Overview of Research Projects with NYU-Poly

Rui Yang
InterDigital Communications, LLC
Melville, NY 11747
• InterDigital Overview
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InterDigital - Wireless Technology Milestones

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**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 1980s:**
- Roaming and handoff techniques
- Distributed base station technologies

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

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

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

**Focused on fundamental system architecture**

- Spectrum Optimization
- Connectivity and Mobility
- Intelligent Data Delivery
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
To achieve the full merit of MIMO communications, channel state info (CSI) is needed at the transmitter to perform transmit processing (e.g. beamforming).

- 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.
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 due to the low resolution CSI quantization.
- Adaptive codebook based CSI prediction & interpolation scheme can improve the system performance significantly.
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

$N_{coop} = 3$

Interference signal

Desired signal

Reduced Interference due to cooperation

Base station in UE’s cooperating set

UE = User Equipment

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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.
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
The demand for more spectrum to meet future cellular communication market needs will continue to grow.

Today, cellular operators have been offloading data traffic from their licensed bands to unlicensed bands using other air interfaces, for example, Wi-Fi 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 / 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
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
• 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.

\[
T_{\text{TimePattern}1} = \max(T^{(u)}, T^{(s)})
\]

\[
T_{\text{TimePattern}2} = \max(T^{(\text{Strategy}1)}, T^{(\text{Strategy}2)}, T^{(\text{Strategy}3)})
\]
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.
THANK YOU!