5G 6G INNOVATION CENTRE
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6G Vision and Research Challenges

Imperial College Seminars Series on Future Communications

Nov 15TH, 2022
London, UK

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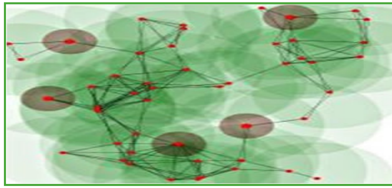
- **Mobile Cellular**
- **WiFi**
- **Satellite Communications & Broadcast**
  - Broadband Fixed
  - Broadband Mobile – BB on the move
  - Broadcast – passenger vehicles
- **Internet of Things**
- **Vehicle Communications**
- **Future Internet**

From Theory to Innovation



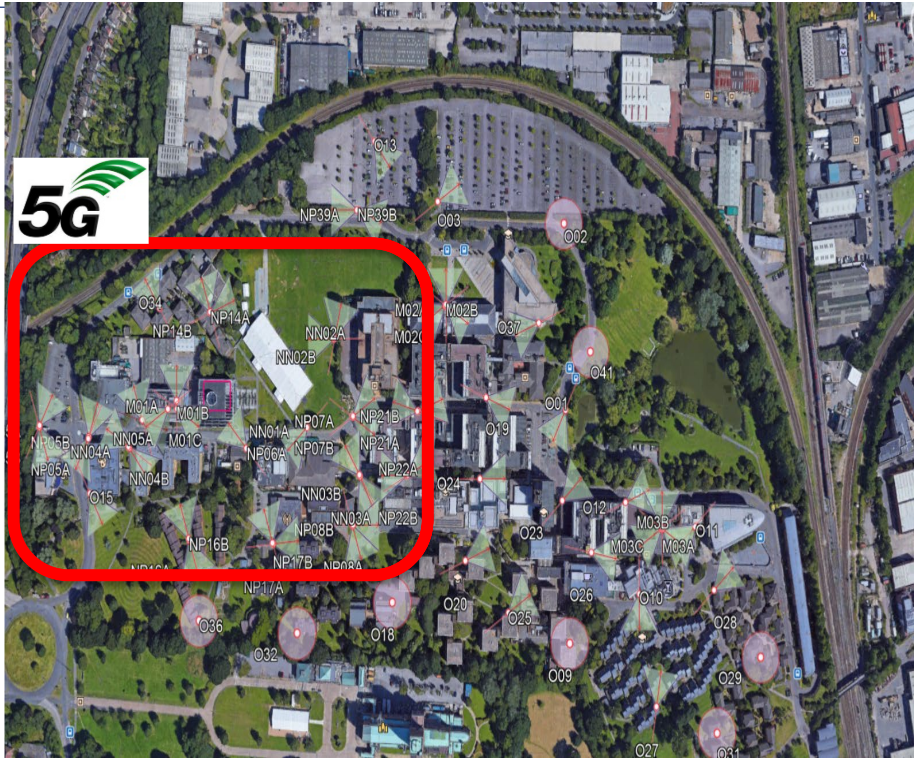


Testbed: 4G & 5G Multi-Radio access network Environment Coverage

Outdoor

- 4km² coverage of dense cells
- Ultra dense C-RAN of 44 4G-TDD sites & 66 Cells
- Cell Cluster operated as 1xMacro & 15xSmallCell site/Cluster
- eMBB D-RAN of 7 5G-TDD(3.5G) Sites & 9 Cells
- URLLC RAN of 1 5G-TDD(3.5G) site & single cell
- 700MHz 4G-FDD 1 site
- 60GHz backhaul system
- Combination of SDR & 60GHz supported on a drone for popup-network
- Satellite backhauling



Indoor – Over 2 Floors

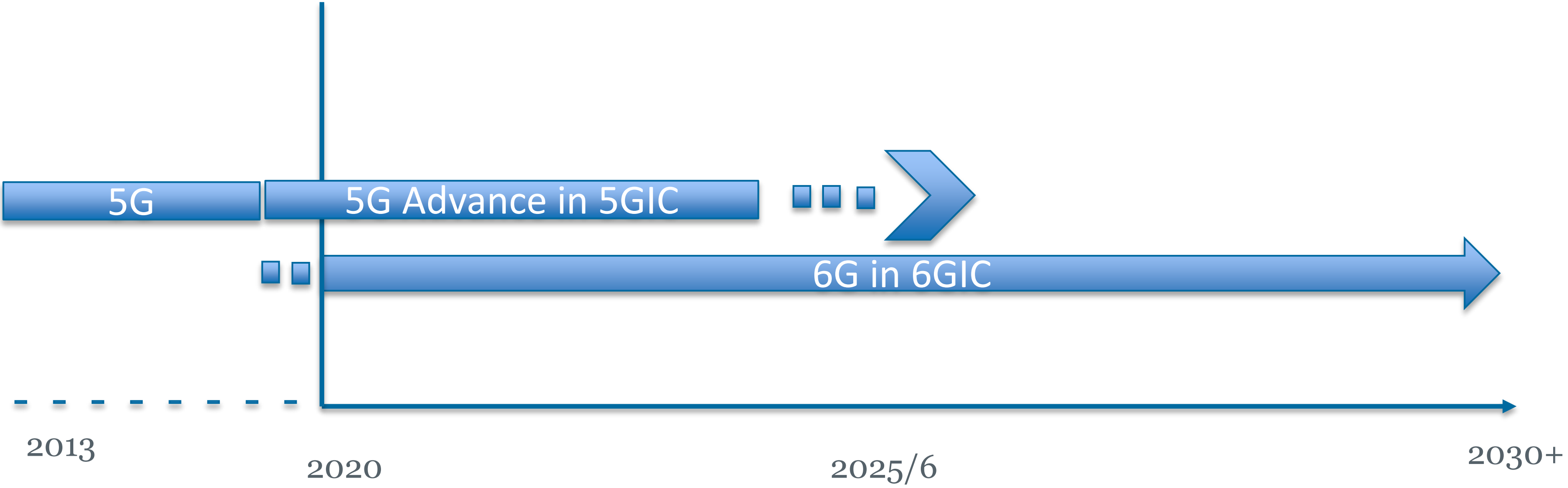
- C-RAN of 4G-TDD 6 Cells
- 4G-FDD femtos cells
- 6 x Wi-Fi-A

