Towards Fully Connected World

Mobile Communication and Digital Revolution

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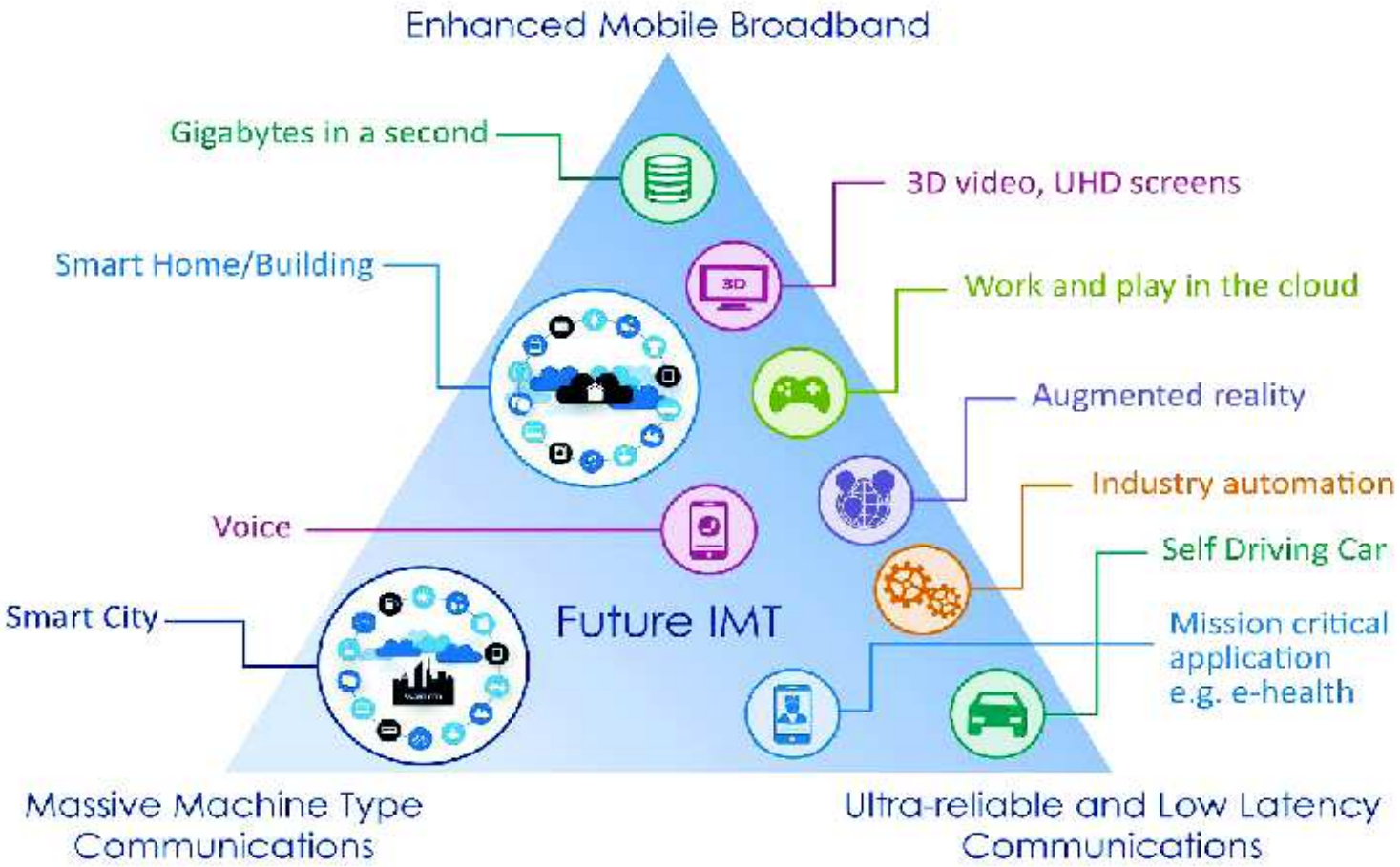
Communication and Computing Revolution

- What can you get from ELEC6214 module?
  - To answer this question, you need to see the **big picture**
  - We are in an exciting communication and computing **revolution**, which is fundamentally changing our **life**
- Information management and processing is as old as **human society**
  - **Computing** and **communication** are two pillars of our information society
- **Electronic and digital** revolution, **mobile communication** revolution lead to our connected digital world
  - Mobile communications went through from birth (1G) to 4G, and We are currently in 5G revolution – actually in 6G revolution

5G Revolution



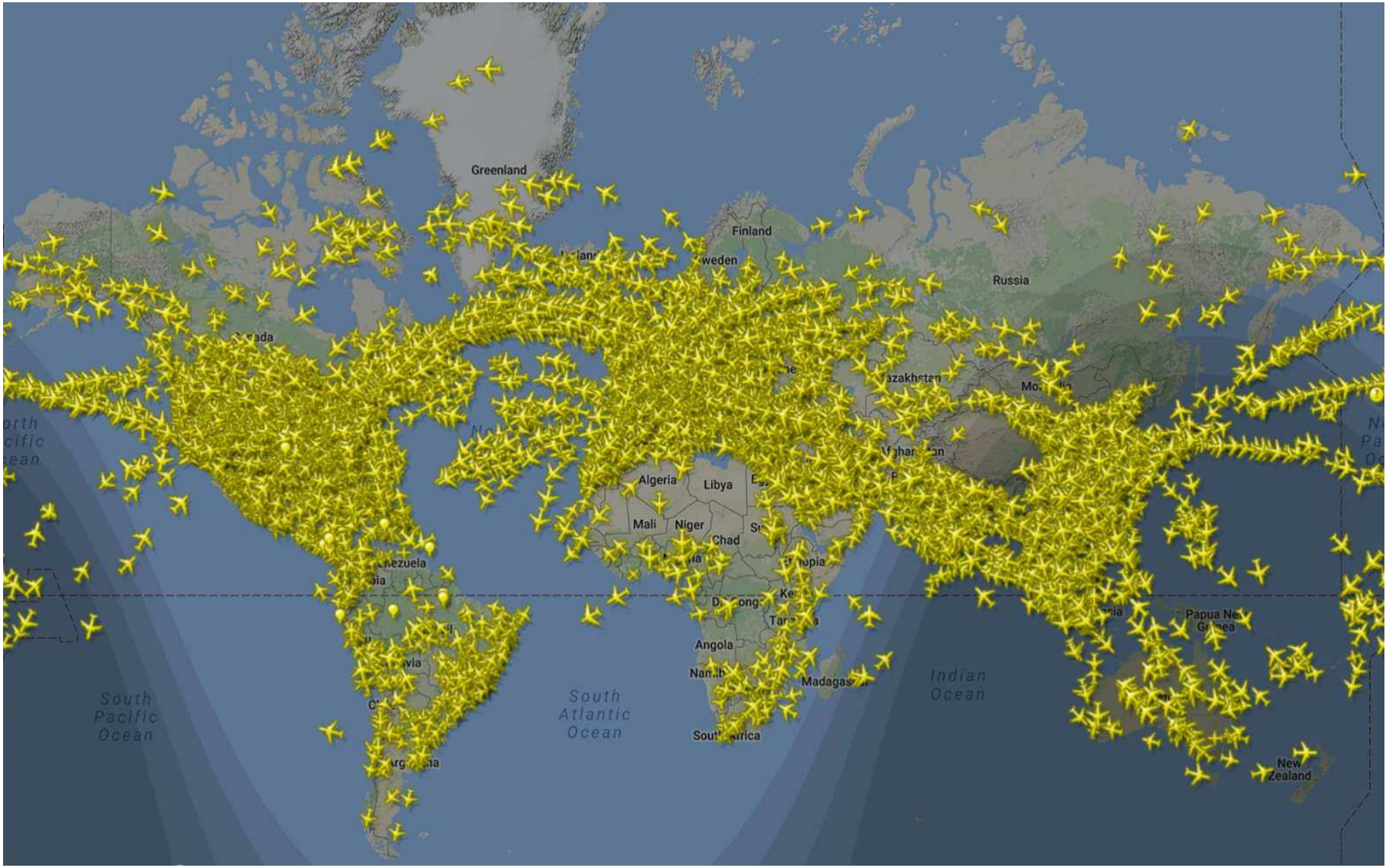
- **eMBB**: enhanced mobile broadband (deployed)
- **mMTC**: massive machine-type communications (in progress)
- **URLLC**: ultra-reliable and low latency communications (in progress)

