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Lectio praecursoria

Millimeter-Wave Communication and Mobile Relaying in 5G Cellular Networks

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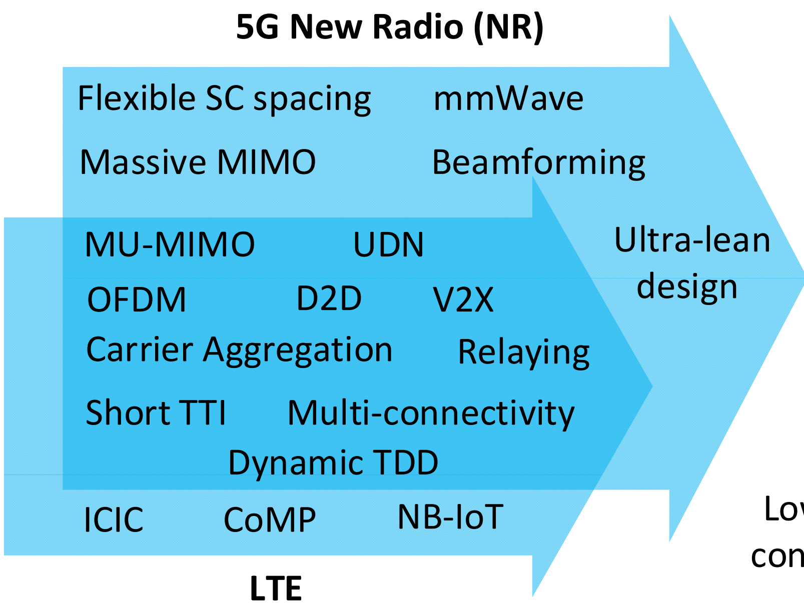
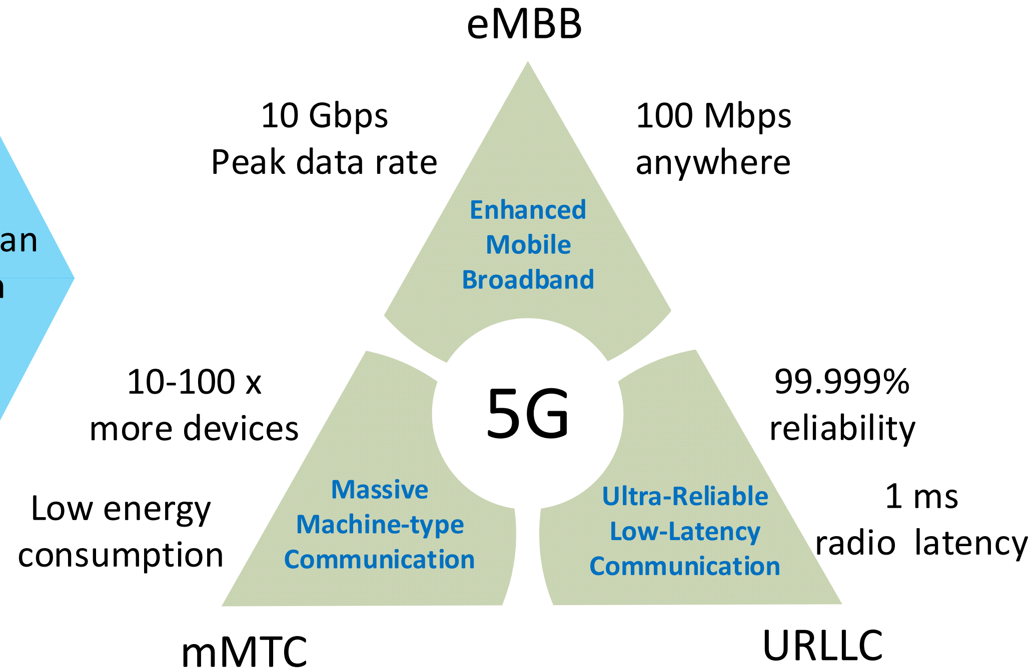
Tampere University of Technology

5G Requirements and Enabling Technologies



3GPP



ITU IMT-2020

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5G NR Spectrum

Wide & reliable coverage but limited bandwidth

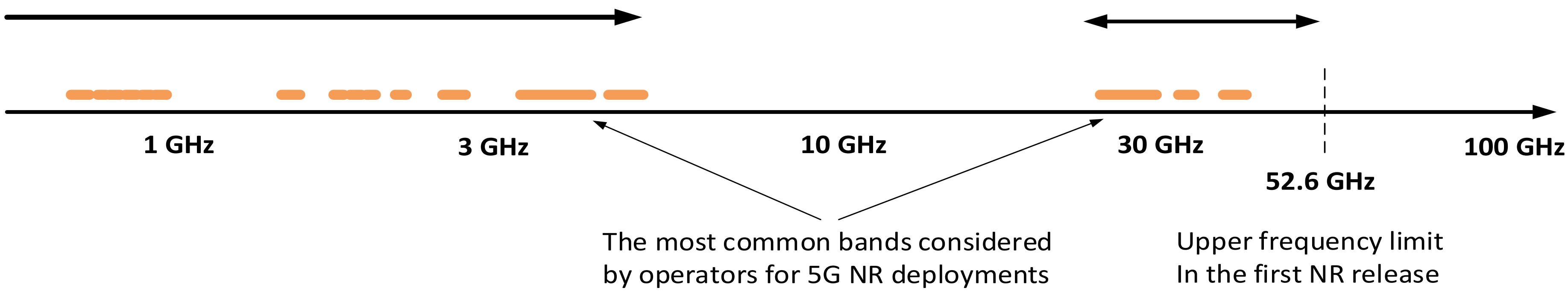
Frequency Range 1 (0.45 - 6 GHz)

