Integrated Satellite-Terrestrial Networks Towards 6G: Architectures, Applications, and Challenges

Chunxiao Jiang
Associate Professor
Tsinghua University

2021. 07.20

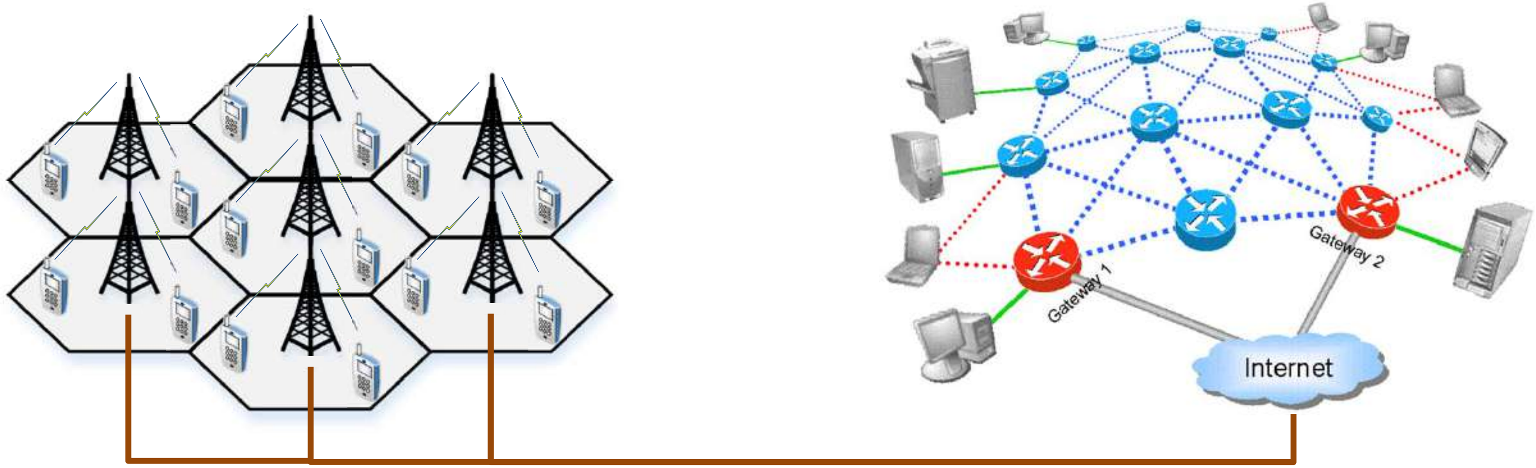
Outline

- **Background**
- **Integrated Satellite-Terrestrial Networks Towards 6G**
- **Application Case**
- **Challenges for Integration**
- **Techniques and Future Direction**

Contemporary Network Architecture

Network consists of the access network and the main parts of the Internet

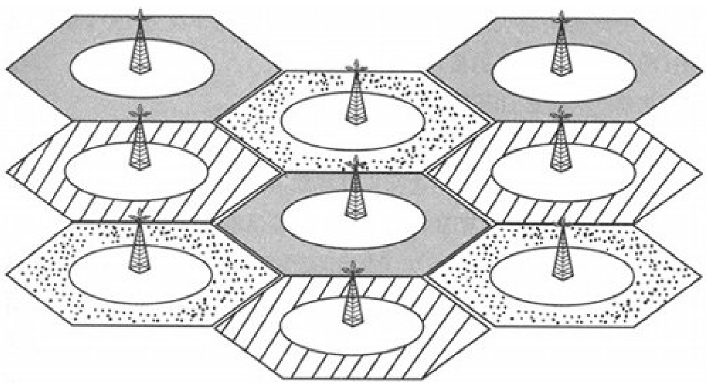
Access Network **Internet**



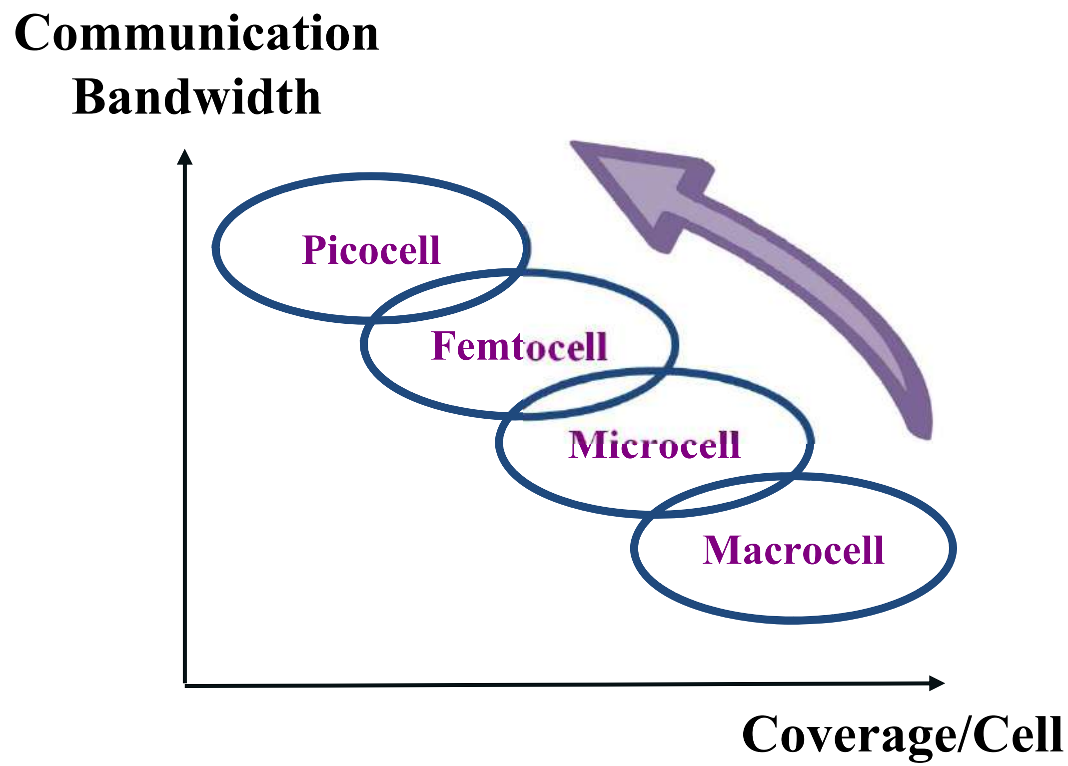
Represented by mobile communication network

Dominated by the TCP/IP

Existing Mobile Communication Network



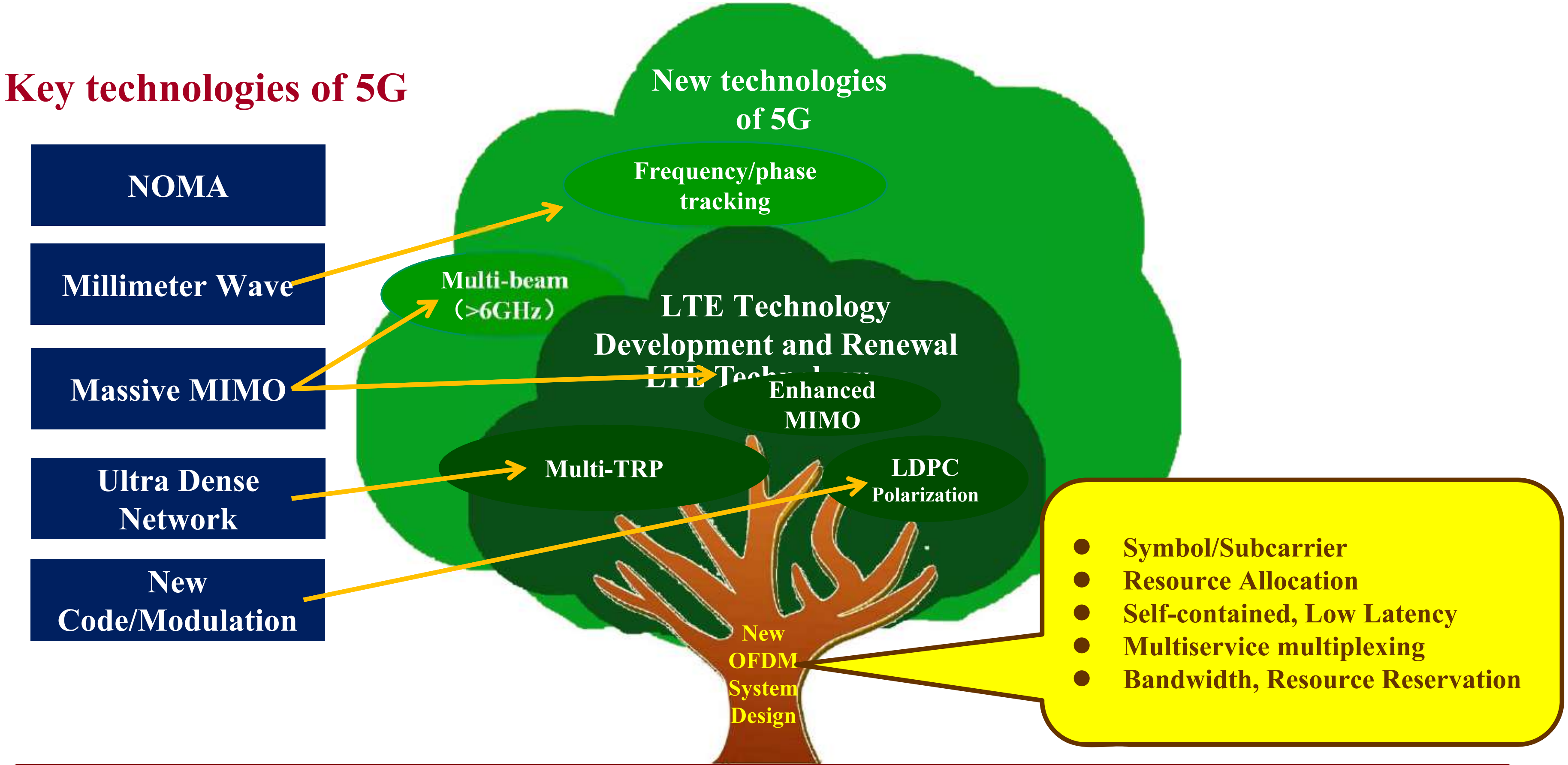
Cellular Network



The core architecture of mobile communication network is cellular architecture

Higher thoughput is achieved by more dense cells

4G LTE→5G：Further Dense Networking

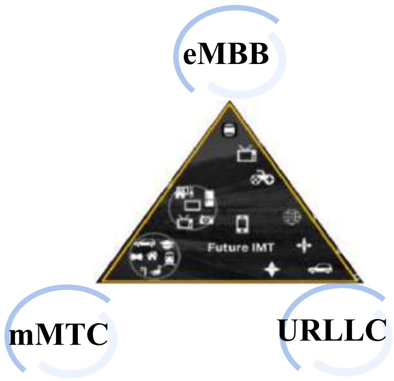


In the enabling technology of 5G, dense networking on the access side is the core

6G: the Next Generation Network

Communication evolves from information ubiquity to intelligence ubiquity

Information Ubiquity → **Perception Ubiquity** → **Intelligence Ubiquity**



5G

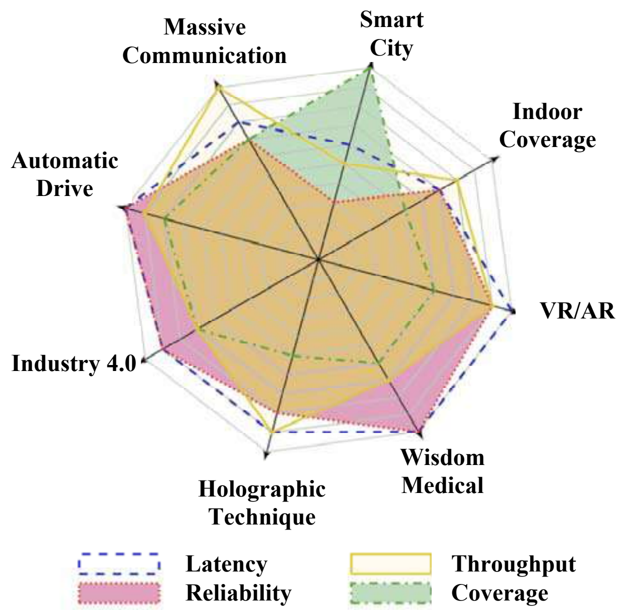
- Customized Network
- Open Ability
- Valued Data
- Inteligent Service

B5G

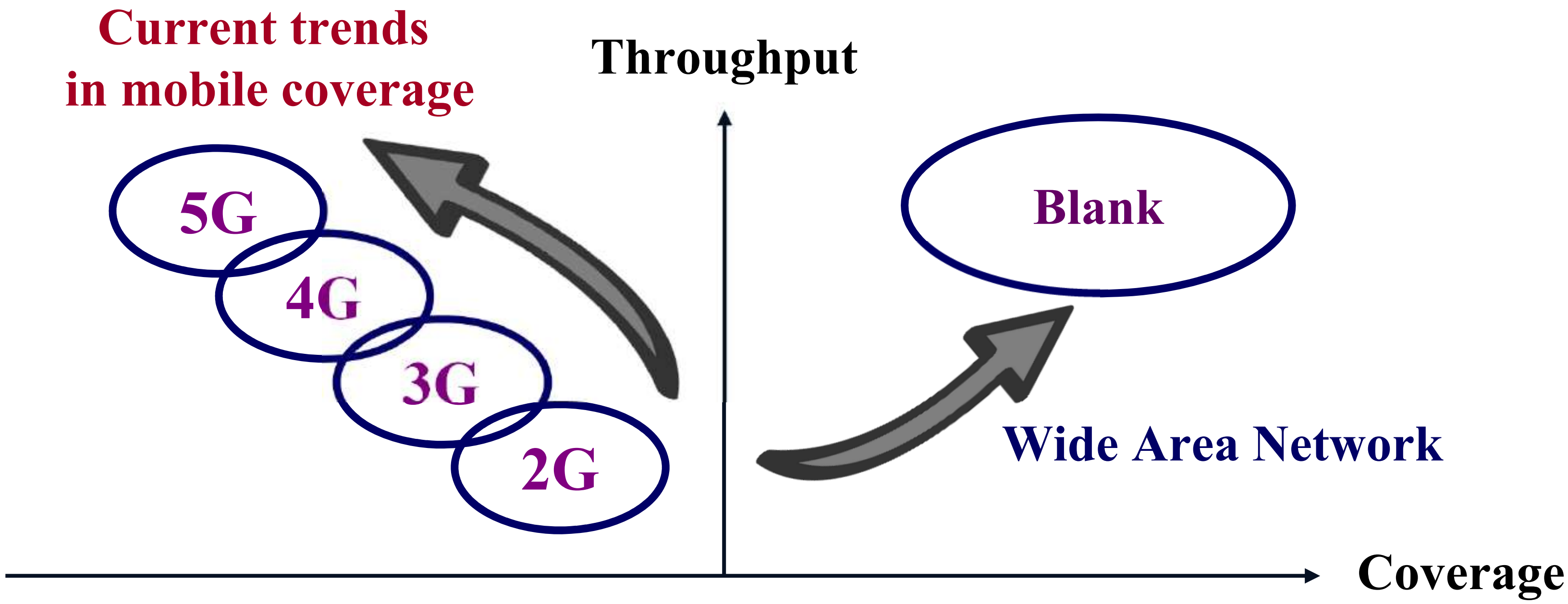
- Concise Network
- Flexible Network
- Endogenous intelligence
- Endogenous Security
- …

6G

6G Indicators



Something Behind the Prosperity……



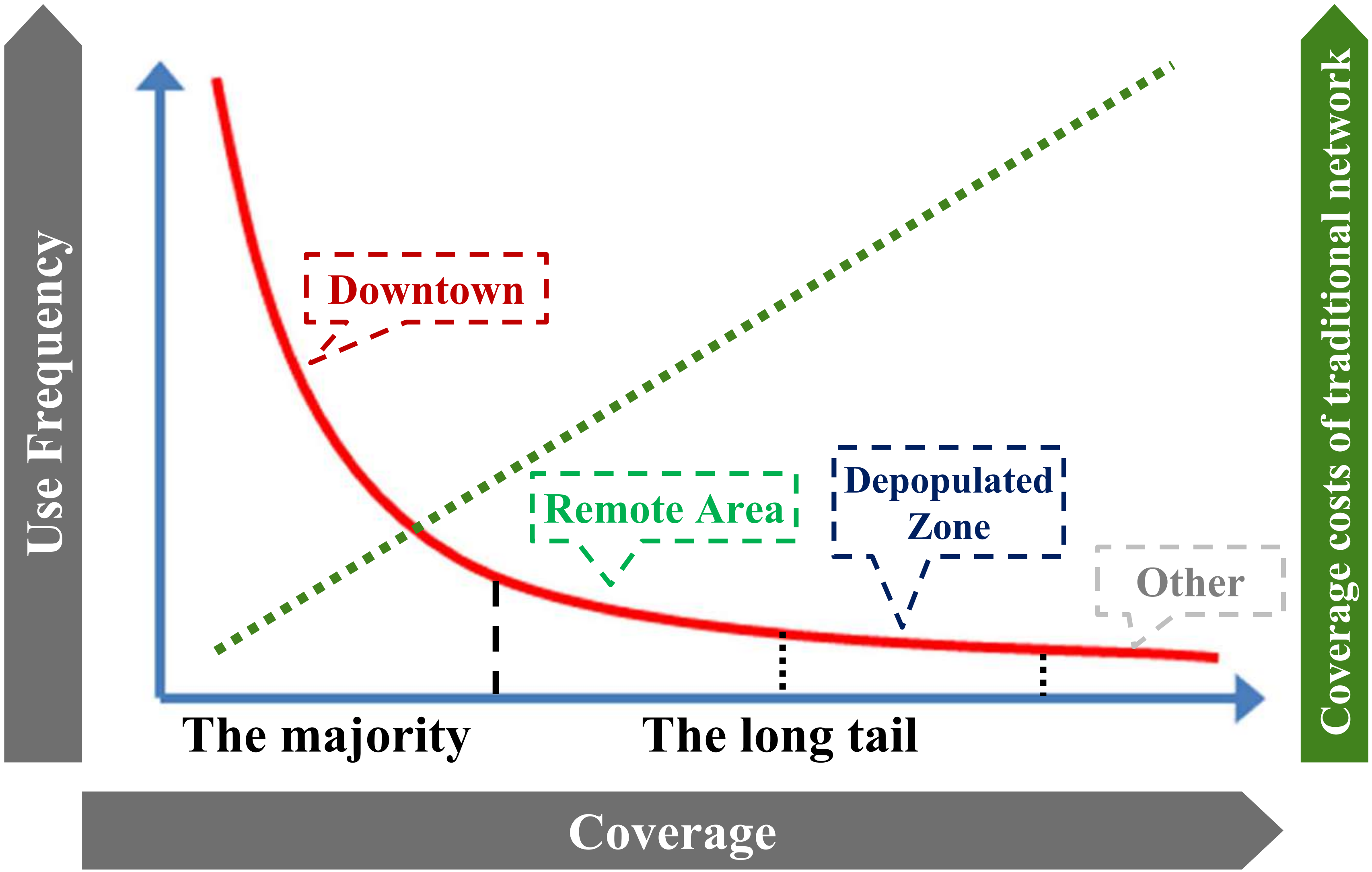
5G KPI： peak rate、connection density、latency、traffic density、mobility、energy efficiency、spectrum efficiency

Wide Area (Satellite) Network： +coverage、+security、+low-power、+small size…

Mobile coverage has a long way to go

Future network needs to connect the wide blank area

Contradiction: Coverage VS Cost



Terrestrial Networks are Insufficient

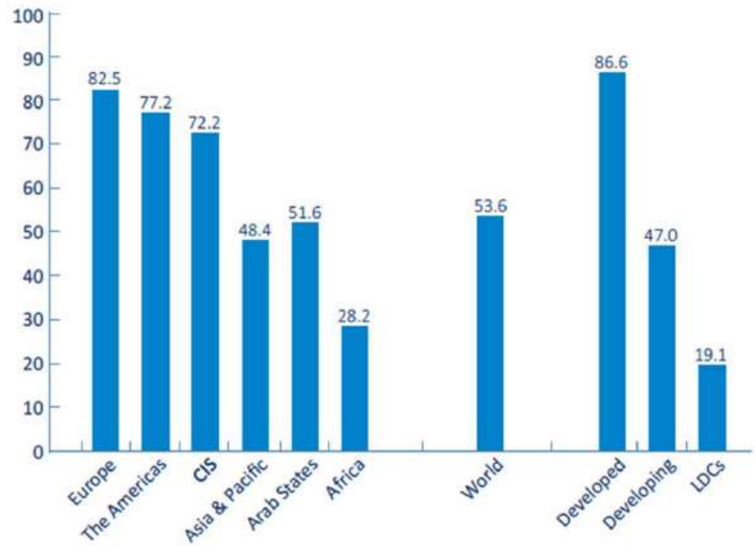
- **Population Coverage of Internet：**

  （ITU - Facts and figures 2019）

  Global： 53.6%

  Developed Country： 47.0%

  Less Developed Country： 19.1%



- **Terrestrial network coverage： Land 20% Ocean 5%**

Traditional terrestrial networks are constructed based on optical fiber. Achieving global terrestrial coverage require more than 10 trillion dollars and 20～25 years. Moreover, broadband communication for maritime and aviation is unrealizable for terrestrial networks.