Fully Connected World

- **5G** is revolutionizing our society
  - **Massive rate**, 1 to 10 Gbps end to end
  - **Massive connections**, IoTs – every device connected
  - **Ultra low latency** for autonomous driving, intelligent transport system, etc
- With 5G, fully connected world anywhere anytime? – We are connected **anywhere anytime** on **land**, but not in **sky** or on **ocean**
  - Step on jumbo jet, we disappear into a non-G **black hole**
  - Holiday on cruise ship, we disappear into a non-G **black hole**
- Researchers including in Southampton are considering **fully connected** world by
  - Connecting City in the **Sky** to realize Internet above the Cloud
  - Connecting City on the **Ocean** to realize Internet above the Wave
- 5G is just being deployed, and we have already working on 6G

City in the Sky

- Normal snapshot of world's commercial **airspace**

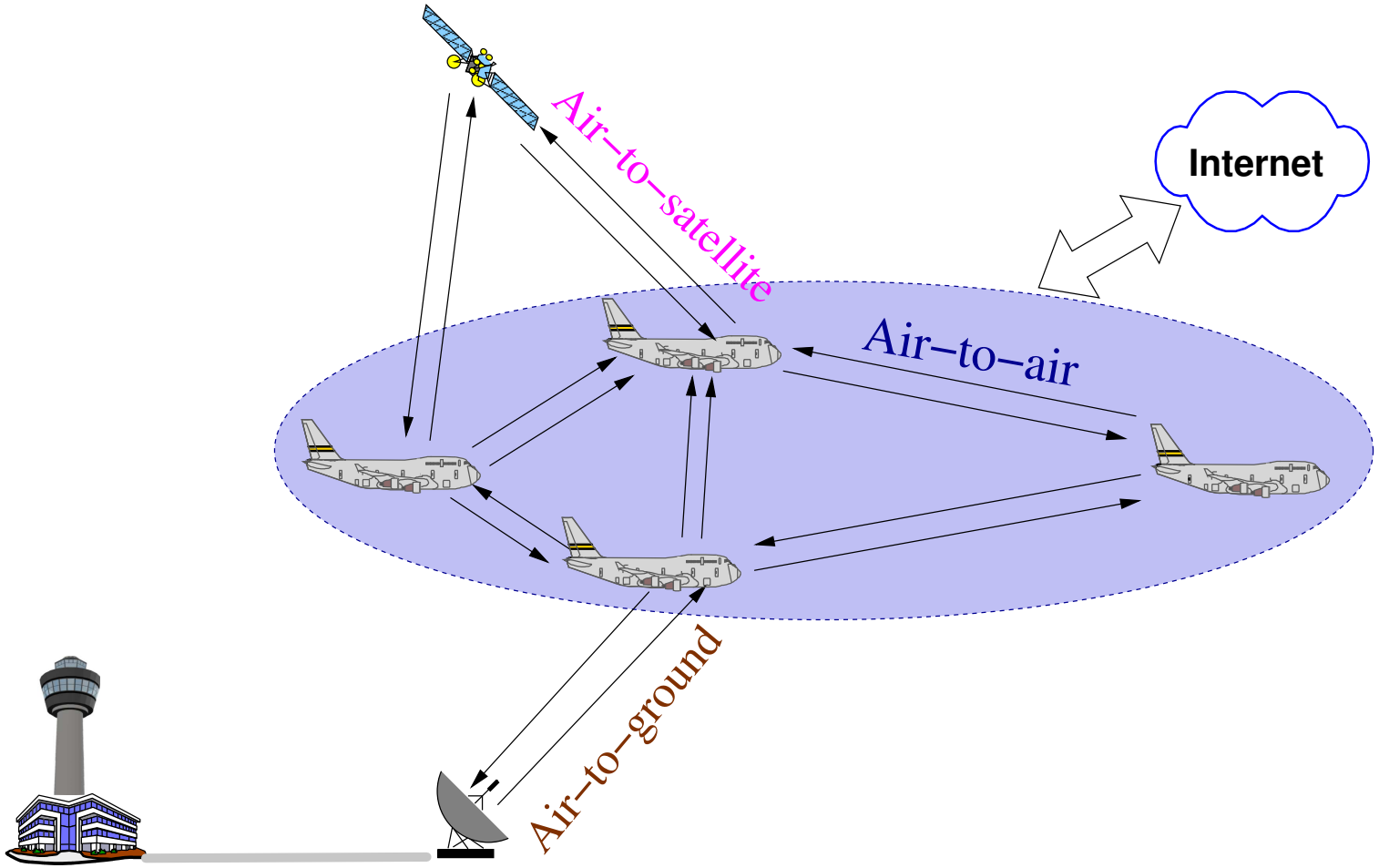


Internet above the Cloud

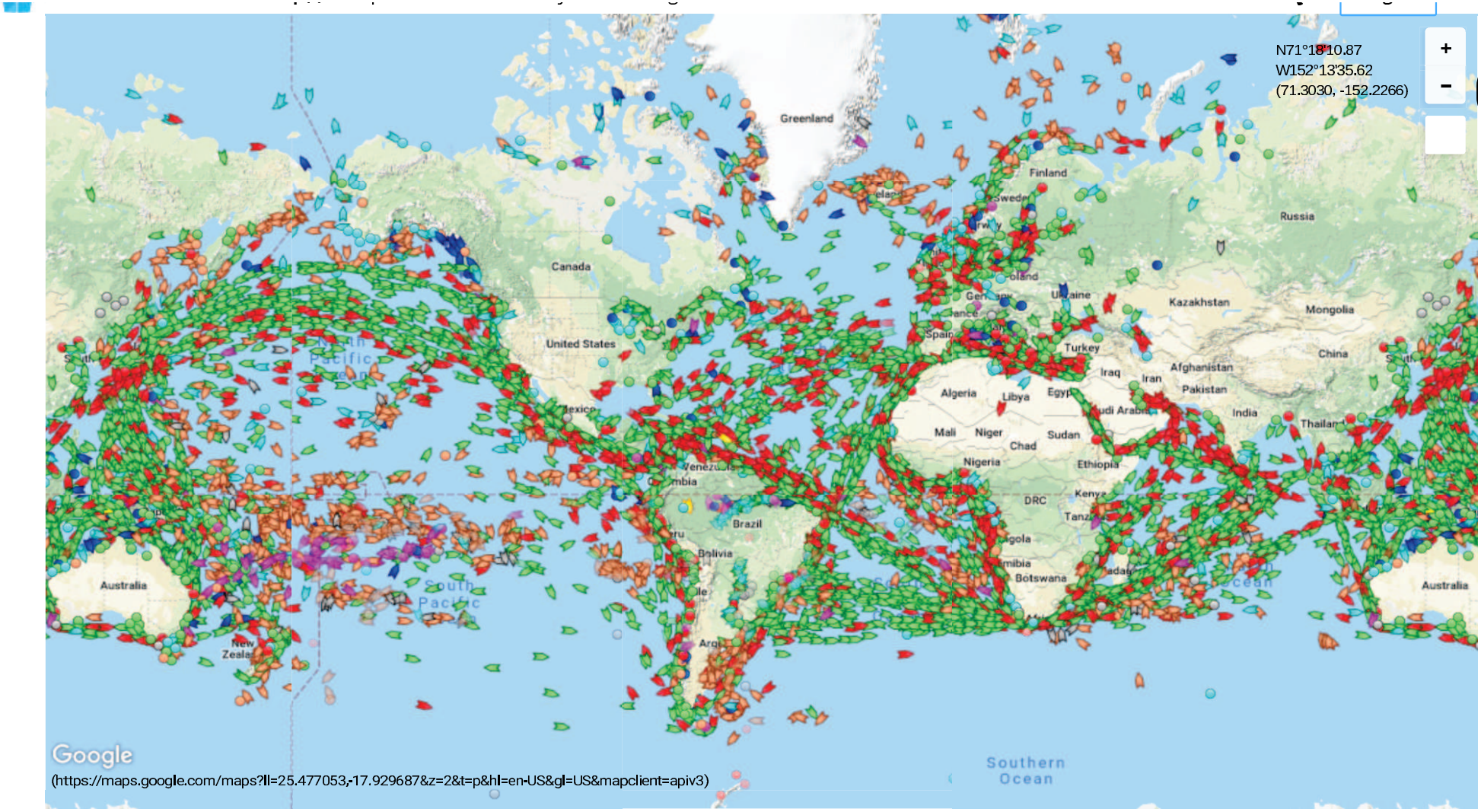
- Huge number of **people** are travelling by **aeroplane**, and sky is full of jumbo jets
  - We all dream '**Internet above the Cloud**'
- **Vey important**: We are not talking aeronautical systems for air traffic control, surveillance, safety monitoring, etc
  - We **CANNOT** do anything even **near** to these systems!
- We are thinking **NEW** commercial **aeronautical ad hoc network** (AANET)
  - which enables us to do usual things at home, at work or travelling on land
- In this globally interconnected AANET, apart from **higher-layer** protocols to be defined, including Internet gateway, cache policy, etc
  - **Physical layer** transmission protocol is key to connect **City in the Sky**
  - Our current technologies capable of realizing such an AANET

Aeronautical Ad Hoc Network

- Jumbo jet is a moving 'cell', where 'base station' and all its 'mobiles' or passengers move together
- 'Mobiles' or passengers can access to 'base station' via standard technique, such as WiFi
- **Air-to-air** transmissions, acting like **backhaul**, is really key to connect **City in the Sky**



Our Ocean



- Normal snapshot of world's commercial maritime traffic: truly **City on the Ocean**

