Wireless networks Empowered by Non-orthogonal Multiple Access and AI

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• Nestor Chatzidiamantis, Assistant Professor
• Dr. Panagiotis D. Diamantoulakis
• 5 PhD students
• Supervising 17 Diploma Theses
• Research Areas
  ❖ Wireless Communications
  ❖ Optical Wireless Communications
  ❖ Wireless Power Transfer and Applications
  ❖ Communications and SP for Biomedical Engineering
• More than 550 published papers in journals and conferences
• Seven (7) patents

http://geokarag.webpages.auth.gr/
Outline

- Overview & Motivation
- Common misconceptions
- NOMA compared to OMA
- NOMA in systems with new types of resources
- Resource allocation
- Research directions
Everything is connected

**Everything connected by wireless**
Monitor/collect information & control devices

- Multiple personal devices
  - Interaction across multiple devices
- Transportation (Car/Bus/Train)
  - Entertainment, Navigation Traffic information
- Consumer electronics
  - Watch/jewelry/cloths
  - Remote operation using personal terminal
- House
  - Remote control of facilities
  - House security
- Sensors
  - Smart power grid
  - Agriculture and farming
  - Factory automation
  - Weather/Environment
- Cloud computing
  - All kinds of services supported by the mobile personal cloud

**Extension/enrichment of wireless services**
Deliver rich content in real-time & ensure safety

- Video streaming
  - 4K/8K video resolutions
  - Video on newspapers
  - Background video
- New types of terminal/Hi
  - Glasses/Tactile Internet
- Healthcare
  - Remote health check & counseling
- Education
  - Distance (remote) learning
  - Any lesson anywhere/anytime
- Safety and lifeline system
  - Prevention of accidents
  - Robustness to disasters

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Traffic estimates

Report ITU-R M.2370, “IMT traffic estimates for the years 2020 to 2030”
Enabling technologies

Better Spectral Efficiency
- Massive MIMO
- Interference Management
- Full Duplex Radio

Higher Network Densification
- Spectrum Sharing
- Cloud-RAN
- Small Cells
- D2D

More Spectrum
- Carrier Aggregation
- Mm-Wave (60GHz)
- THz Com
- Optical Wireless Com
Multiple systems into a broader network while sharing information in real time, improving communication across Services, geographies, and domains while developing a common picture of the battlefield to improve situational awareness. This improved connectivity may in turn enable a host of new technologies and missions, from hypersonics and hypersonic defense to resilient satellite constellations and mesh networks.

Spectrum will play a key role in the operation, development and roll-out of 5G. Peak data rates are driven by the amount of spectrum that is available to a wireless service. In 4G, up to five 20 MHz channels can be bonded together. But in 5G, up to five 100 MHz channels can be bonded together, enabling speeds approximately 20x faster than 4G and 4G LTE. While some 5G technology will be deployed in the currently-used cellular spectrum and achieve modest gains in performance (LTE is already fairly well optimized), full 5G development will require significantly more spectrum to provide another step-change improvement in performance for consumers, DoD or otherwise.

Countries are pursuing two separate approaches to deploy hundreds of MHz of new spectrum for 5G. The first focuses on the use of Electromagnetic (EM) spectrum below 6 GHz (³Low Band Spectrum,´ utilized for 3 and 4 GHz band). The second approach focuses on the use of EM spectrum between 24 and 300 GHz (³High Band Spectrum,´ allocated for mmWave), and is taken by the US, Chinese, and South Korean governments (although all three countries are also exploring sub-6 to various degrees). US carriers are primarily focused on mmWave deployment for 5G because most of the 3 and 4 GHz spectrum being used by the rest of the world for 5G are exclusive Federal bands in the United States, extensively used by DoD in particular.

The question of spectrum allocation is at the heart of the 5G competition, for the spectrum band of choice, whether sub-6 or mmWave, impacts nearly every other aspect of 5G development. Spectrum bands in the 3 and 4 GHz range dominate global 5G activity because of improved propagation (range) over mmWave spectrum, resulting in far fewer base stations needed to be deployed to deliver the same coverage and performance. Because large swaths of the sub-6 bands in the United States are not available for civil/commercial use, US carriers and the FCC (which controls civil spectrum in the US) are betting on mmWave spectrum as the core domestic 5G approach.