Subcarrier spacing	15/30/60 kHz
Max carrier bandwidth	50/100/200 MHz

Large continuous bandwidth but vulnerable to blockage

Frequency Range 2 (24.25 - 52.6 GHz)

Subcarrier spacing	60/120 kHz
Max carrier bandwidth	200/400 MHz

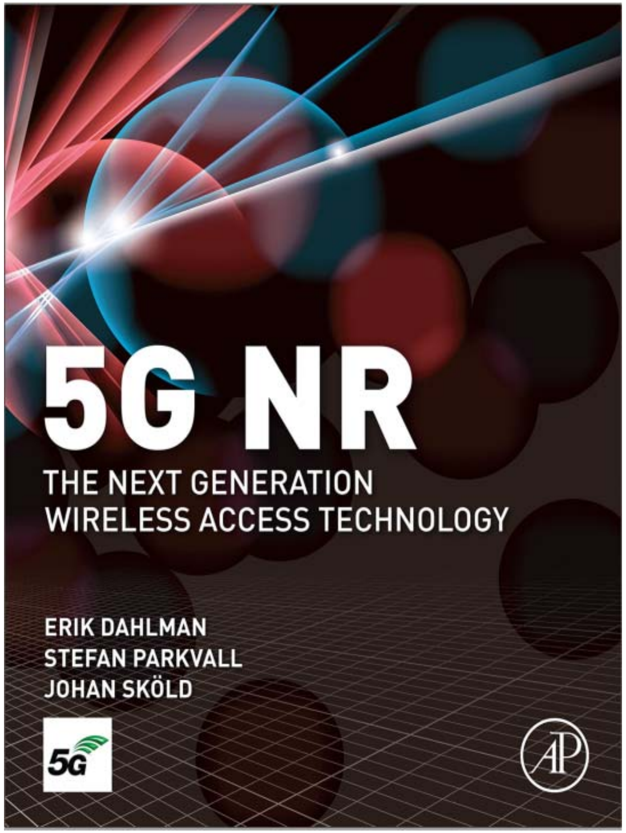


IoT mMTC URLLC

eMBB

5G is ready

- 2017-12: First non-standalone (NSA) 5G **New Radio (NR)** Specification
- 2018-06: First standalone (SA) 5G NR Specification
- 2019-10: World Radiocommunication Conference 2019 (WRC-19)



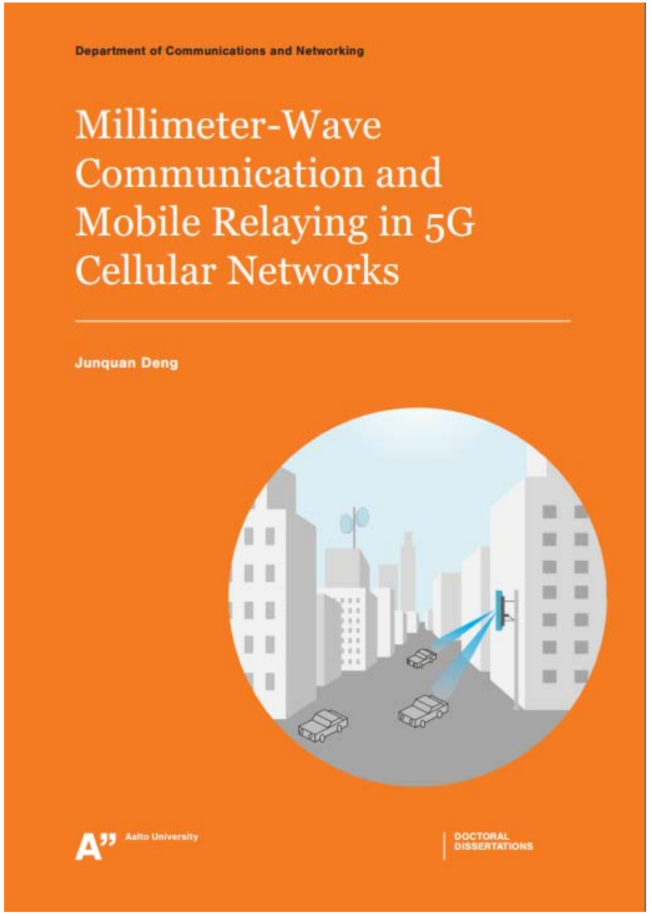
Challenges in 5G Deployment

- Dense infrastructures required to provide **consistent user experience** for eMBB
- High capital expenditure for operators
- High operating expenditure for operators
- High charge for mobile users

