Wireless networks Empowered by Non-orthogonal Multiple Access and AI

PANAGIOTIS D. DIAMANTOULAKIS (ARISTOTLE UNIVERSITY OF THESSALONIKI)

- **Head**: George K. Karagiannidis, Professor, IEEE Fellow, Highly Cited Researcher 2015-2019
- 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

School of Electrical & Computer Engineering
Aristotle University of Thessaloniki

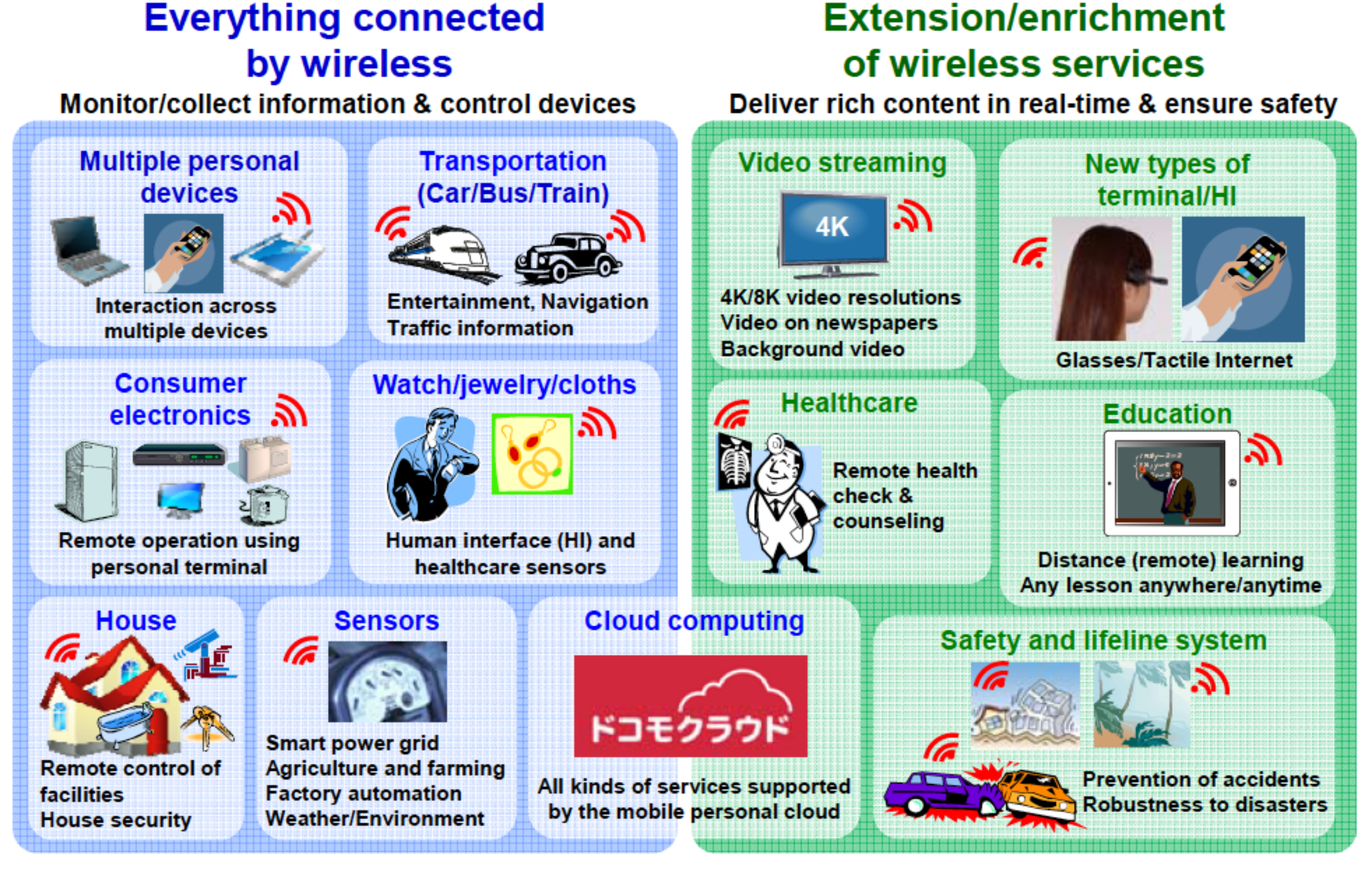
Wireless Communications Systems Group
WCSG

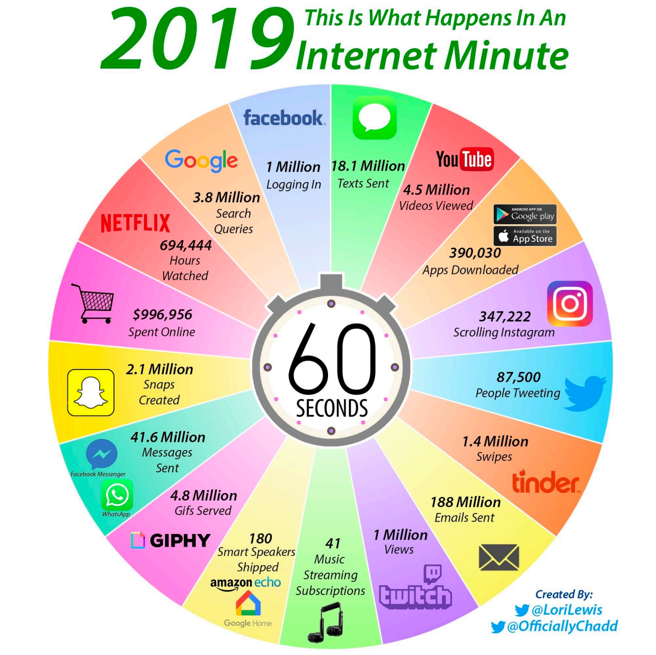
http://geokarag.webpages.auth.gr/

Outline

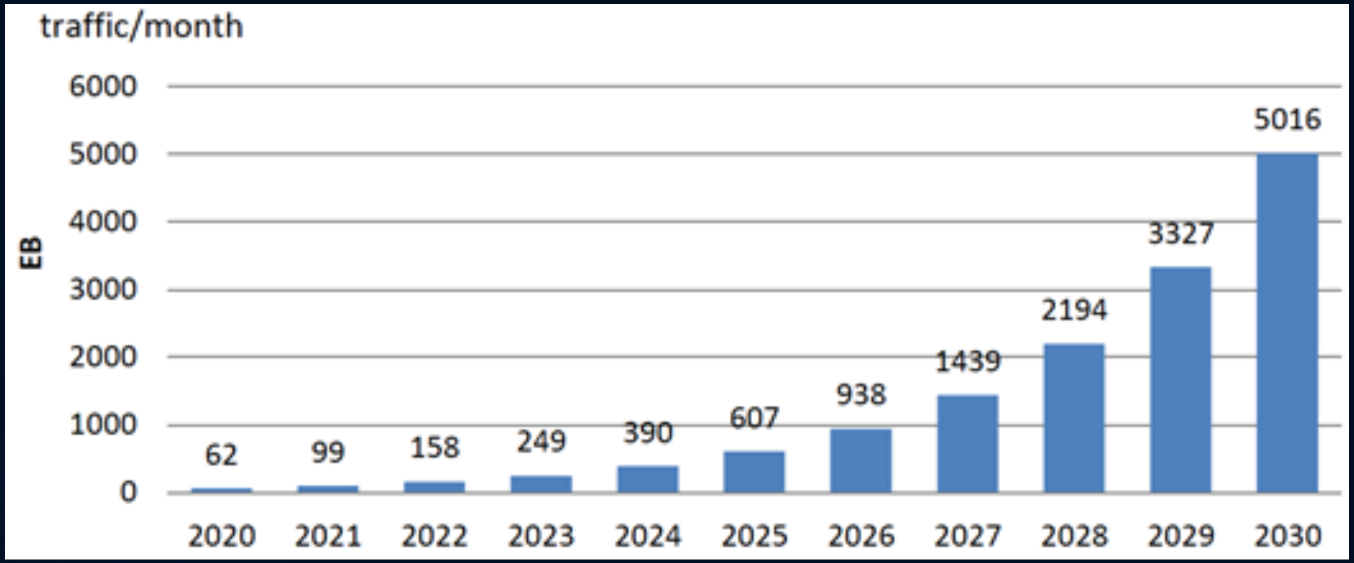
- Overview & Motivation
- Common misconceptions
- NOMA compared to OMA
- NOMA in systems with new types of resources
- Resource allocation
- Research directions