5GIC: World's first 5G Centre

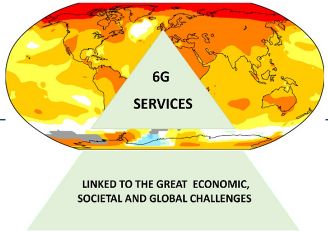
ART OF POSSIBLE

Winner of Royal Academy of Engineering (RAEng) 2021 for best Industry-Academia Collaboration

Parallel Approach



6GIC Vision and Strategy for 2030+



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Why

- Environment
- Society
- Economy

How

- Ultra Energy Efficiency
- Robust Privacy & Trust
- Solve Digital Divide
- Full 5G Capability
- Clear Use Case
- Clear Business Case

What

- 4D Video (Teleportation)*
- Intelligent Surfaces
- Sensing & Sensing Network
- Network of Networks

* R. TAFAZOLLI, Future Wireless world, TEDx 2015

Mobile System Generations Evolution

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Always reflection of demands

6G
Communications & Sensing

5G
Communications & Automation

4G
Communications & Internet
Data (Video)

3G
Communications
Voice & Data (Image)

2G
Communications
Voice Telephony

Social, Environment & Industry

- More Capacity,
- Social Inclusion,
- Environment Sustainability,
- Industry Productivity,

Social & Industry (vertical)

- Start of New Era for wireless connectivity
- Capacity crunch, Low latency, reliability, mass connectivity

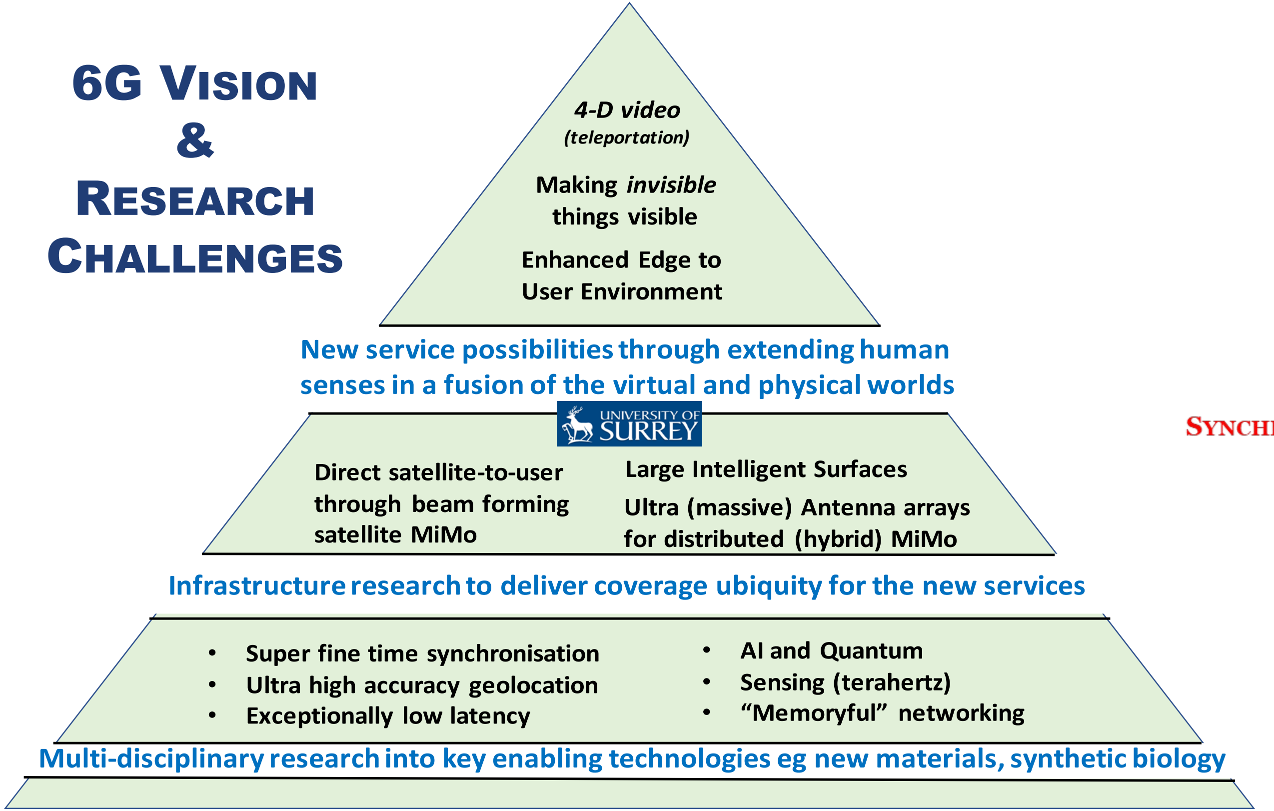
Social Needs: From 2G to 4G

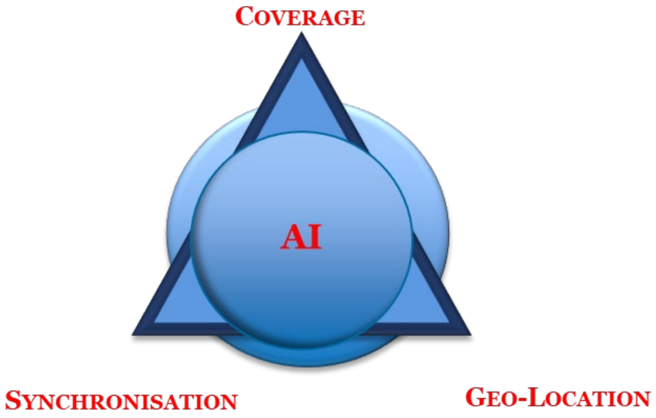
More Capacity and gradually more emphasise on Broadband Data on the Move than telephony services

Integrated Communication and Sensing (ICS)

Figure 1: 6G vision supported by new cross-functional research and development programme

6G Vision & Research Challenges





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Integrated

Communication
&
Sensing

(ICS)