5G Operator

Towards Cost-Effective 5G Cellular Systems

- Utilize D2D technology and the availability of ubiquitous user devices to relay the network traffic
  - Low-complexity algorithms for relay selection, resource allocation and interference management
- Low-cost mmWave BS architectures with cheap radio-frequency components
  - Efficient mmWave channel estimation and MU-MIMO precoding/combing schemes



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Contributions of the Thesis

- **Investigate the performances of D2D relaying in various network settings**
  - Uplink D2D Relaying under Cellular Power Control
  - Downlink D2D Relaying with Interference Management
  - MmWave D2D Relaying for Blockage Avoidance
  - D2D Relaying in Integrated mmWave/sub-6-GHz Networks
- **Design low-cost mmWave BS architectures for dense network deployments**
  - MmWave BS Architecture with Subarrays and Quantized Phase-Shifters
  - MmWave Channel Estimation based on Compressive Sensing
  - Low-complexity Multi-User MIMO Precoding and Combining

Research Methods

Theoretical analysis

- With simplified system models
- Interference analysis
- SINR
- Shannon Formula
- …

Numerical simulation

- With detailed system models
- Practical network scenarios
- 3GPP channel models
- Ray tracing channel models
- …

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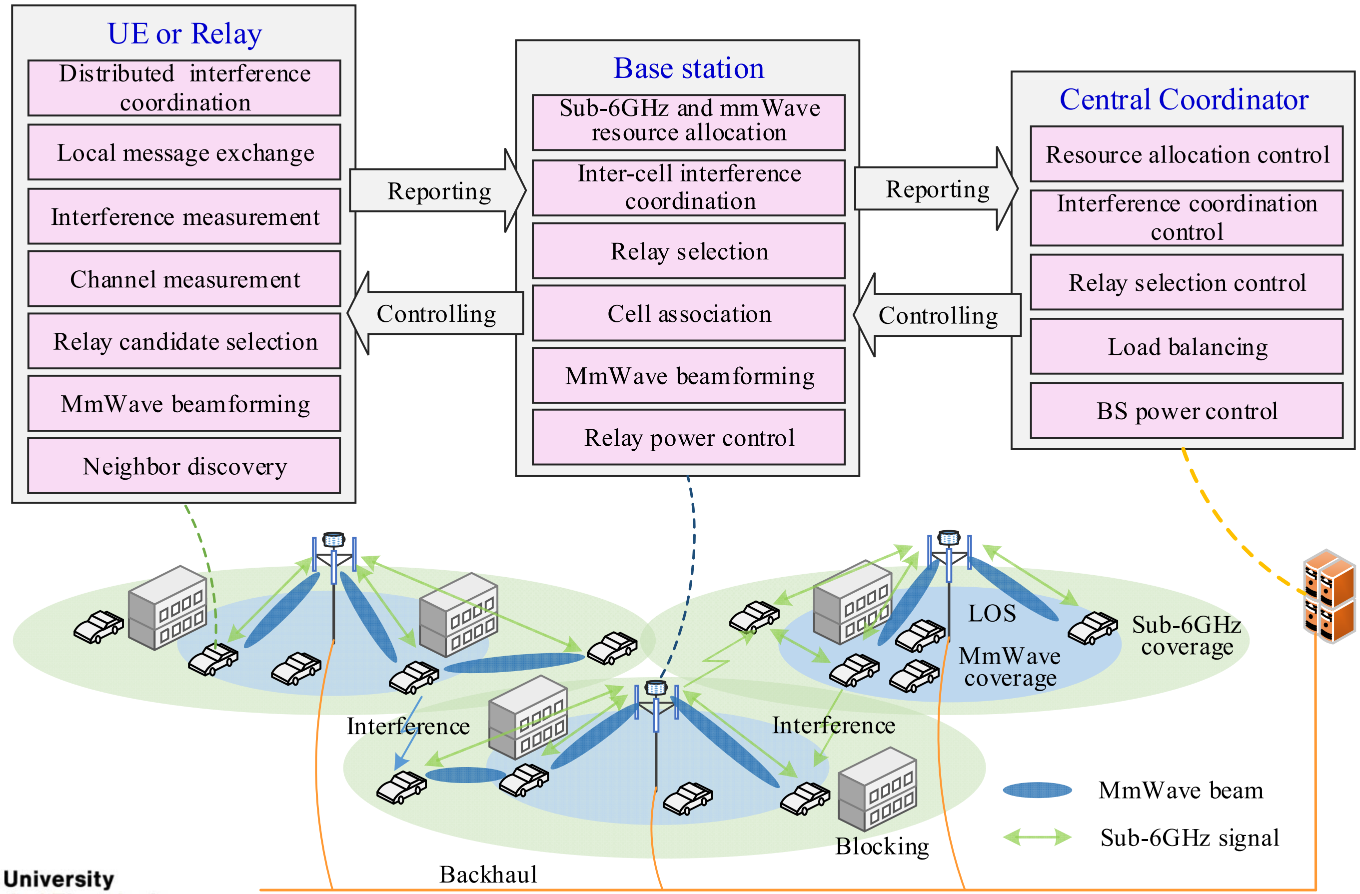
Design and Evaluation of Device-to-Device Relaying in Various Network Scenarios