Everything is connected



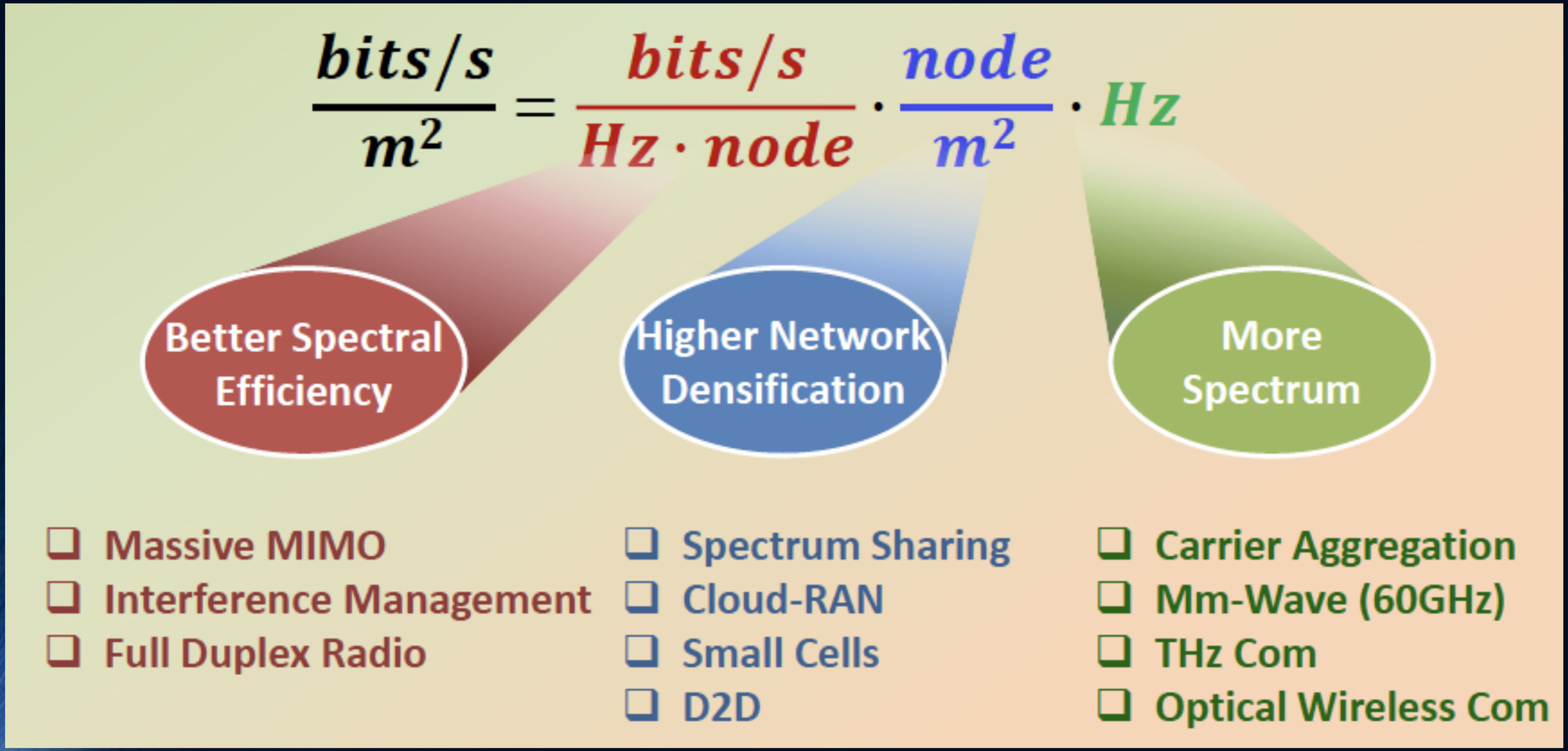


Traffic estimates

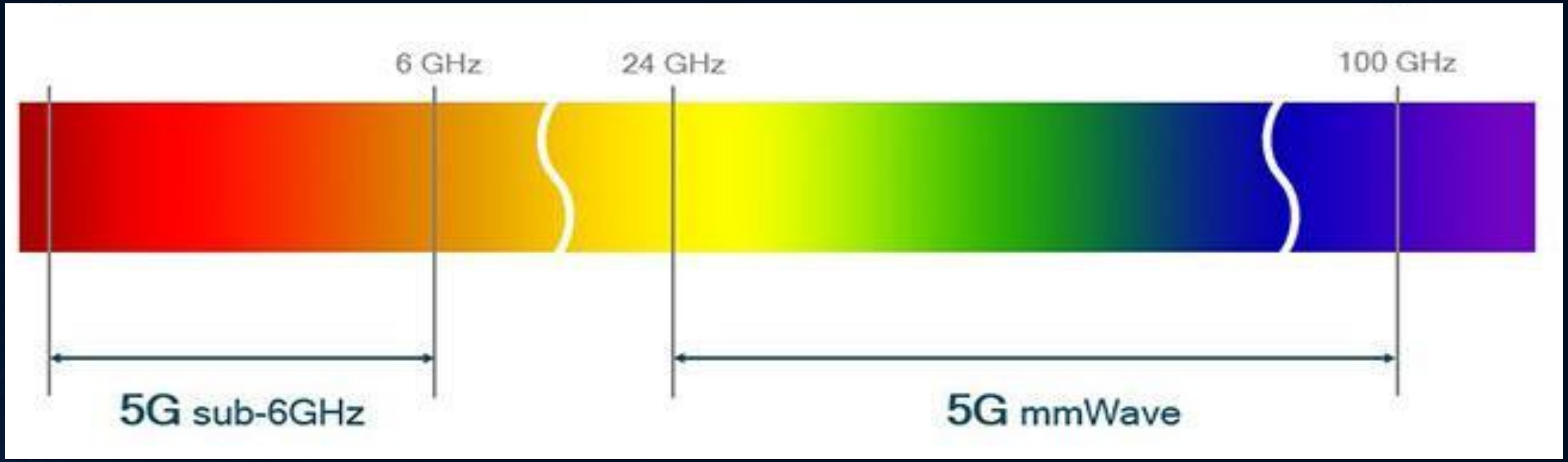


Report ITU-R M.2370, "*IMT traffic estimates for the years 2020 to 2030*"

Enabling technologies



The 5G spectrum



Next Generation Internet of Things (NGIoT)

Foundational Challenges include:

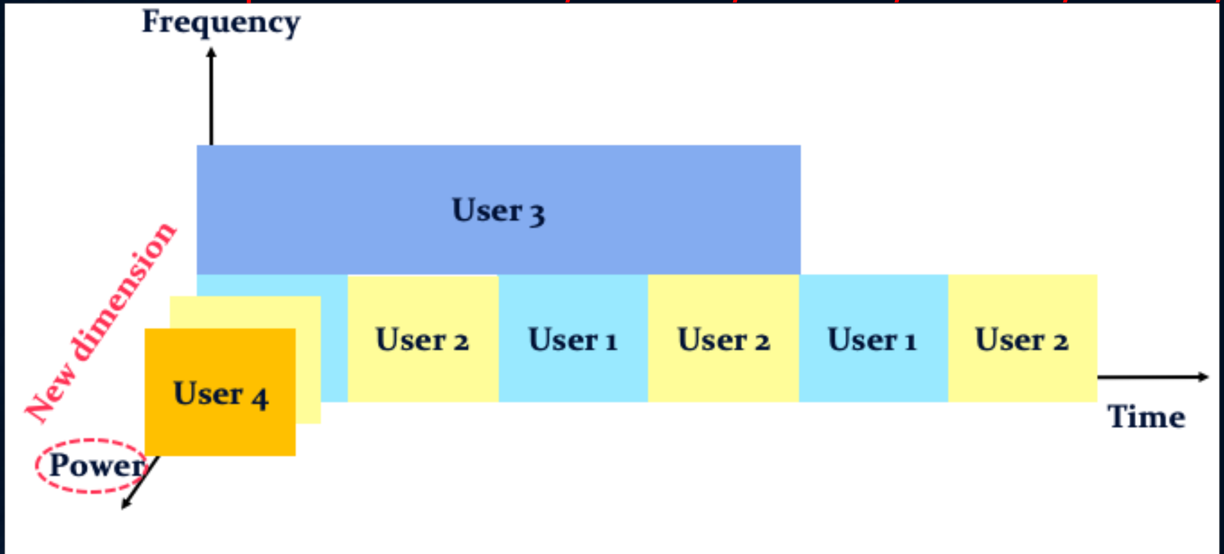
- Reliable, low cost, sustainable and scalable IoT networks
- Next Generation IoT data processing architectures
- Security/cybersecurity, privacy, safety, interoperability
- Real time decision-making for IoT
- Autonomous IoT solutions
- IoT miniaturization, energy harvesting and pervasiveness

A. Brekine et al., "Building a Roadmap for the Next Generation Internet of Things. Research, Innovation and Implementation 2021 –2027 (Scoping Paper)," Sep. 2019.

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

A promising idea is to break orthogonality

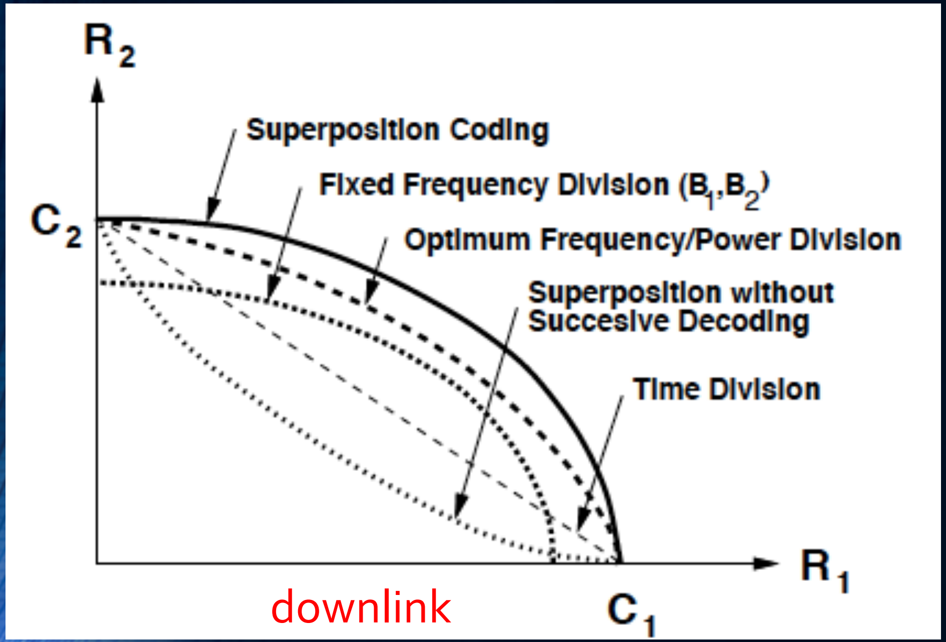
- The key idea of NOMA is to encourage spectrum sharing
- Advantages in terms of connectivity, spectral and/or energy efficiency.
- NOMA performs closer to the information theoretic bounds
- Many different forms: power-domain, MUSA, SCMA, PDMA,RSMA, IGMA, WSMA, IDMA, etc

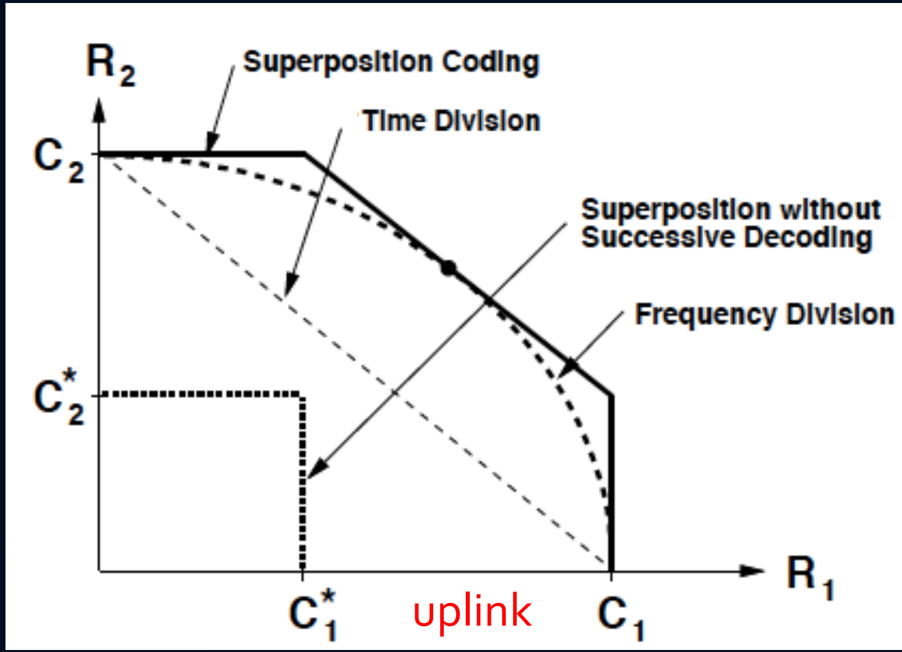


Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan and V. K. Bhargava, "A Survey on Non-Orthogonal Multiple Access for 5G Networks: Research Challenges and Future Trends," in IEEE Journal on Selected Areas in Communications, vol. 35, no. 10, pp. 2181-2195, Oct. 2017

Power domain NOMA

The two-user capacity region in NOMA is given by





A. Goldsmith, Design and Performance of High-Speed Communication Systems over Time-Varying Radio Channels, 1994

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.