In a
Network-of-Networks
Infrastructure

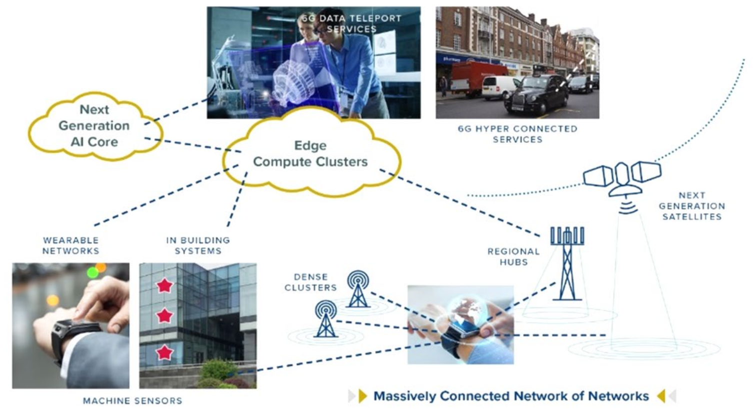

Figure 2: 6G services supported by next generation AI and network of networks

Sat Comms Networks Direct to UE + Sensing + **Cellular Pub/Non-Public Networks + Sensing** + **Personal Area Sensing Network**

Suburban & Rural Coverage | **Urban & Indoor** | **Ambient Sensing**

Principle Technologies for 6G

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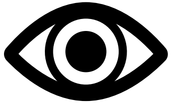
- Sensing ==============================



- Computing & Intelligence (AI)==============

- Block Chain & Time Synchronisation (Heartbeat)===========

- Virtualisation================================== Freedom

- Semantics & AI (Inference & learning)==========

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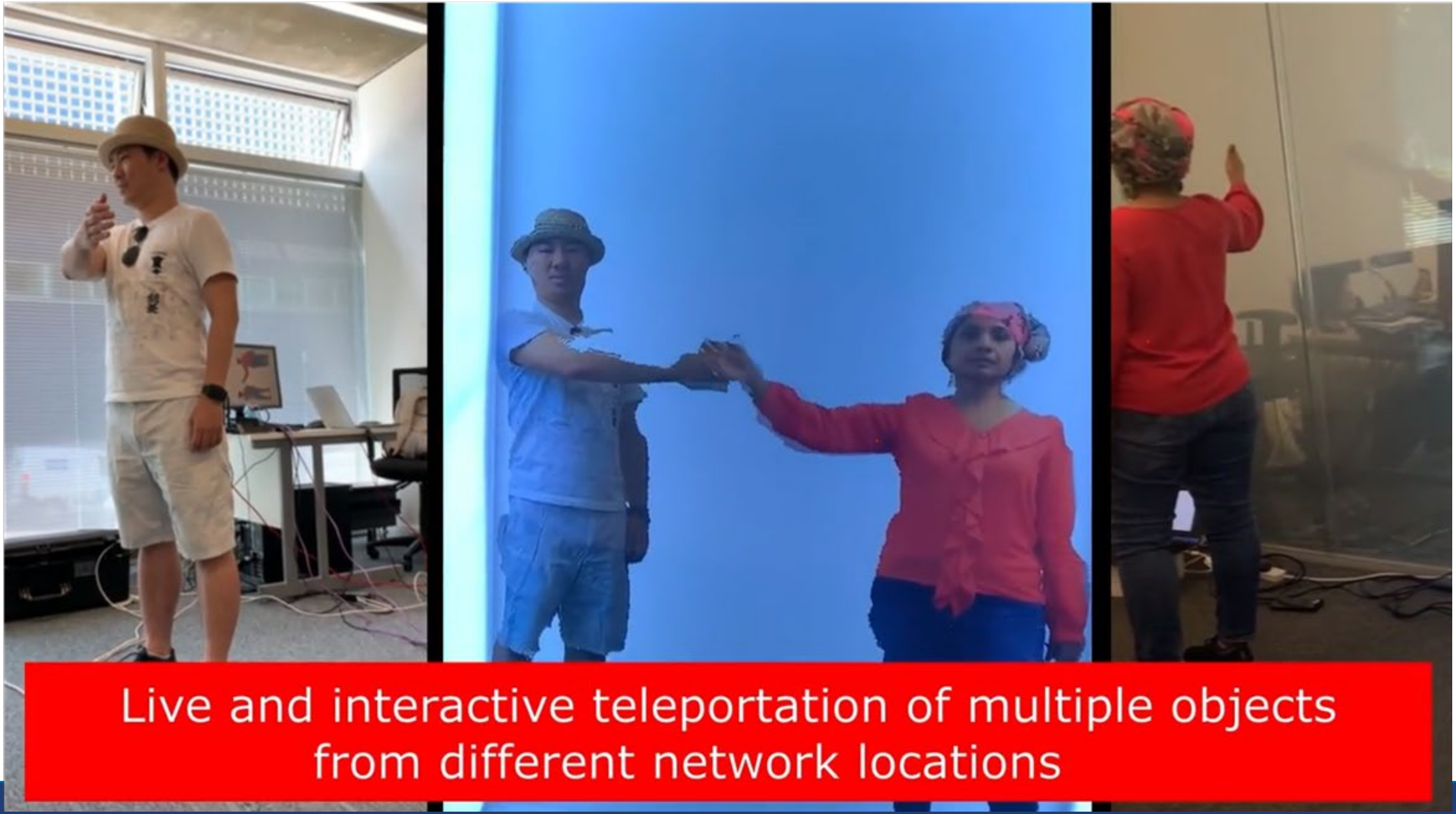
INTERACTIVITY BETWEEN AND WITHIN

VIRTUAL AND PHYSICAL WORLDS

6G: Virtual and Physical Worlds Interactions

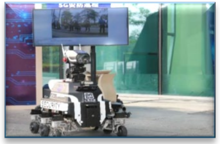
Teleportation



New Generation of Use cases with enabled with Interactivity

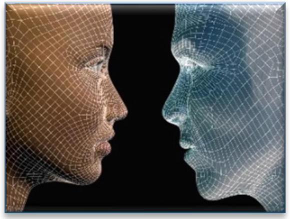
5G
Enabled by Low latency and reliability

- Connected vehicles
- Manufacturing
- Games/Entertainment
- Health
- Education
- …



6G
Enabled by Low latency + Time synchronisation + Sensing Information

- High Speed Driver-Less and cooperative driving
- Interactive Cooperative Manufacturing
- Interactive Agriculture
- Interactive entertainment
- Interactive Telecare
- Interactive Tele-education
- Teleportation
- …..