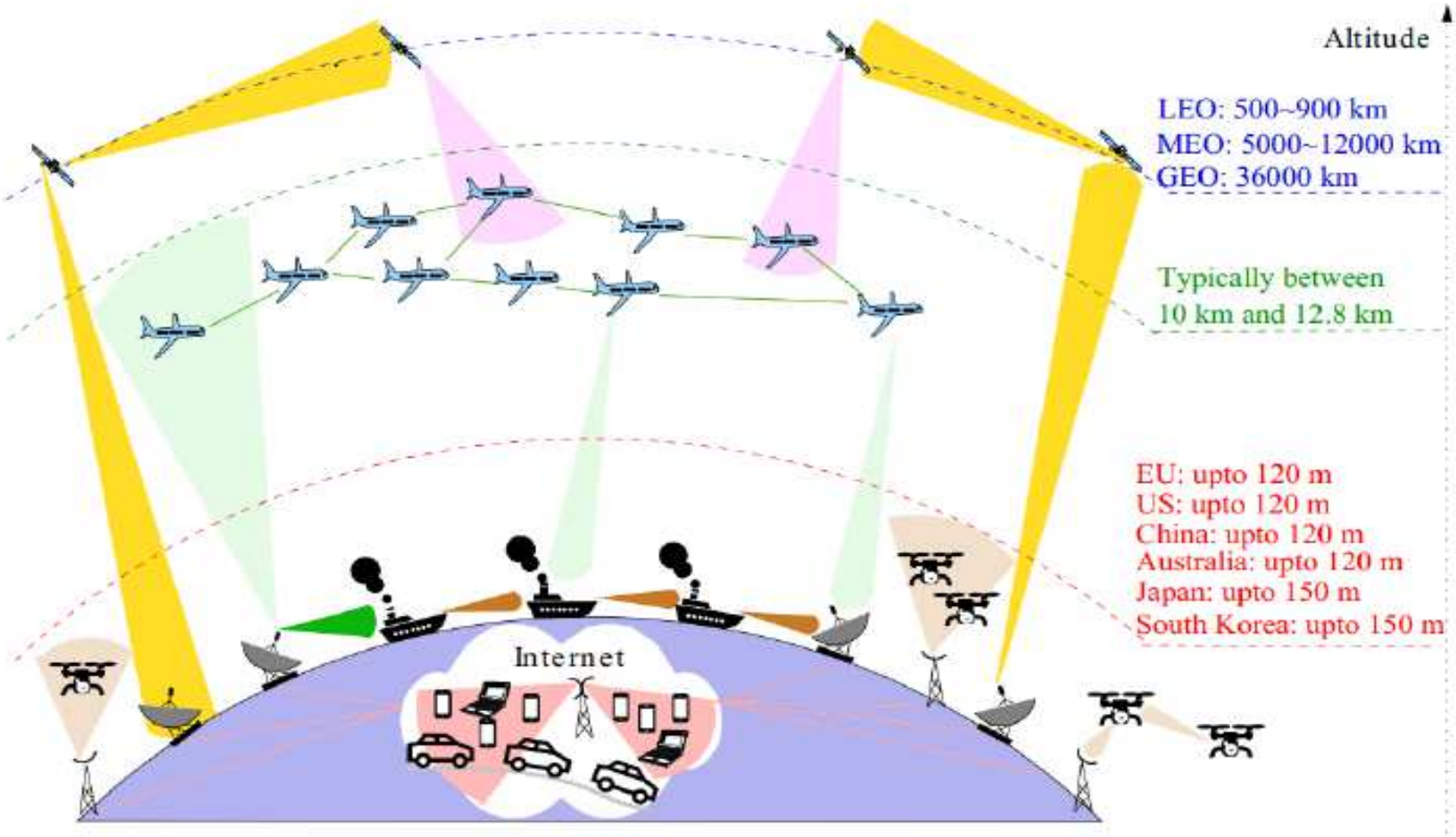
Connecting City on the Ocean

- Current research proposal attempts connecting **every ship** to land mobile network via a **shore station** or **satellite**
  - Connection by satellite is extremely expensive and offers very **low data rate**, moreover, impossible to have satellite capacity to support this application
  - Shore station can only reach a ship **a few km away** with **low data rate** and **impossible** to built sufficient number of shore stations

- Rather than impossible task of connecting every ship to land mobile network via, e.g., shore station, we connect ships to form oceanic ad hoc network (OANET)
  - To **connect** '**City on the Ocean**' and realizing '**Internet above the Wave**'

- This globally interconnected OANET needs international agreement on **higher-layer** protocols, Internet gateway, cache policy, etc, and **physical layer** protocol
  - Our current technology capable of realizing such an OANET

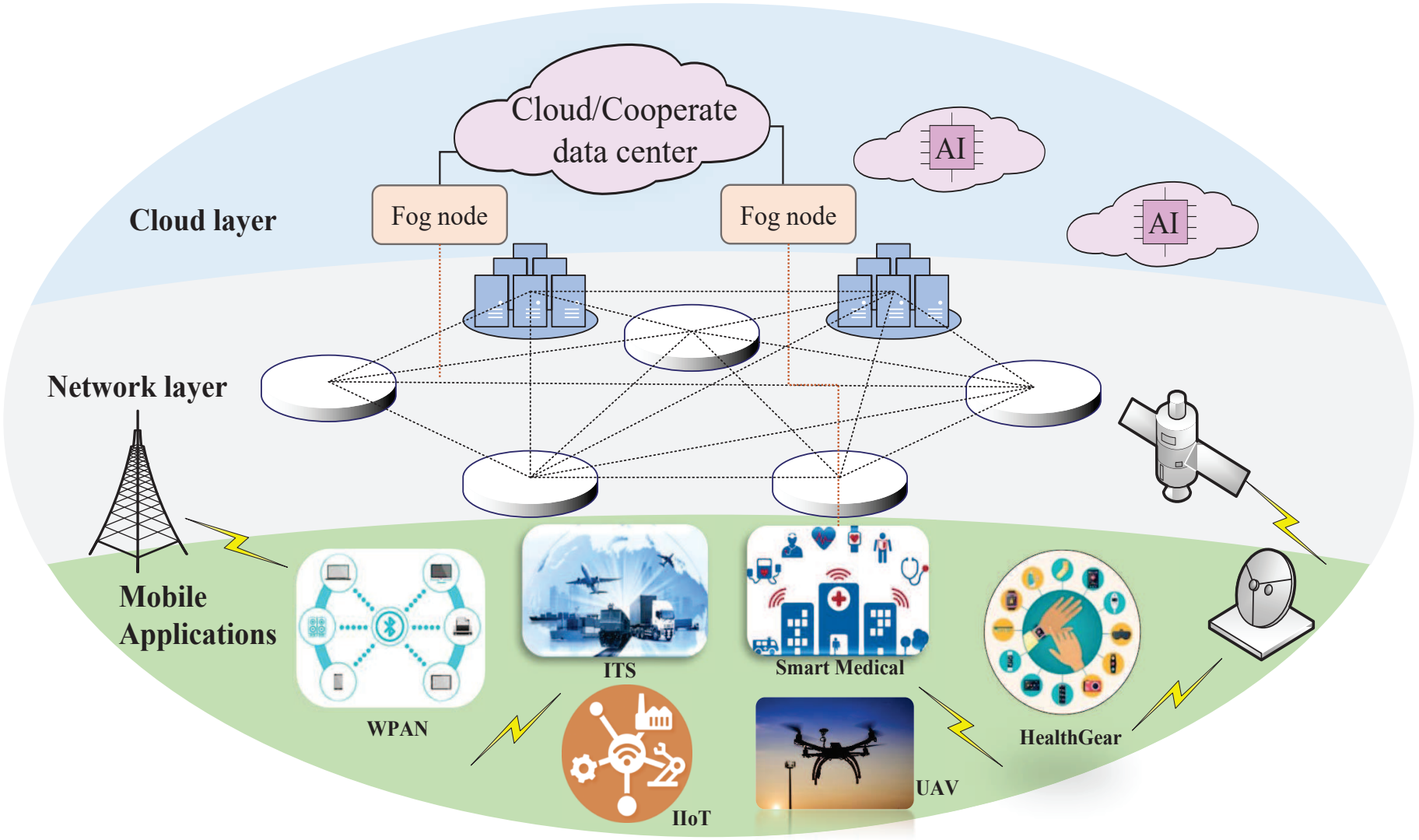
Towards Fully Connected World



- Global land network and Internet, AANET, OANET, and **space network**:
  - City on land, City in air, City on ocean, City in space are interconnected - truly connected anywhere anytime