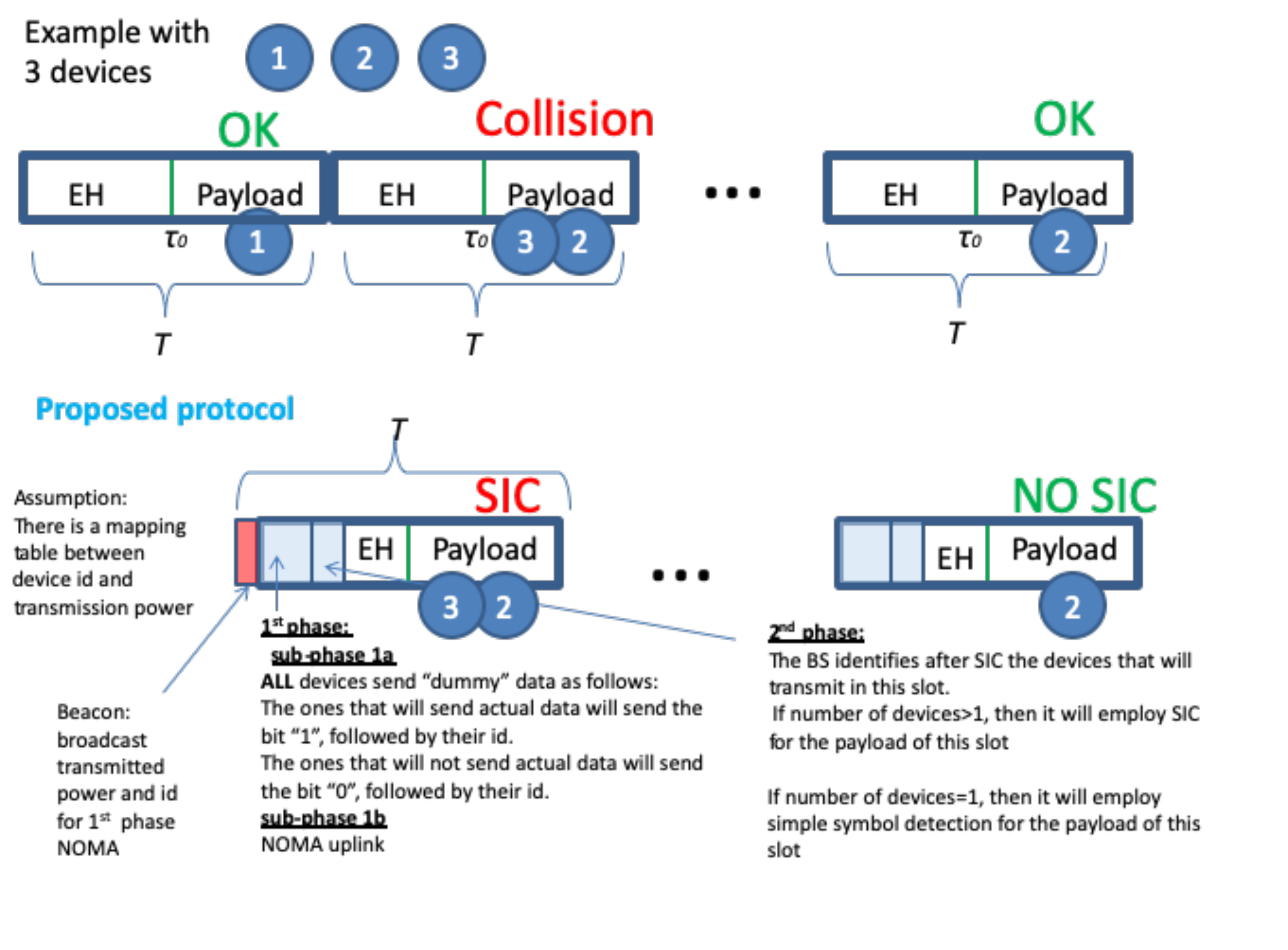
NOMA in systems with different types of resources

- 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

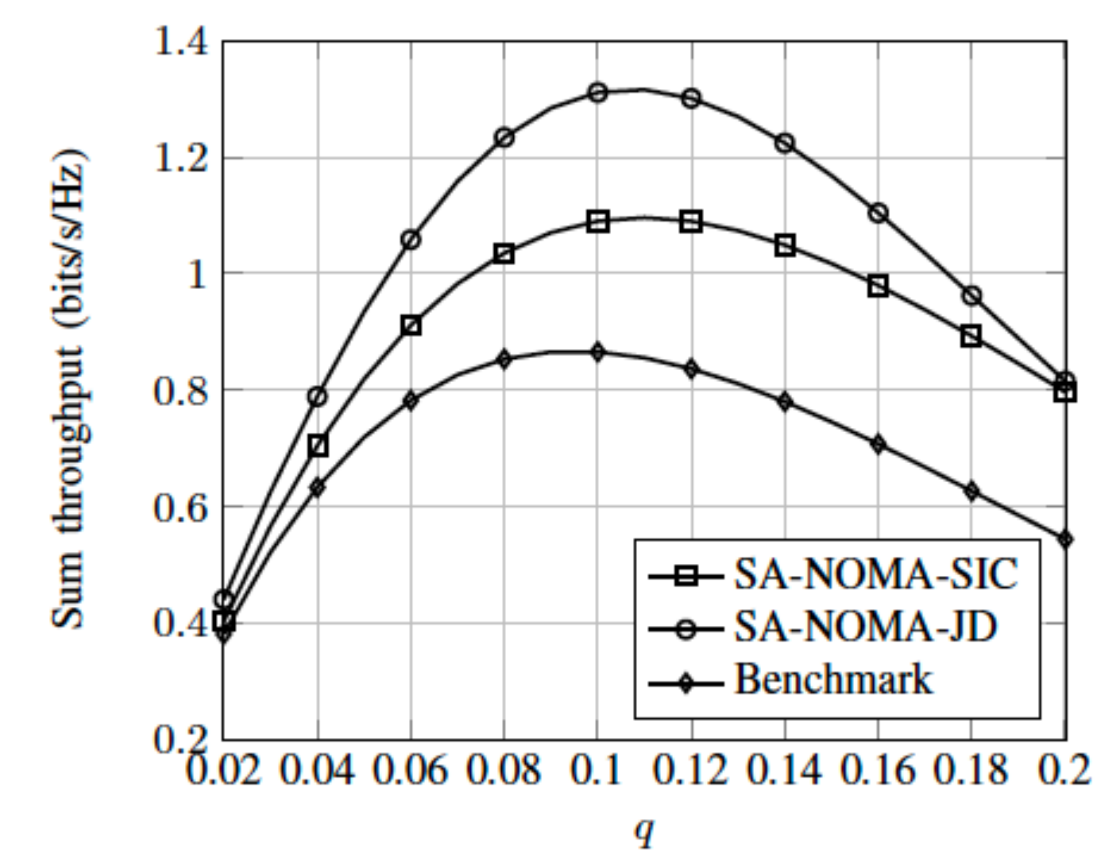
- In IoT sources with sparse activity are usually used
- RA is a key technology for the medium access control layer of IoT
- RA offers small latency for small payload transmissions (no initial setup requirements, no dedicated resource allocation, less signalling)
- Slotted ALOHA avoids avoids collisions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