U.S. carriers may continue to pursue mmWave, but it is impossible to lead in the 5G field without followers. Leadership in wireless networks requires the global market to subscribe to The 5G spectrum

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Foundational Challenges include:

- Reliable, low cost, sustainable and scalable IoT networks
- Next Generation IoT data processing architectures
- Security/cybersecurity, privacy, safety, interoperability
- Real time decision-making for IoT
- Autonomous IoT solutions
- IoT miniaturization, energy harvesting and pervasiveness

Non-orthogonal multiple access (NOMA): An idea whose time has come

A promising idea is to break orthogonality
- The key idea of NOMA is to encourage spectrum sharing
- Advantages in terms of connectivity, spectral and/or energy efficiency.
- NOMA performs closer to the information theoretic bounds
- Many different forms: power-domain, MUSA, SCMA, PDMA, RSMA, IGMA, WSMA, IDMA, etc

Power domain NOMA

The two-user capacity region in NOMA is given by

Common misconceptions

- NOMA always allocates more power to users with poor channels
- NOMA users must have different channel gains
- The main reason behind using NOMA is to improve spectral efficiency
- Decoding complexity of NOMA is prohibitively high
- Downlink NOMA compromises security and privacy
- Downlink NOMA: SIC decoding order varies with power allocation
- Uplink NOMA: The SIC decoding order should be fixed and depends only on the channel conditions
- NOMA and OMA are mainly competitive technologies
- NOMA is not compatible with network slicing in the RAN
NOMA compared to OMA

- Let’s assume that a user is an IoT device requiring only a low data rate.
- If OFDMA is used, this user is allocated a separate subcarrier, which lead to low spectral efficiency.
- When NOMA is used, a broadband user can also have access to this subcarrier.
- Resource allocation for OMA can also increase spectral efficiency.
- By using optimization theory, it can be rigorously proved that NOMA always outperforms OMA.
NOMA in systems with different types of resources

• The substantial improvement of performance depends on the ability to efficiently use NEW resources, e.g.,
  ➢ Memory
  ➢ New bandwidth
  ➢ Relays and distributed antennas
  ➢ Cloud, and edge infrastructure
  ➢ Resources that refer to IoT and EH systems

• Can NOMA be useful in this direction?
Random access is revisited

- In IoT sources with sparse activity are usually used
- RA is a key technology for the medium access control layer of IoT
- RA offers small latency for small payload transmissions (no initial setup requirements, no dedicated resource allocation, less signalling)
- Slotted ALOHA avoids collisions due to partially overlapping transmissions
- Used in RFID, LTE, MTC
- One of the candidates 5G RA protocols for M2M communications
Slotted ALOHA with NOMA for the NGIoT

Example with 3 devices

**OK**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>EH</td>
<td>Payload</td>
<td></td>
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</table>

**Collision**

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**Proposed protocol**

Assumption:
There is a mapping table between device id and transmission power

Beacon:
broadcast transmitted power and id for 1st phase NOMA

1\textsuperscript{st} phase, sub-phase 1a:
All devices send “dummy” data as follows:
The ones that will send actual data will send the bit “1”, followed by their id.
The ones that will not send actual data will send the bit “0”, followed by their id.

sub-phase 1b:
NOMA uplink

2\textsuperscript{nd} phase:
The BS identifies after SIC the devices that will transmit in this slot.
If number of devices=1, then it will employ SIC for the payload of this slot
If number of devices=1, then it will employ simple symbol detection for the payload of this slot


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Slotted ALOHA with NOMA for the NGIoT
Cloud-radio access networks (C-RAN), Suggested architectures

- Fully Centralized
- Partial Centralized

*Image source: China Mobile*

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Distributed uplink-NOMA for CRAN


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Non-orthogonal multiple access for FSO backhauling

Hybrid lightwave/RF cooperative networks with NOMA

Yue Xiao, Panagiotis D. Diamantoulakis, Zheng Ma, Li Hao, and George K. Karagiannidis, “Hybrid Lightwave/RF Cooperative Networks with Non-Orthogonal Multiple Access”, IEEE Transactions on Wireless Communications
Resource allocation

• NOMA and OMA are not competitive technologies

• Resource allocation in hybrid systems with multiple types of resources is a major challenge

• Multi-objective optimization and Pareto optimality can be used

Resource management optimization

Both discrete and continuous resources:
Subcarrier, cell association, transmit power,
time allocated to energy harvesting

QoS constraints

Global vs Heuristic algorithms
• Exponential time complexity
• Non-scalable

• Hard to design good ones
• Optimality gap
• Possibly non-real time
Resource allocation

**Applications**
- Resource allocation: Transmit power, user association, spectrum management
- Security and privacy: Physical layer security, connectivity preservation
- Network planning, traffic engineering, localization services
- MEC: edge caching, computation offloading, resource allocation, privacy and security, big data analytics, mobile crowdsensing,
Imitation learning: “a combination of Supervised & Reinforcement Learning”

- Learn the pruning policy in the Branch-and-Bound
- Advantages
  - Near-optimal performance with few training samples
  - Faster than current state-of-the-art methods
  - Scalable


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Mobile edge computing with NOMA and AI


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Challenges and future research directions

- Investigation of NOMA under practical conditions and assumptions
- Investigation of NOMA in delay sensitive applications
- New algorithms to facilitate the resource allocation, self-organization, and division into clusters, e.g., by using AI
- Compatibility issues: Hybrid architectures for smooth transition from existing systems to systems with NOMA
- Convergence of multiple access, computing and AI, e.g., by using federated learning
Thank you!