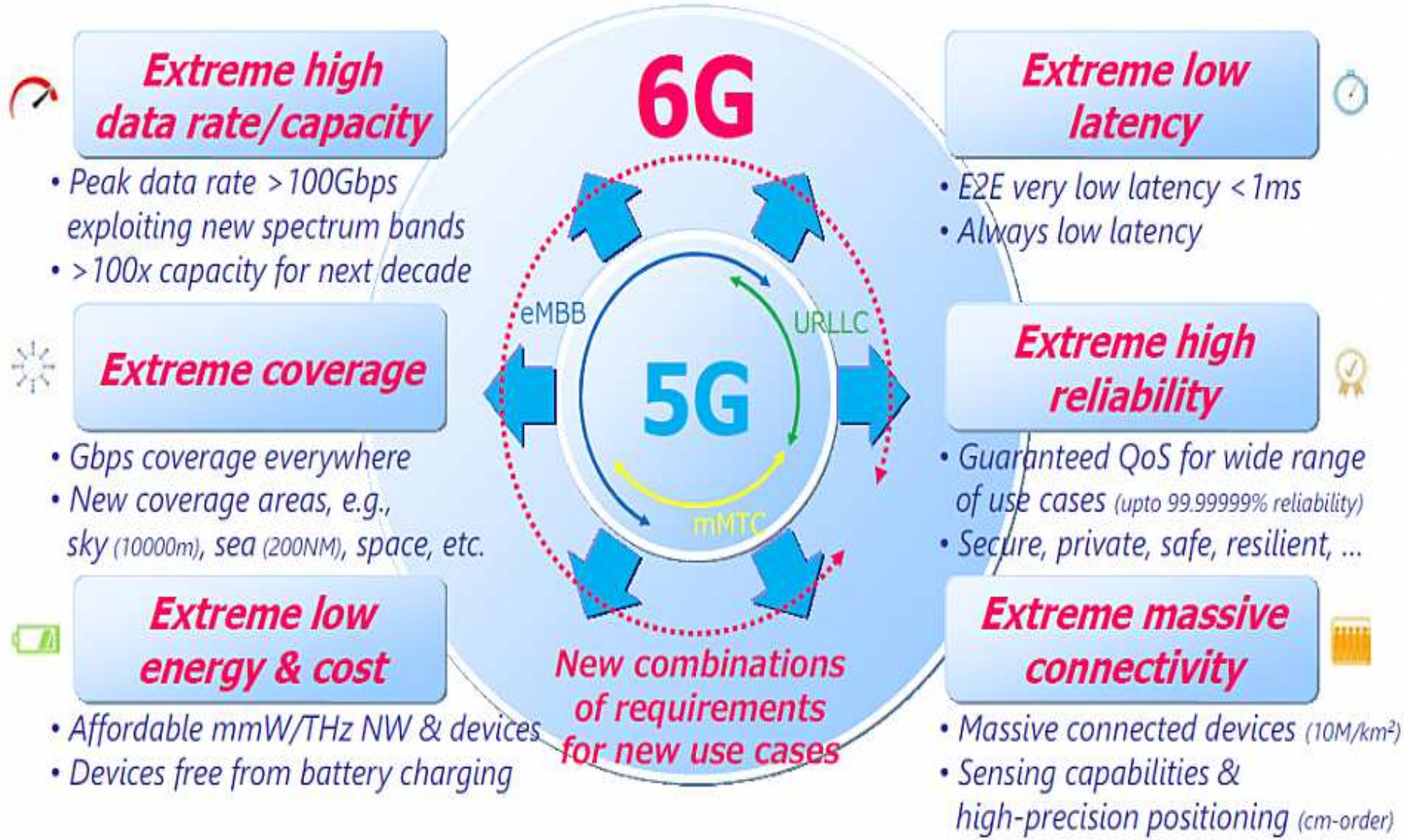
Any Where Any Time Fully Connected

- You are fully connected as long as covered by **mobile** and/or **WiFi** access points
- Many places/times you **are not** covered by mobile and/or WiFi access points
  - What can you do? Look for direct connection through **satellite**
- SpaceX satellite communication terminal or device, quite big - certainly cannot put in pocket, need **big antenna**
  - Use by USA military, which we do not know anything
  - We know they gave lots of these satellite comm terminals Ukraine military
- (09/2023): **Biggest new** – HUAWEI Mate60 smart phone can connect to satellite
  - How do they do it? without need of big antenna!
  - Also (09/2023): some European company has **just** successfully **test** mobile phone connection to satellite



- **Our digital world**: AI-enabled network architecture for 5G and beyond

What Will 6G Be

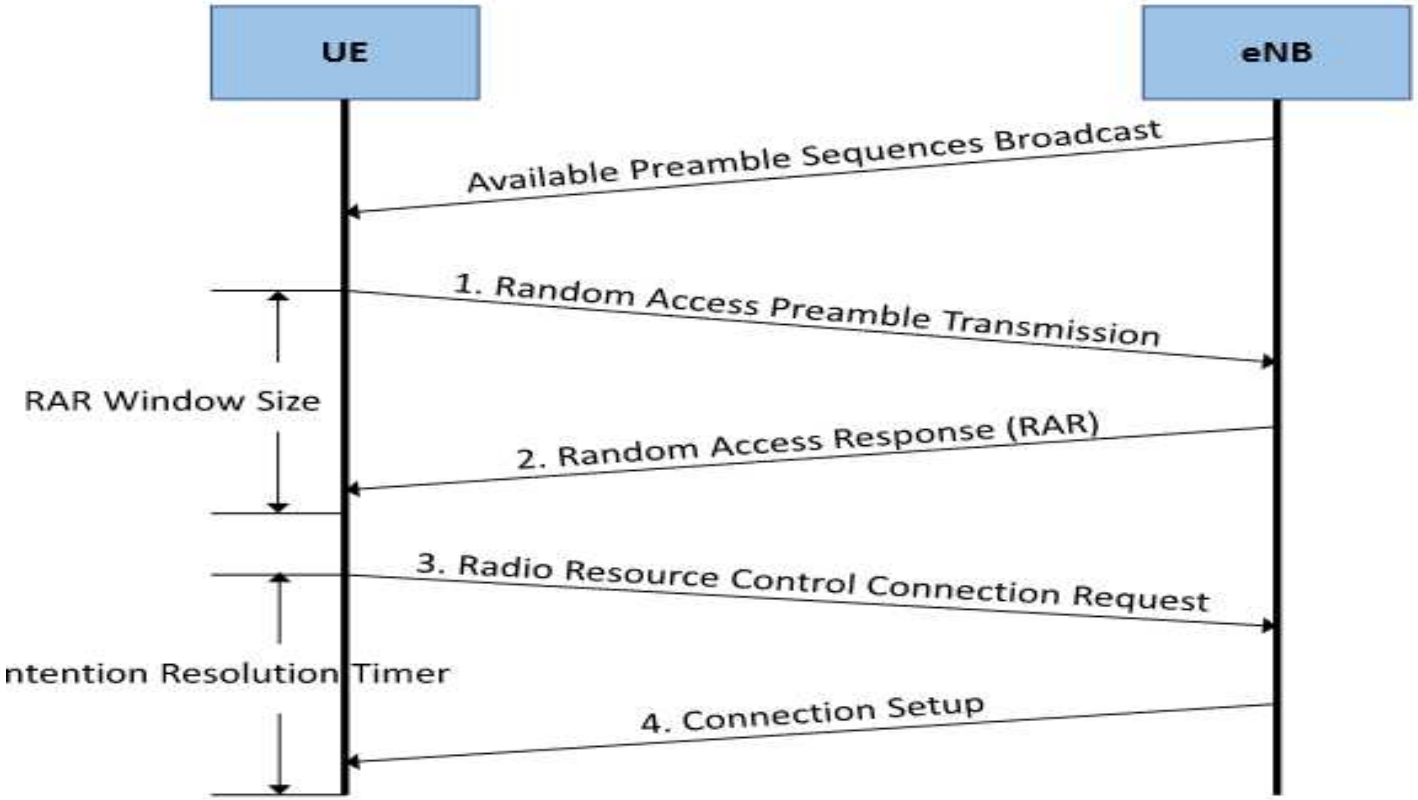


6G Development

- 6G Internet supports Terabyte/s one microsecond-latency communication
  - Edge and core computing seamlessly integrated as part of 6G
  - Mobile edge computing and AI are built in 6G
- 2021, China launched 6G test satellite equipped with THz system
- 'Technology imperialism': you can't compete with best (5G), you ban it
  - Starlink: SpaceX's satellite Internet project, 'space imperialism'?
  - **Hugh Lewis, head of Astronautics Research Group, UoS: Starlink satellites represent the single main sources of collision risk in low Earth orbit** (2019)
  - Two SpaceX's satellites changed orbit, threatened Chinese space station
- IEEE is starting to prepare 7G standards
- **Green** communication and computing is crucial for our future