Considered Framework for D2D relaying in 5G



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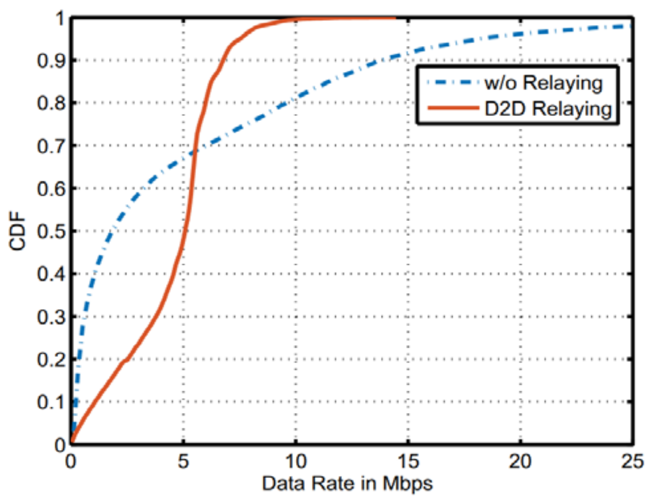
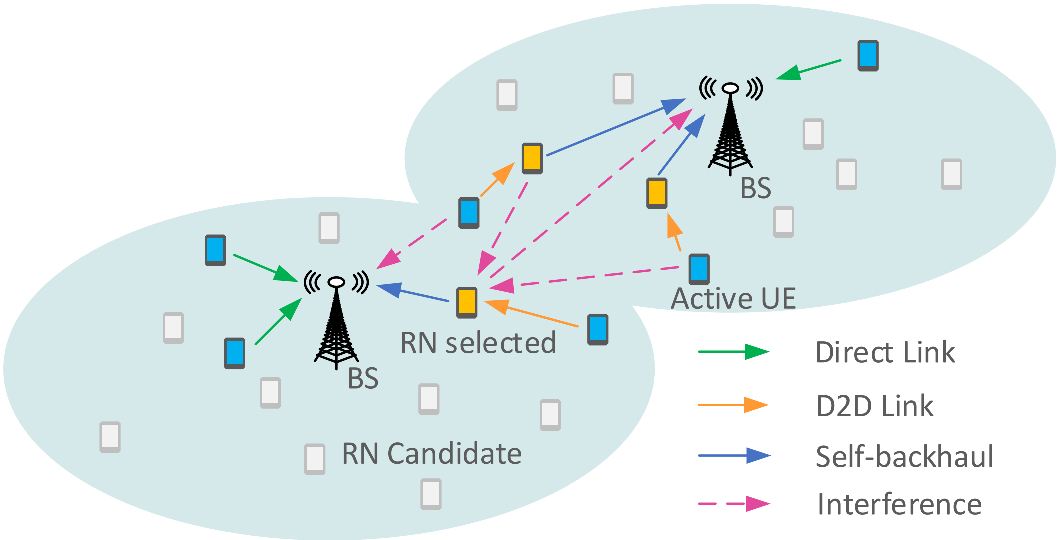
Scenario 1: Uplink D2D Relaying under Cellular Power Control

- Sub-6-GHz, wide coverage, mMTC & URLLC
- Power-limited for cell-edge users
- Cell-edge users with limited power budgets can use more resource blocks for transmissions to the BS with D2D relaying