Satellite Communication Demands

Economic Development

Global seamless coverage

Environment Monitoring

Monitoring changes in resources and environment

Aerospace

Emergency Rescue

Satellite communication networks become the development trend of future networks

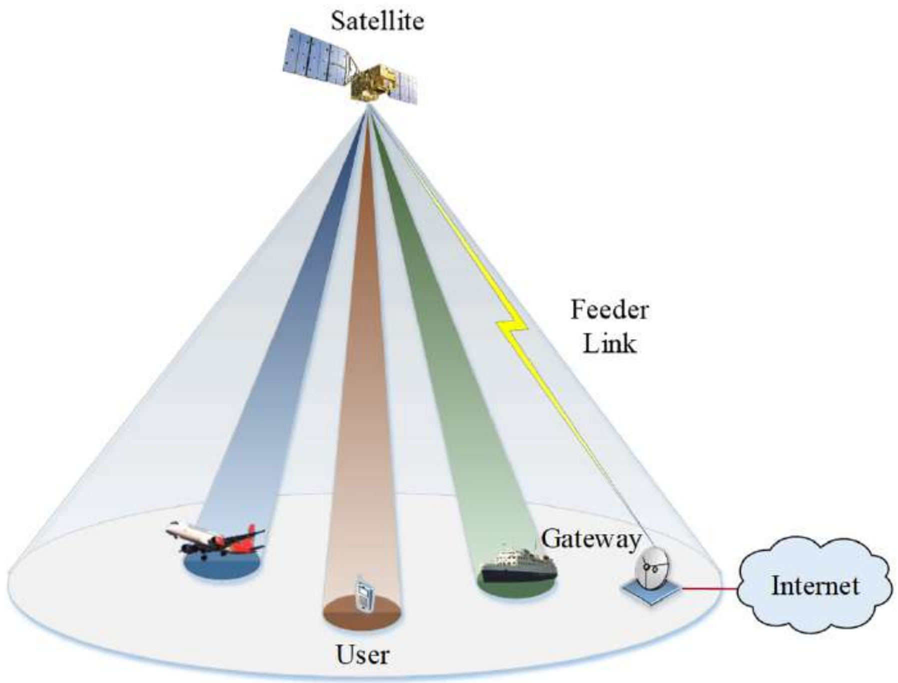
Satellite Communication Networks

Solution for coverage	→	Satellite communication networks

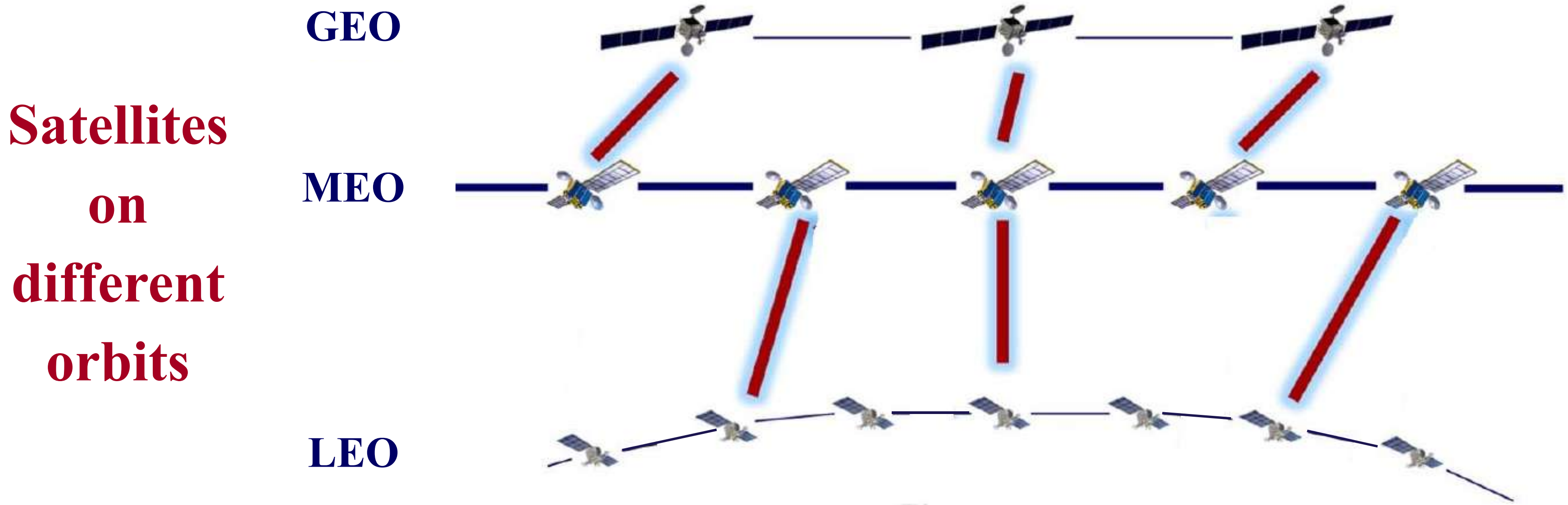
Communication Mode

- **Fixed satellite services (FSS)**
  - ➢ Fixed devices on the ground
  - ➢ Large antennas
  - ➢ VSAT communication, Television broadcast

- **Mobile satellite services (MSS)**
  - ➢ Portable mobile devices
  - ➢ Limited antennas
  - ➢ Cars, ships, airplanes, individual users



Satellite Communication Networks



	LEO	MEO	GEO
Orbit Altitude	500 ~ 2000 km	2000 ~ 36000 km	36000 km
Orbit Type	Dynamic	Dynamic	Fixed
Orbit Resource	Sufficient	Sufficient	Limited
Coverage	Medium	Large	Large
Delay	Low	Medium	High
Attenuation	Low	Medium	High

Increasing Development of Satellite Networks

Satellite Project	Frequency	Satellite Number
OneWeb	Ku, V	720 - 2882
SpaceX	Ku, V	4425 - 42000
Boeing	V	147-3103
LeoSat	Ka	84-108
Telesat	Ka, V	117-234
YaLiny	Ka, V	140
Samsung	MMW	4600
Astrome Technologies	MMW	150
KasKilo (M2M)	Ka	288
CAST	-	60
Helios Wires (M2M)	S	30
Sky & Space Global	S, L	200
Astrocast (M2M)	-	64
Kepler (M2M)	Ku	140
Lucky Star	-	156

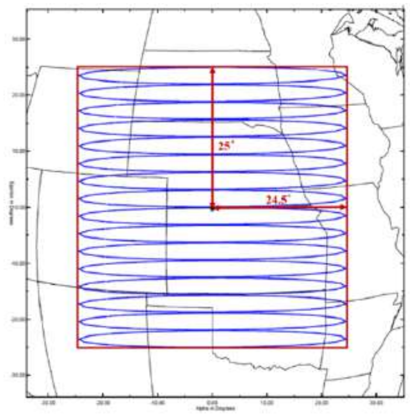
Satellite Constellation Project

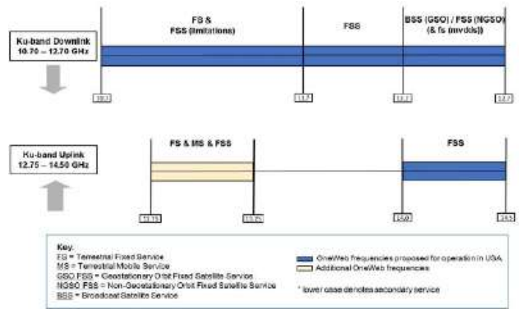
- **O3b(other 3 billion)**
- **MEO constellation on the orbit of 8062 km**
- **Invested by Google, operated in 2014, provide broadband Internet access of 10 Gbps**
- **Target: Cover countries of low and middle latitude, replace fiber optics**

Satellite Constellation Project

- **OneWeb**
  - LEO constellation on the orbit of 1200 km
  - Consist of 720 satellites on 18 orbital planes
  - Frequency band: Ku + Ka

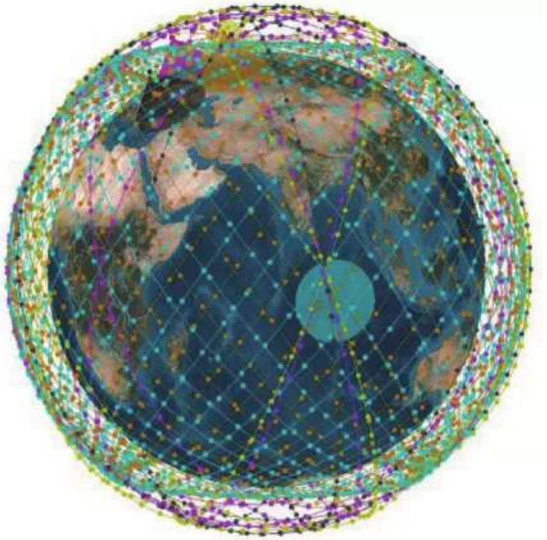
- More than 200 satellites have been launched
- Extend the connectivity all areas above 50 degrees north latitude by June 2021
- Provide global service in 2022





Satellite Constellation Project

- **SpaceX**
  - **LEO constellation on the orbit of 550 - 1100 km**
  - **Consist of 4425 satellites on multiple orbital planes (10k+ later)**
  - **Frequency band: Ku + Ka**
- **More than 1600 satellites have been launched**
- **Service is now available in the United States and other countries, with more than half a million users.**



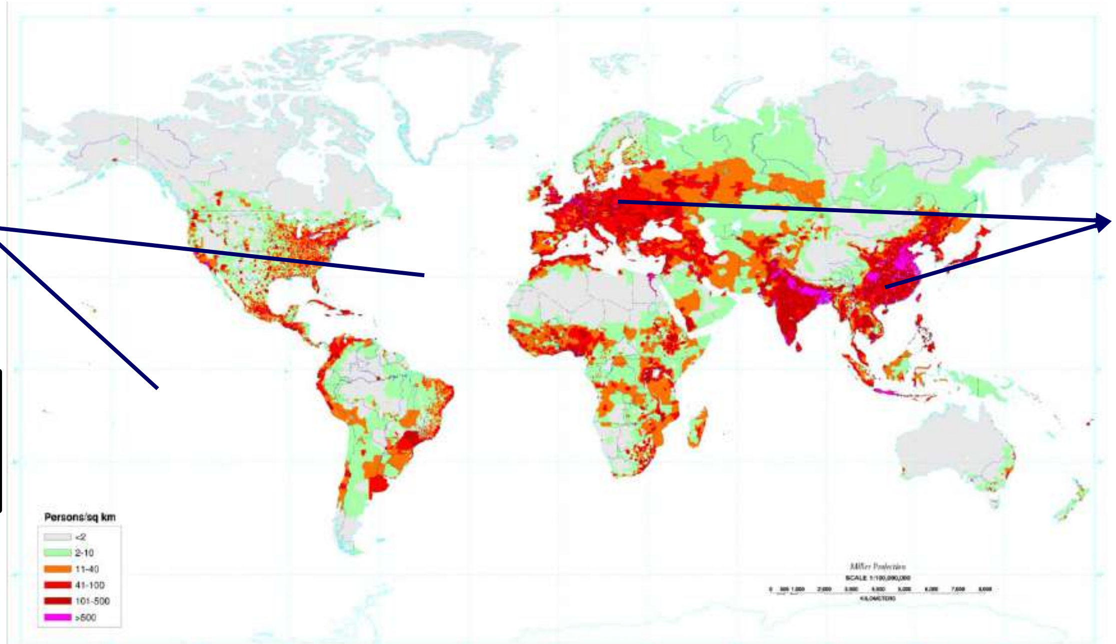
Outline

- Background
- Integrated Satellite-Terrestrial Networks Towards 6G
- Application Case
- Challenges for Integration
- Techniques and Future Direction

