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Overview of Research Projects with NYU-Poly

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Outline

- InterDigital Overview
- Relationship with NYU-Poly
- Overview of Recent Projects
- Conclusion

InterDigital - Wireless Technology Milestones

Generation	1G	2G	3G	4G
Technologies	*Analog*	*Digital*	*Broadband*	*Network of Networks*
Services	Voice	Data	Multimedia	Seamless Mobility

1992
First B-CDMA system
InterDigital completed prototype of the world's first broadband CDMA system

Technology development ahead of the curve

- When analog cellular started to gain traction, **we were already working on digital wireless systems**
- When the world was focused on voice, **our focus was data**
- When others looked at narrowband, **we were developing wideband**

In the early 1990s:
- ✓*Power control*
- ✓*Handoff*
- ✓*Pilot codes*
- ✓*Multi-channel arrangements*

1985
First digital wireless call
InterDigital demonstrates prototype of its digital wireless system

In the early 1980s:
- ✓*Roaming and handoff techniques*
- ✓*Distributed base station technologies*

Focused on fundamental system architecture

- Spectrum Optimization
- Connectivity and Mobility
- Intelligent Data Delivery

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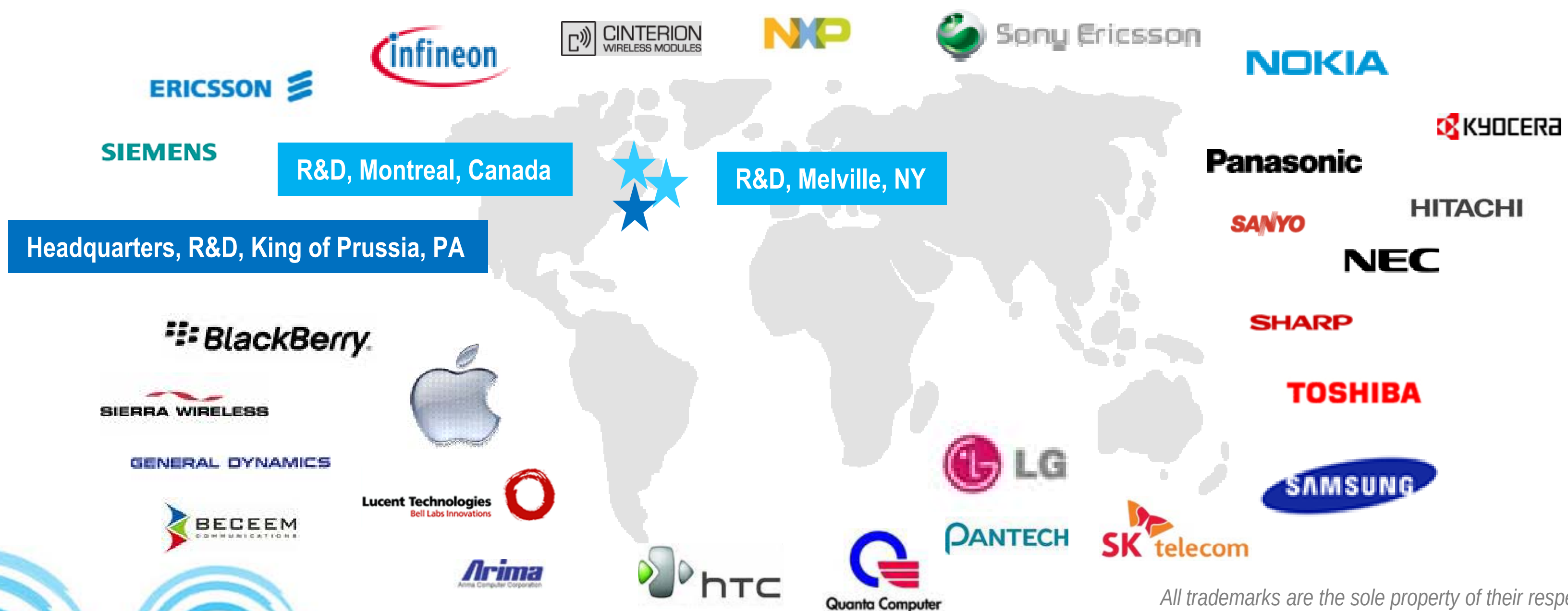
Company Overview

- Strong wireless technology expertise
  - ~ 200 engineers; 80% with advanced degrees
  - Over 17,000 issued patents and applications
- Technology used in every cellular device
- Deep relationships in wireless ecosystem
  - 50%+ of 3G market under license
  - 4 of top 5 handset vendors
  - Software in millions of 3G devices