Sensing

- Enhances efficiency at all layers of communications: Phy, Mac, Net,..& system
- Improves Energy & spectrum Efficiency
- Enable smarter applications
- Two broad categories of Sensing:
  - System Level
  - User Level (Ambient Information)

Some Examples

Traffic Sensing

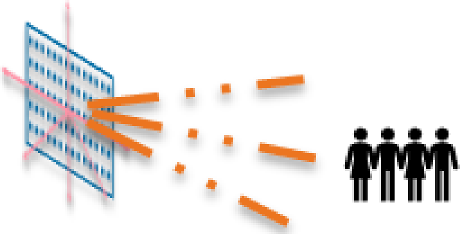
Camera

Interference Management

Earth Observation/Sensing

Various applications
incl: Security

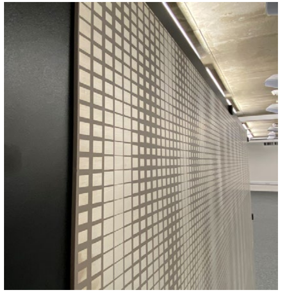
Traffic Location and Mobility Sensing



Resource Management, Beam Forming & Tracking

EM Sensing

Intelligent Surfaces
with Metamaterial



Coverage Extension

Change of Environment (Channel) Sensing

Camera
Radar/Lidar

Channel Equalization

Adding User-Level Sensing to Interactive VR

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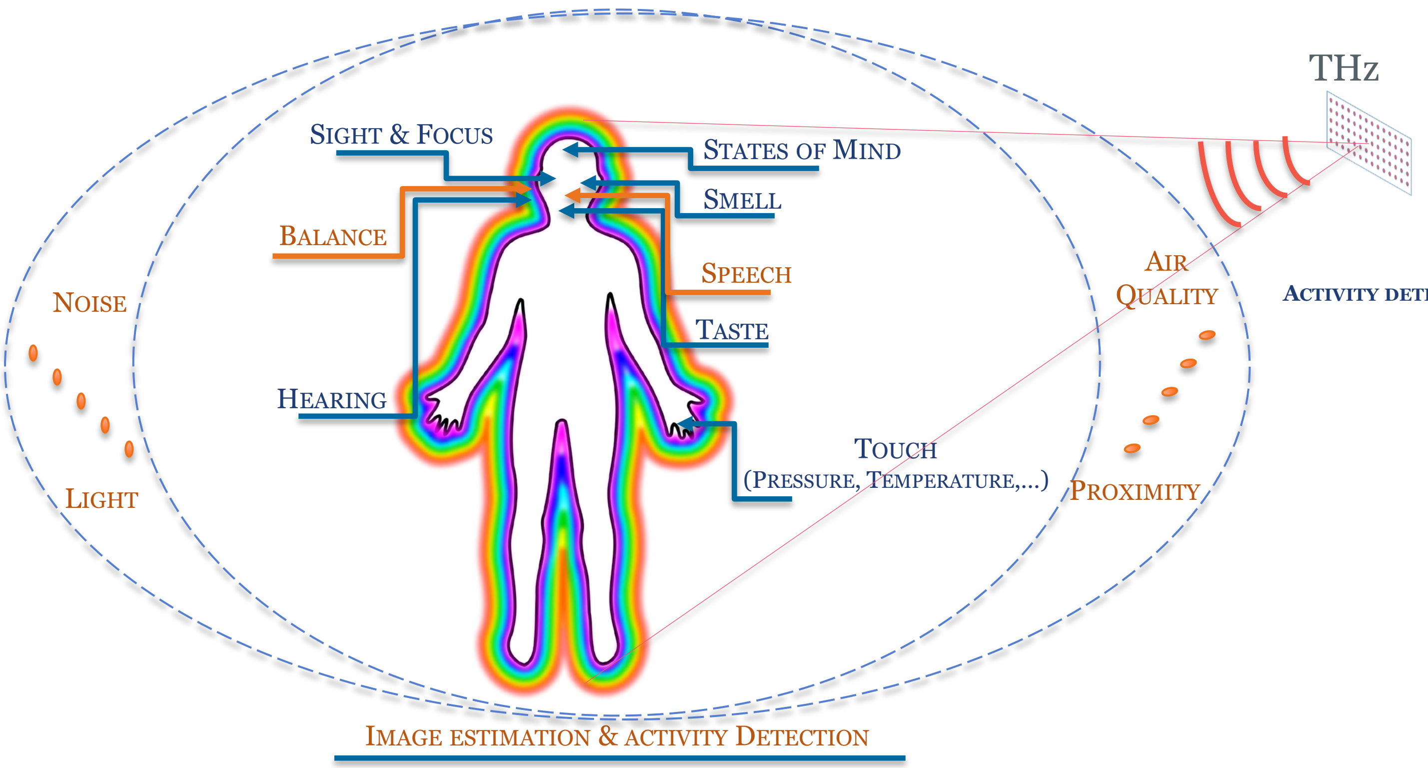
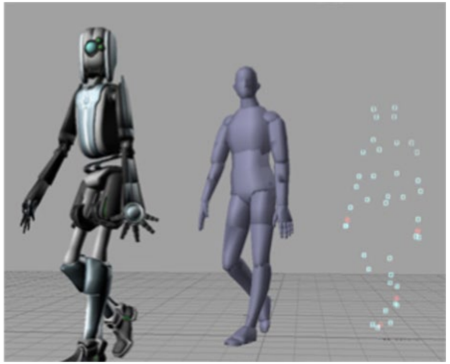