Development Dilemma: Satellite

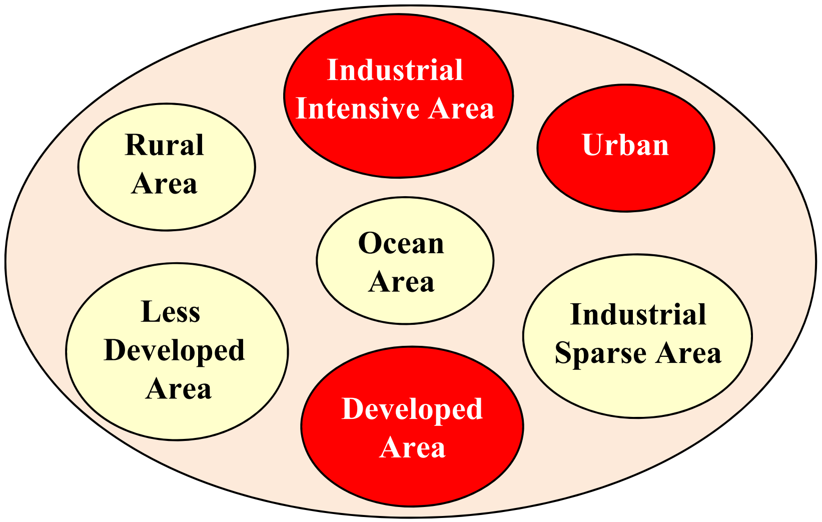
Ocean Area
71%

Traffic distributes extremely sparsely



90% of the population is concentrated on 10% of the land

Traffic on land is concentrative

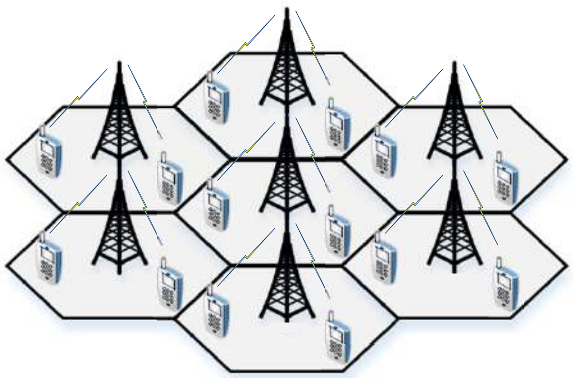


Uneven Communication Demand

Uniform coverage is of low efficiency

Integrated Satellite-Terrestrial Network

Terrestrial Network

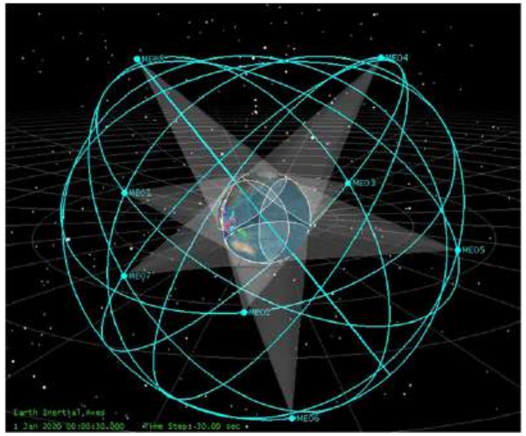


Low Cost Broadband Service

Mutual Complementarity

+

Satellite Network



Global Seamless Coverage

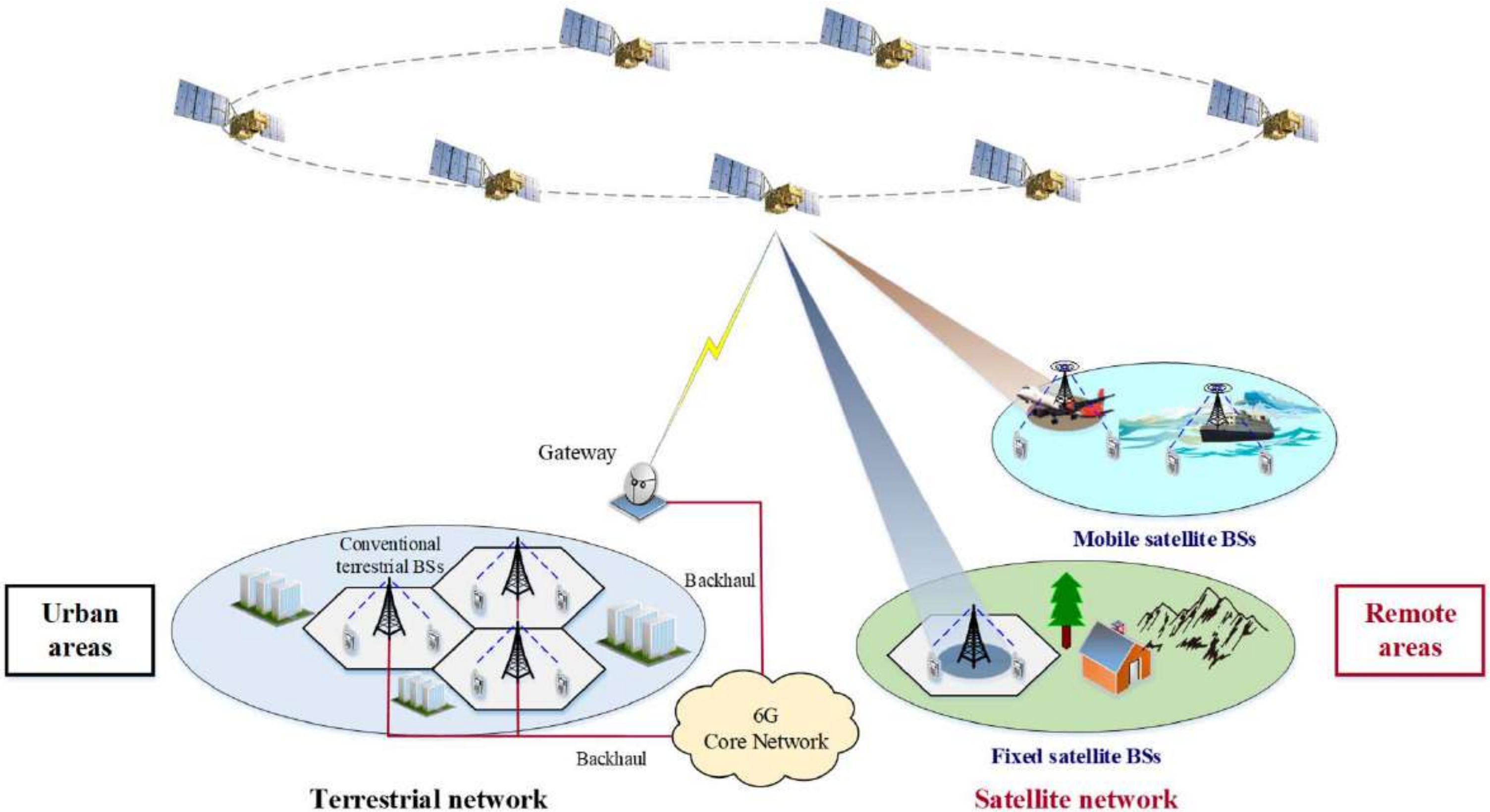
⬇

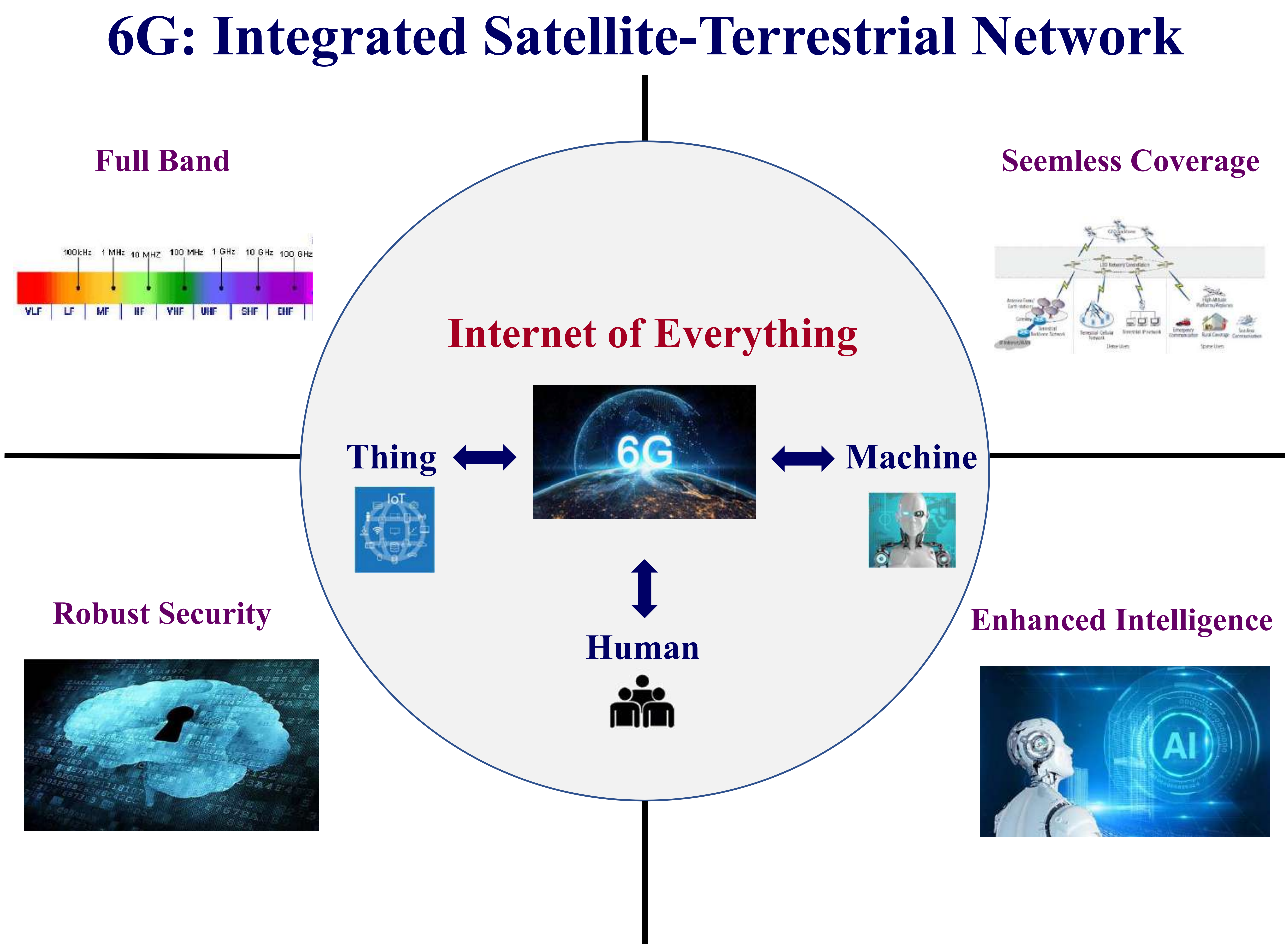
Breakthrough the bottleneck of the existing network development mode

6G: Integrated Satellite-Terrestrial Network

- **6G White Paper**

The future wireless network must be able to seamlessly interface with terrestrial and satellite networks




6G: Integrated Satellite-Terrestrial Network
Full Band
100kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
Seemless Coverage
Internet of Everything
Thing
IoT
6G
Machine
Human
Robust Security
Enhanced Intelligence
AI

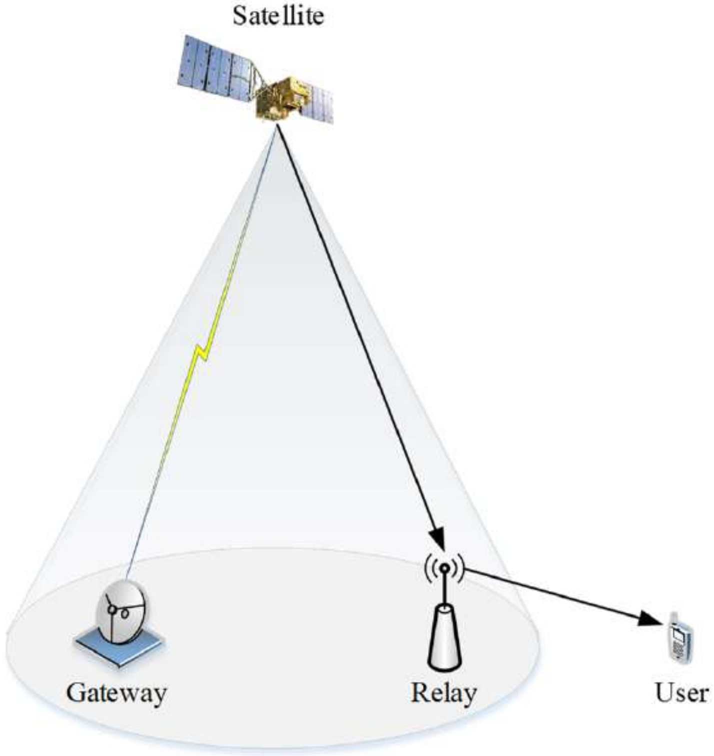
Hybrid Satellite-Terrestrial Relay Networks

- **Basic Relay Architecture**

Rain/fog attenuation	Poor elevation angles	Obstacles

↓

Direct link to the user is unstable due to masking effect



- **Phase 1**
  - ➢ **Satellite to Relay**
- **Phase 2**
  - ➢ **Relay to User**

Communication outage can be avoided

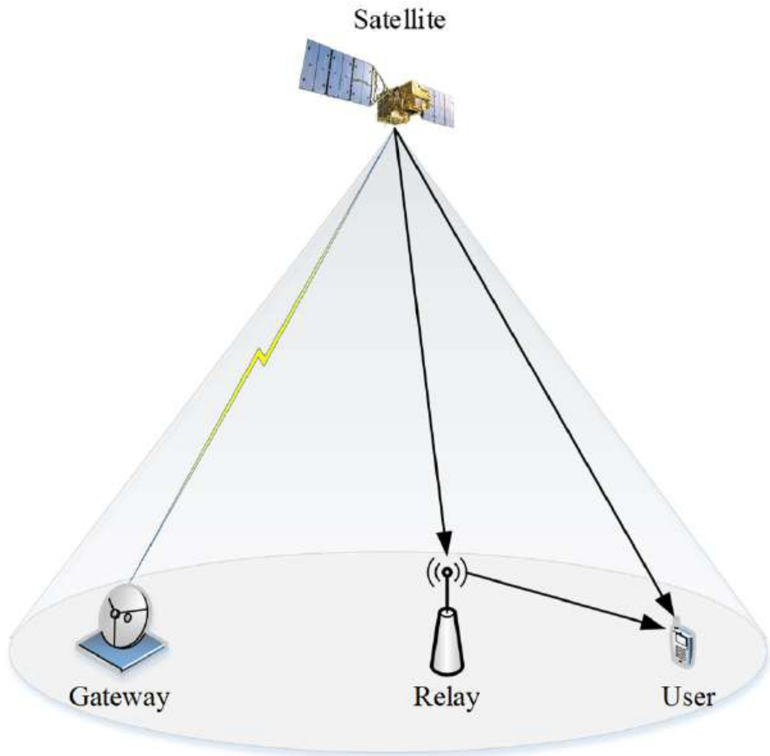
System stability is increased

Hybrid Satellite-Terrestrial Relay Networks

- **Cooperative Relay Architecture**

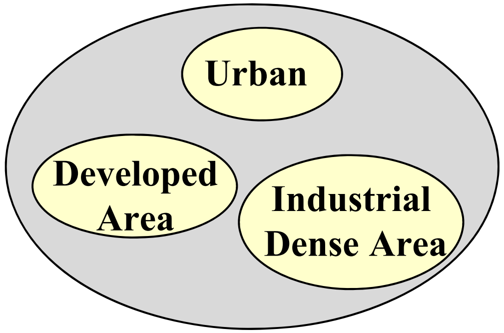
  Considering both the masked direct link and the relay link

- **Phase 1**
  - ➢ **Satellite to Relay**
  - ➢ **Satellite to User**
- **Phase 2**
  - ➢ **Relay to User**
  - ➢ **User combine the two signals by techniques such as MRC**

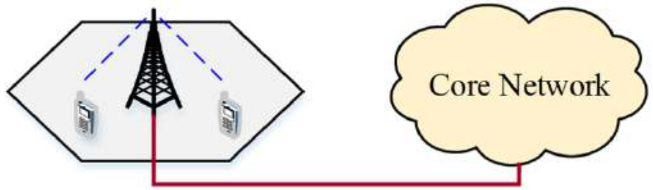


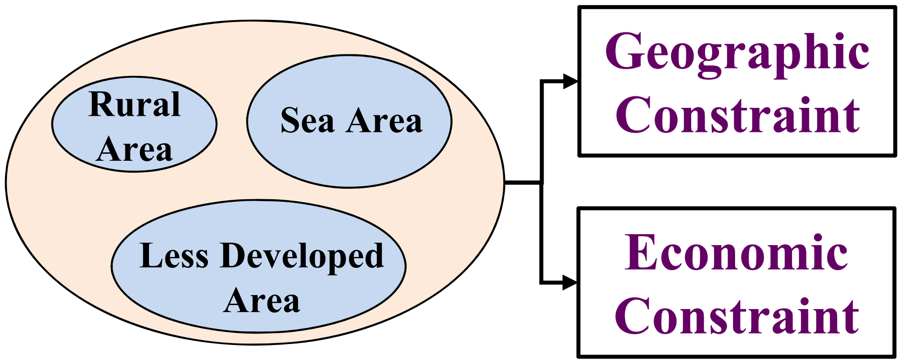
Spatial diversity can be exploited when the direct link is masked

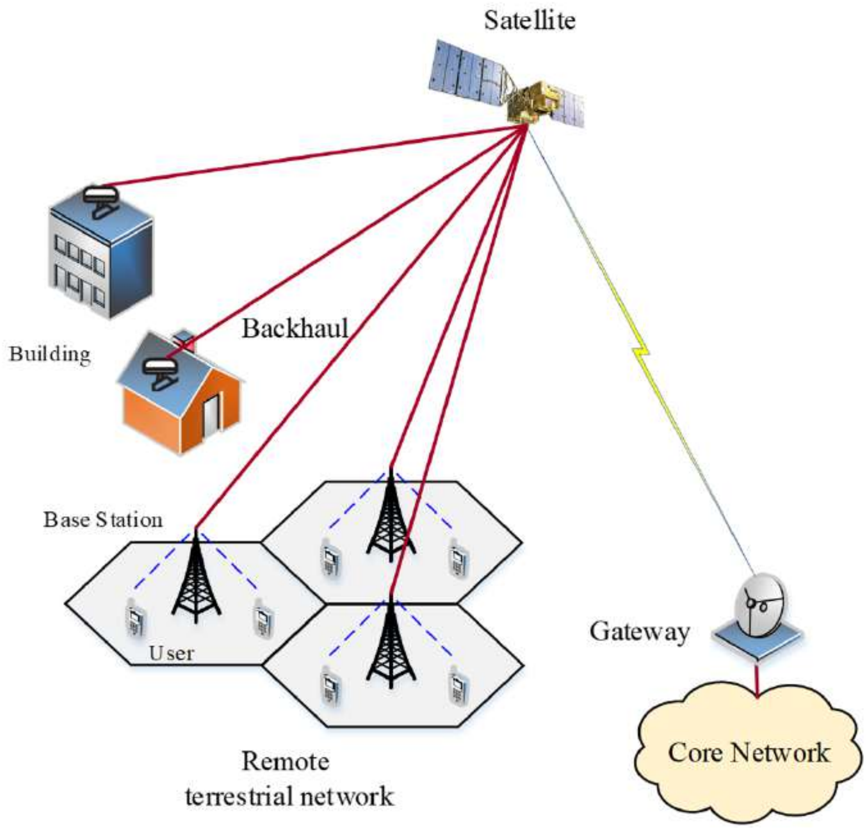
Satellite-Terrestrial Backhaul Networks



Backhaul Link
Optical Fiber

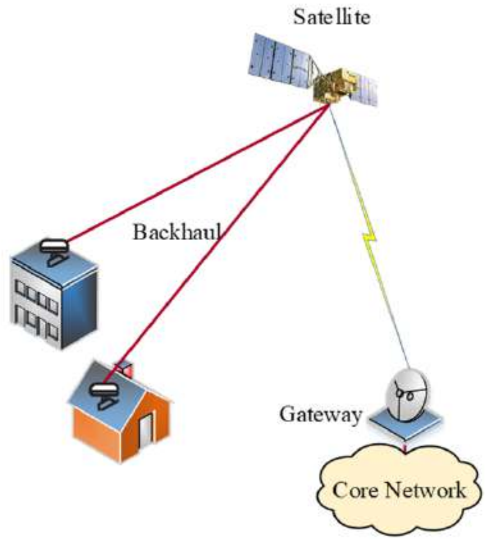




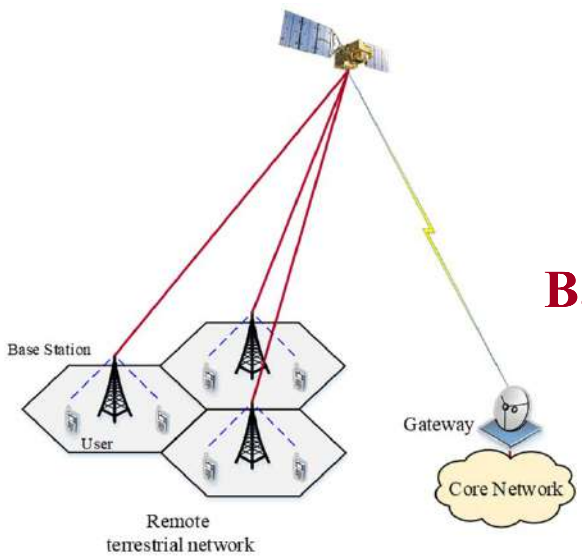


Optical Fiber Unavailable ➡ **Satellite Backhaul Link**

Satellite-Terrestrial Backhaul Networks



Satellite-Terrestrial Backhaul Transmission with Building ➡ **User Access Wi-Fi**



Satellite-Terrestrial Backhaul Transmission with Base Station ➡ **User Access 5G/6G Technologies**

Cognitive Satellite-Terrestrial Networks

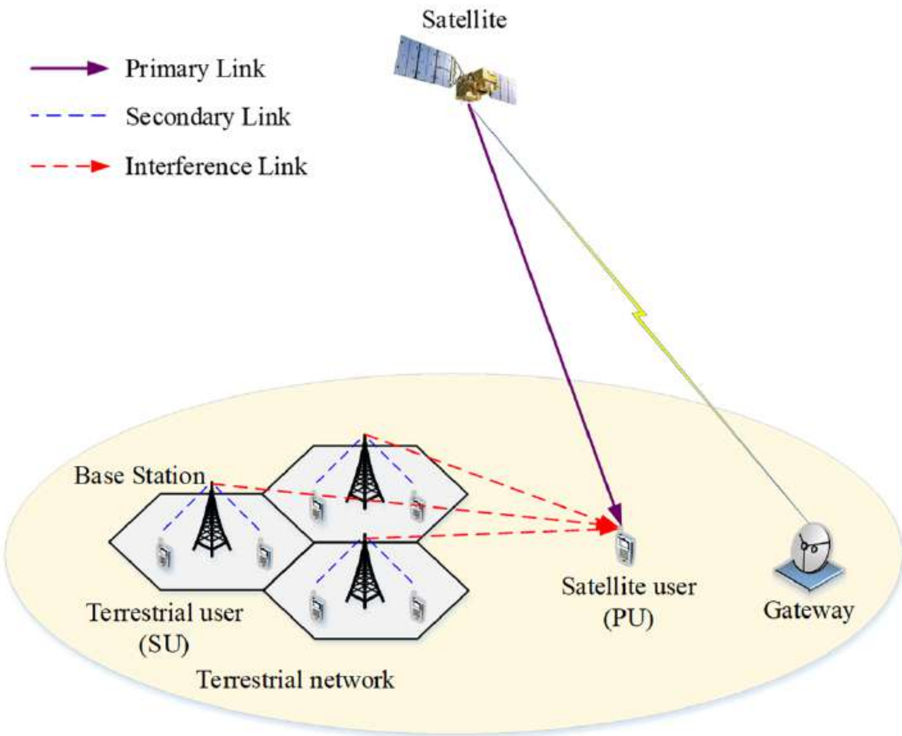
- **Basic Cognitive Architecture**

Increasing Demand of Spectrum

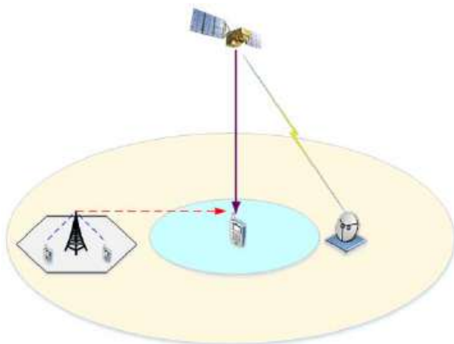
⬇

Spectrum Sharing
Cognitive Ratio

Underlay | **Overlay** | **Interweave**



Interference Mitigation



Exclusion Zone

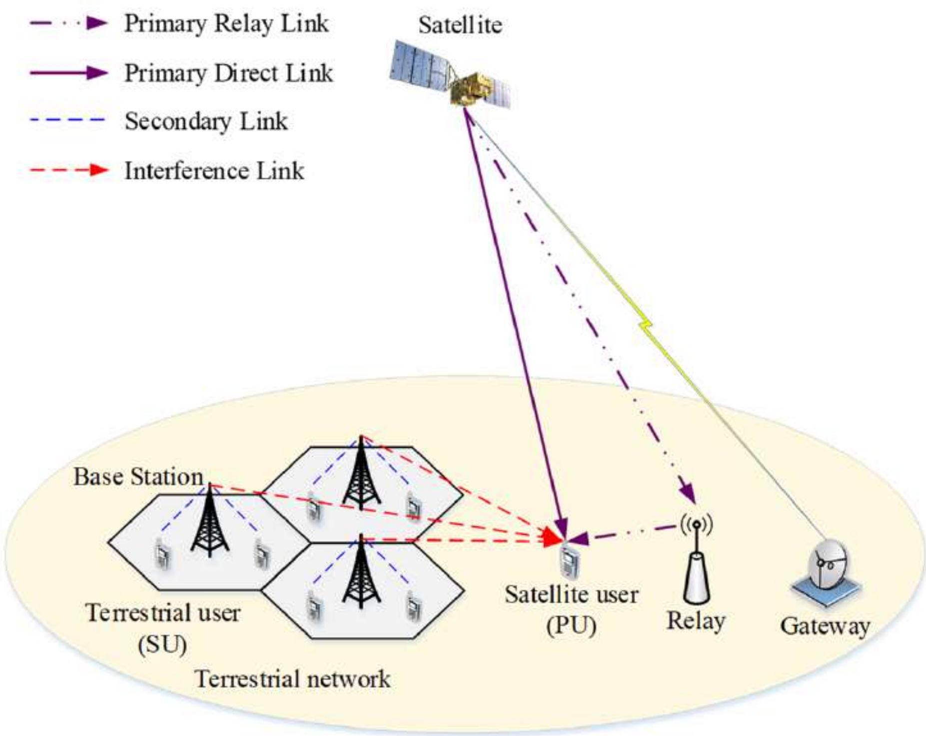
Cognitive Satellite-Terrestrial Networks