- Financial strength and stability
  - First Nine Months 2010 revenues: ~$300 million
  - Highly profitable and superior operating leverage
  - Cash: $564 million, virtually no debt*
  - Market capitalization: ~$1.5 billion (NASDAQ: IDCC)
  - Ranked #2 in best small companies by Forbes (2010)

* at 9/30/2010



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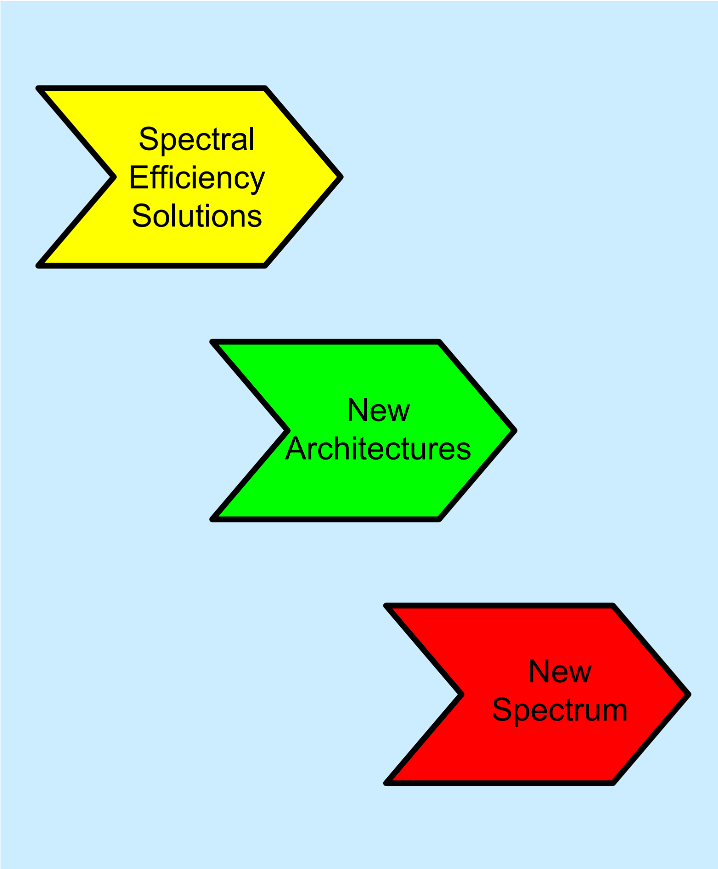
InterDigital and NYU-Poly

- InterDigital and NYU-Poly have a long-standing collaborative research relationship in advanced wireless technology
  - Cellular systems: 3G, 4G, and beyond
    - UMTS WCDMA, LTE, and future standards
  - High speed wireless LAN technology: 802.11n
- The company benefits from this relationship with
  - Leading edge and forward-looking technologies
  - Contributions to prominent wireless standards bodies
  - Access to top notch faculties and students
- Internship Opportunities
  - Over the past several years, many students from NYU-Poly joined the research teams at InterDigital via internship programs.
- Full time staff members
  - InterDigital hires graduate students as full-time employees who have been contributing to InterDigital's advanced technology development and business growth

InterDigital's Next Generation Cellular Project



Look beyond LTE-Advanced and the newest WiMax standards

Develop novel radio system architectures and air interface solutions that meet projected requirements anywhere, any time, across any wireless networks

Recent NYU-Poly Projects Align with InterDigital Goals

- Enhanced Coordinated Multi-point (CoMP) Network
  - Channel State Information (CSI) Prediction and Interpolation in MIMO-OFDM Systems

    Jiang Chang, I-Tai Lu and Yingxue (Kevin) Li
  - UE Centric Coordinated Beamforming in LTE

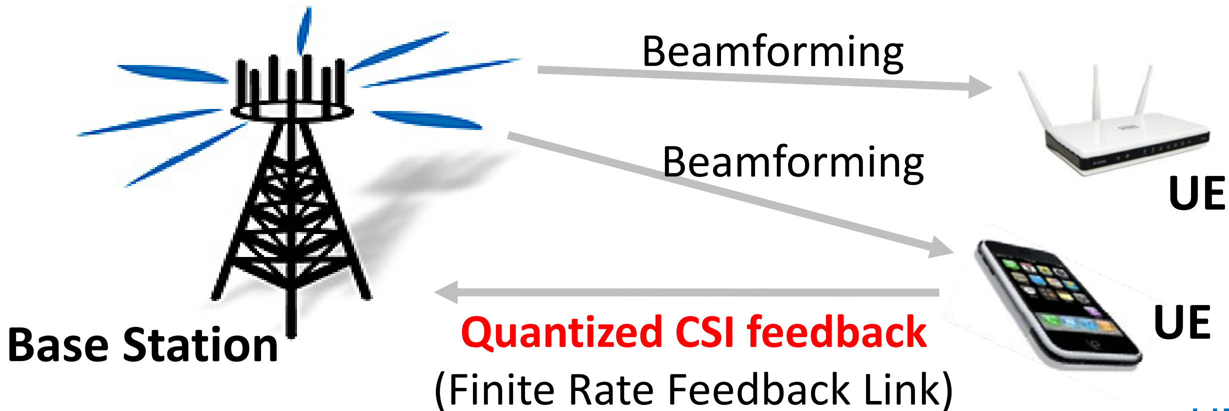
    Jialing (Alice) Li, Yingxue (Kevin) Li and I-Tai Lu
- Carrier Aggregation
  - LTE Carrier Aggregation into Unlicensed Band