Activity detection and Location Estimation (sub-cm) and real-time Tracking

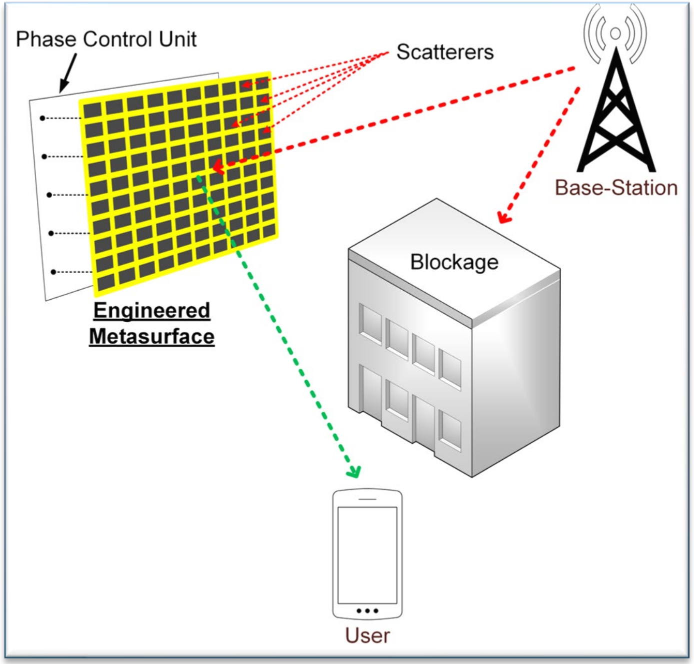


THz Imaging

Sensing Challenges

- Optimum resources balancing for sensing and communications
    - How much for sensing and how much for communications and how much for AI
- How to Integrate sensing information with communications
- High quality time/Frequency synchronisation
- Edge processing and computing and task offloading between UE and networks
- Semantic Communication and Sensing
- Privacy preserving and bilateral (distributed) authentication protocols between sensing nodes

Coverage & Energy Efficiency



RECONFIGURABLE

REFLECTING/TRANSMITTING

SURFACES

ENERGY EFFICIENT COVERAGE:

OUTDOOR 2 OUTDOOR

OUTDOOR 2 INDOOR

INDOOR 2 INDOOR

6GIC- World's first working RIS based on Holography Principle

Reflective Intelligent Surfaces (RIS)

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- Thickness: 3mm
- Unit cells: 11000
- Beams: 2 reflected beams towards $\pm 45^{o}$
- Measured Gain: 20 dB
- Bandwidth: 400MHz (3.3 GHz- 3.7 GHz)
- Input power: zero

DYNAMIC RIS

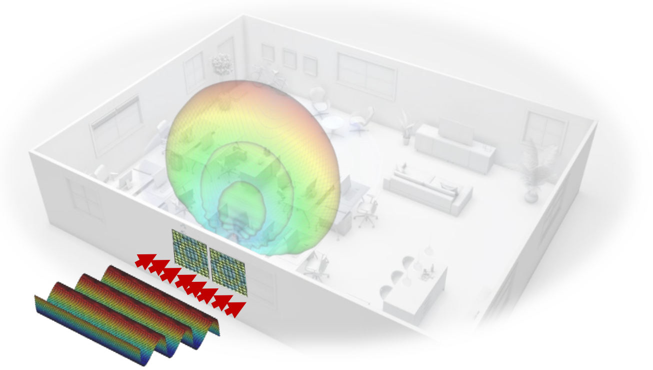
- SUBSTRATE THICKNESS: 1.524mm
- UNIT CELLS: 3000
- MEASURED GAIN: 17dB
- BANDWIDTH:700MHz (3.1 GHz- 3.8 GHz)

Transmissive (Conductive Glass) and Reflective RIS

- Interrogates 3.3~3.7 GHz from outdoor
- Polarization insensitive
- Wide incident angle insensitive
- Passive and small ($\sim 15\lambda \times \sim 15\lambda$)
- Easy to implement

Single glazing

Double glazing



Satellite Role: Applications & Use Cases

Rural Land, Sea and Air

- Mobile Broadband
- Internet of Thing
  - Narrow-Medium-Broadband applications
    - Connected transportation, e-Agri, e-Manufacturing,….

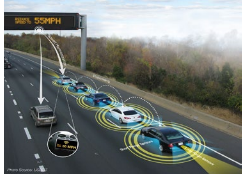
5G (Communications & Automation)

- PNT
- Quantum Key Distribution
- Beyond LoS for UAV
- Direct Sat-To- UE
- Earth Observation

6G (Communications & Sensing)



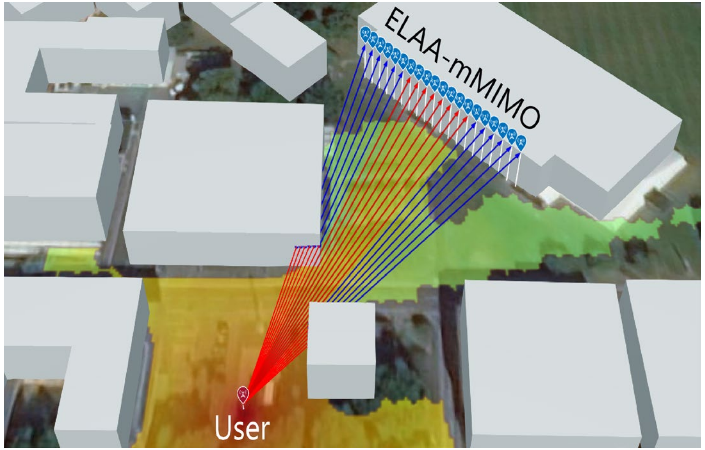



- AI/ML FOR WIRELESS NETWORKS
  - DEEP NEURAL NETWORK (DNN)S FOR JOINT SOURCE CHANNEL CODING (JSCC)
  - MIMO CHANNEL ESTIMATION AND FEEDBACK
  - NEURAL MMWAVE BEAM MANAGEMENT FOR SENSING-AIDED COMMUNICATIONS
  - MODEL-BASED LEARNING FOR COMMUNICATIONS
  - DNN-BASED SEMANTIC AND EFFECTIVE COMMUNICATIONS
  - NETWORK AUTOMATION E.G, 6GANA

MIMO, mMIMO or umMIMO are important components of 5G, 6G,…..

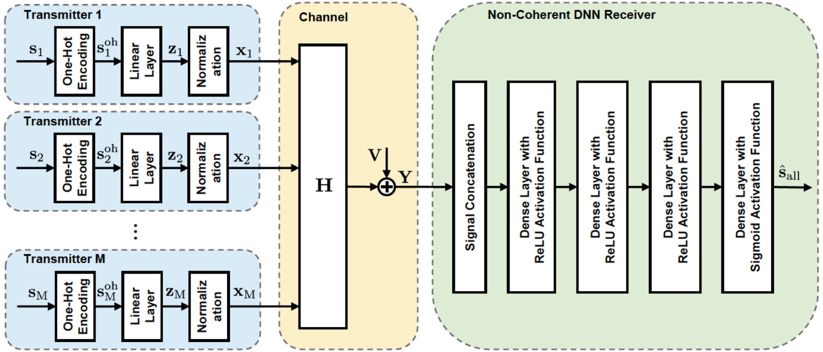
Why there is so much gap between theoretical and practical performances?