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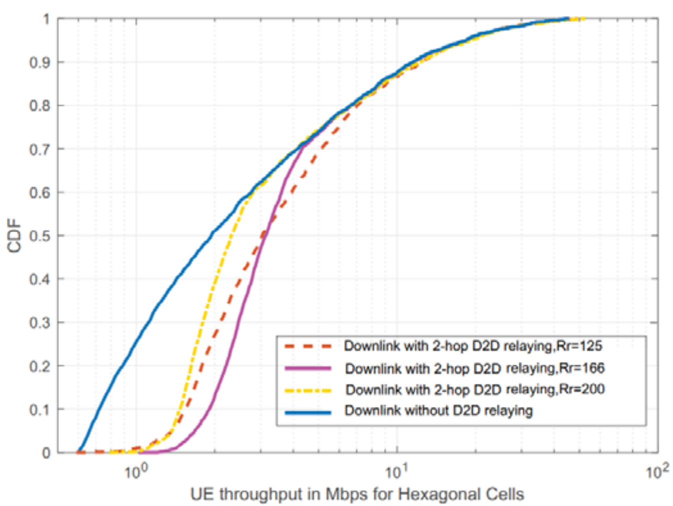
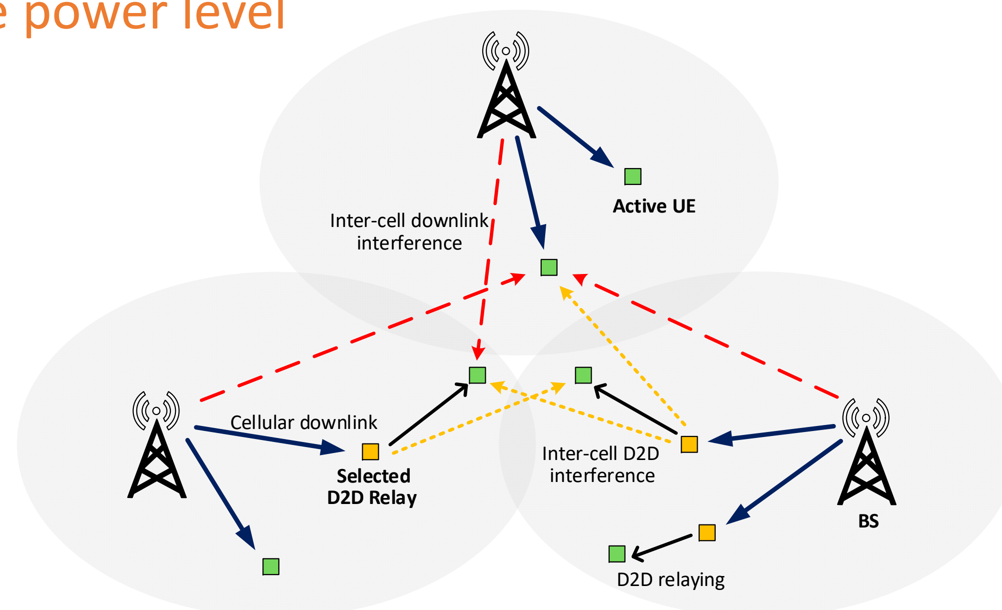
Scenario 2: Downlink D2D Relaying with Interference Management

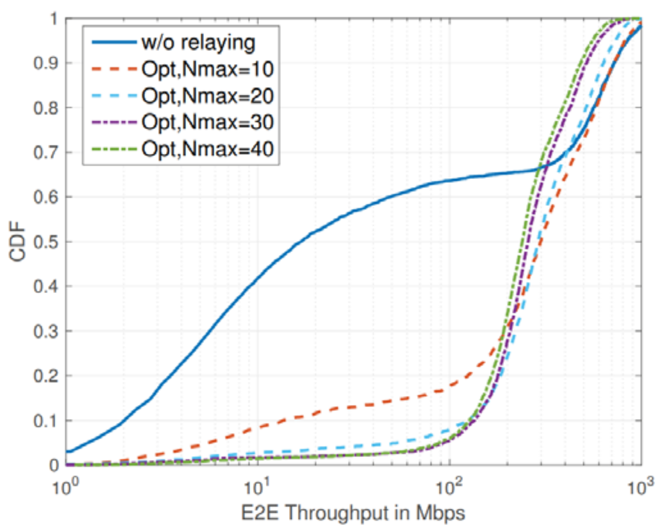
- Sub-6-GHz, wide coverage, mMTC & URLLC
- Interference-limited for cell-edge UEs
- D2D relaying helps to reduce the overall BS transmission power and hence the inter-cell interference power level

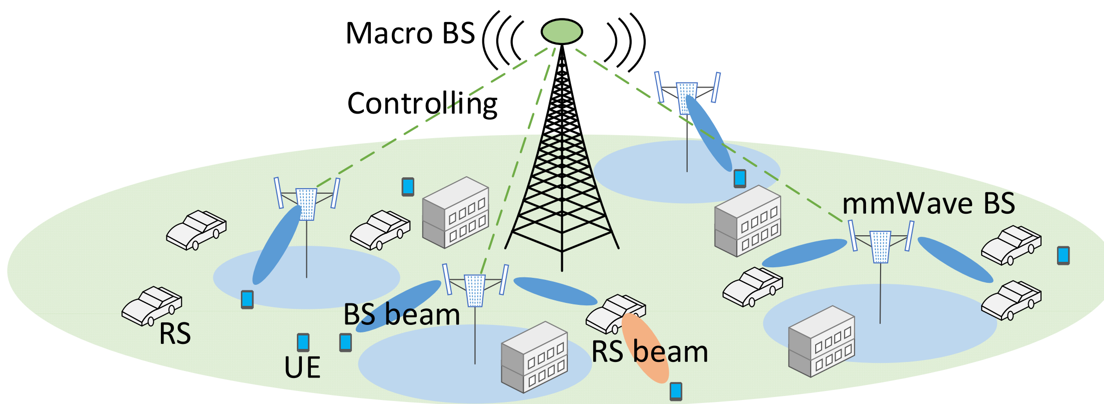




Scenario 3: MmWave D2D Relaying for Blockage Avoidance

- Standalone mmWave, analog beamforming, eMBB
- Power-limited for blocked UEs
- Increase the two-hop LoS probability and reduce the end-to-end pathloss by finding suitable two-hop mmWave connections