    Feilu Liu, Erdem Bala, Samian Kaur and Rui Yang
- Enhanced Relays
  - Interference Mitigation Schemes for Relay Networks

    Kagan Bakanoglu and Elza Erkip

Jiang Chang, I-Tai Lu and Yingxue (Kevin) Li

To achieve the full merit of MIMO communications, channel state info (CSI) is needed at the transmitter to perform transmit processing (e.g. beamforming).



UE = User Equipment

- **Examples of CSI**
  - Channel transfer function (time or frequency domain)
  - Channel statistics (e.g. transmit covariance E[H*H])
  - Channel eigenspace (e.g. the channel direction of a vector channel)
  - Precoder information, etc.

CSI Prediction and Interpolation in MIMO-OFDM Systems (cont.)

Practical CSI feedback issues will cause performance degradation in MIMO-OFDM systems:

- CSI quantization error

  Solution: High-resolution feedback schemes (e.g adaptive codebook)

- CSI feedback delay

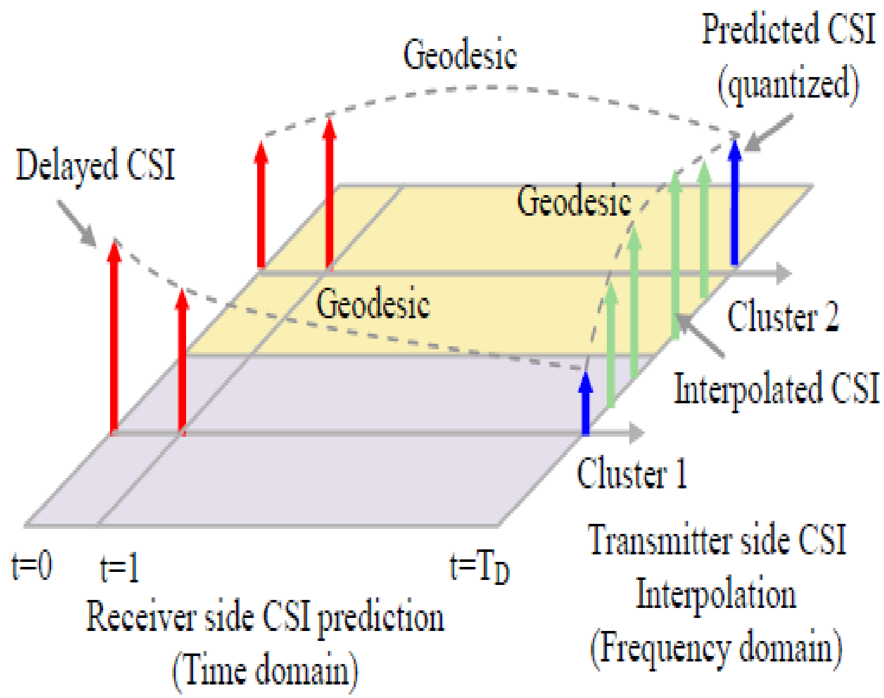
  Caused by the transceiver processing, propagation and network delay.