- **Cognitive Relay Architecture**

Hybrid Satellite-Terrestrial Relay Networks	Terrestrial Networks

Spectrum Sharing

- **Merge terrestrial relay and terrestrial BS**
- **Phase 1**
  - ➢ **Satellite to BS**
- **Phase 2**
  - ➢ **BS to Satellite User**
  - ➢ **BS to Terrestrial User by CR**



Extended From Hybrid Satellite-Terrestrial Relay Networks

Cooperative Satellite-Terrestrial Networks

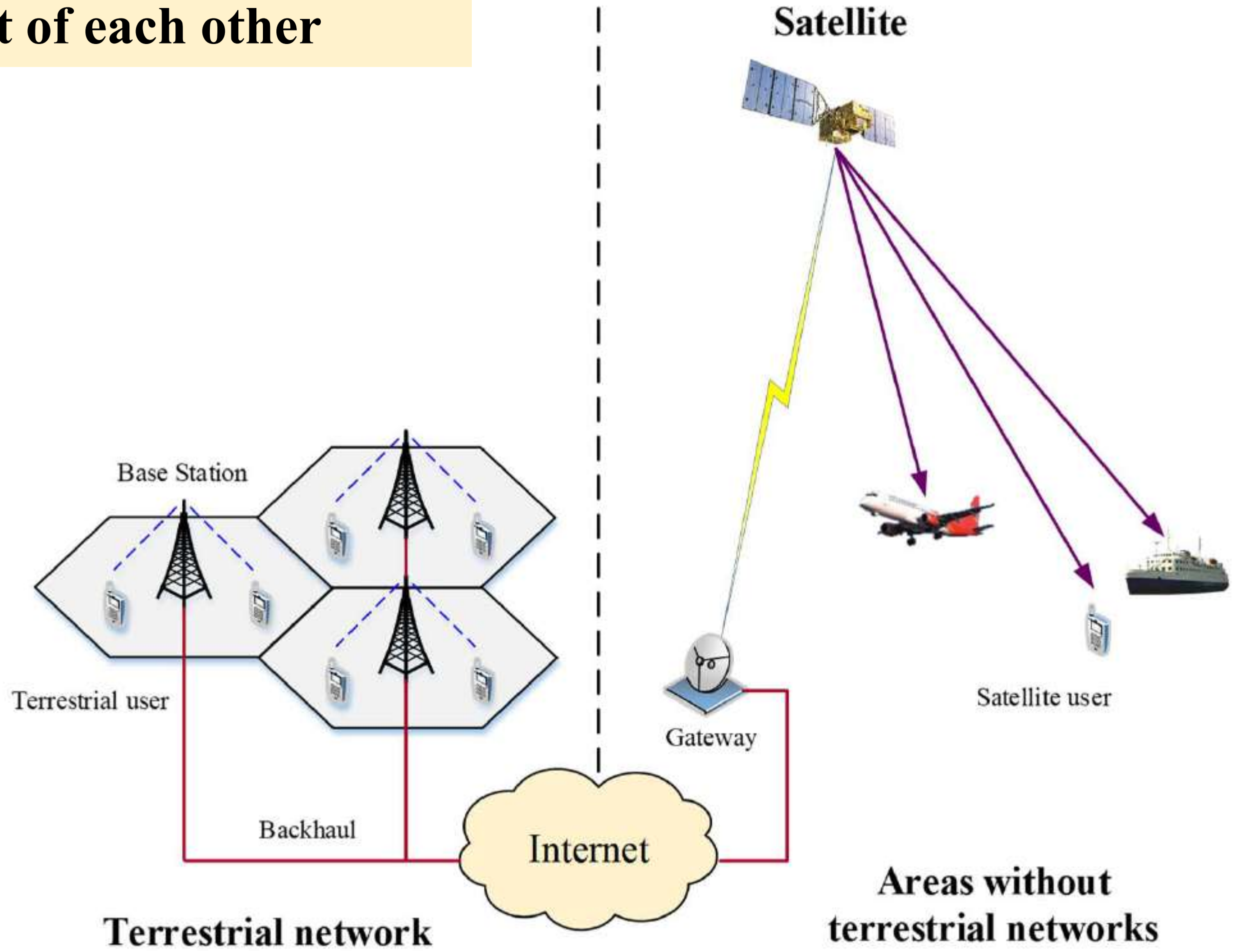
- **Complementary Architecture**

Satellite network and the terrestrial network act as the complement of each other

- **Terrestrial Network**
  - **Broadband access to the Internet at low cost**
- **Satellite Network**
  - **Ubiquitous coverage**

⬇

Continuous service
Internet of Everything

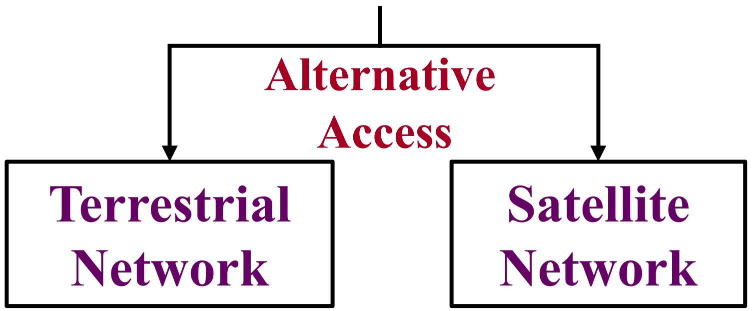


Cooperative Satellite-Terrestrial Networks

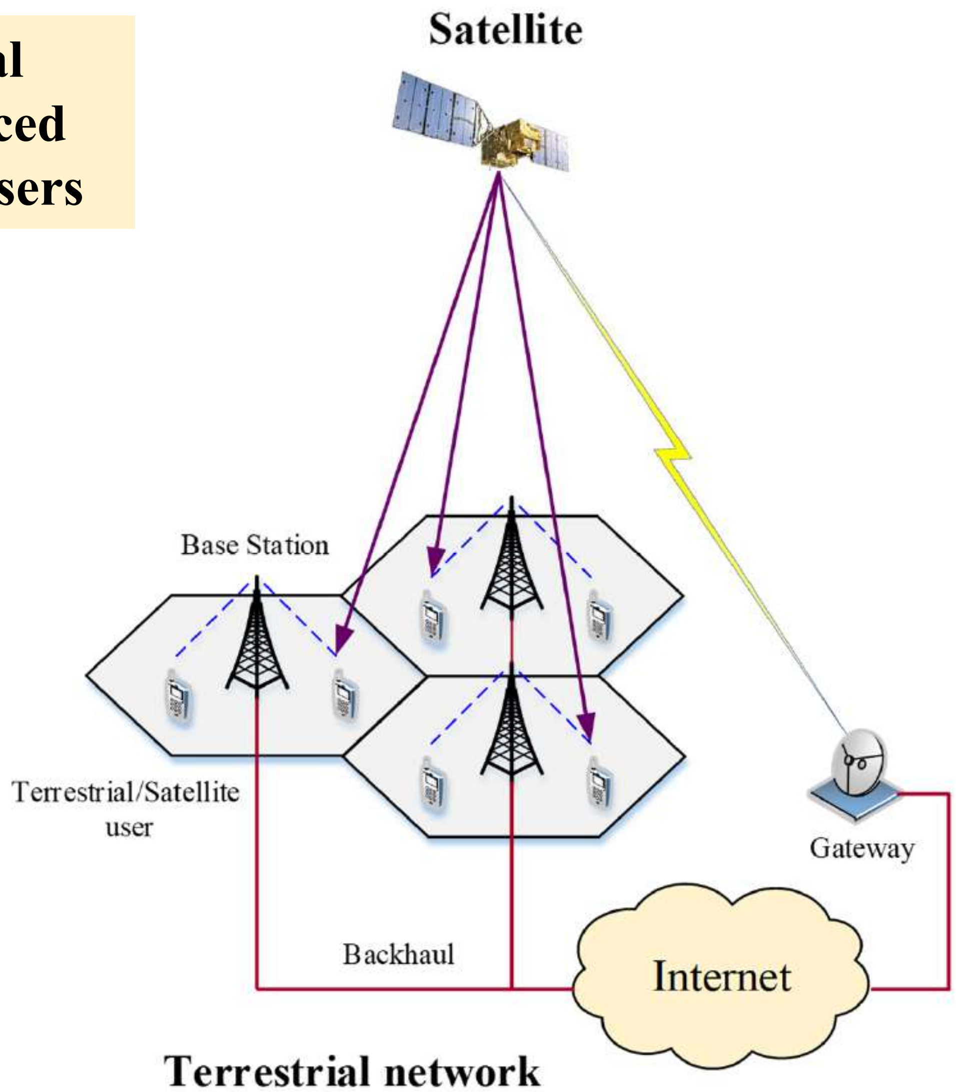
- **Enhanced Architecture**

Satellite network and the terrestrial network cooperate to provide enhanced communication services for ground users

Dual-mode Terminals



- ➢ **Offloading terrestrial traffic**
- ➢ **Diversity gain**
- ➢ **Combined unicast and multicast**



Satellite-Air-Terrestrial Networks

Air Network: **Provide coverage and capacity enhancement with mobility support**

- **High altitude platforms**

  Balloons Airplanes

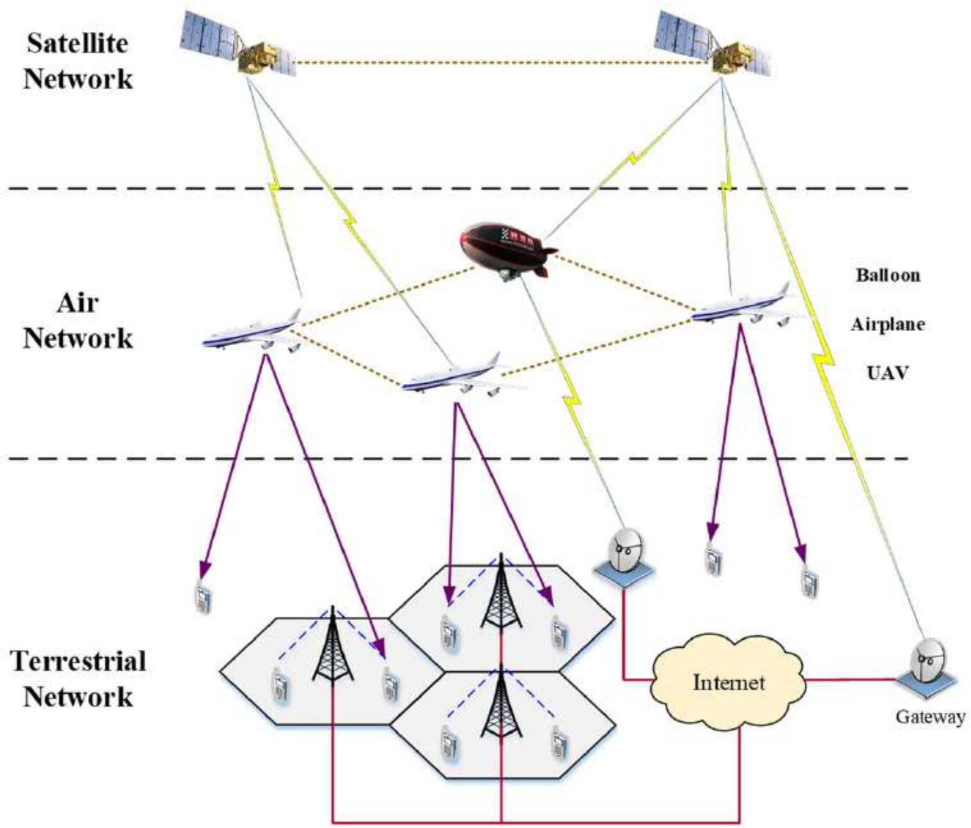
- **Low altitude platforms**

  Unmanned aerial vehicles (UAVs)

Lower cost | Higher mobility | Ease of deployment

➢ Provide continuous service in uncovered areas

➢ Enhance transmission in hotspot areas



Integration Architecture

Satellite-Terrestrial Relay Networks	Basic Relay Architecture	Terrestrial relays are utilized to forward satellite signals to ground satellite users, when the direct satellite link is unavailable due to the masking effect.
	Cooperative Relay Architecture	Terrestrial relays are utilized to forward satellite signals to ground satellite users. Then, users combine the signals from both satellites and relays to improve the system performance when the direct satellite link is masked.
Satellite-Terrestrial Backhaul Networks	\	Satellites are utilized to provide backhaul transmission for BSs in remote areas without optical fiber backhaul links.
Cognitive Satellite-Terrestrial Networks	Basic Cognitive Architecture	Satellite networks and terrestrial networks share the same spectrum resources for transmission with the technique of CR.
	Cognitive Relay Architecture	Satellite relay networks and terrestrial networks share the same spectrum resources for transmission with the technique of CR.

Integration Architecture

Cooperative Satellite-Terrestrial Networks	Complementary Architecture	Satellite networks and terrestrial networks act as the complement of each other to achieve ubiquitous coverage and continuous service.
	Enhanced Architecture	Users can access the terrestrial network and the satellite network simultaneously. Satellite networks and terrestrial networks cooperate to provide enhanced communication services for ground users.
Satellite-Air-Terrestrial Networks	\	The satellite network, the air network, and the terrestrial network are integrated, where the air network is further deployed to provide coverage and capacity enhancement with mobility support.

Outline

- Background
- Integrated Satellite-Terrestrial Networks Towards 6G
- Application Case
- Challenges for Integration
- Techniques and Future Direction

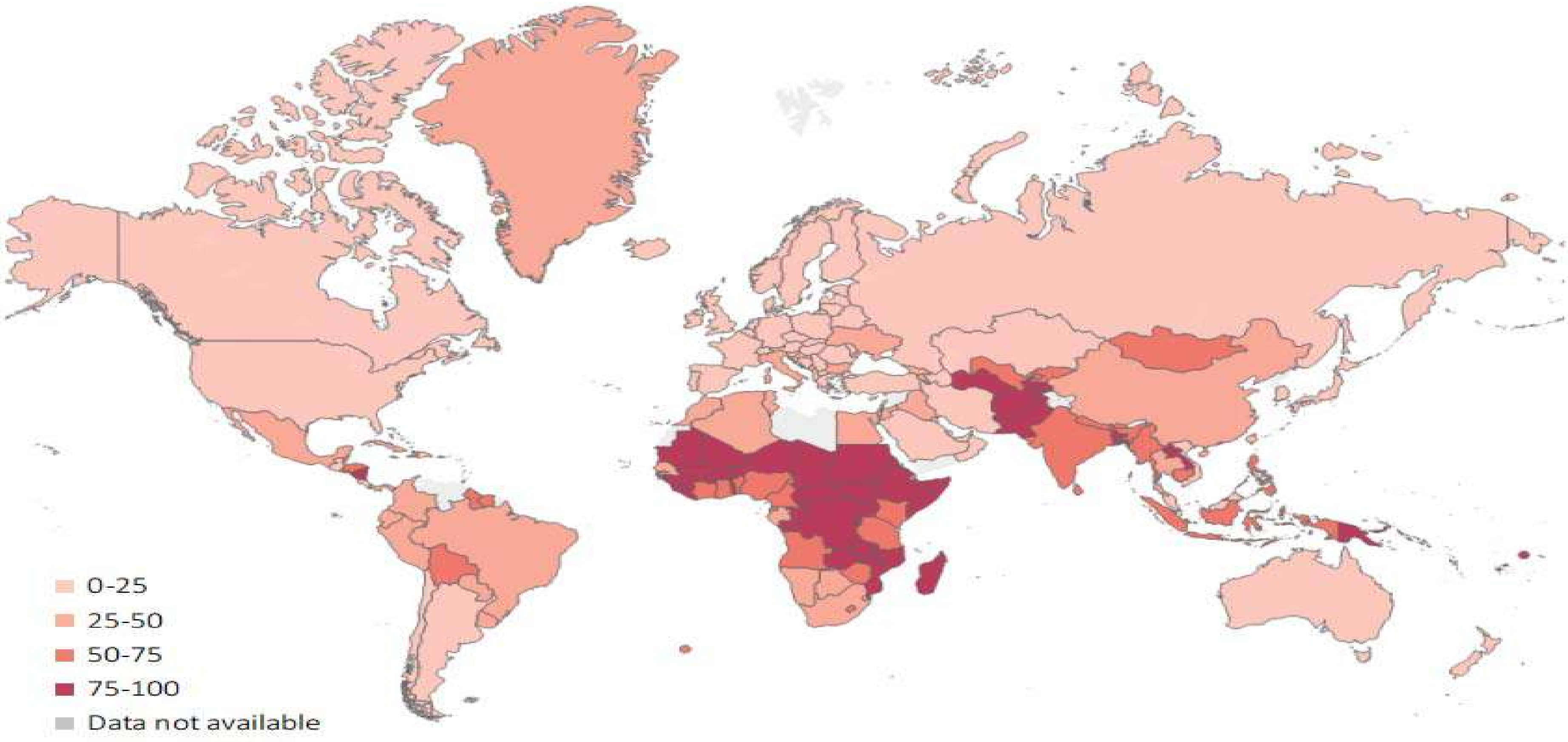
Rural Coverage

- **Population Coverage of Internet：**

  (ITU - Facts and figures 2019)

  Global：53.6%　　Developed Country：47.0%　　Less Developed Country：19.1%

- **Percentage of the population not using the Internet, 2019**



Rural Coverage

Starlink:

A satellite costs 0.5 million US dollars

4425 satellites covers the world

Total cost: 2212 million US dollars

The satellite-terrestrial network can achieve rural coverage at a lower cost !

- **Sparsely Populated Rural Areas:** Access the satellite-terrestrial network by mobile terminals
- **Densely Populated Rural Areas:** Access the satellite-terrestrial network by BSs or other access points with satellite backhauls
- **Residences/Buildings in Rural Areas:** Fixed satellite antennas can be deployed to provide relative broadband service for users inside based on 6G or Wi-Fi

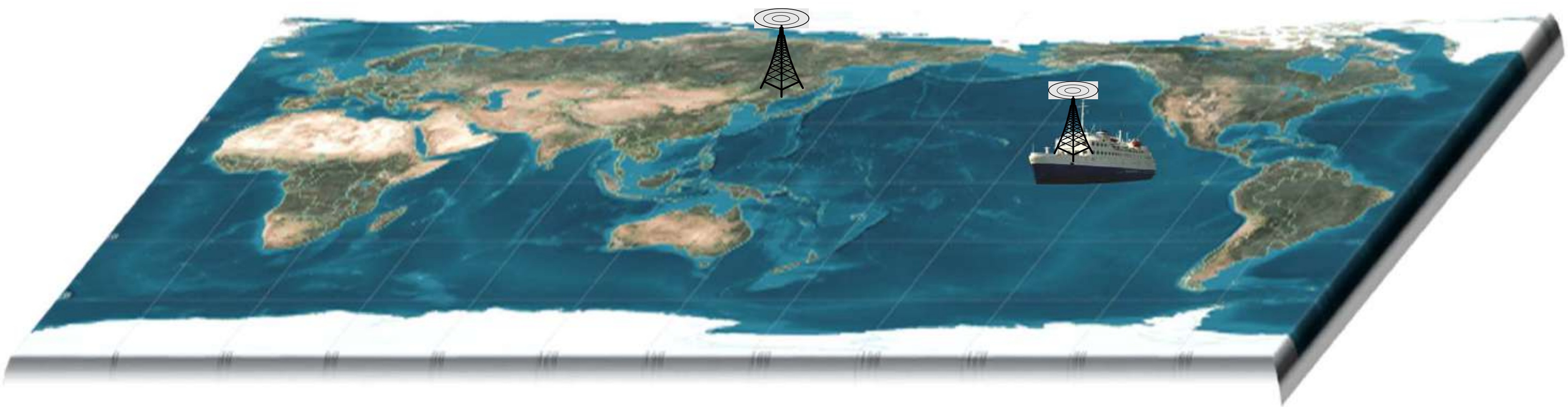
Sea Area Communication

- **Ground Mobile Network Coverage:**

  Land 20%   **Sea 5%**

- **Sea area accounts for 71% of the entire surface of the earth.**

Shore BSs → 5km   **Ship-by-Ship Relay → 100km**



Ground networks are impossible to realize the communication of the entire sea area !