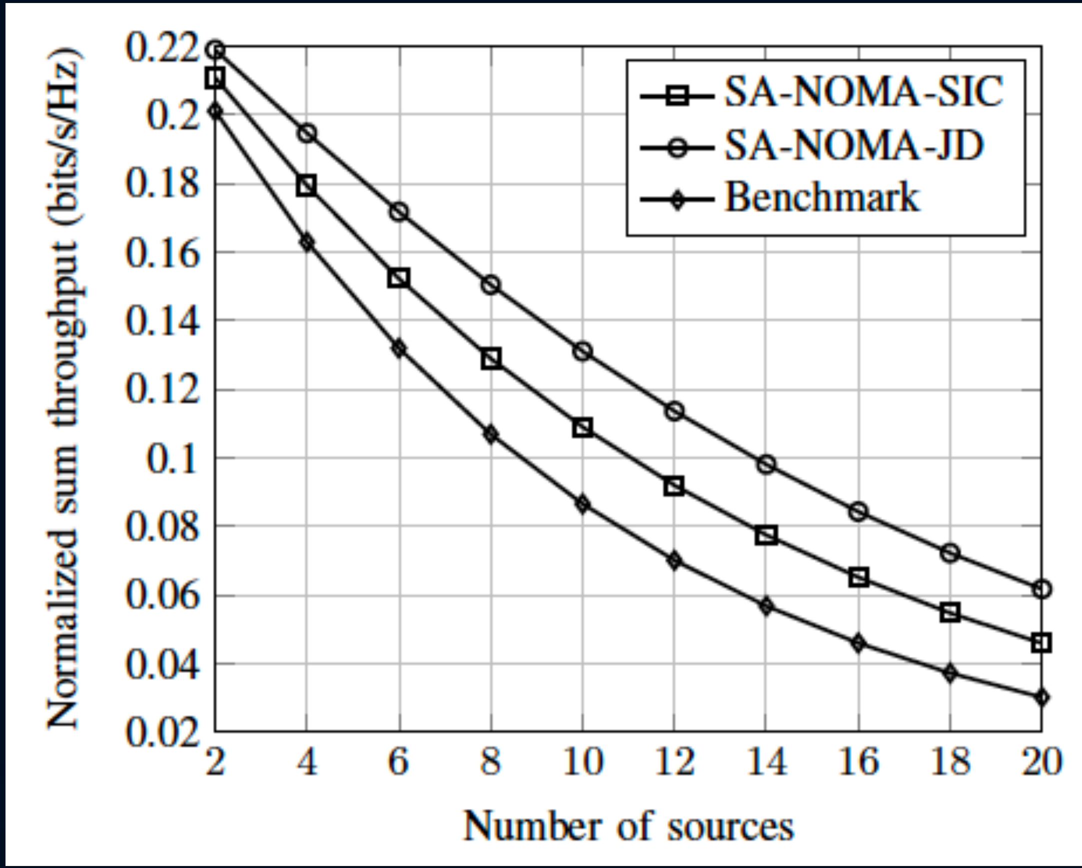
Slotted ALOHA with NOMA for the NGIoT



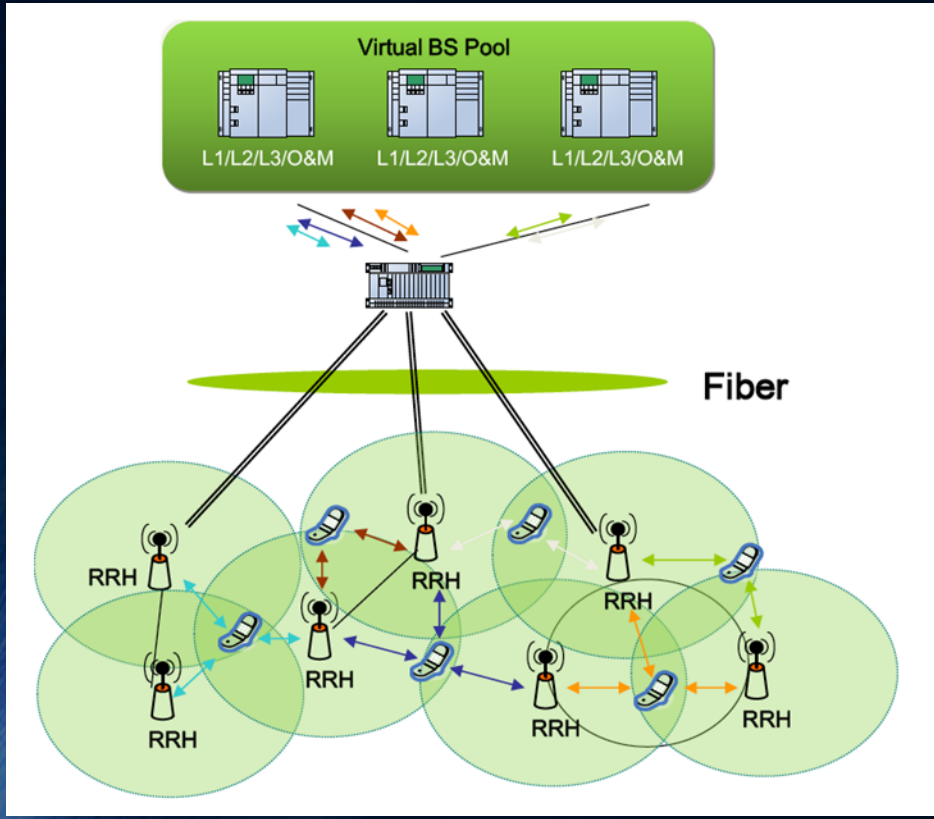
S. A. Tegos, P. D. Diamantoulakis, A. S. Lioumpas, and G. K. Karagiannidis, "Slotted ALOHA with NOMA for the Next Generation IoT," submitted to IEEE Transactions on Communications, Jan. 2019