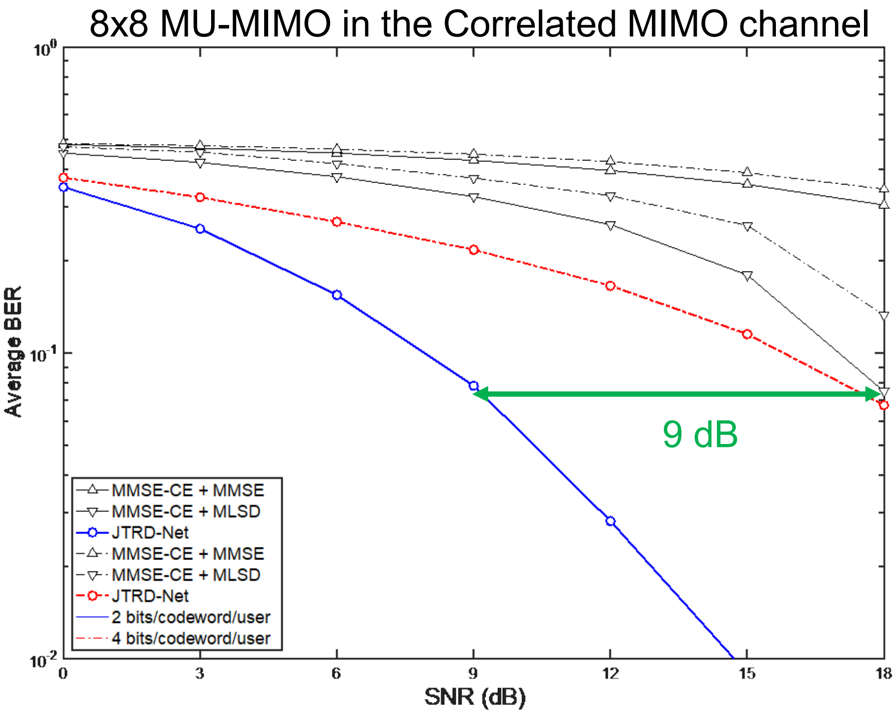


- Channel Spatial Non-Stationarity in MIMO with an extremely large aperture array
- Non-Linear distortions (analog-to-digital conversion, power amplifier, etc.)
- Non-Gaussian noise and interferences due to device nonlinearities
- Non-Ergodic communication due to shot finite-length transmissions

MU-MIMO (Non-Ergodic)

End-to-End Deep Learning for Multiuser-MIMO Joint Tx-Rx Design





- A well-designed multiuser codebook can help short block-length MU-MIMO uplink to have a non-coherent multiuser detection performance which is much better than that of coherent detections.
- End-to-end deep learning is an effective way to design such a codebook [3, 4].
- Use continuous learning to improve the system adaptability [5].

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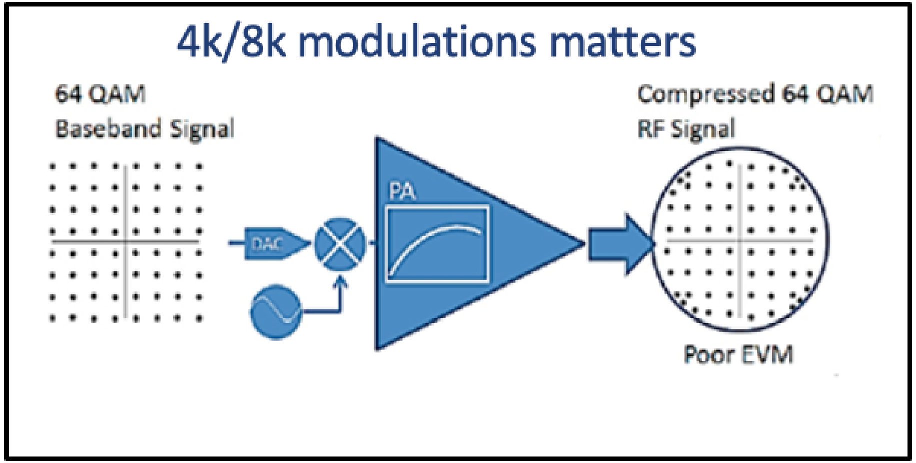
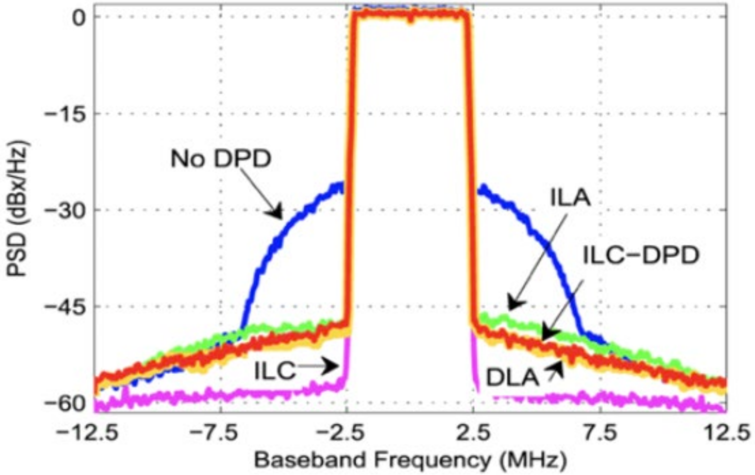
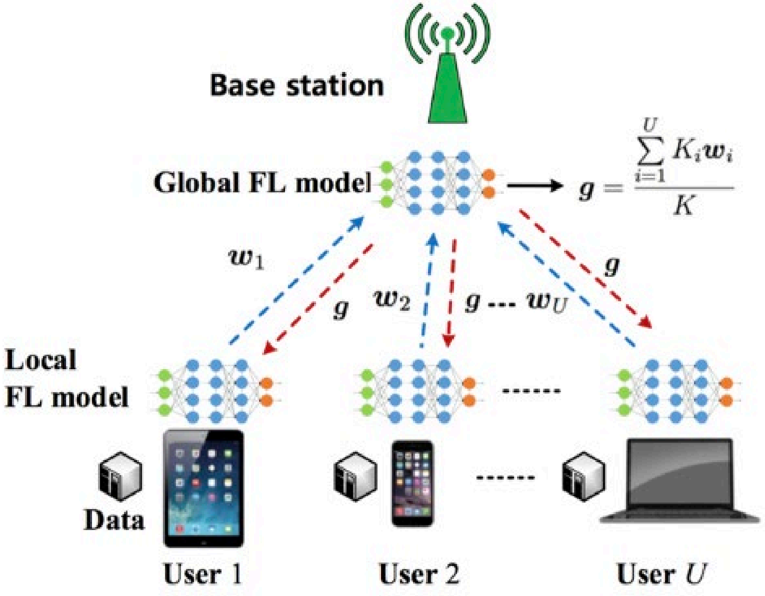
NEW DEEP LEARNING ARCHITECTURE FOR PA LINEARISATION