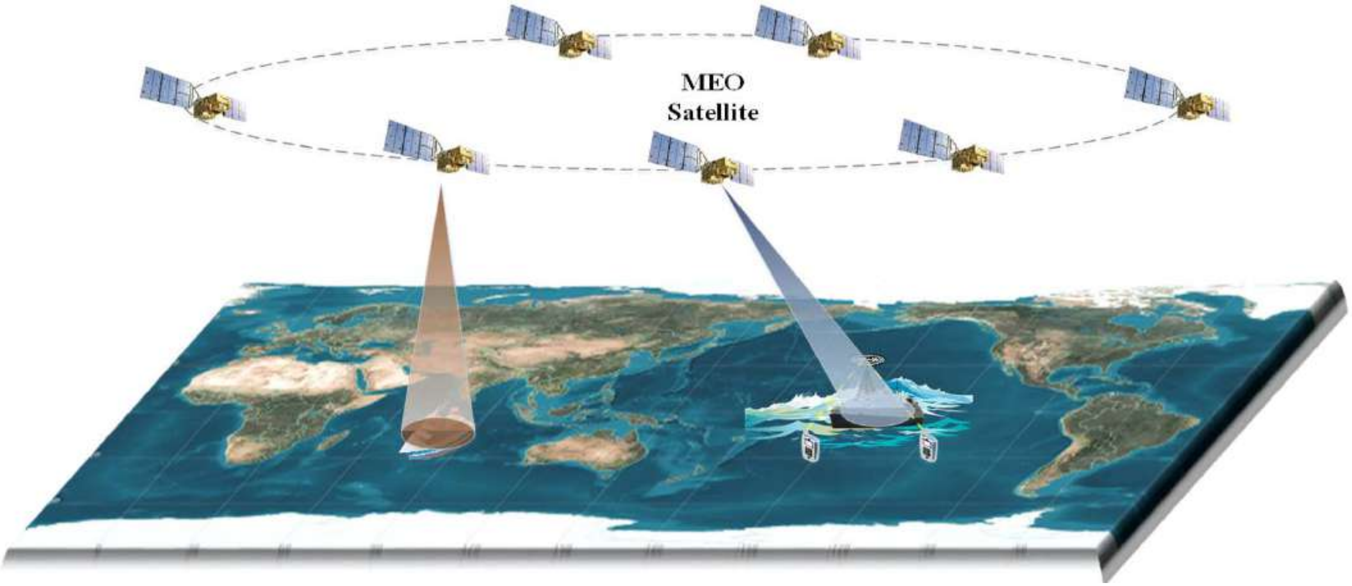
Sea Area Communication

➤ **Expand the communication range：**

- **Extend the connectivity to remote or isolated areas on the earth.**
- **For a cruise line on the sea, the users inside can obtain the same terrestrial services as on land based on the integrated satellite-terrestrial network.**

➤ **Maritime information collection and maritime monitoring：**

- **Provide efficient storage, transmission and calculation for the collected maritime information.**
- **Improving the ability of continuous situational awareness of the sea area.**



Airborne Communication

- **Airborne network**

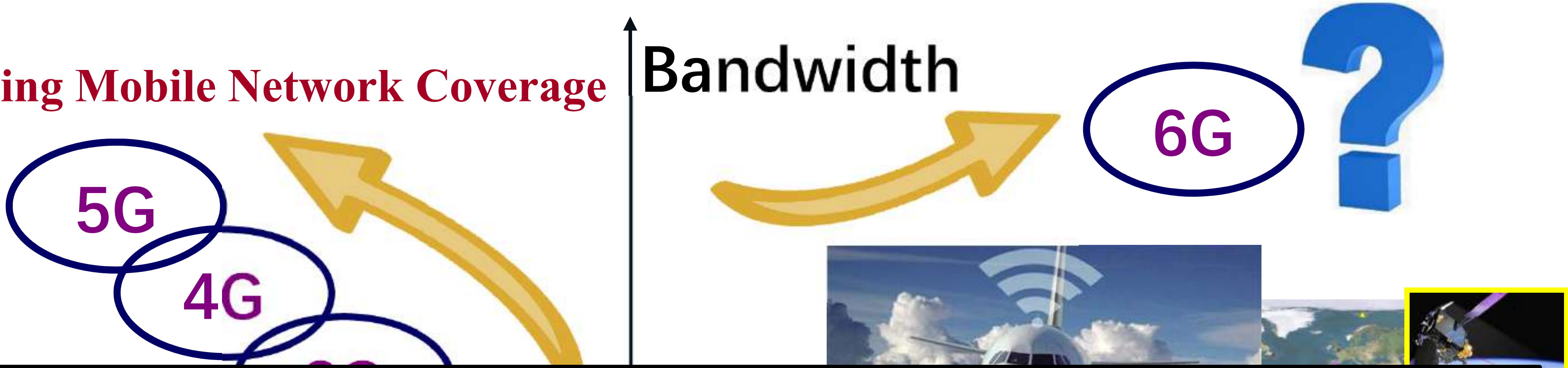
  The airborne network generally consists of airplanes, balloons and UAVs, among which airplanes are in great need of broadband access.

- **Air Transport Market**

  2017： 4.08 billion passengers worldwide

  70% of passengers are willing to pay for WiFi. (Date comes from CAAC.)

Existing Mobile Network Coverage



The integrated satellite-terrestrial network is a key to extend the connectivity to airborne networks !

Emergency Communication

- **Natural Disaster**

  Natural disasters cost the world $75 billion and claimed roughly 2,200 lives during the first half of 2020.

Earthquake

Typhoon/Hurricane

- **Unexpected Events**

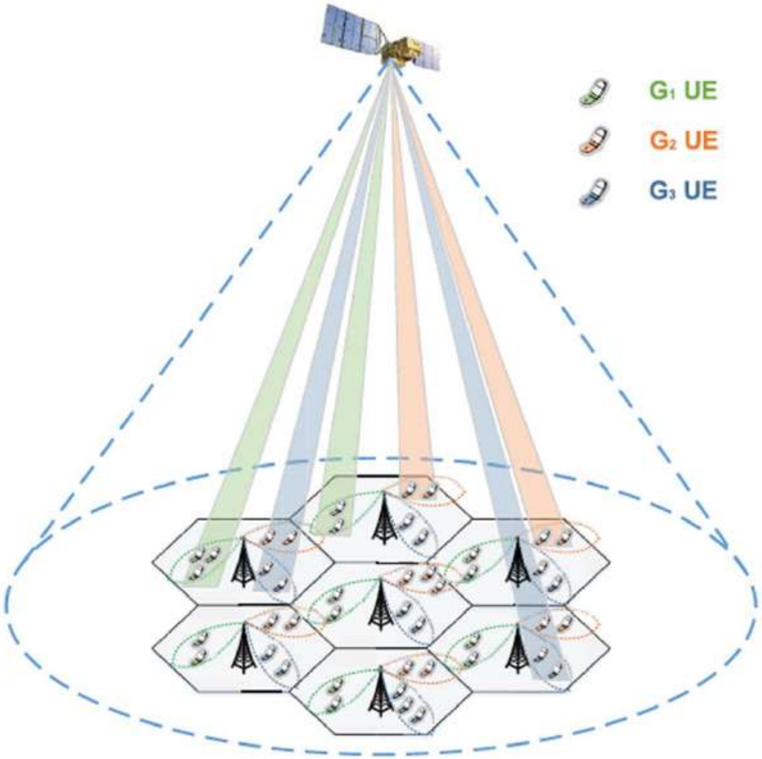
Flight Distress

Outdoor Self-help

The integrated satellite-terrestrial network is more reliable and resistant to paroxysmal disasters !

Multicast/Broadcast Transmission

Multicast/broadcast transmission can be utilized for simultaneous transmission to multiple users that require the same contents

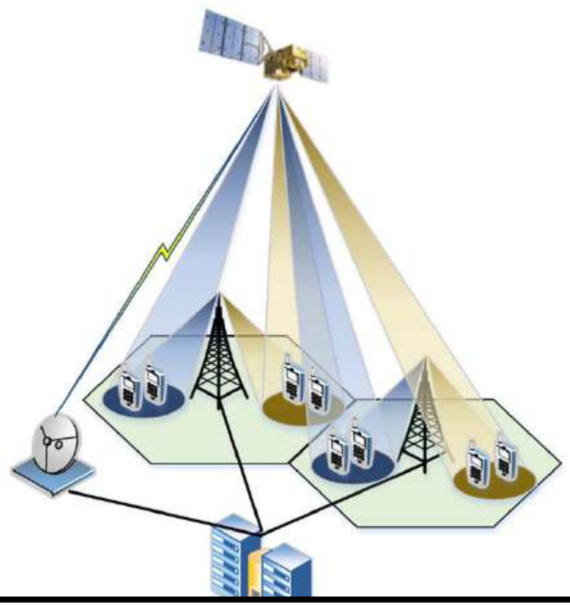


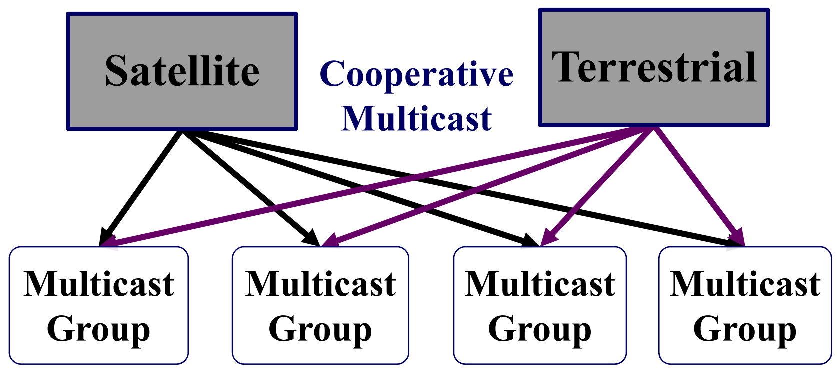
- **Three Models**
  - **Cooperative multicast transmission mode: Overcome the large fluctuation of terrestrial channels.**
  - **Combined unicast and multicast transmission mode: Content delivery.**
  - **Multicast backhaul and caching mode: Efficient content fetch from the service provider with the STBN architecture.**

Multicast/Broadcast Transmission

Multicast in Single Network
- **Terrestrial : Channel fluctuation** ➡ **Bottleneck User**
- **Satellite : Limited Power** ➡ **Limited Rate**

- **Cooperative Multicast Transmission**





Serve the same user groups cooperatively

Maximize the minimum SINR

Significantly increase the transmission capacity of bottleneck users in traditional multicast transmission

Outline

- **Background**
- **Integrated Satellite-Terrestrial Networks Towards 6G**
- **Application Case**
- **Challenges for Integration**
- **Techniques and Future Direction**

Long Propagation Delay

- For GEO, the propagation delay are 240 milliseconds.
- For MEO/LEO, the propagation delay are tens of milliseconds.
- Propagation delay of satellites is much longer than the 5G latency requirement of 1 ms.

TABLE: Propagation delay of satellites

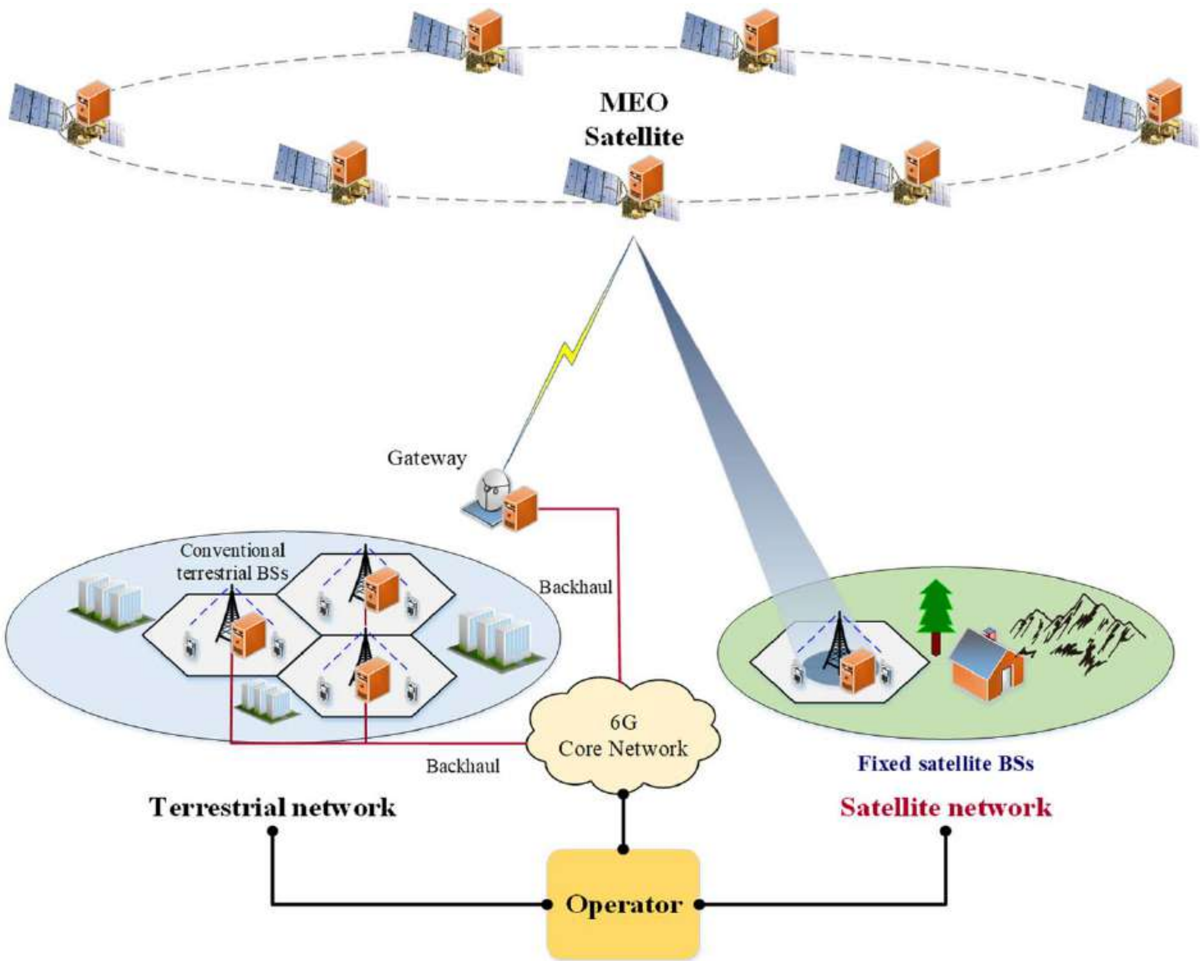
Satellite type	Altitude	One-way propagation delay
GEO	36,000 km	240 ms
MEO	20,000 km	133.33 ms
MEO	10,000 km	66.67 ms
MEO	3,000 km	20 ms
LEO	1,000 km	6.67 ms
LEO	600 km	4 ms

To improve the QoS of users, efforts are needed to reduce the communication latency in cooperative satellite-terrestrial network (CooSTN) !

Long Propagation Delay

- Mobile edge computing (MEC)

MEC ➡ BS, Satellites and Gateways ➡ Reduce Latency



Complex Link Conditions

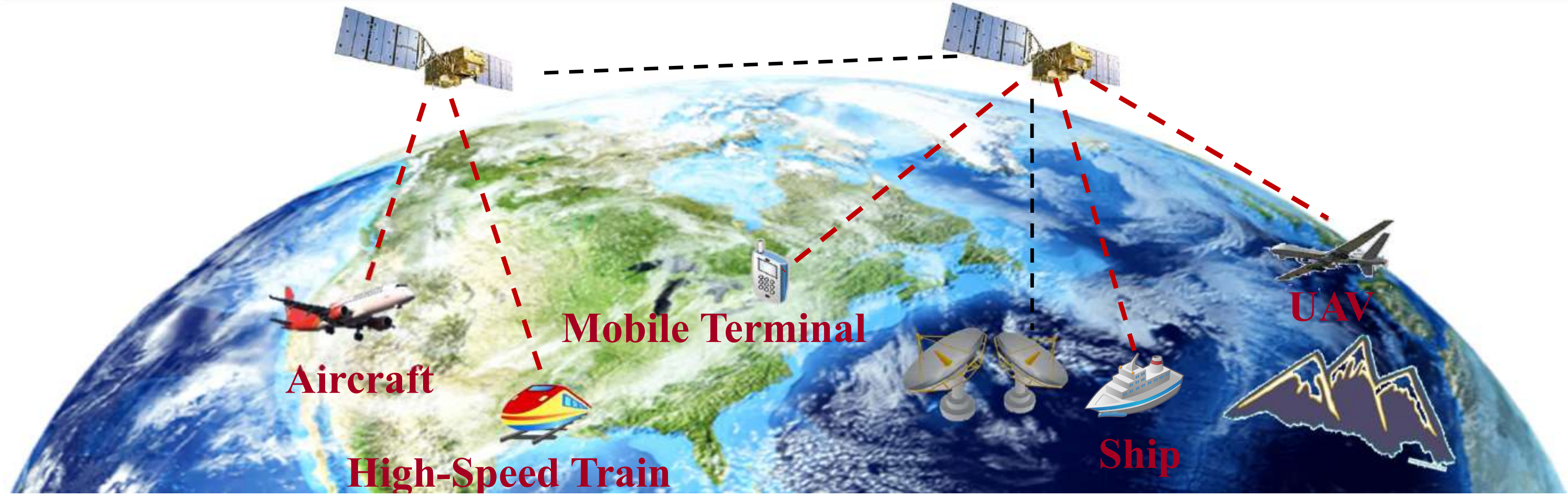
- **Unfavourable Weather Conditions**

Rain, cloud, water vapour and fog ⇨ Critical signal attenuation

- **High Speed Movement**

High speed of MEO/LEO satellites ⇨ Time-variation Doppler shift; Large phase shift

Reliable modulation and coding schemes can be designed and utilized for quickly adaptation to complex link conditions.