  Solution: CSI prediction

- CSI cluster feedback

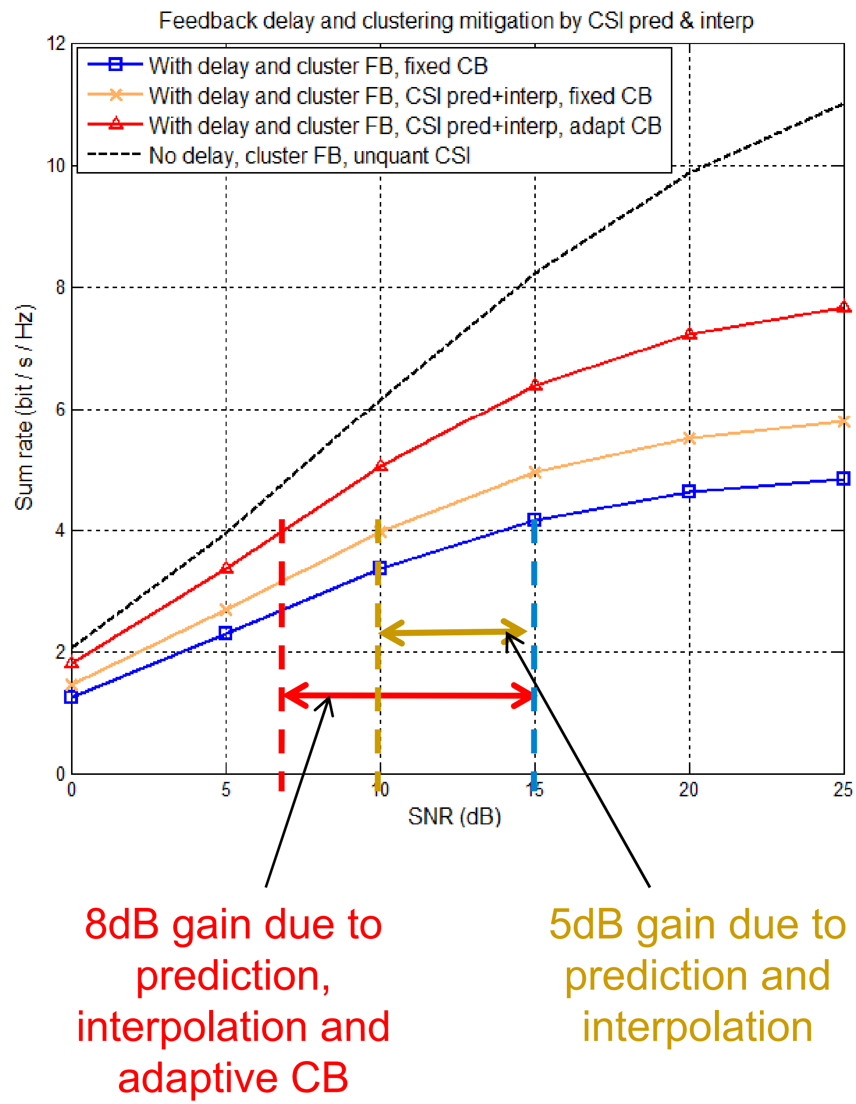
  One CSI feedback is used to represent a cluster of adjacent subcarriers for feedback reduction.

  Solution: CSI interpolation



Results:

- CSI prediction & interpolation can mitigate the performance loss due to CSI feedback delay and cluster feedback
- The performance gain provided by the CSI prediction & interpolation may diminish duo to the low resolution CSI quantization.
- Adaptive codebook based CSI prediction & interpolation scheme can improve the system performance significantly



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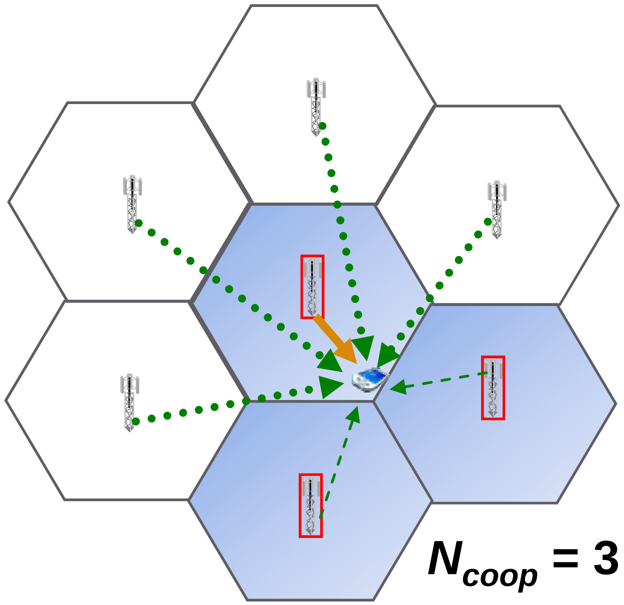
UE Centric Coordinated Beamforming in LTE

Jialing (Alice) Li, Yingxue (Kevin) Li, I-Tai Lu

❑ UE Centric Coordinated Beamforming (CBF)

➢ The base station in each UE's cooperating set (of size N_{coop}) coordinate their transmissions to mitigate inter-cell interference.