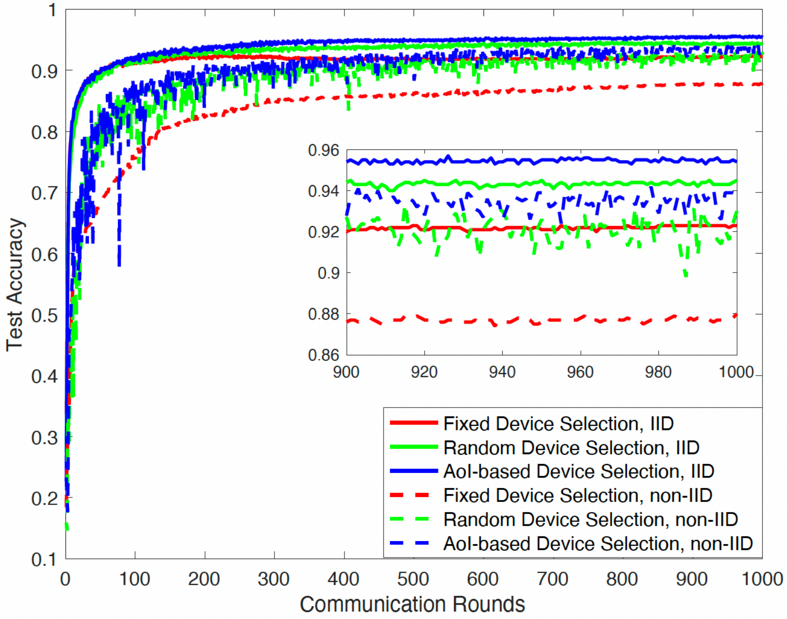




USING ITERATIVE LEARNING CONTROL (ILC) PRINCIPLE IN DEEP LEARNING FOR DPD CAN SIGNIFICANTLY IMPROVE THE PA LINEARIZATION PERFORMANCE (10 – 15 dB GAIN IN PSD)

Communications optimised for federated learning



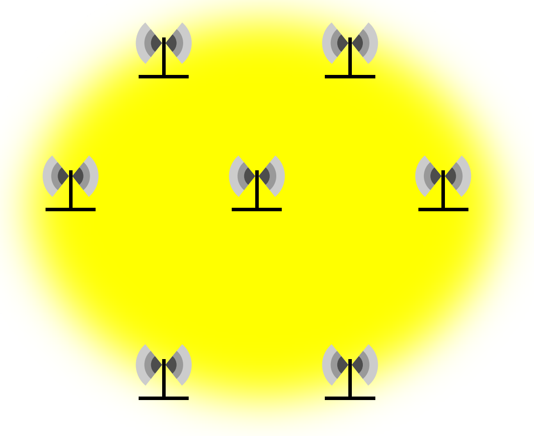


Age of Information (AoI) aware device selection can offer faster convergence and higher test accuracy in federated learning because aged information is more critical particularly for non-IID data.

USER SCHEDULING

SCENARIO & PROBLEM

- **SCENARIO: A SET OF BASE STATIONS WHICH CAN CHOOSE A PARTICULAR SCHEDULING SCHEME TO OPERATE**
- **QUESTION: WHAT COMBINATION OF SCHEDULERS WILL DELIVER THE USER EXPERIENCE?**



IEEE Transactions on Cognitive Communications and Networking (2020)

IEEE TRANSACTIONS ON COGNITIVE COMMUNICATIONS AND NETWORKING, VOL. 6, NO. 2, JUNE 2020 575

Dynamic Scheduler Management Using Deep Learning

James Hall, Klaus Moessner, *Senior Member, IEEE*, Richard MacKenzie, Francois Carrez, and Chuan Heng Foh, *Senior Member, IEEE*

***Abstract*—The ability to manage the distributed functionality of large multi-vendor networks will be an important step towards ultra-dense 5G networks. Managing distributed scheduling functionality is particularly important, due to its influence over inter-cell interference and the lack of standardization for schedulers. In this paper, we formulate a method of managing distributed scheduling methods across a small cluster of cells by dynamically selecting schedulers to be implemented at each cell. We use deep reinforcement learning methods to identify suitable joint scheduling policies, based on the current state of the network observed from data already available in the RAN.**

influences the high level performance metrics used to assess the network, including throughput, fairness and latency. These indicators are monitored because of their influence on the quality of service provided to users in the network.