Mobility and Handover Management

Handovers

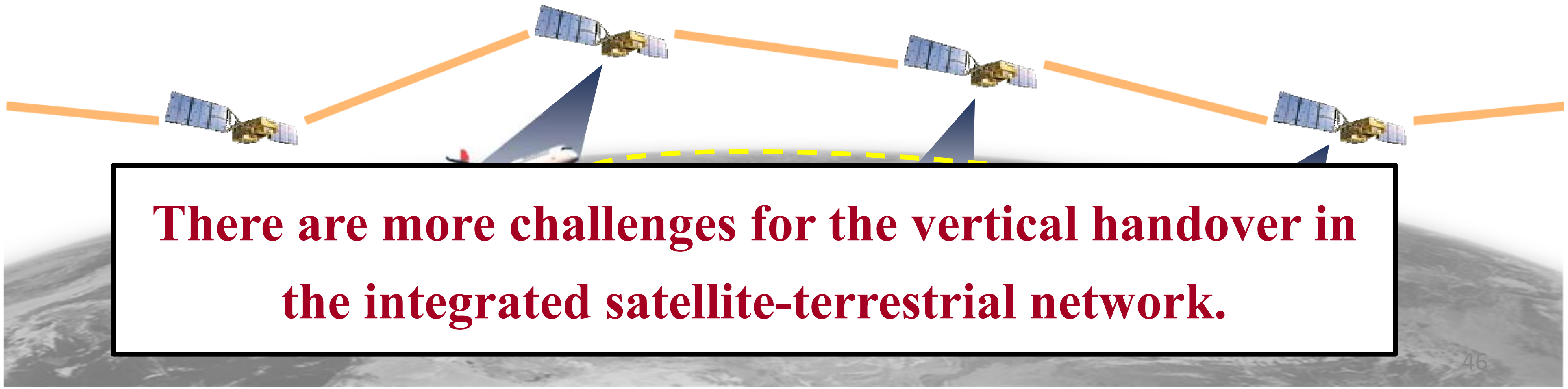
- **Horizontal handover** → It occurs when the connection is transferred between terrestrial cells, between satellite spot-beams, or between satellites.
- **Vertical handover** → It occurs when the connection is transferred between the terrestrial network and the satellite network.

Lack of Research

Orbital motion of MEO/LEO satellites

Mobility of mobile users

→ **Handovers occur more frequently**



There are more challenges for the vertical handover in the integrated satellite-terrestrial network.

Traffic Offloading

- **High Dynamic Nature**
  - **High mobility of MEO/LEO satellites** ➡ **Unstable satellite links**
Short connection time
- **High Latency**
  - **High propagation latency of satellites**
  - **Different propagation delay of different satellites**
- **Limited Resources:**
  - **Limited resources (e.g. power, bandwidth, data processing power)**

Considering the unique characteristics of satellite networks, satellite-based traffic offloading is more complex compared with conventional traffic offloading schemes in terrestrial networks.

Routing and Path Selection

- **High dynamic links:**

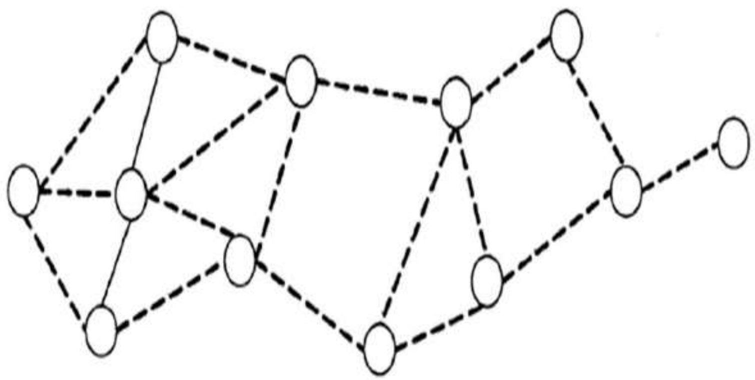
Time-varying topology of the network

↓

Routing oscillation

↓

Frequent link interruptions



- **Large routing table:**

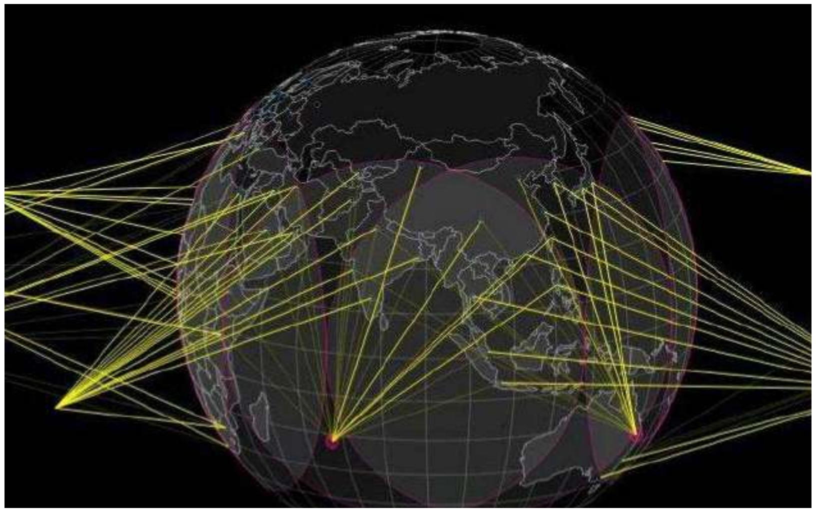
Wide coverage of the satellite

↓

Large routing table

↓

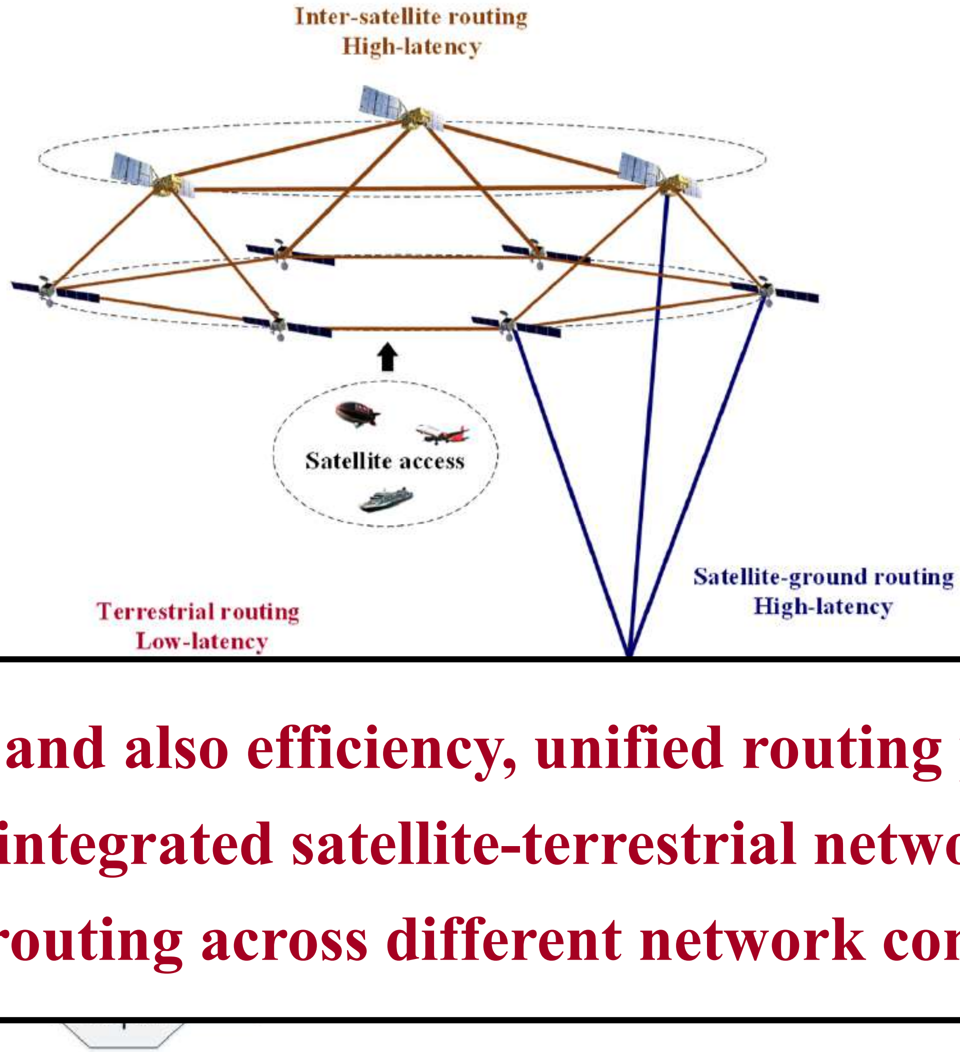
High complexity of routing strategies



Routing and Path Selection

- **Different propagation delays:**

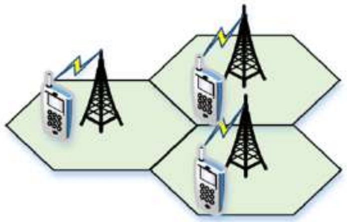
Delay-sensitive traffic → Low-latency paths → Avoid long propagation delays



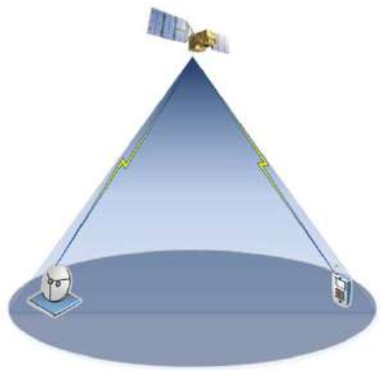
For continuity and also efficiency, unified routing protocols are required in the integrated satellite-terrestrial network to support integrated routing across different network components.

Resource Management

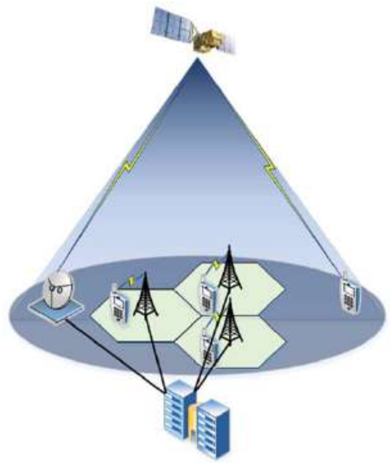
Terrestrial Network



Satellite Network



Integrated Network



Independent System

Independent resource utilization → **Flexible resource sharing**

Integrated System

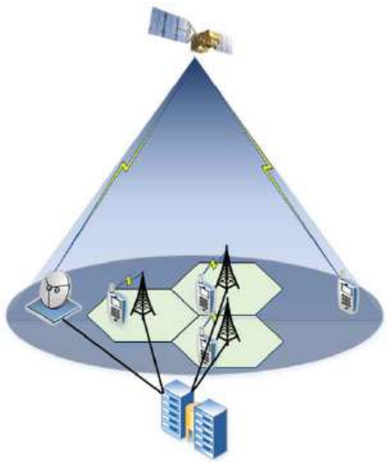
Terrestrial Network:
- Spectrum Resource
- Computing Resource
- Energy Resource

Satellite Network:
- Spectrum Resource
- Computing Resource
- Energy Resource
- Orbit Resource
- Gateway Resource

How to achieve the joint resource management ?

Resource Management

- **Integrated Resource Management**



Resource Pool

Centralized resource and interference management

Spectrum | **Computing** | **Energy**

- **Two-Layer Game**

Evolutionary Game

User ⟷ User

Dynamic Resource Competition

Stackelberg Game

Operator ⟷ User User

Resource Optimization

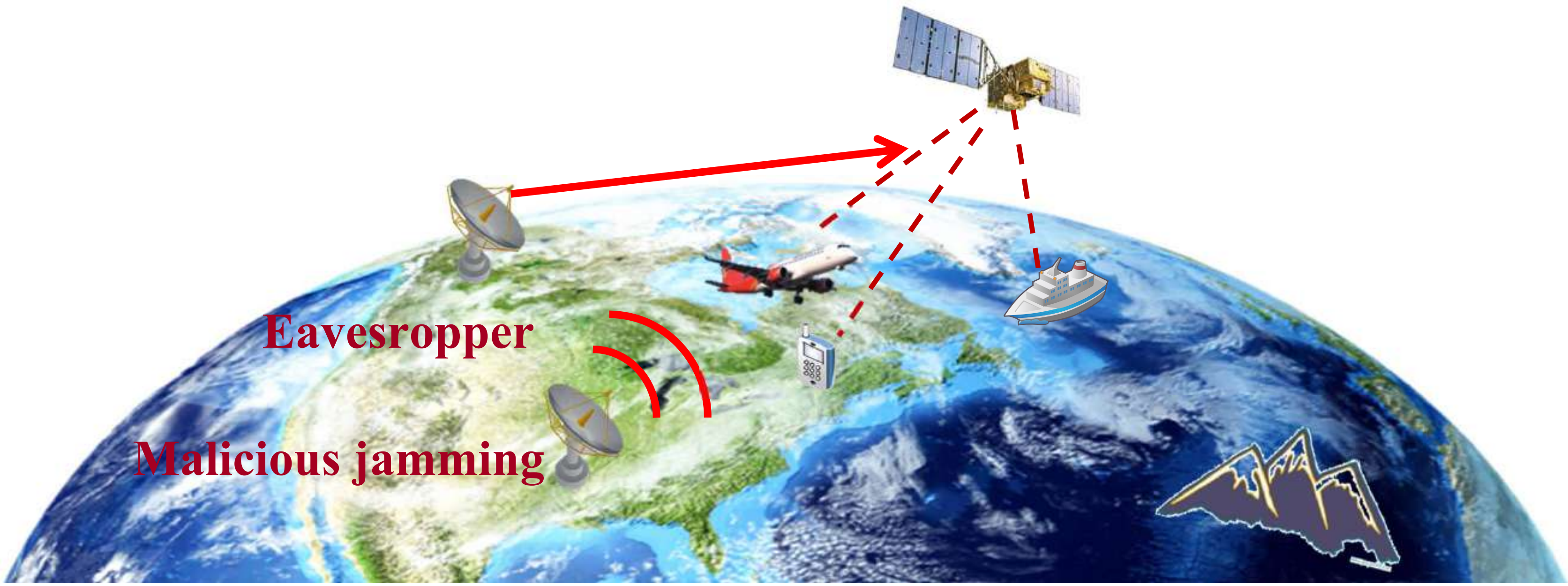
Dynamic Service Selection

Game based integrated resource management

- X. Zhu, **Chunxiao Jiang**, L. Kuang, Z. Zhao, and S. Guo, "Two-Layer Game Based Resource Allocation in Cloud Based Integrated Terrestrial-Satellite Networks", *IEEE Transactions on Cognitive Communications and Networking*, vol. 6, no. 2, pp. 509-522, Jun. 2020.

Security Guarantee

Traditional Encryption techniques	→	Additional communication latency
Wide coverage and long propagation delay	→	More complex key management
Open environment of satellite-ground links	→	Illegal access or privacy leaks

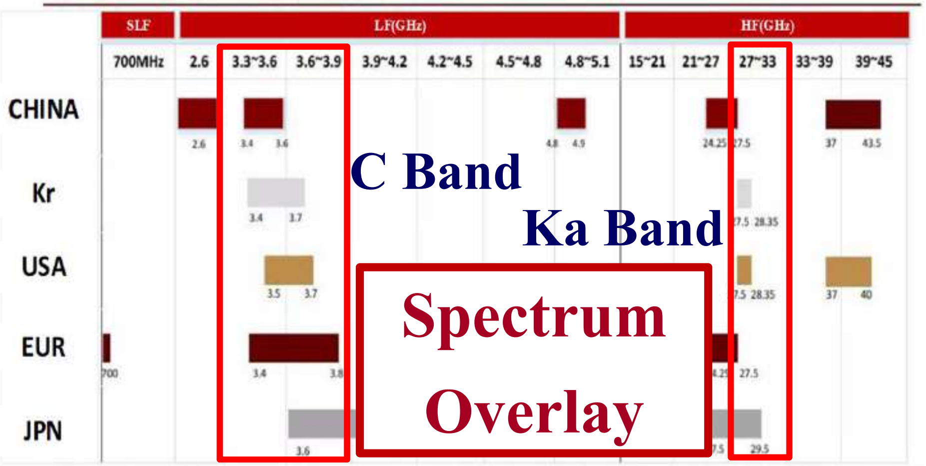


Outline

- Background
- Integrated Satellite-Terrestrial Networks Towards 6G
- Application Case
- Challenges for Integration
- Techniques and Future Direction

Spectrum Sharing

➢ 5G spectrum planning



➢ Satellite spectrum

	上行	下行
C Band	5850-6425MHz	3625-4200MHz
C Band Extension	6425-6725MHz	3400-3700MHz
Ka Band	27.5-31GHz	17.7-21.2GHz

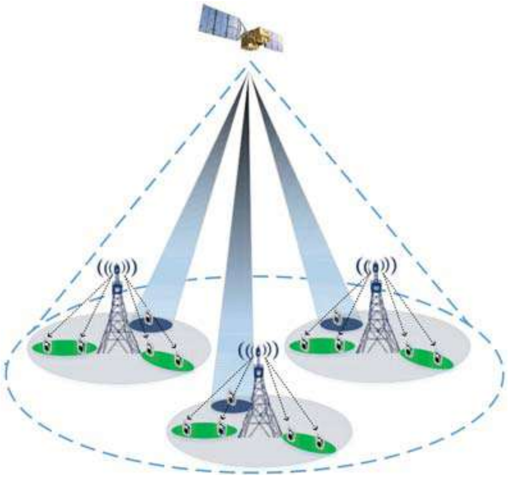
➢ Terrestrial-satellite Spectrum Sharing

- **Complementary coverage**
- **On-demand transmission**
- **Cooperative transmission**
- **Efficient resource utilization**

- L. Kuang, X. Chen, **Chunxiao Jiang**, H. Zhang, and S. Wu, "Radio Resource Management in Future Terrestrial-Satellite Communication Networks", *IEEE Wireless Communications*, vol. 24, no. 5, pp. 81-87, Oct. 2017.

Spectrum Sharing

➢ NOMA-Based Cooperative Transmission Scheme



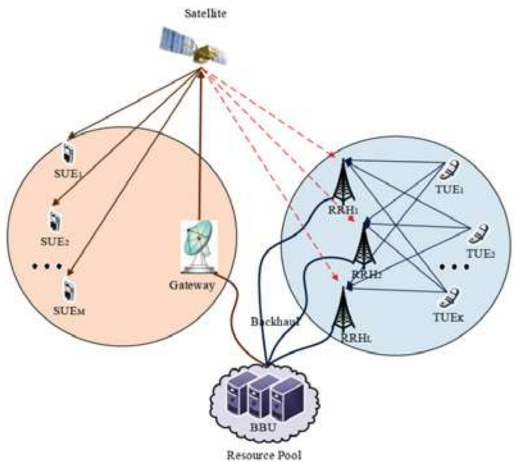
Conventional Exclusive Mode

⬇

Full Spectrum Sharing

- **Serve more users**
- **Achieve larger transmission capacity**

➢ Cloud-Based Cooperative Transmission Scheme



Centralized Baseband Processing at the Cloud

⬇

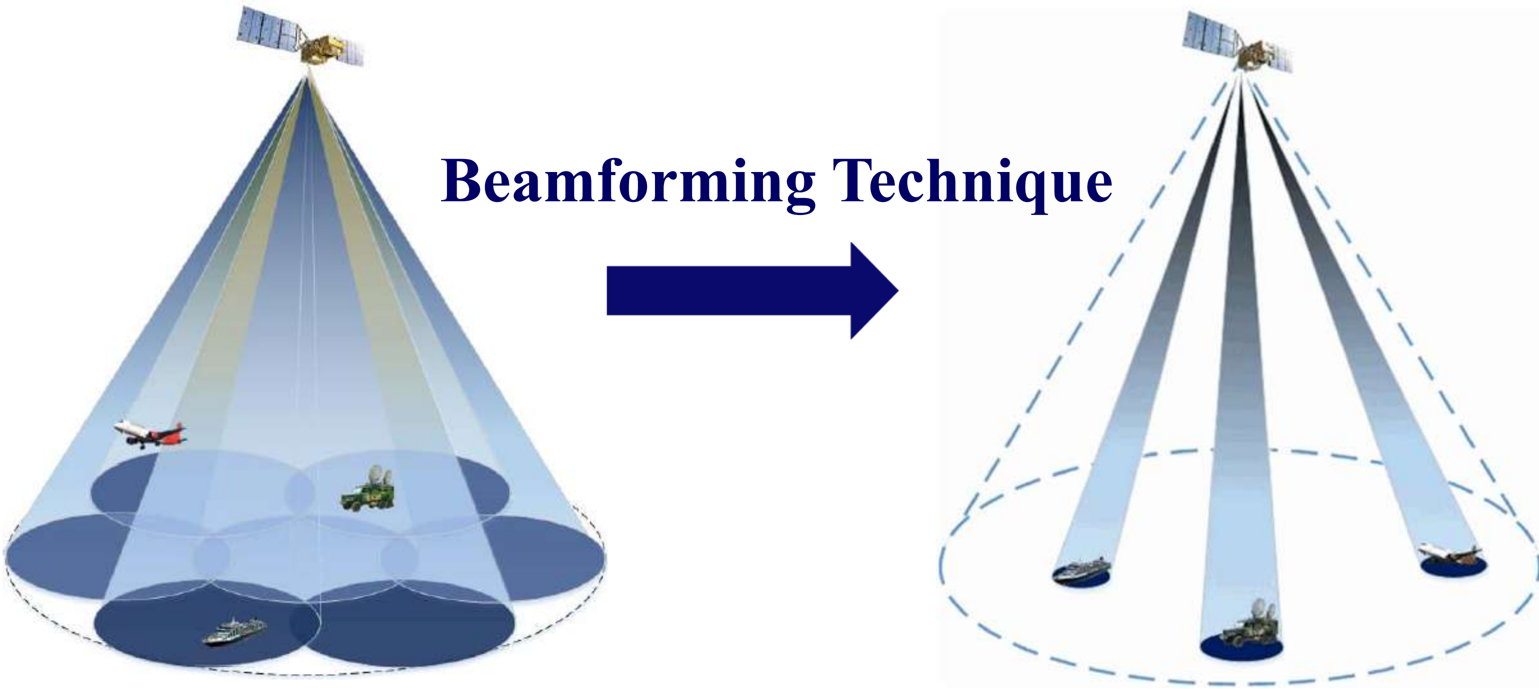
Terrestrial users and the satellite can share the same spectrum for transmission

Extending the network coverage with limited spectrum resources.