❑ **Problem: What is the "optimal" solution so that**

- System performance (e.g., spectral efficiency) is maximized
- Fairness among UEs is maintained.
- Overhead and scheduling complexity are low

Interference signal — Reduced Interference due to cooperation

Desired signal — Base station in UE's cooperating set

UE = User Equipment

UE Centric Coordinated Beamforming in LTE (cont.)

Method

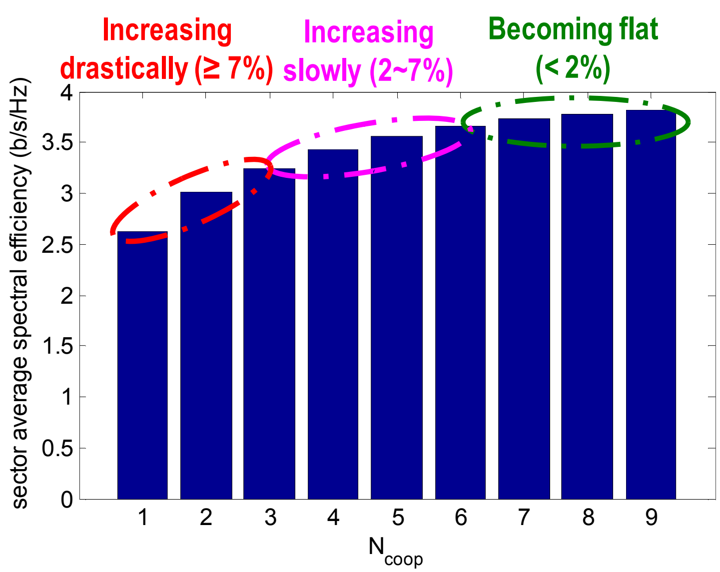
- Applying Joint Space-Time-Frequency Proportionally Fair (STF-PF) scheduling

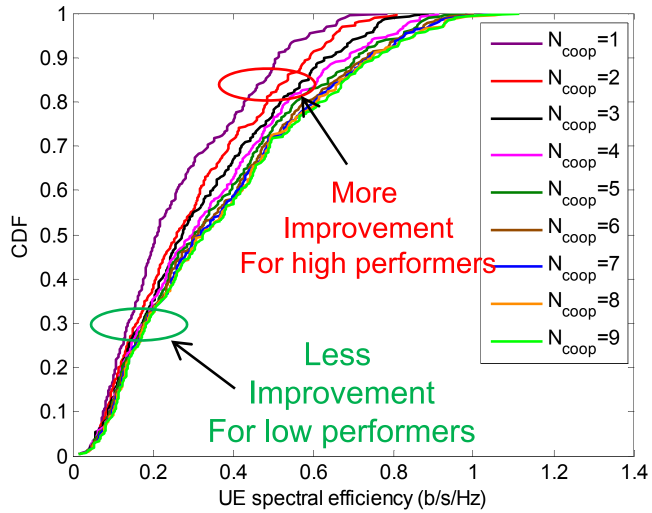
- Selecting UE for SU-MIMO or MU-MIMO at each base station iteratively, based on the scheduling decision at other base stations.

- Using maximum Signal to Leakage Ratio (SLR) precoder to minimize the intra-cell and inter-cell interference from the base station in the cooperating set.

UE Centric Coordinated Beamforming in LTE (cont.)

- **Results:**
  - Larger cooperating set leads to higher UE spectral efficiency, but improvement becomes insignificant after $N_{coop} > 6$
  - Fairness is generally maintained as the cooperating set gets larger ($N_{coop} \geq 6$)





Optimum coop. set size (N_{coop}):

6

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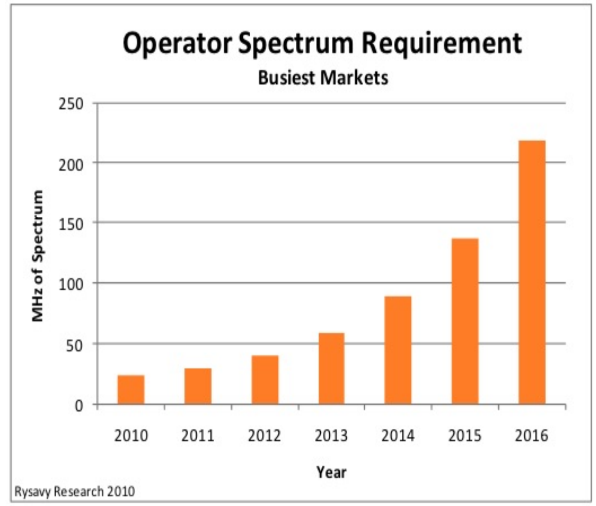
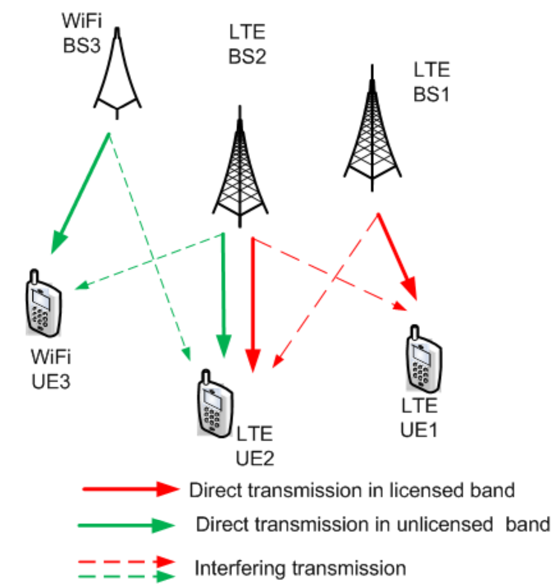
LTE Carrier Aggregation into Unlicensed Band