Grant-free Multiple Access

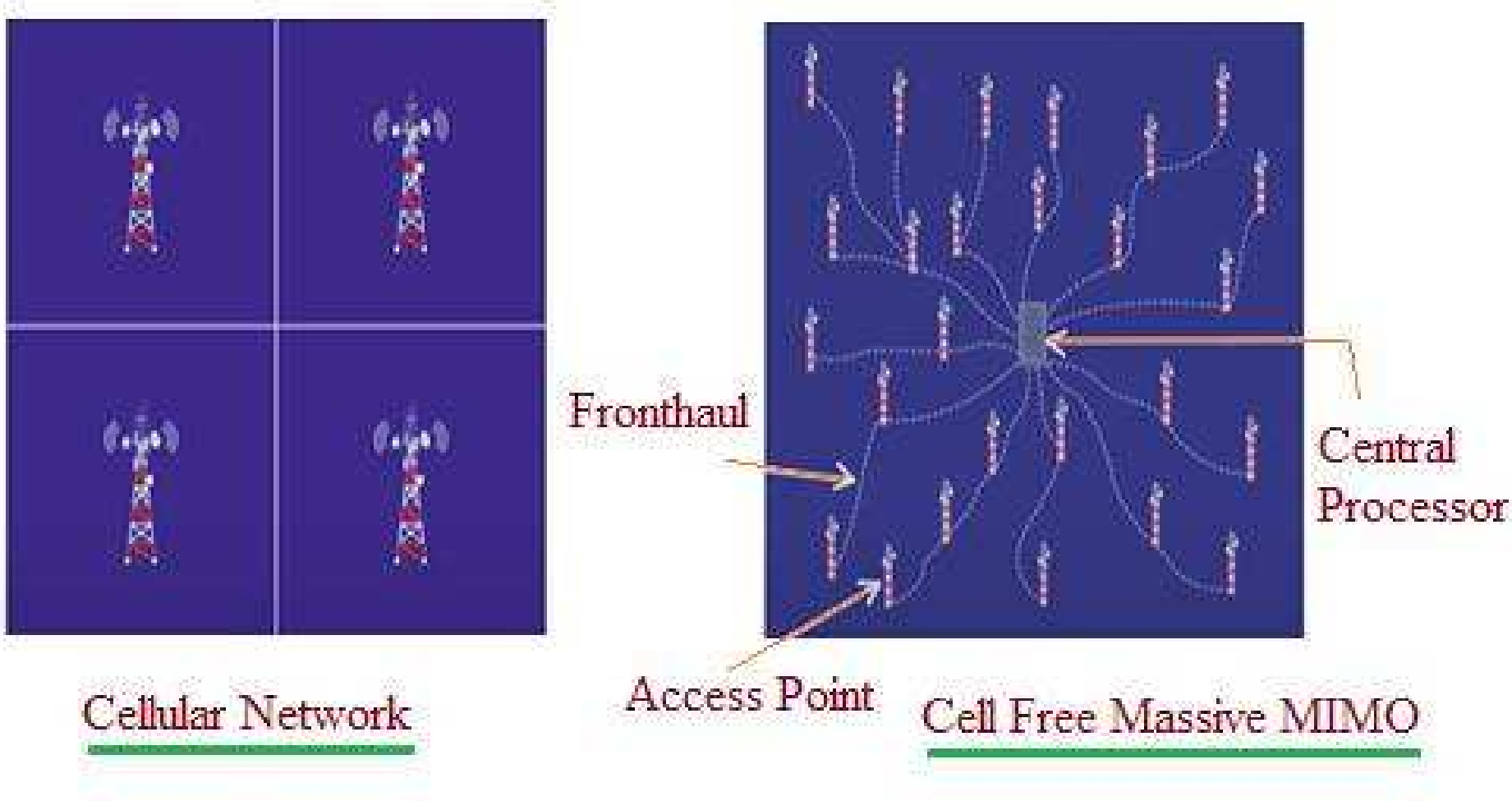
- **Grant-based** multiple access (4G/5G): 2 handshakes, unsuitable for short data, such as mMTC