- X. Zhu, **Chunxiao Jiang**, L. Kuang, N. Ge and J. Lu, "Non-orthogonal Multiple Access Based Integrated Terrestrial-Satellite Networks", *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2253-2267, Oct. 2017.

Beamforming

Beamforming → **Focuses a wireless signal towards a specific receiving device**

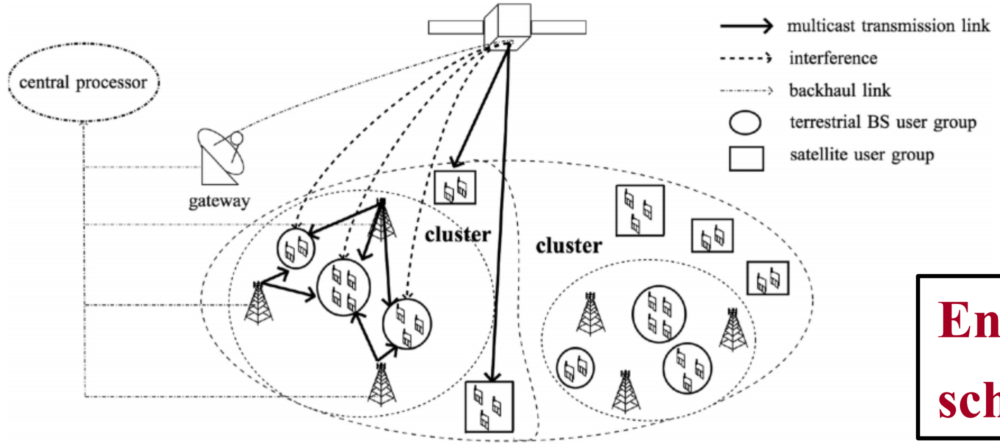


Advantages:

- **Improve the capacity performance**
- **Achieve higher transmission gains**
- **Mitigate the interference in the integrated satellite-terrestrial network**

Beamforming

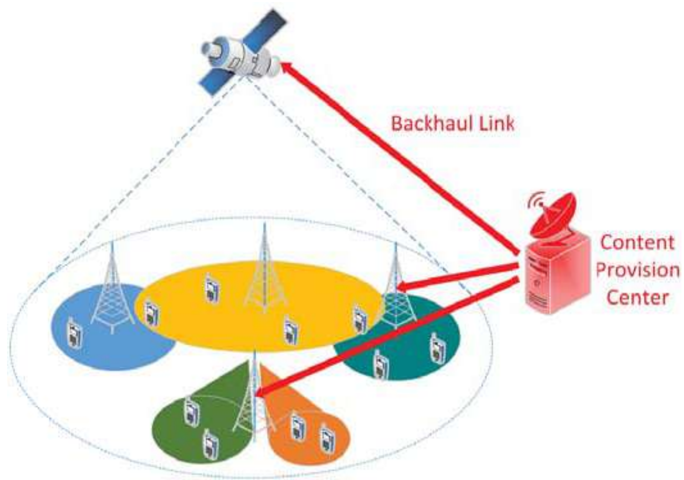
➢ Cloud-based Beamforming Architecture



Cloud-computing Based Centralized Processor

Enable cooperative design of joint user scheduling and multicast beamforming

➢ Multicast Multigroup Beamforming Design



Consider Unique and Common Content Demands of Users

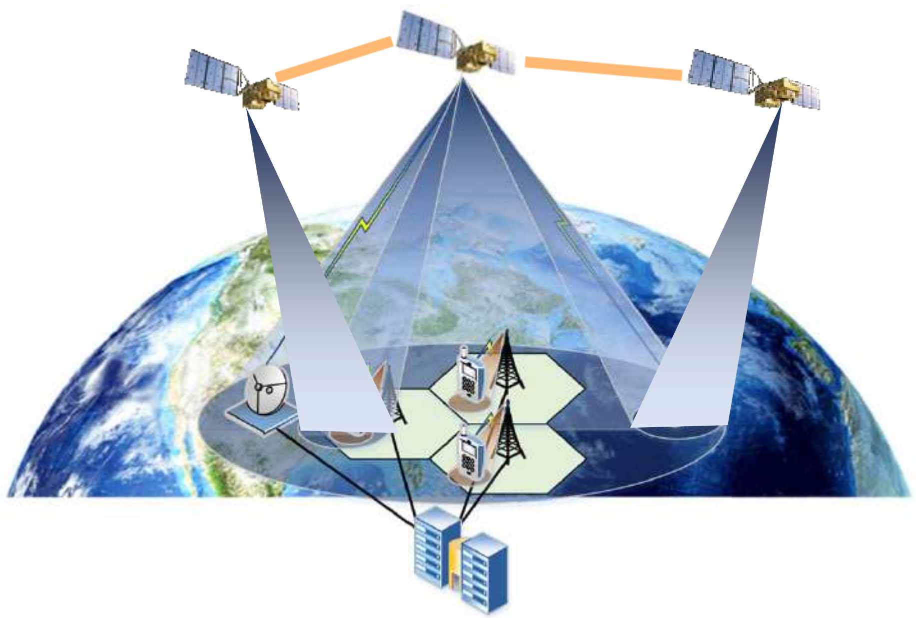
Optimize the system throughput by efficient grouping and multicast beamforming schemes

- Y. Zhang, L. Yin, **Chunxiao Jiang**, and Y. Qian, "Joint Beamforming Design and Resource Allocation for Terrestrial-Satellite Cooperation System", *IEEE Transactions on Communications*, vol. 68, no. 2, pp. 778-791, Feb. 2020.

Diversity Technique

➢ Diversity Reception

- **Users are free to select one or multiple links from all the available networks** → **Cooperative multi-group multicast transmission** → **Eliminate the channel fluctuation and shadowing effect**
- **Distinct channel of different satellites** → **Diversity gain**

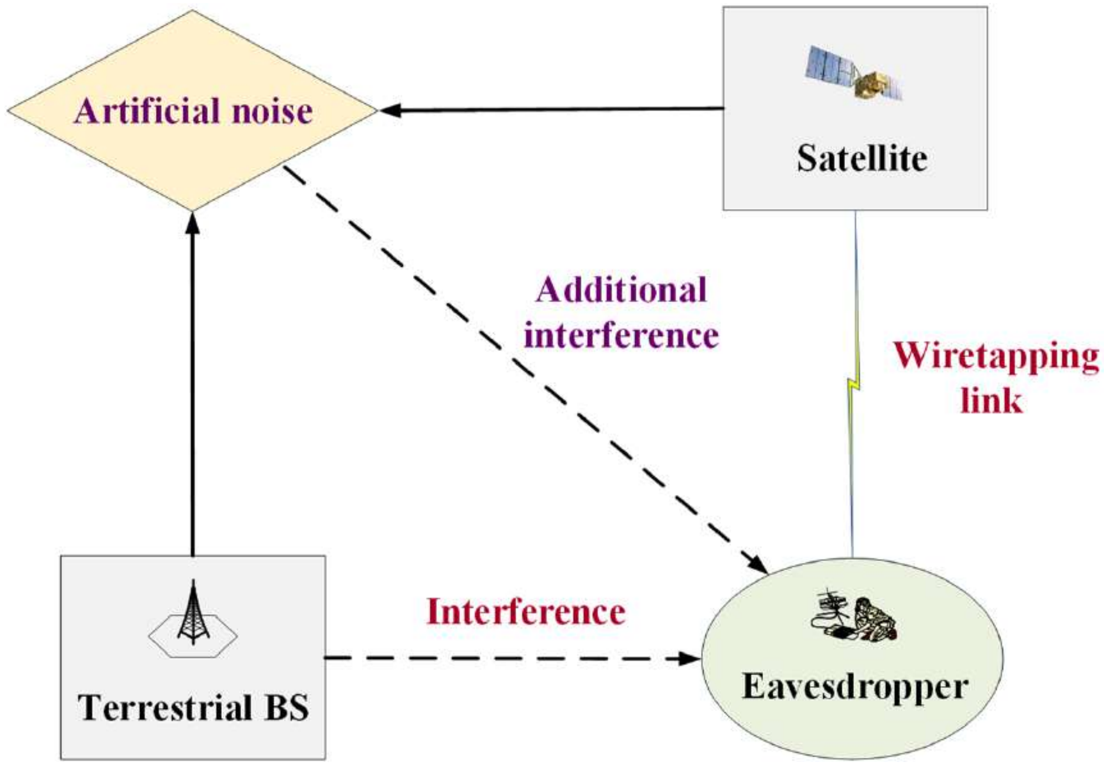


- X. Zhu, **Chunxiao Jiang**, L. Kuang, N. Ge, S. Guo, and J. Lu, "Cooperative Transmission in Integrated Terrestrial-Satellite Networks", *IEEE Network*, vol. 33, no. 3, pp. 204-210, Jun. 2019.

Cooperative Secure Transmission

Open environment ➡ **Satellite-ground links are vulnerable to eavesdropping and jamming**

By building the physical layer security with cooperative secure transmission, the information security of users can be enhanced.



Cooperative Secure Transmission

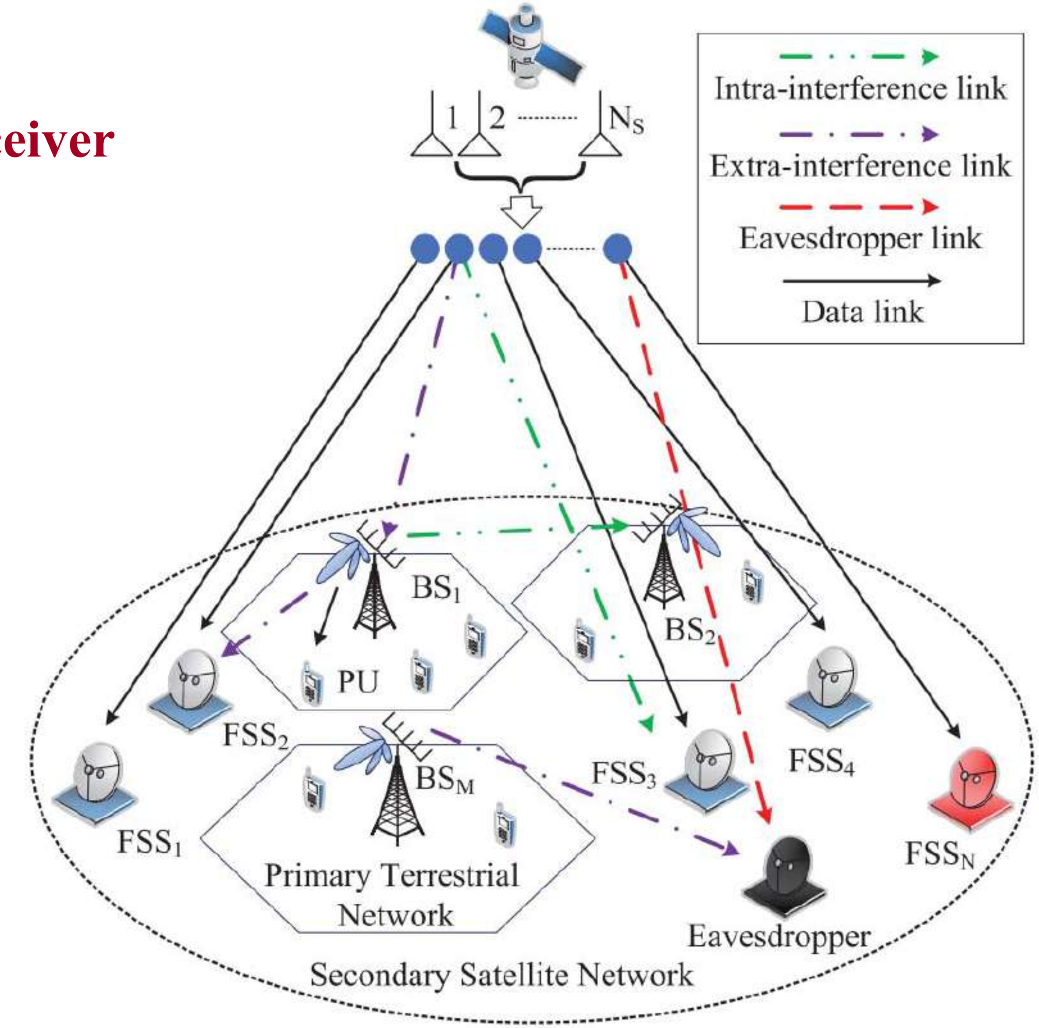
Transmitter

Add the artificial noise

Deteriorate the received SINR of eavesdroppers

Eliminate

Receiver

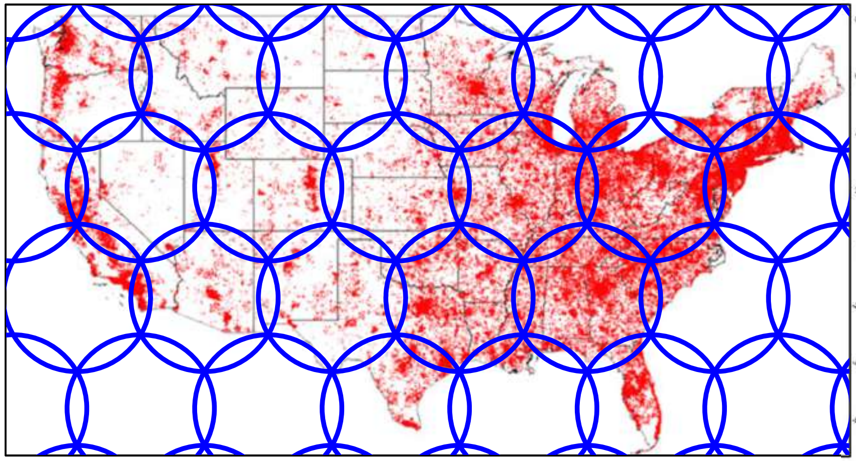


- J. Du, **Chunxiao Jiang**, H. Zhang, X. Wang, Y. Ren and M. Debbah, "Secure Satellite-Terrestrial Transmission Over Incumbent Terrestrial Networks via Cooperative Beamforming", *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 7, pp. 1367-1382, Jul. 2018.

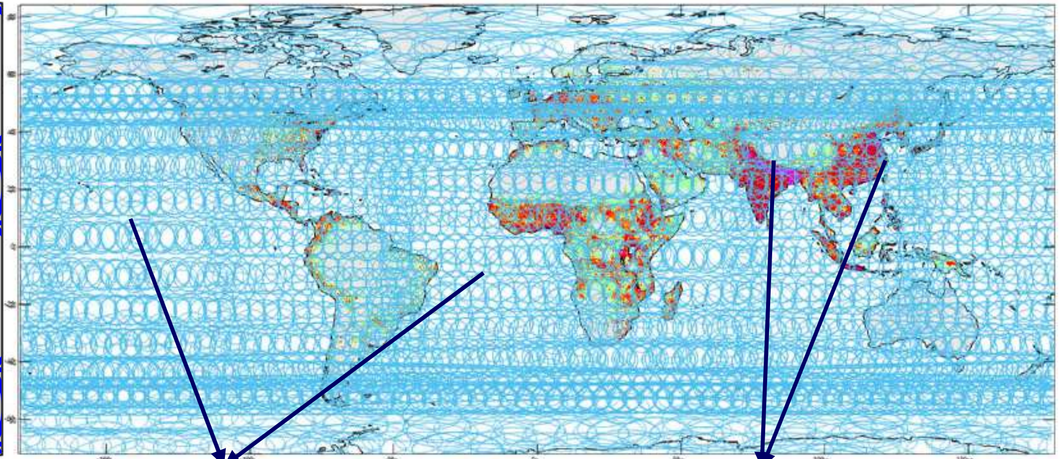
On-Demand Communication

Non-uniform distribution of wide-area satellite users

Distribution of ViaSat U.S. Subscribers



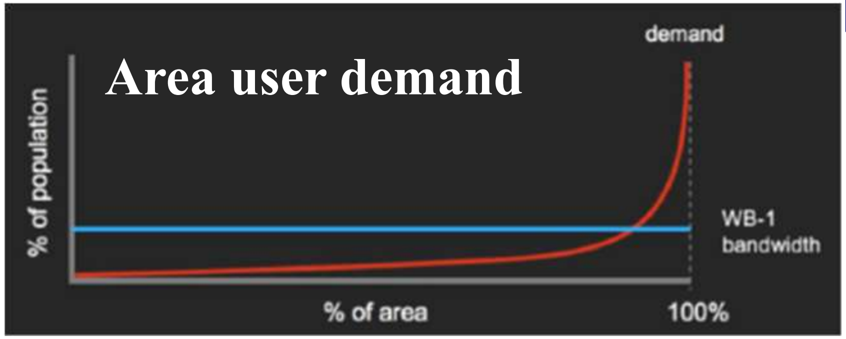
Non-uniform distribution of global population



Sea area accounts for 71%

90% people concentrate on 10% of land

Non-uniform user density



Satellite efficiency calculation [1] :

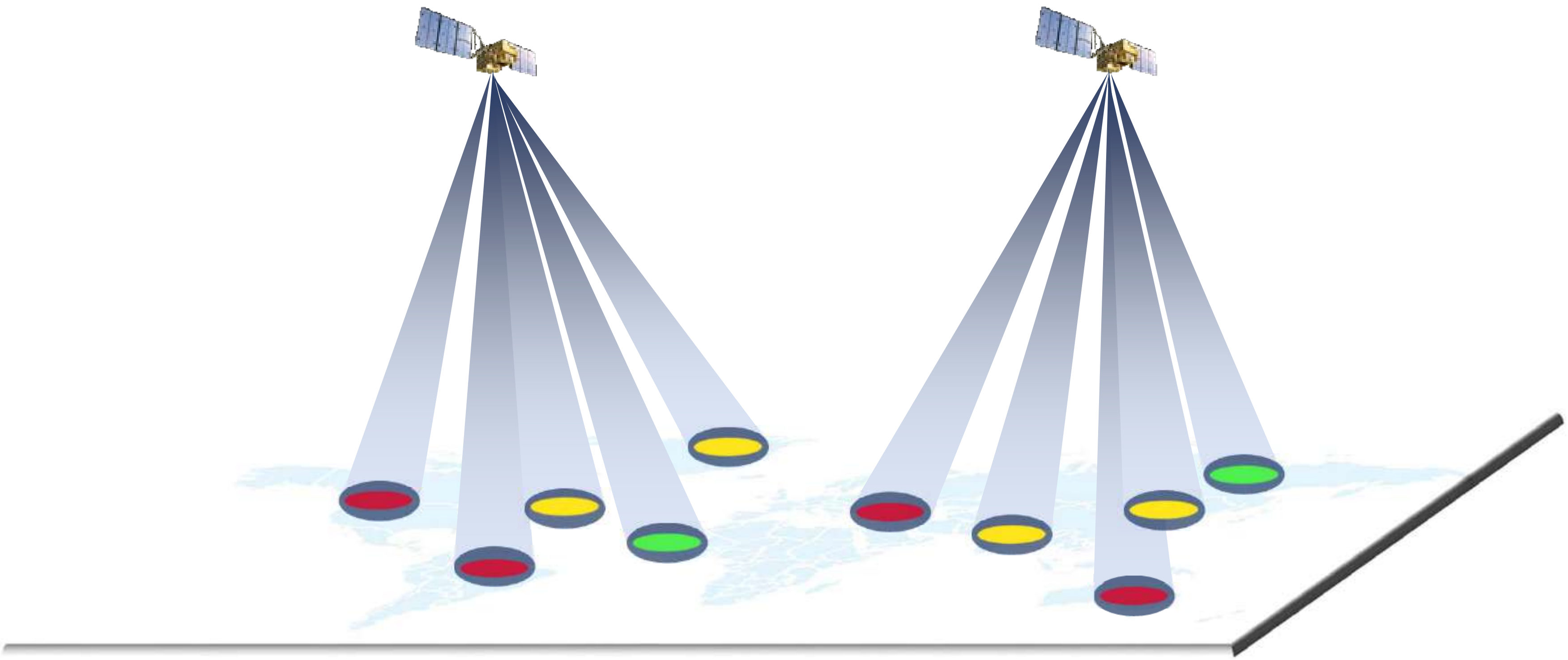
Starlink → 25.1%

[1] I. del Portillo, B.G. Cameron, E.F. Crawley, "A technical comparison of three low earth orbit satellite constellation systems to provide global broadband," in Acta Astronautica, vol. 159, pp. 123-135, Jun. 2019.