Feilu Liu, Erdem Bala, Samian Kaur, Rui Yang

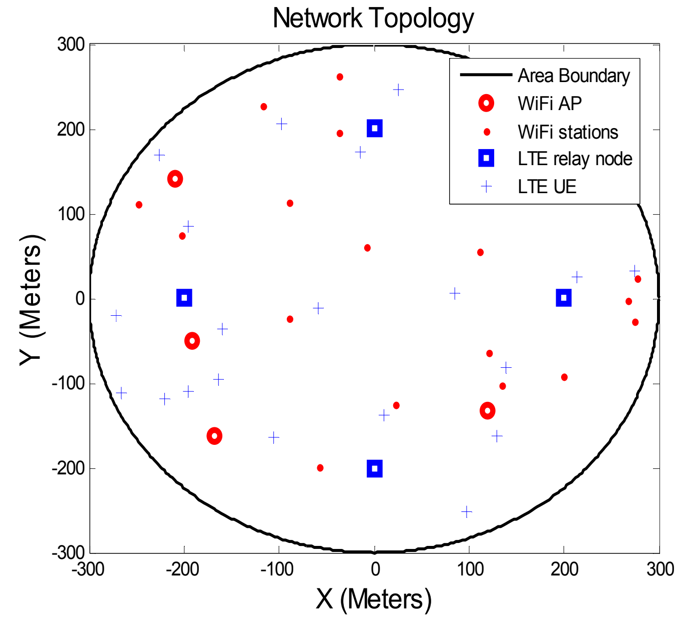
- The demand for more spectrum to meet future cellular communication market needs will continue grow
- Today, cellular operators have been offloading data traffic from their licensed bands to unlicensed bands using other air interfaces, for example, Wi-Fi
  - Other air interfaces are not designed for cellular networks and are less spectrally efficient
- **Questions**: If using LTE in both licensed and unlicensed bands in a proper manner (e.g. “listen before talk” on unlicensed band),
  - What would be the impact to the Wi-Fi network?
  - What would be the impact to the cellular network?





LTE Carrier Aggregation into Unlicensed Band (cont.)

- LTE / Wi-Fi Coexistence Simulations
  - Simulation test bench developed based on CoopMAC Simulator
    - Funded by WiCAT and CATT
  - For different WiFi and LTE traffic loads, the simulation measures the reduction of WiFi network throughput and increase in latency