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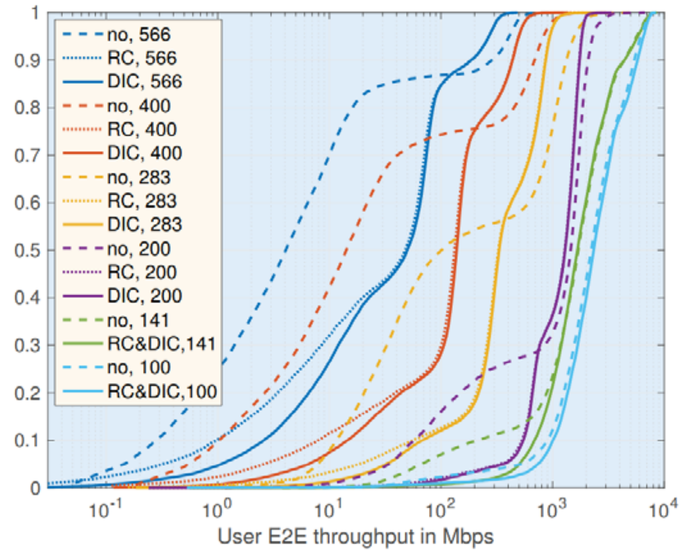
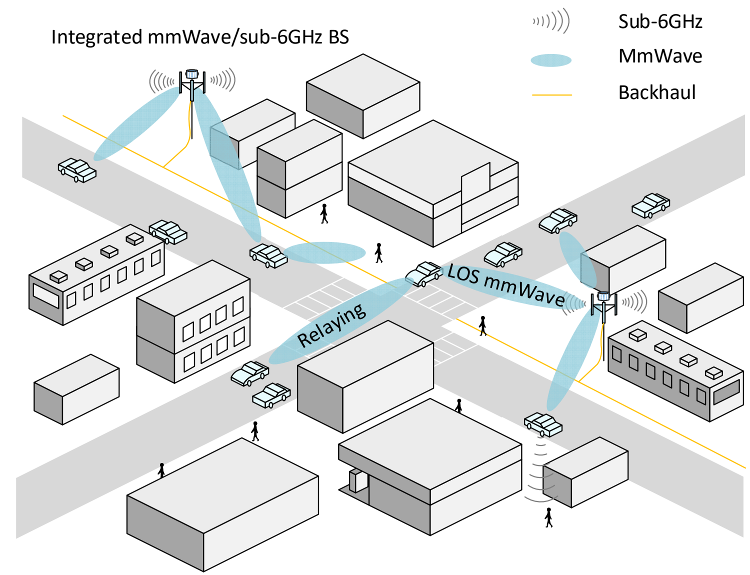
Scenario 4: Relaying in Integrated mmWave/Sub-6GHz Networks

- Joint mmWave/sub-6GHz in dense urban, analog beamforming, eMBB
- Power-limited for blocked UEs
- D2D relaying enhance the network performance provided by the multi-RAT connectivity





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Design and Evaluation of Low-complexity mmWave Architecture for Multi-User MIMO