- **Grant-free** multiple access

Cell-free Massive MIMO

- Cell free

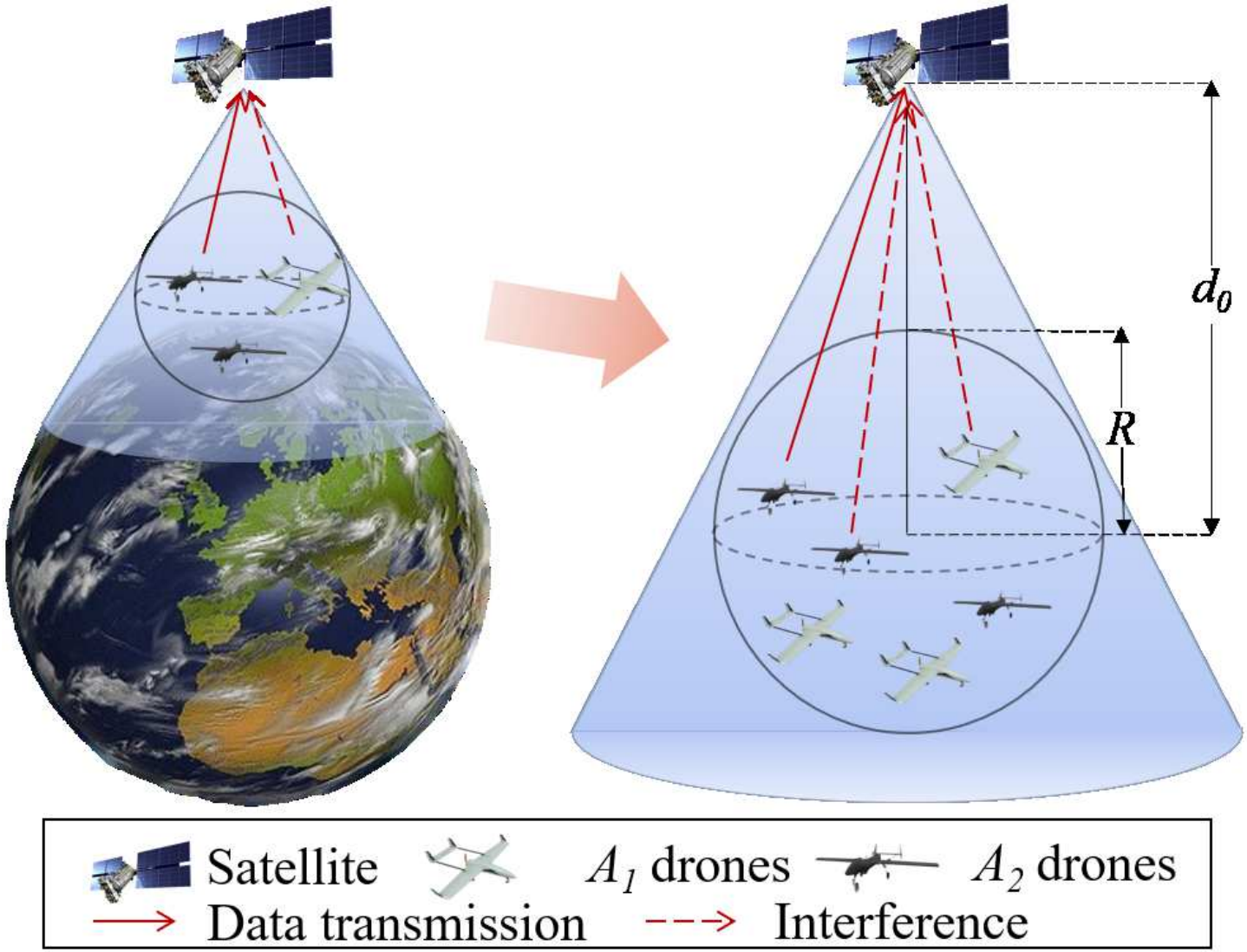


https://www.rfwireless-world.com/Terminology/Difference-between-cellular-network-and-cell-free-network.html

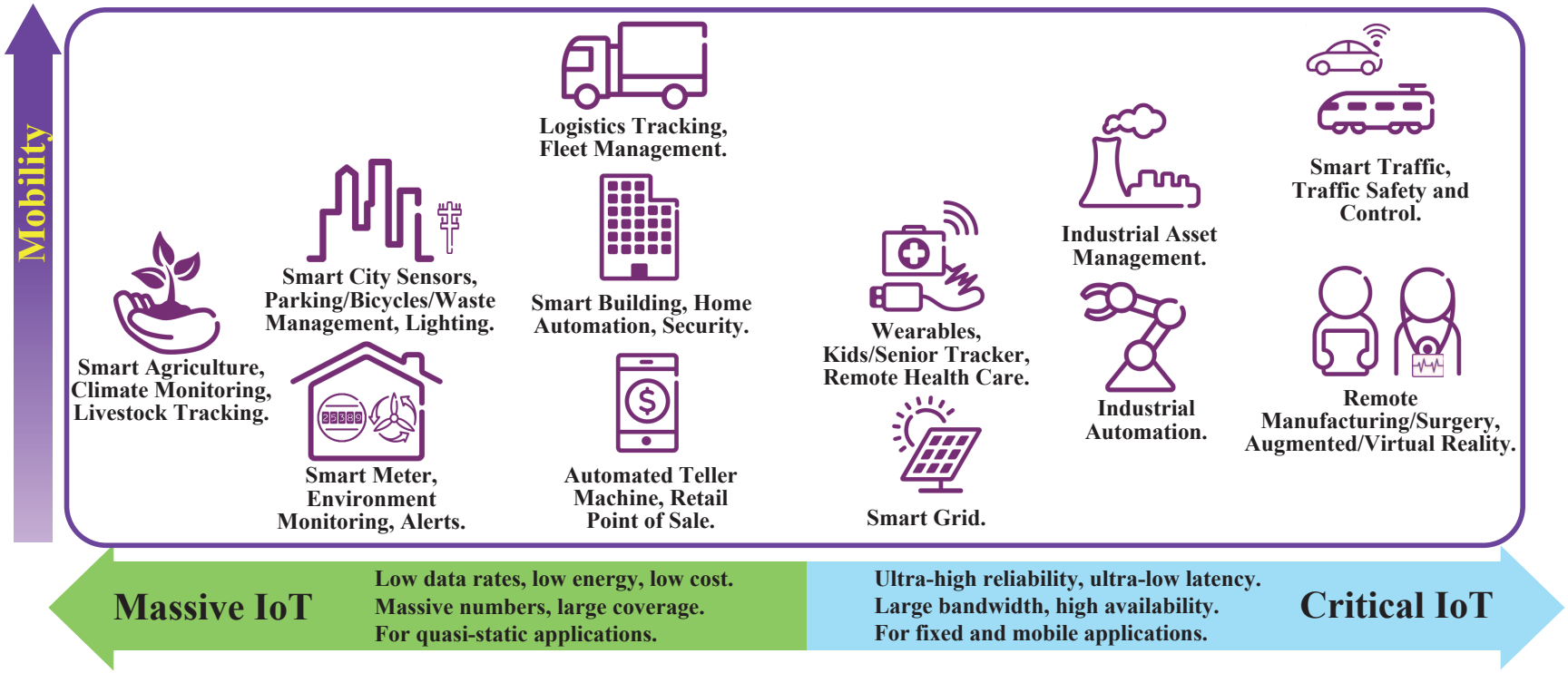
Heterogenous Non-terrestrial Networks

Huge amount works on:

- Heterogenous **satellite-aerial** networks
- Integrating **non-terrestrial** networks with **terrestrial** networks