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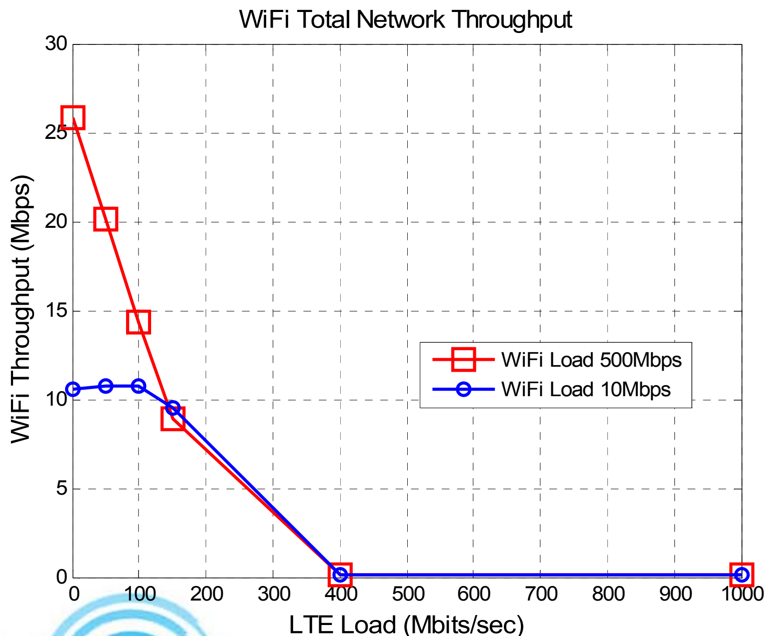
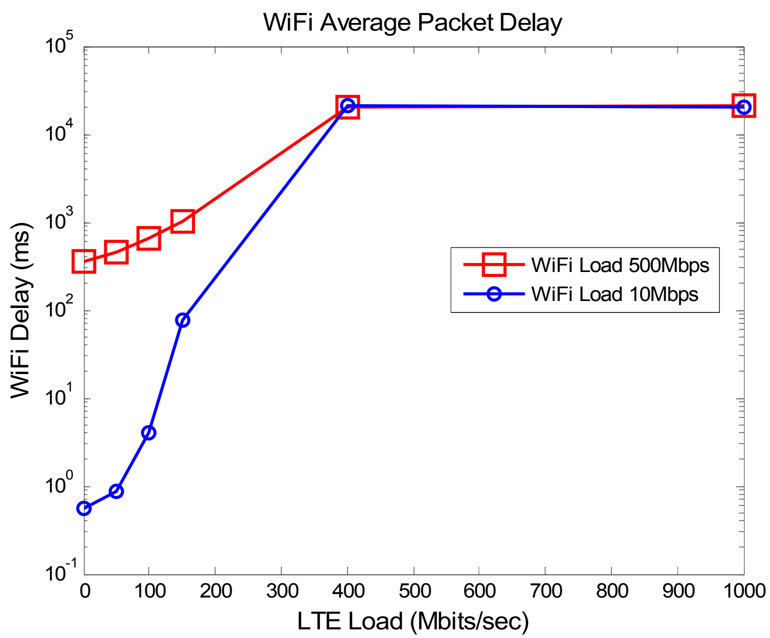
LTE Carrier Aggregation into Unlicensed Band (cont.)

Results:

- High WiFi load environment (500Mbps): *Large WiFi Throughput degradation*
  - Drop by 60% if LTE load = 150Mbps
  - Drop to *zero* if LTE load = 400Mbps
- Low WiFi load environment (10Mbps): *Small WiFi Throughput degradation*
  - Drop by 0% if LTE load < 100Mbps
  - WiFi delay increases, but still very small (< 5ms) if LTE load < 100Mbps