Slotted ALOHA with NOMA for the NGIoT

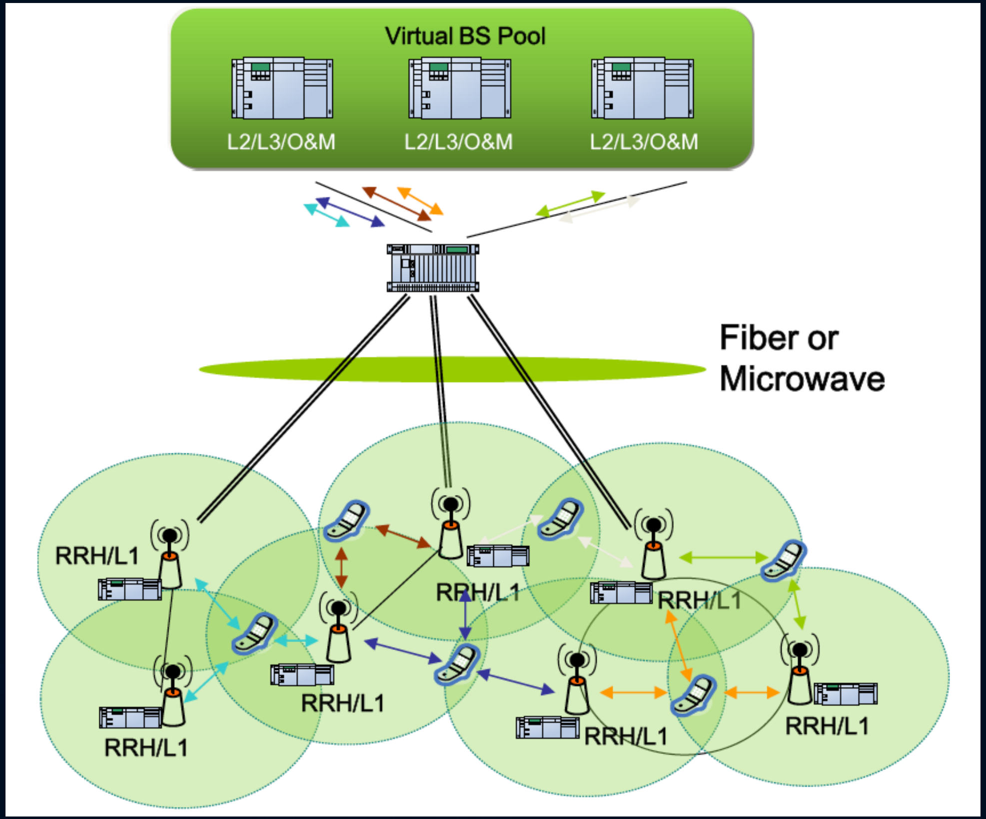




Cloud-radio access networks (C-RAN), Suggested architectures



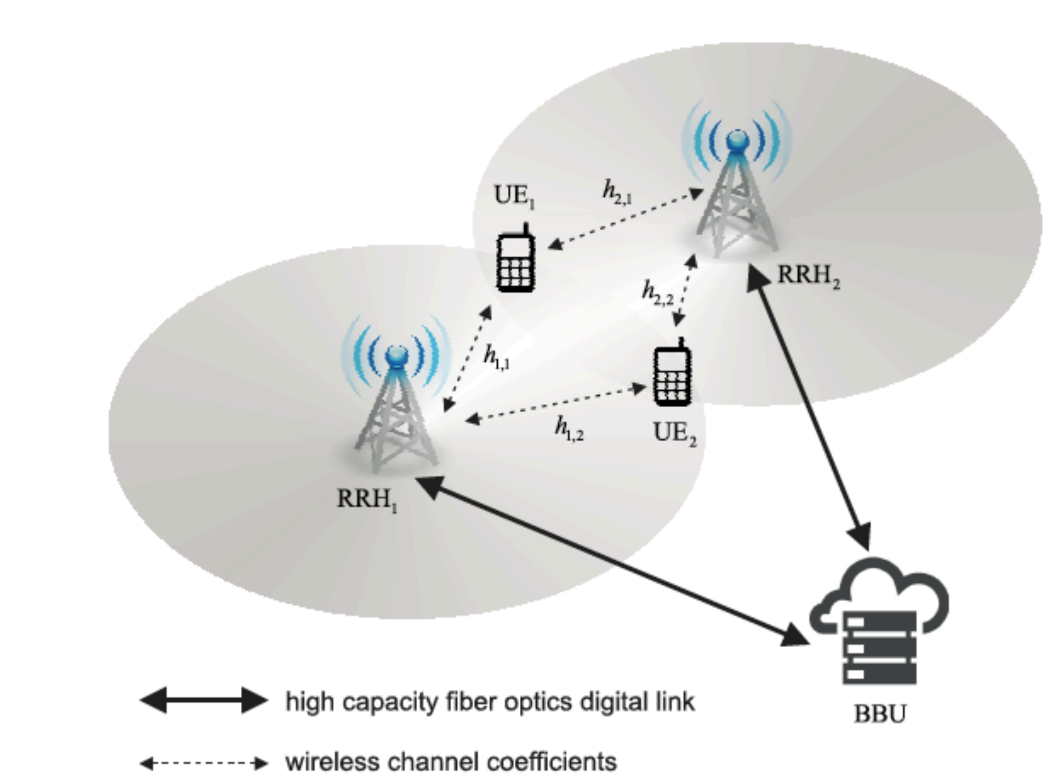
Fully Centralized

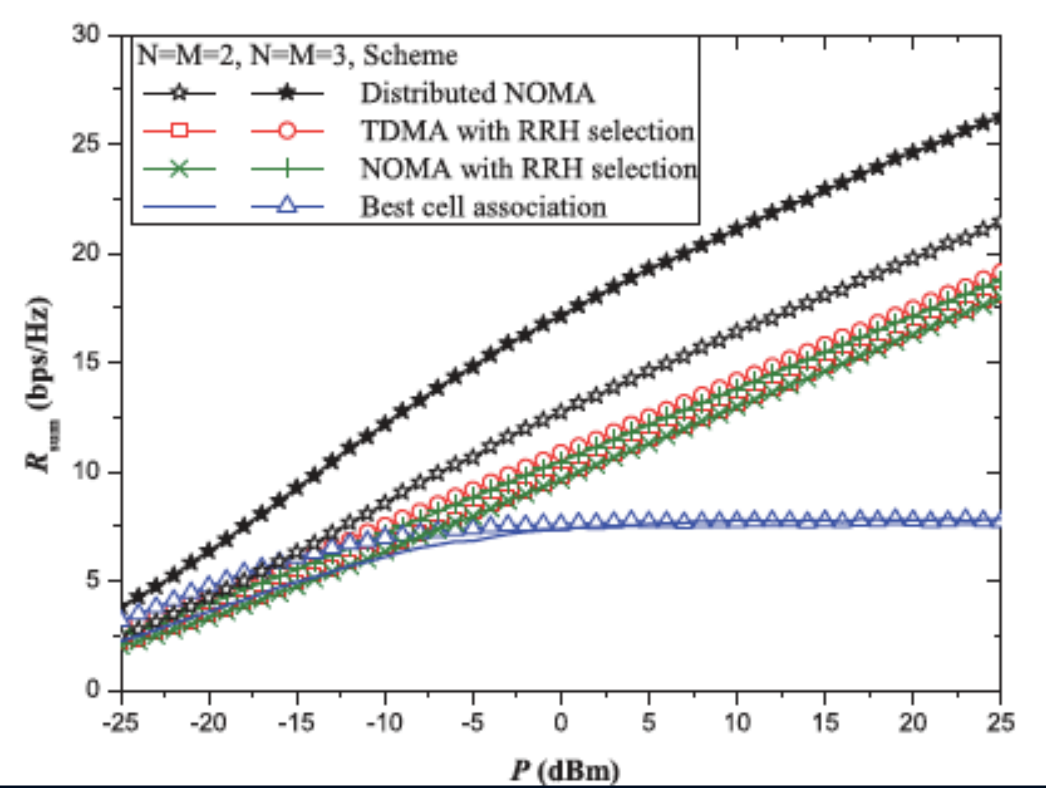


Partial Centralized

- *Image source: China Mobile*

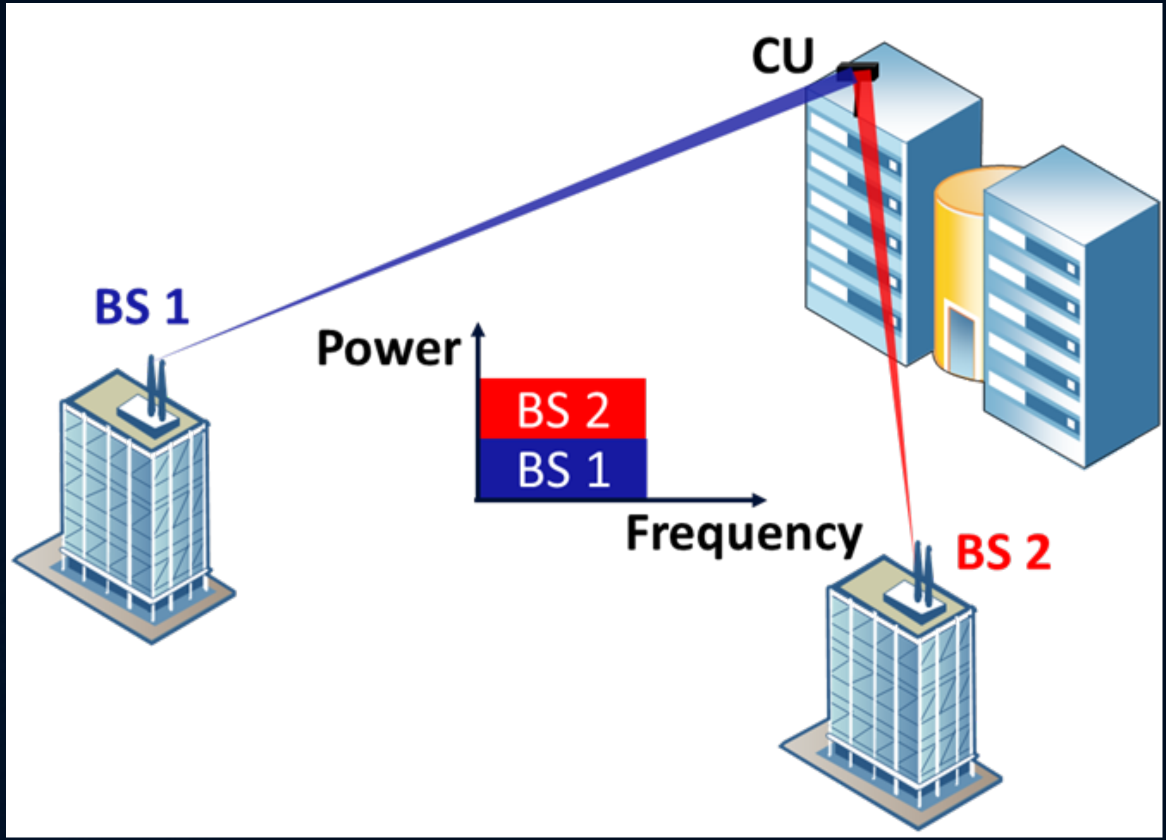
Distributed uplink-NOMA for CRAN





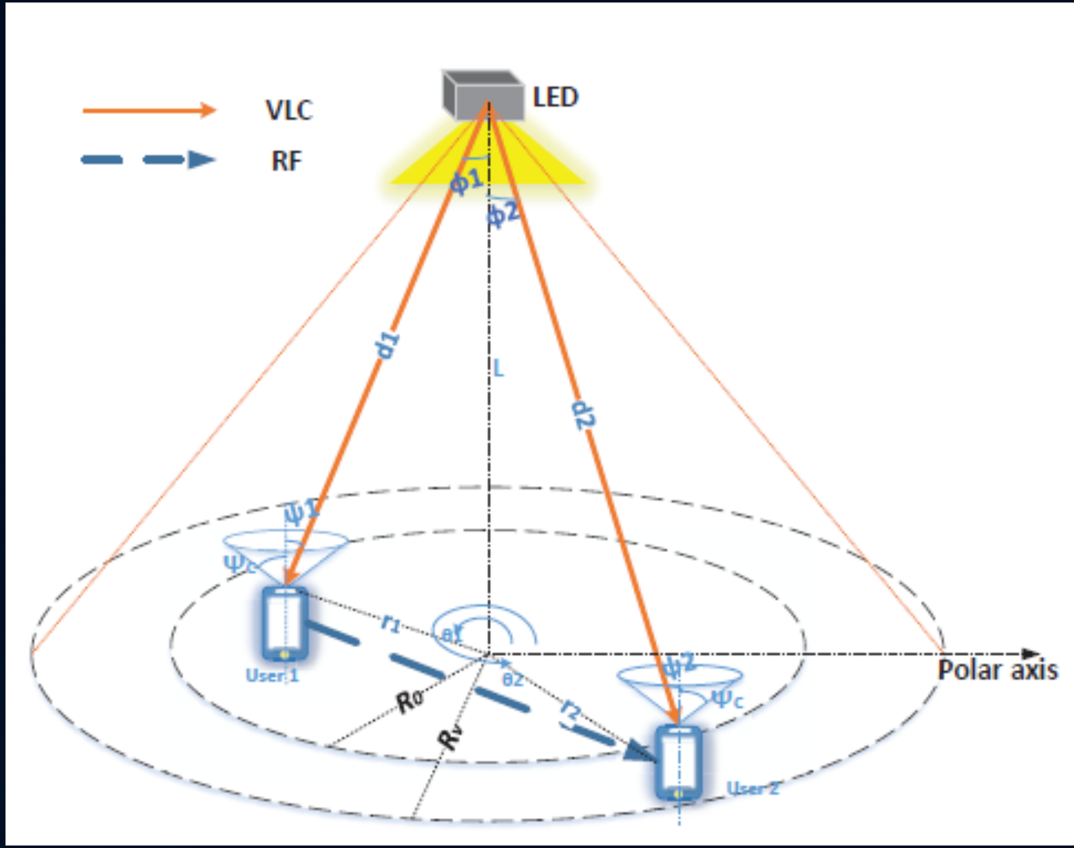
K. N. Pappi, P. D. Diamantoulakis, and G. K. Karagiannidis, "Distributed Uplink-NOMA for Cloud Radio Access Networks," IEEE Communications Letters, vol. 21, no. 10, pp. 2274-2277, Oct. 2017

Non-orthogonal multiple access for FSO backhauling



M. Najafi, H. Ajam, V. Jamali, P. D. Diamantoulakis, G. K. Karagiannidis, and R. Schober, "Statistical Modeling of FSO Fronthaul Channel for Drone-based Networks," in Proc. IEEE International Conference on Communications (ICC), Kansas City, Kansas City, MO, USA, May 2018