On-Demand Communication

Key idea:

Use limited resources to areas that need to be covered



- B. Deng, **Chunxiao Jiang**, J. Yan, N. Ge, S. Guo and S. Zhao, "Joint Multigroup Precoding and Resource Allocation in Integrated Terrestrial-Satellite Networks", *IEEE Transactions on Vehicular Technology*, vol. 68, no. 8, pp. 8075-8090, Aug. 2019.

On-Demand Communication

Key idea:

Use limited resources to areas that need to be covered

On-Demand Network	On-Demand Coverage	On-Demand Service
Design the network to adapt to the demands of users	Intelligent and accurate spot beams	Sophisticatedly differentiate the security level and priority
Network connection is reliable and controllable	Dynamic coverage driven by user demands	Provided services to users satisfying individual demands

On-demand communication is an effective way to improve resource utilization efficiency

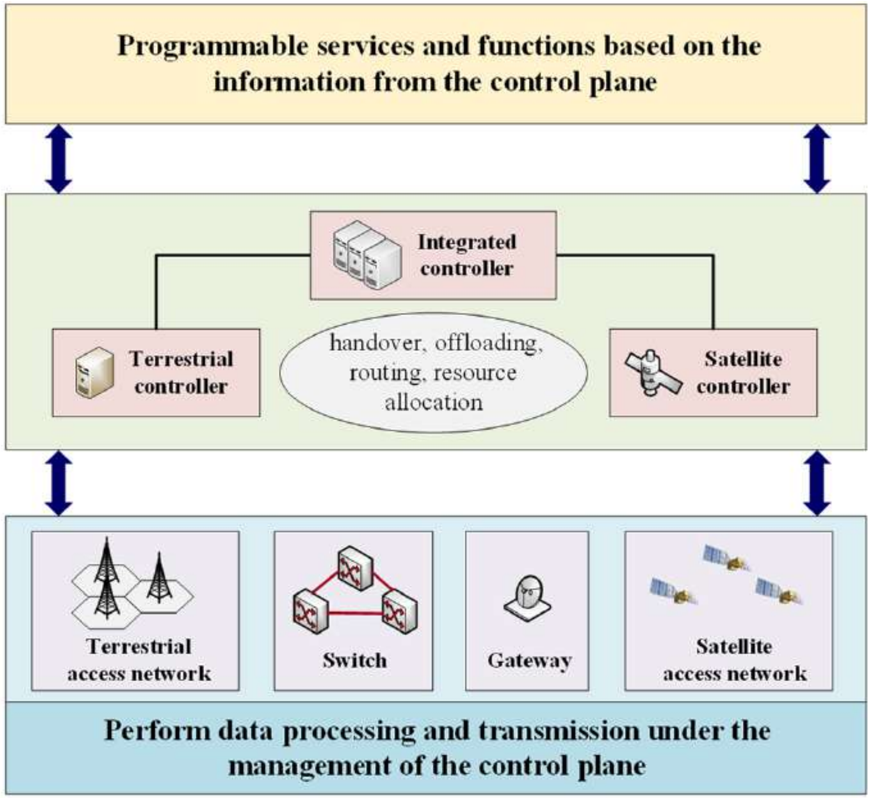
SDN

Software-Defined Networking (SDN) → **Enable efficient and intelligent network management**

Application Plane

Control Plane

Data Plane



→ **Programmable services and functions**

→ **Coexistence of Terrestrial Controller and Satellite controller: Overcome the Long Link delay**

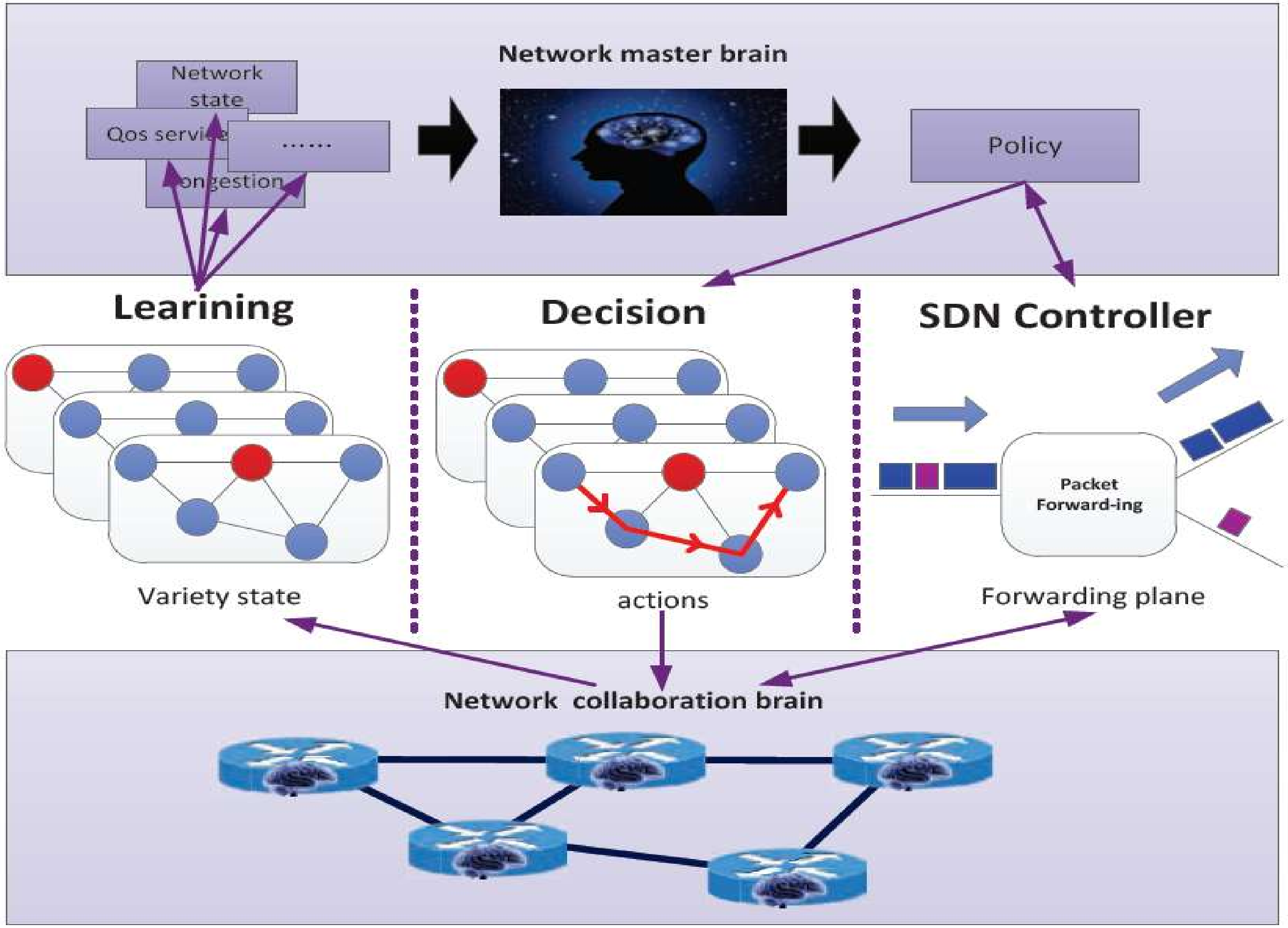
→ **Actual Infrastructure and Devices**

- J. Du, **Chunxiao Jiang**, H. Zhang, Y. Ren and M. Guizani, "Auction Design and Analysis for SDN-based Traffic Offloading in Hybrid Satellite-Terrestrial Networks", *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 10, pp. 2202-2217, Oct. 2018.

Artificial Intelligence

➢ **Reduce the Routing Delay**

High dynamics and delay of satellite links ➡ **Increase the routing delay**



Convolutional Neural Network (CNN)

⬇

Learn Traffic Patterns

⬇

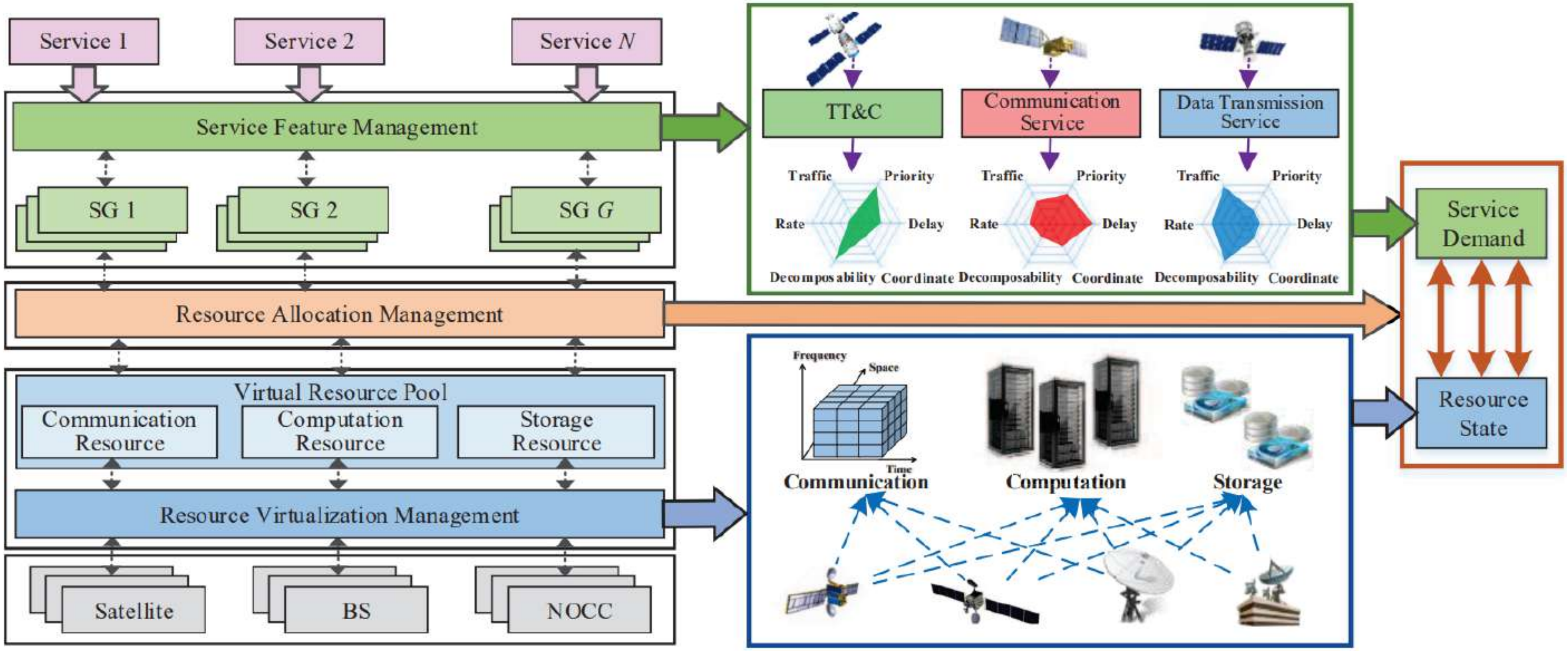
Design Routing Policy

⬇

Achieve Traffic Balance

Artificial Intelligence

➢ Intelligent Resource Allocation



Multi-objective Reinforcement Learning

Multiagent Reinforcement Learning

➡ **Strong ability in the optimal matching between resources and services**

- **Chunxiao Jiang**, H. Zhang, Y. Ren, Z. Han, K. Chen, and L. Hanzo, "Machine Learning Paradigms for Next-Generation Wireless Networks", IEEE Wireless Communications, vol. 24, no. 2, pp. 98-105, Apr. 2017.
- J. Wang, **Chunxiao Jiang**, H. Zhang, Y. Ren, K. -C. Chen, and L. Hanzo, "Thirty Years of Machine Learning: The Road to Pareto-Optimal Wireless Networks", IEEE Communications Surveys & Tutorials, vol. 22, no. 3, pp. 1472-1514, thirdquarter. 2020.
- J. Du, **Chunxiao Jiang**, J. Wang, Y. Ren and M. Debbah, "Machine Learning for 6G Wireless Networks: Carrying Forward Enhanced Bandwidth, Massive Access, and Ultrareliable/Low-Latency Service", IEEE Vehicular Technology Magazine, vol. 15, no. 4, pp. 122-134, Dec. 2020.

Publications

[1] X. Zhu, **Chunxiao Jiang**, L. Kuang, Z. Zhao, and S. Guo, "Two-Layer Game Based Resource Allocation in Cloud Based Integrated Terrestrial-Satellite Networks", *IEEE Transactions on Cognitive Communications and Networking*, vol. 6, no. 2, pp. 509-522, Jun. 2020.

[2] Y. Zhang, L. Yin, **Chunxiao Jiang**, and Y. Qian, "Joint Beamforming Design and Resource Allocation for Terrestrial-Satellite Cooperation System", *IEEE Transactions on Communications*, vol. 68, no. 2, pp. 778-791, Feb. 2020.

[3] B. Deng, **Chunxiao Jiang**, J. Yan, N. Ge, S. Guo and S. Zhao, "Joint Multigroup Precoding and Resource Allocation in Integrated Terrestrial-Satellite Networks", *IEEE Transactions on Vehicular Technology*, vol. 68, no. 8, pp. 8075-8090, Aug. 2019.

[4] X. Zhu, **Chunxiao Jiang**, L. Kuang, N. Ge, S. Guo, and J. Lu, "Cooperative Transmission in Integrated Terrestrial-Satellite Networks", *IEEE Network*, vol. 33, no. 3, pp. 204-210, Jun. 2019.

[5] J. Du, **Chunxiao Jiang**, H. Zhang, Y. Ren and M. Guizani, "Auction Design and Analysis for SDN-based Traffic Offloading in Hybrid Satellite-Terrestrial Networks", *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 10, pp. 2202-2217, Oct. 2018.

[6] J. Du, **Chunxiao Jiang**, H. Zhang, X. Wang, Y. Ren and M. Debbah, "Secure Satellite-Terrestrial Transmission Over Incumbent Terrestrial Networks via Cooperative Beamforming", *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 7, pp. 1367-1382, Jul. 2018.

Publications

[7] X. Zhu, **Chunxiao Jiang**, L. Yin, L. Kuang, N. Ge and J. Lu, "Cooperative Multigroup Multicast Transmission in Integrated Terrestrial-Satellite Networks", *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 5, pp. 981-992, May. 2018.

[8] X. Zhu, **Chunxiao Jiang**, L. Kuang, N. Ge and J. Lu, "Non-orthogonal Multiple Access Based Integrated Terrestrial-Satellite Networks", *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2253-2267, Oct. 2017.

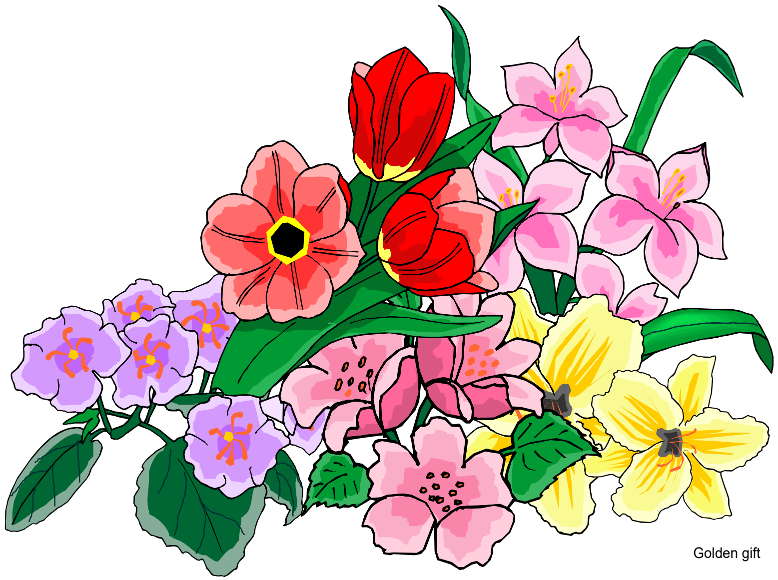
[9] L. Kuang, X. Chen, **Chunxiao Jiang**, H. Zhang, and S. Wu, "Radio Resource Management in Future Terrestrial-Satellite Communication Networks", *IEEE Wireless Communications*, vol. 24, no. 5, pp. 81-87, Oct. 2017.

[10] **Chunxiao Jiang**, H. Zhang, Y. Ren, Z. Han, K. Chen, and L. Hanzo, "Machine Learning Paradigms for Next-Generation Wireless Networks", *IEEE Wireless Communications*, vol. 24, no. 2, pp. 98-105, Apr. 2017.

[11] J. Wang, **Chunxiao Jiang**, H. Zhang, Y. Ren, K. -C. Chen, and L. Hanzo, "Thirty Years of Machine Learning: The Road to Pareto-Optimal Wireless Networks", *IEEE Communications Surveys & Tutorials*, vol. 22, no. 3, pp. 1472-1514, thirdquarter. 2020.

[12] J. Du, **Chunxiao Jiang**, J. Wang, Y. Ren and M. Debbah, "Machine Learning for 6G Wireless Networks: Carrying Forward Enhanced Bandwidth, Massive Access, and Ultrareliable/Low-Latency Service", *IEEE Vehicular Technology Magazine*, vol. 15, no. 4, pp. 122-134, Dec. 2020.

Thank you!



Golden gift