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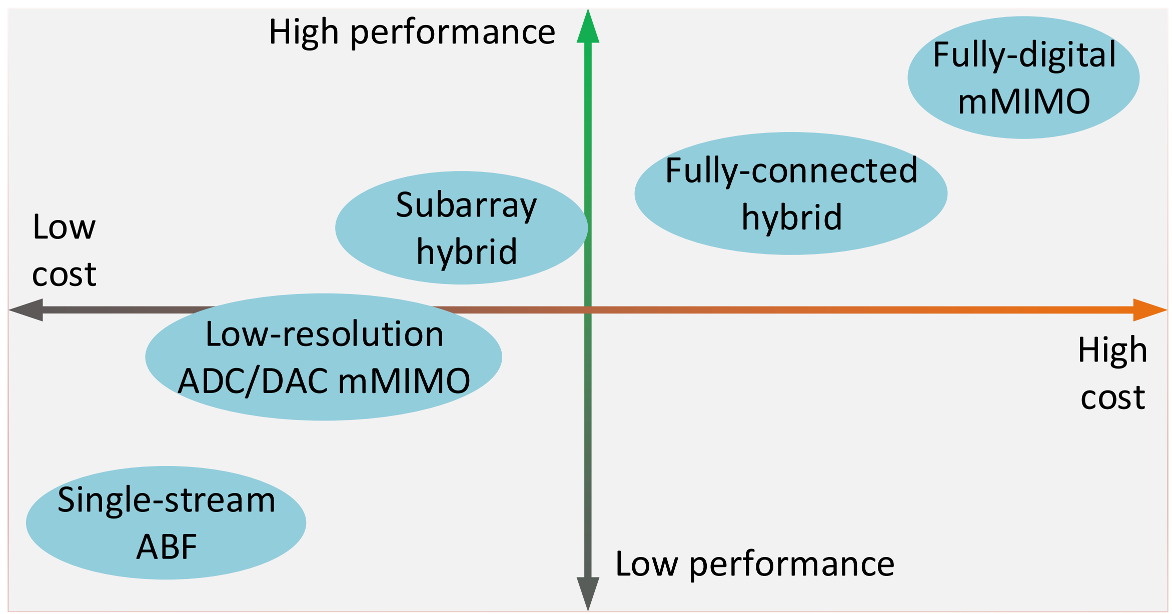
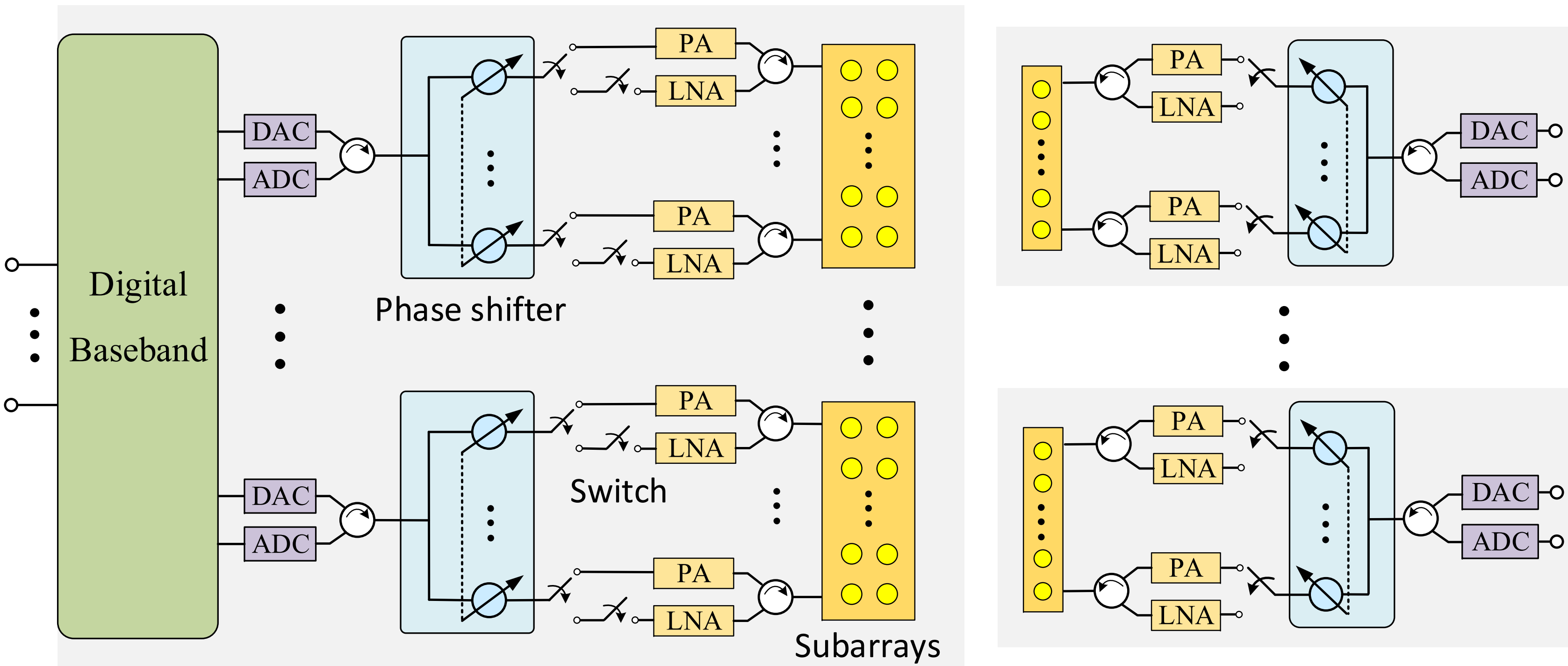
Low-cost mmWave BS architectures for dense network deployments

- Multiple users served by the BS simultaneously
- Use less RF chains than the fully-digital architecture
- Use low-resolution ADCs/DACs and/or analog phase-shifters