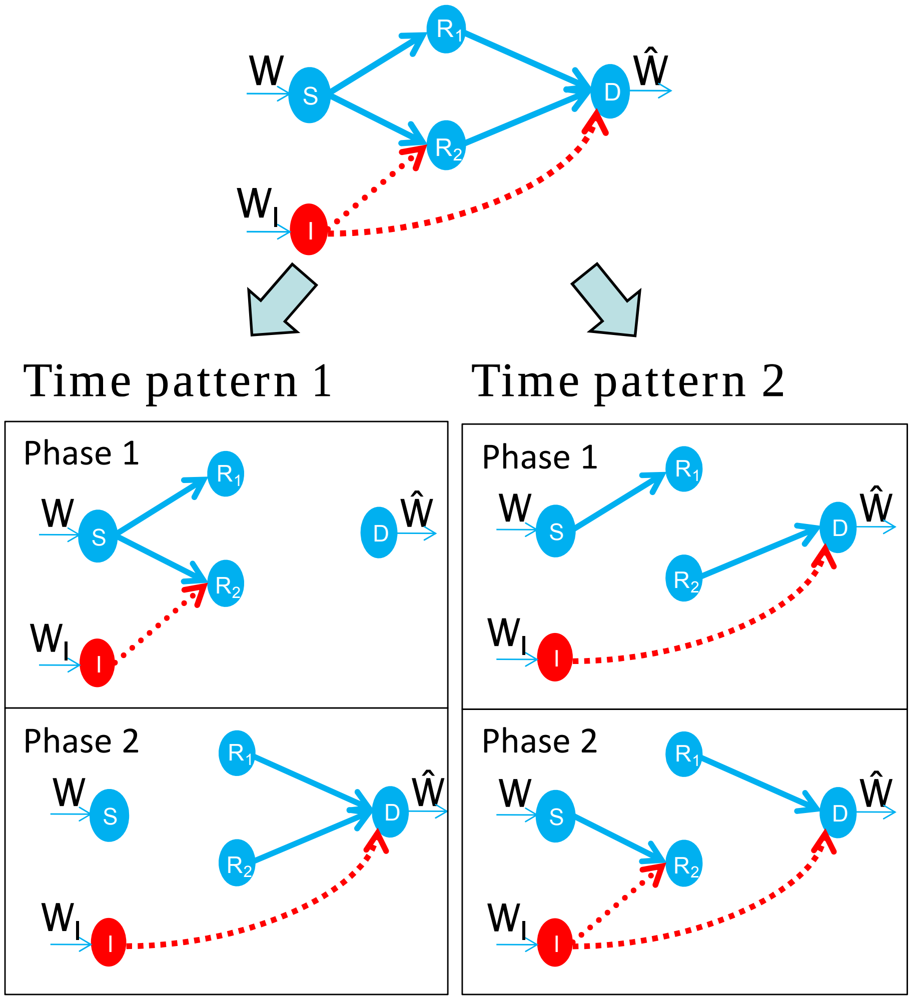




Interference Mitigation Schemes for Relay Networks

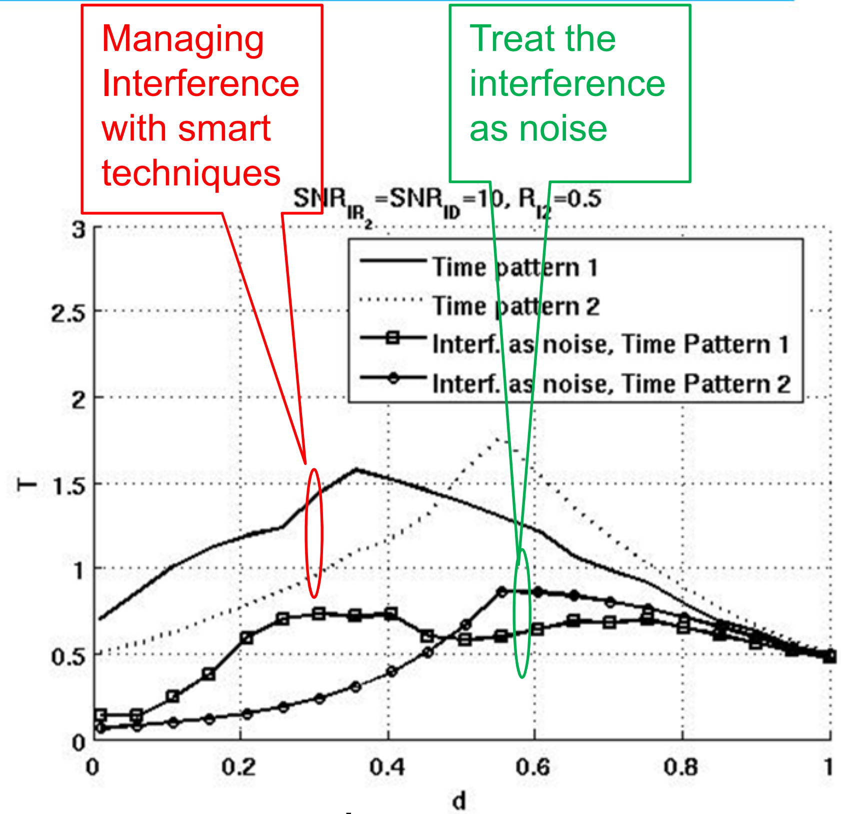
Kagan Bakanoglu and Elza Erkip

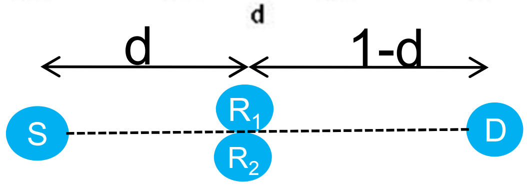
- Diamond relay channel with interference
- Relays can't transmit and receive signals at the same time – half duplex in time domain
- Consider two time patterns
- **Questions**:
  - Should exploit the structure of interference or treat it as noise?
  - What is the best relaying method?



Interference Mitigation Schemes for Relay Networks (cont.)

- Methodology
  - Information theoretical analysis
  - Applying various techniques such as
    - Message splitting
    - Dirty paper coding
    - Successive interference cancellation
- Results
  - The throughput performance by managing the interference is better than treating it as noise
  - Time pattern 1 performs better than Time pattern 2 when relays are close to the source, but worse when they are close to the destination.





$$T^{TimePattern1} = \max(T^{(u)}, T^{(s)})$$

$$T^{TimePattern2} = \max(T^{(Strategy1)}, T^{(Strategy2)}, T^{(Strategy3)})$$

Conclusion

InterDigital looks forward to a long and continuing relationship with NYU-Poly to support our research and development with innovative solutions to difficult problems, to keep us up to date on emerging technology, and to provide a source of top notch interns and employees

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THANK YOU!