Grant-free Massive Access

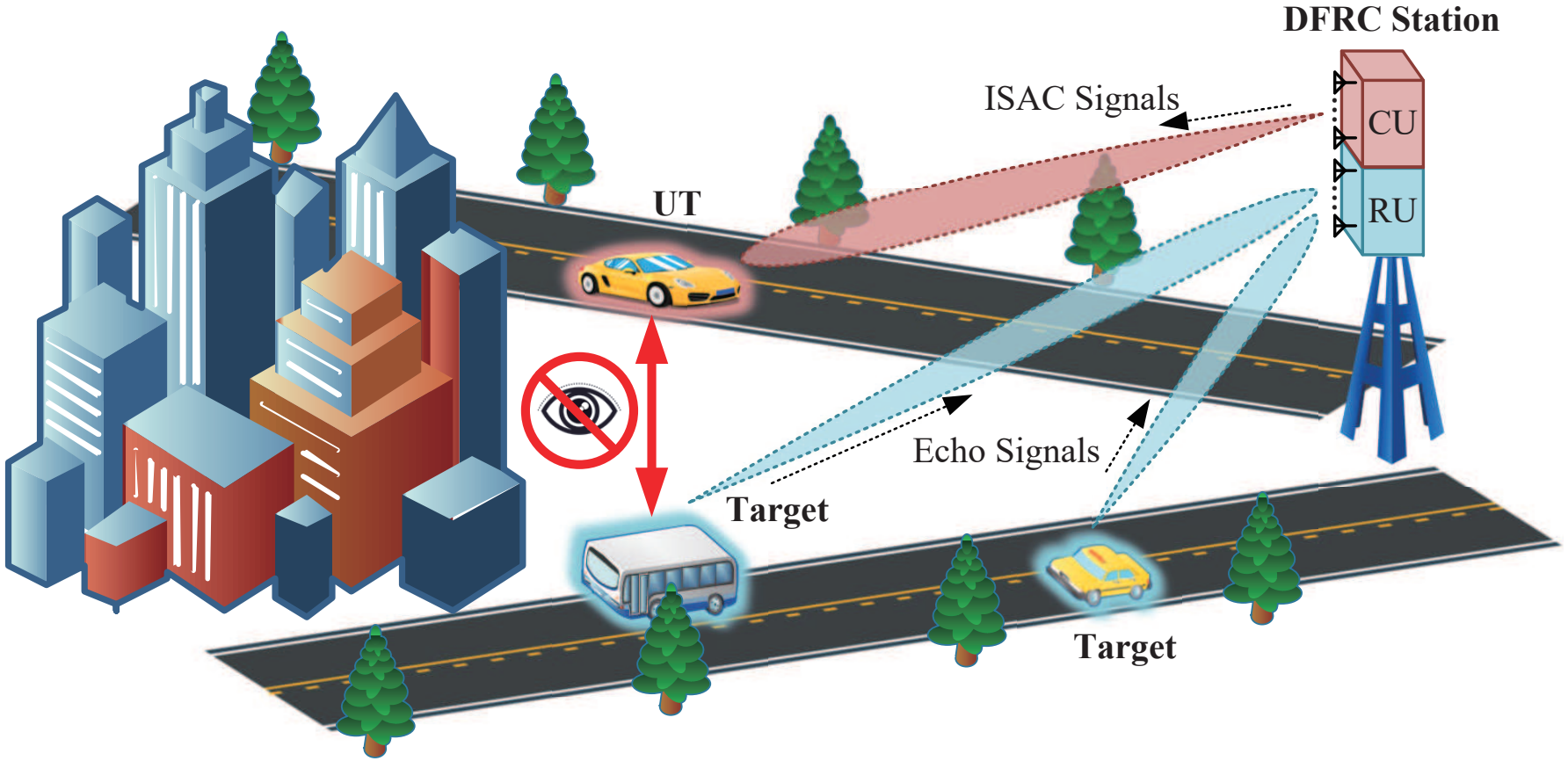


- In 6G, Internet of Things $\Rightarrow$ **Internet of Human-Machine-Things**

- New grant-free **massive access** protocols essential

Gao, Ke, Mei, Qiao, Chen, Ng, Poor, "Compressive sensing-based grant-free massive access for 6G massive communications," *IEEE Internet of Things J.* (early access)

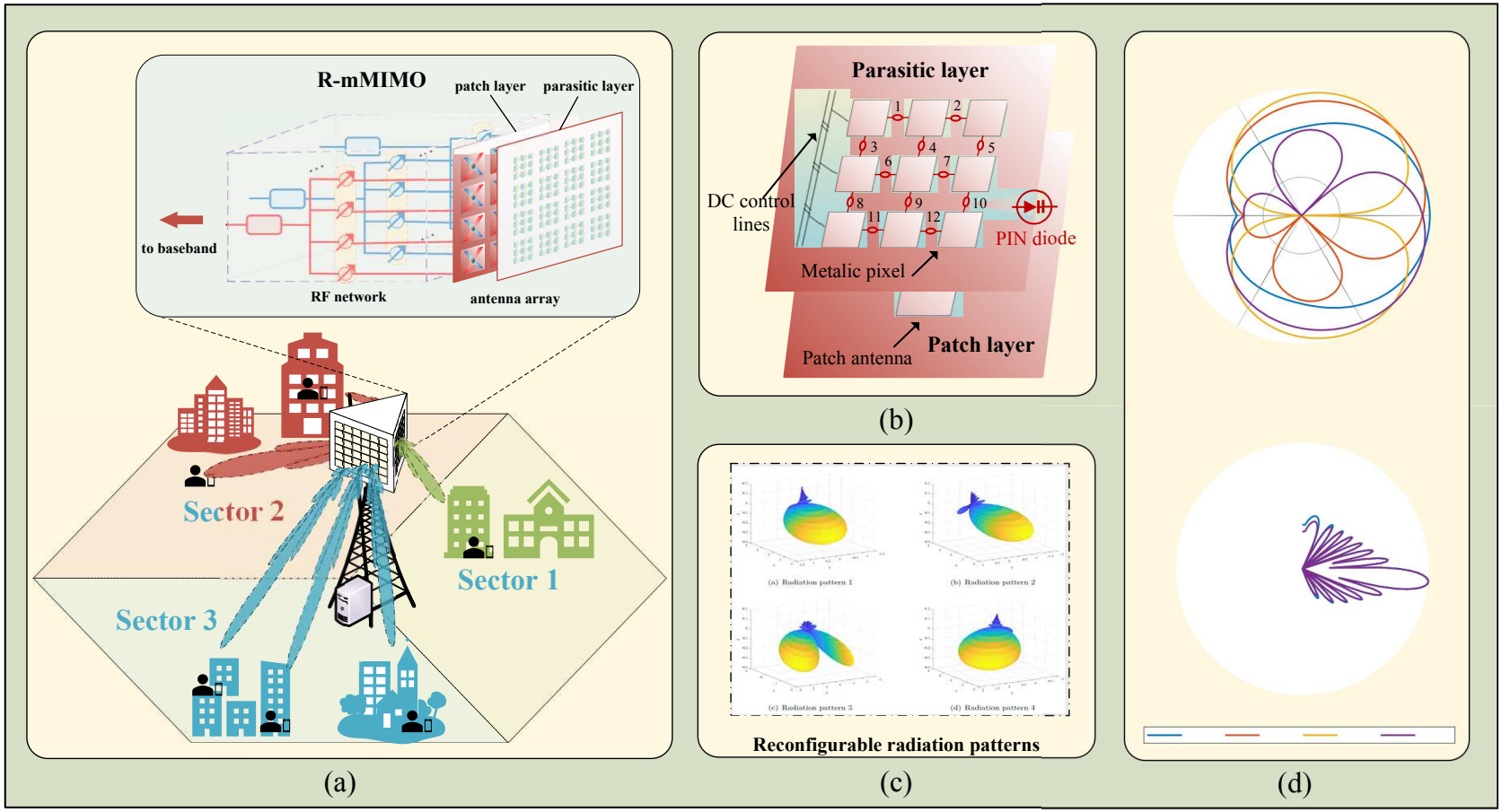
Integrated Senseing and Communication



- Wireless **communication** and radar **sensing** $\Rightarrow$ **Integrated** sensing and communication
- Gaming changing for future wireless systems

Gao, Wen, Zheng, Tan, Masouros, Ng, Chen, "Integrated sensing and communication with mmWave massive MIMO: A compressive sampling perspective," ***IEEE Trans. Wireless Commun.*****, 22(3), 1745-1762, 2023**

Reconfigurable Massive MIMO



- **Reconfigurable massive MIMO**: Harnessing power of electromagnetic domain for enhancing information transfer

Ying, Gao, Chen, Gao, Matthaiou, Zhang, Schober, "Reconfigurable massive MIMO: Harness the power of the electromagnetic domain for enhanced information transfer," ***IEEE Wireless Commun.*** **(early access)**

Conclusions

- We are in an exciting communication and computing revolution
  - It is fundamentally changing our life in every aspect
- Mobile communication is a key enabling technology
  - Mastering it is beneficial to your career
- **ELEC6214** module offers advanced fundamental and state-of-the-art communication technologies
  - e.g., MIMO theory and practice taught in ELEC6214 offers an enabling technology to support 5G three user cases