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

Spectral efficiency

Low complexity

Fairness

Energy Efficiency

Low energy consumption

Etc

Muhammed, Z. Ma, P. D. Diamantoulakis, L. Li, G. K. Karagiannidis, Energy Efficient Resource Allocation in Multicarrier NOMA Systems with Fairness, submitted to IEEE Transactions on Communications, Dec. 2018.

Resource management optimization

$$\begin{aligned} \underset{\boldsymbol{w},\boldsymbol{a}}{\text{minimize}} \quad & f(\boldsymbol{a},\boldsymbol{w}) \\ \text{subject to} \quad & \mathcal{Q}(\boldsymbol{a},\boldsymbol{w}) \leq C \\ & a_i \in \mathbb{N}, w_i \in \mathbb{C}. \end{aligned}$$

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

QoS constraints

Global vs Heuristic algorithms

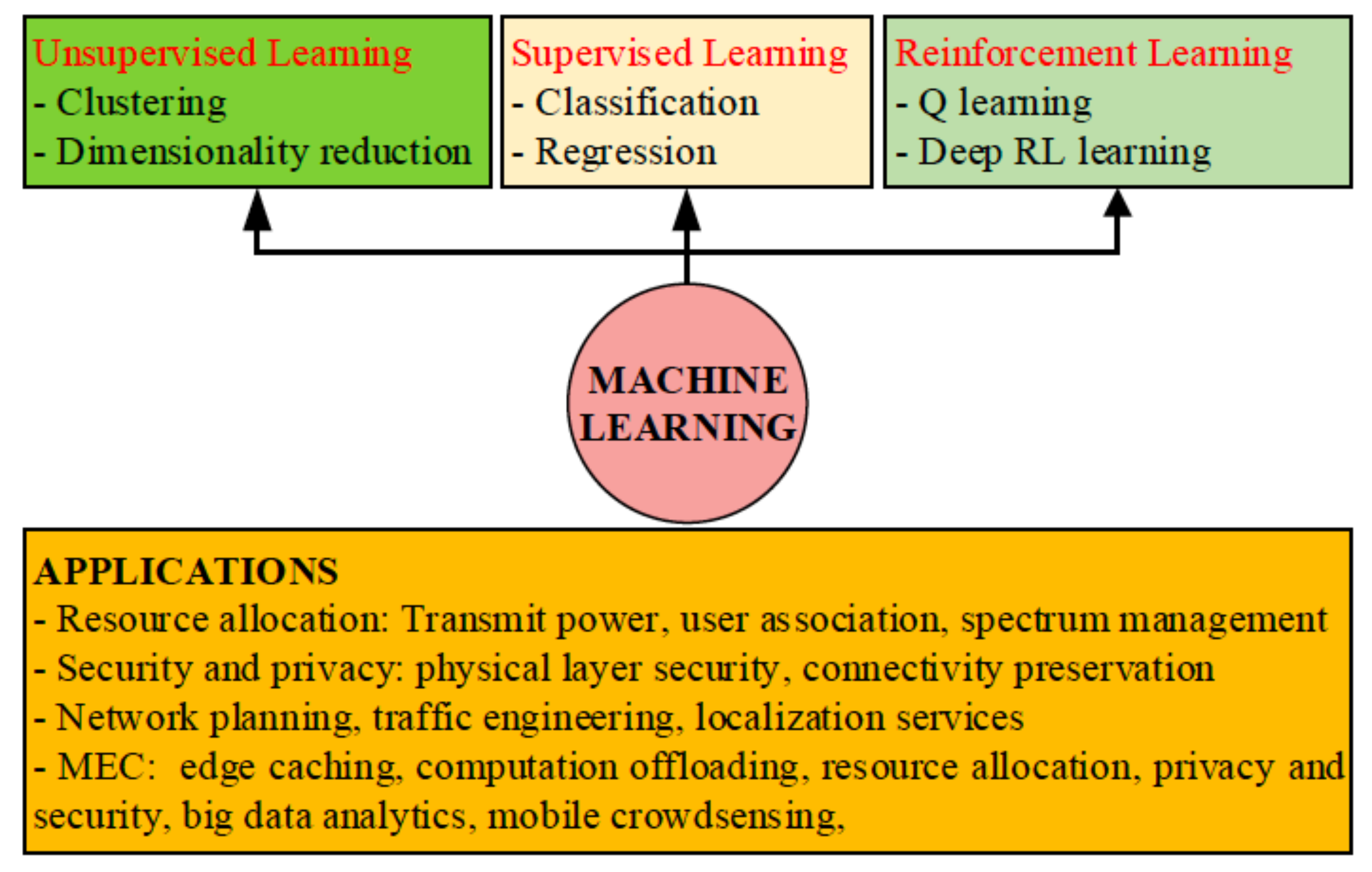
Global:

- Exponential time complexity
- Non-scalable

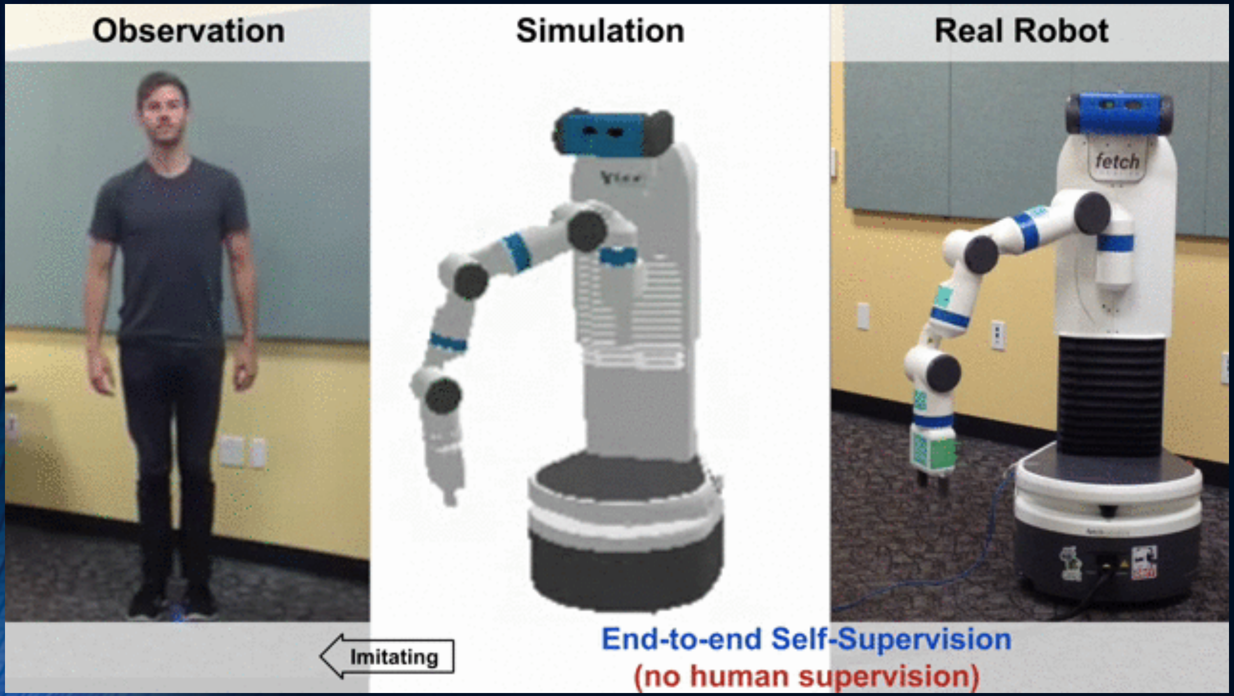
Heuristic algorithms:

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

Resource allocation



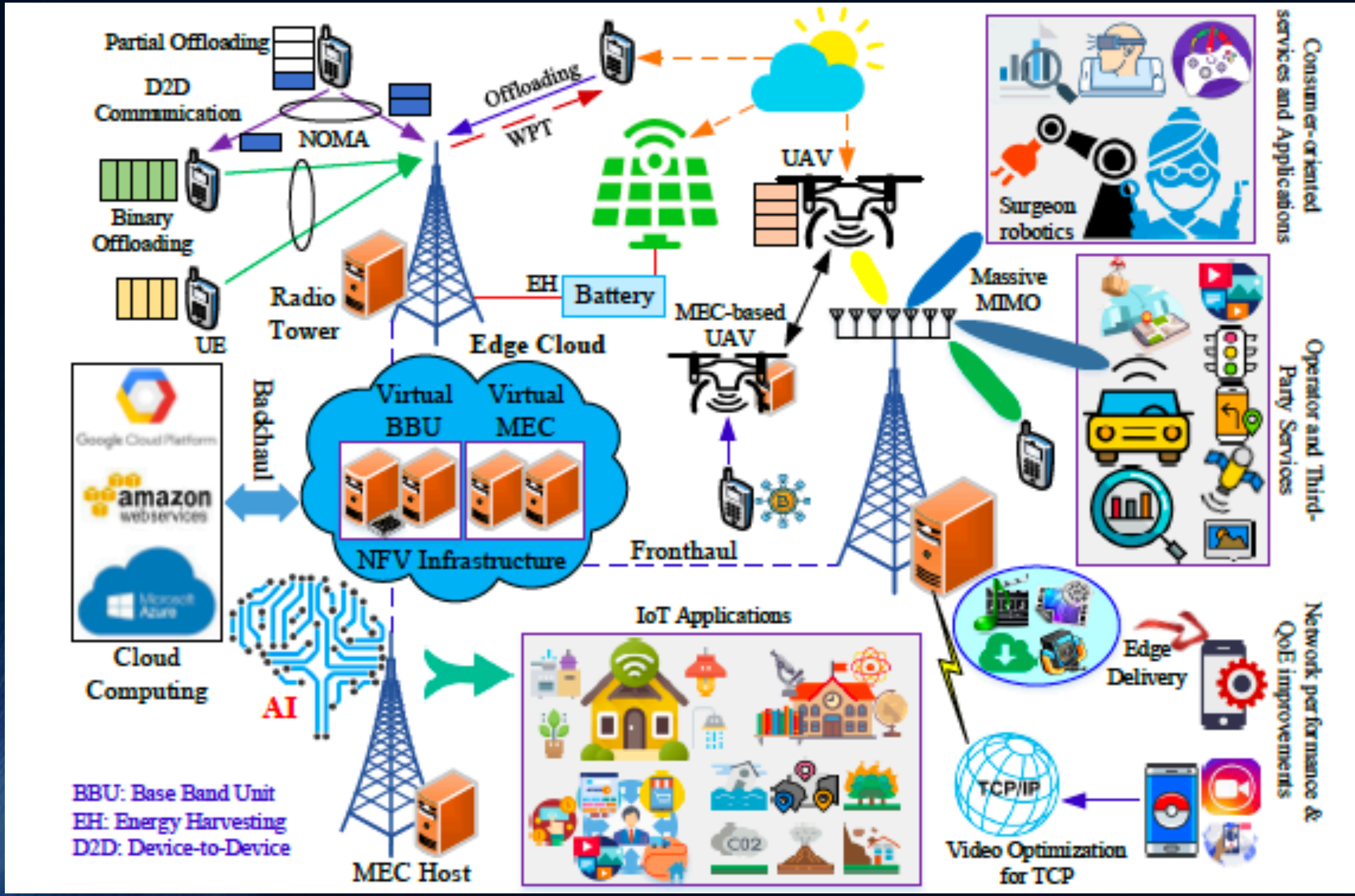
Imitation learning: "a combination of Supervised & Reinforcement Learning"



- 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

Y. Shen, Y. Shi, J. Zhang, and K. B. Letaief, "LORM: Learning to optimize for resource management in wireless networks with few training samples," IEEE Trans. Wireless Communications, to appear

Mobile edge computing with NOMA and AI



Federated learning is the next big thing

Q.-V. PHAM et al., "A Survey of Multi-Access Edge Computing in 5G and Beyond: Fundamentals, Technology Integration, and State-of-the-Art ," IEEE COMMUNICATIONS SURVEYS AND TUTORIALS, Jan. 2020

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!