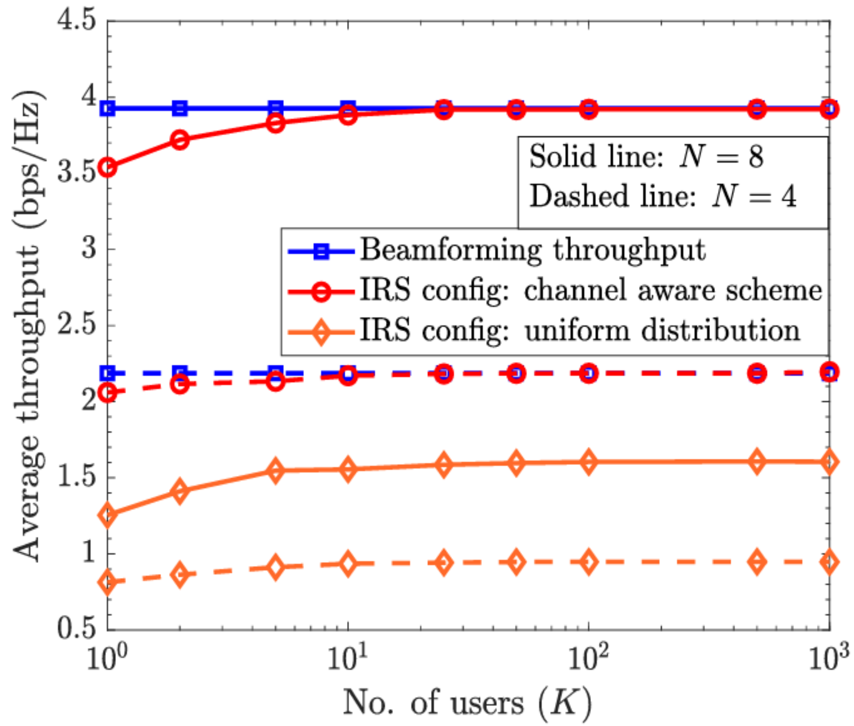
$$T_k(t+1) = \begin{cases} \left(1 - \frac{1}{t_c}\right) T_k(t) + \frac{1}{t_c} R_k(t), & k = k^* \\ \left(1 - \frac{1}{t_c}\right) T_k(t), & k \neq k^*. \end{cases}$$

Randomly chosen IRS configuration will be close to the beamforming (BF) configuration for at least one of the users

* ArXiv: https://arxiv.org/pdf/2203.06313

Performance





Optimal Random Distribution:

$$\theta_i = \frac{2\pi(i-1)d}{\lambda}(\sin(\theta_A) + \sin(\phi)); \phi \sim \mathcal{U}[\phi_0, \phi_1]$$

Rate scaling law:

$$\lim_{K\to\infty}\left(R^{(K)} - \mathcal{O}\left(\log_2\left(1 + \frac{\beta P}{\sigma^2}N^2 \ln K\right)\right)\right) = 0.$$

Outlook

- Lots of interesting work to do in B5G/6G systems
  - Intelligent reflecting surfaces
  - Cell-free systems
  - New frequency bands, mmWave, THz, VLC, etc
  - New waveforms
  - Joint sensing and communications
  - ML-based scheduling, beamforming, subcarrier allocation, security, etc
- Machine learning techniques may play a crucial role
  - Mismatched models
  - Learning to communicate
  - Novel applications with diverse QoS requirements

Summary

- Thank you!
- Questions? Comments?