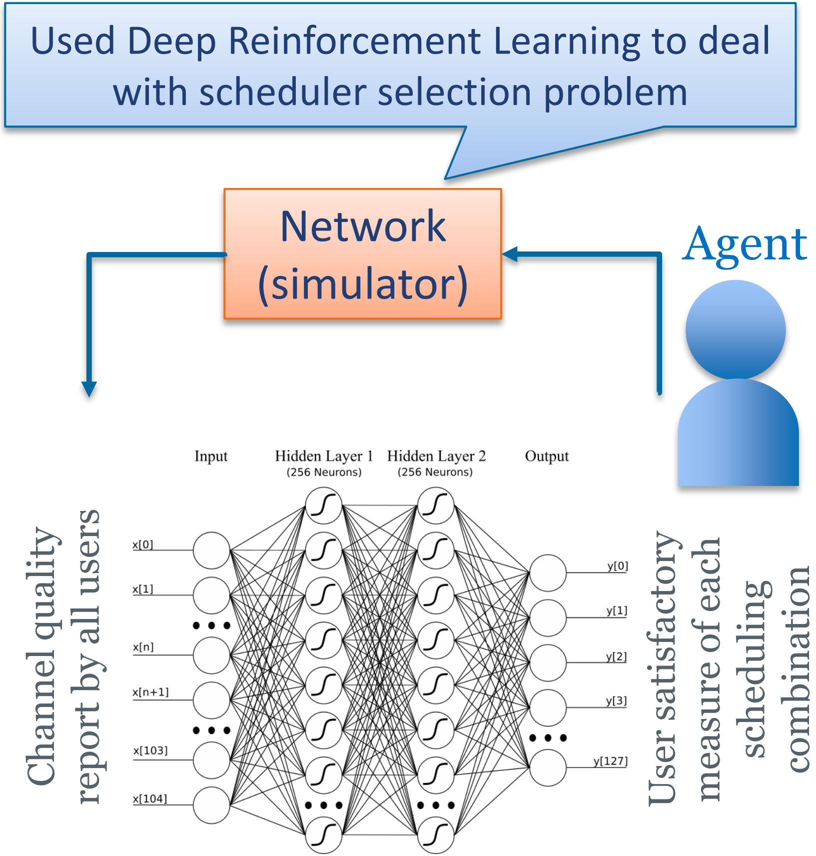
A large body of literature exists around scheduling methods for the LTE network architecture. These methods are evaluated by a number of surveys of the most commonly used scheduling methods for LTE networks, highlighting the key themes and the limitations imposed by the network architecture [1], [2].

User Scheduling

Results

- We use Deep NN as a function approximator
- Distributed Scheduler Selection (DSS):
  - Deep RL & Genetic Algorithm (GA)
- Tested against two cases:
  - σ_0: All Proportional Fair Case
  - σ_{127}: All Margin Adaptive Case

	Deep RL	GA
DSS better than σ_0	92.4 %	87.2 %
DSS better than σ_{127}	83.5 %	84.2%



RAN-AI Scheduler Summary

- For user scheduling, we applied DRL to learn the best scheduler selection meeting user satisfaction.
- By developing a parallel model, we can explain our RNN model and better interpret the outcomes.
- Huge opportunities in network automation for RAN using ML algorithms

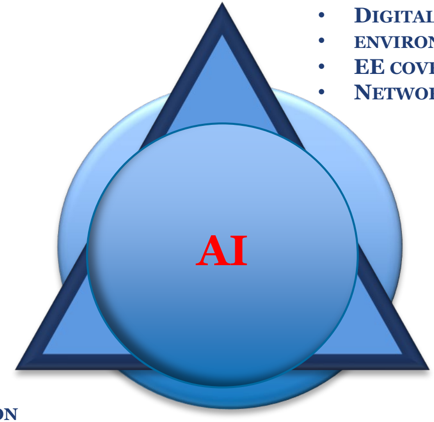
Technical Challenges and Future Directions

- **Technical Challenges:**
  - Data collection and training (mostly offline) overhead
  - Running resource-hungry AI/ML models on handheld devices
  - Runtime latency of AI/ML models
  - Situation or location/… specific AI/ML models, e.g., each BS needs to train its own NN
  - Adaptability challenge
  - Model-based Learning for Communications
    - **Model-based Inference → Analytically understandable but requires simplifying channel assumptions**
    - **Data-driven Inference → Model-agnostic but needs dataset collection and training**
    - **Best of both worlds: Model-based Learning for Communications**
- **Future Directions:**
  - Online training/adaptation of AI/ML models during normal operation of the wireless network (Meta-learning, Few-shot learning, NN simplification techniques)
  - Spectrum, energy efficient, and green distributed AI/ML (OTA learning, Knowledge distillation)
  - Wireless Networks for AI/ML
    - **Collaborative Learning (CL) over Wireless Networks**
    - **Over-the-Air Computation (OTAC) for Distributed Learning over Wireless Networks**

Integrated Communication and Sensing in 3D Network

Coverage

- Digital inclusion,
- environment sustainability,
- EE coverage extension
- Network of Networks



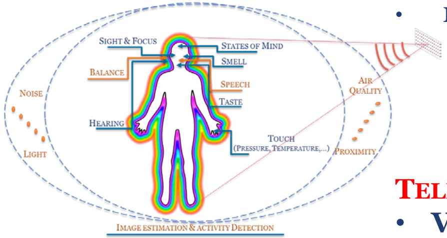
Synchronisation

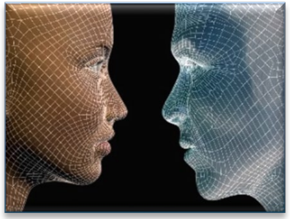
- 4D Video, Physical & Virtual worlds interactivity Driverless transportation
- Interactive e-Health,....
- Interactive robotics

Sensing & Geo-Location

(Human and environment and Network sensing)

- Environmental information
- Natural Interactivity between Physical & Virtual worlds
- Resources efficiency
- Many New Smart services,





Teleportation:

- VR + Synchronisation+ User Level Sensing

References & Related Reading

[1] J. Liu, Y. Ma, et al, "A novel stochastic spatially non-stationary channel model and capacity analysis for ELAA," **IEEE Globecom** 2021(submitted).

[2] L. Liu, Y. Ma, N. Yi and R. Tafazolli, "Hermite expansion model and LMMSE analysis for low-resolution quantized MIMO detection," **IEEE Trans. Signal Process.**, 2021 (Under Review)

[3] S. Xue, Y. Ma, and N. Yi, "Unsupervised deep learning for MU-SIMO joint transmitter and non-coherent receiver design," **IEEE Wireless Commun. Letts.**, 2018.

[4] S. Xue, Y. Ma, and N. Yi, "End-to-End learning for uplink MU-SIMO joint transmitter and non-coherent receiver design in fading channels," **IEEE Trans. Wireless Commun.**, 2021 (Xplore Early Access).

[5] S. Xue, Y. Ma, R. Tafazolli, "An orthogonal-SGD based learning approach for MIMO detection under multiple channel models," **IEEE ICC2020 Workshops**.

Acknowledgement:

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Thank You

https://www.surrey.ac.uk/sites/default/files/2020-11/6g-wireless-a-new-strategic-vision-paper.pdf