Cost/Performance Tradeoff



Proposed MmWave Multi-User MIMO Architectures

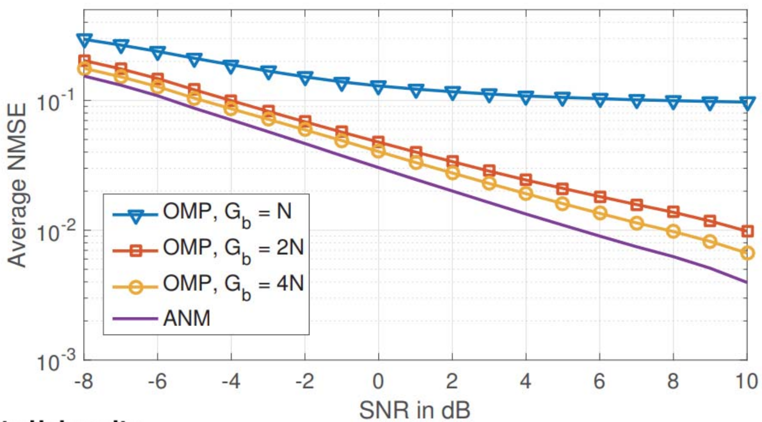


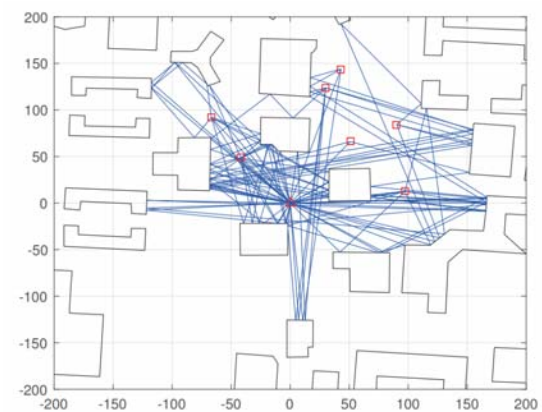
BS

UEs

MmWave Channel Estimation for Multi-User MIMO

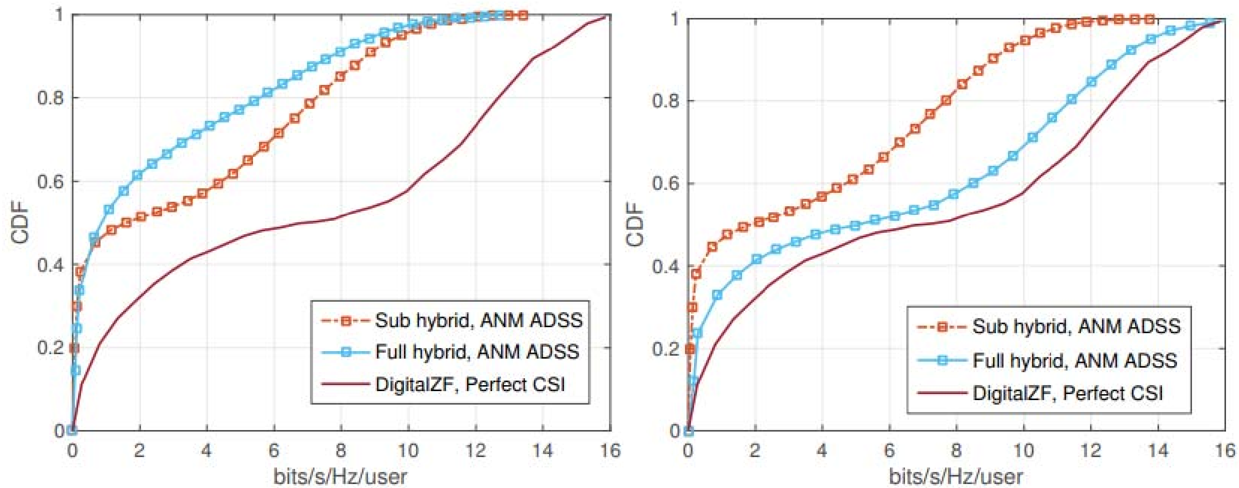
- Channel state information required for the BS
  - Increase received power for each user
  - Mitigate inter-user interference
- Channel estimation based on compressive-sensing
  - MmWave channels dominated a few propagation paths
  - **Measurement** based on antenna-domain sub-sampling (ADSS) via the switches
  - Full channel **recovery** based on atomic norm minimization (ANM) which is grid-less





MmWave Multi-User MIMO with Sub-arrays and Quantized Phase Shifters

- 3GPP mmWave Channel Model (TR 38.901)
- Both LoS and NLoS user are considered
- Analog-domain beamforming with digital-domain Zero-Forcing



(a) Beam-steering codebook $\{\mathcal{F}_q\}$ with 4-bit phase shifters

(b) Independent phase-shifting codebook $\{\mathcal{P}_q\}$ with 4-bit phase shifters

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Thesis publications:

I. J. Deng, A. A. Dowhuszko, R. Freij and O. Tirkkonen. Relay Selection and Resource Allocation for D2D-Relaying under Uplink Cellular Power Control. In *IEEE Globecom Workshops (GC Wkshps)*, Dec. 2015.

II. J. Deng, O. Tirkkonen and T. Chen. D2D Relay Management in Multicell Networks. In IEEE International Conference on Communications (ICC), May 2017.

III. J. Deng, O. Tirkkonen, Tao Chen and N. Nikaein. Scalable Two-hop Relaying for mmWave Networks. In European Conference on Networks and Communications (EuCNC), June 2017.

IV. J. Deng, O. Tirkkonen, R. Freij-Hollanti, T. Chen and N. Nikaein. Resource Allocation and Interference Management for Opportunistic Relaying in Integrated mmWave/sub-6 GHz 5G Networks. IEEE Communications Magazine, vol. 55, no. 6, pp. 94-101, June 2017.

V. J. Deng, O. Tirkkonen and C. Studer. MmWave Channel Estimation via Atomic Norm Minimization for Multi-user Hybrid Precoding. In IEEE Wireless Communications and Networking Conference (WCNC), April 2018.

VI. J. Deng, O. Tirkkonen and C. Studer. MmWave Multiuser MIMO Precoding with Fixed Subarrays and Quantized Phase Shifters. Submitted to IEEE Transactions on Vehicular Technology, August 2018.


The Future
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