Panel Contributors

Chair

Brian Kelley, University of Texas at San Antonio, USA

Panelists

Eugen Borcoci, University POLITEHNICA Bucharest, Romania
Dirceu Cavendish, Kyushu Institute of Technology USA/Japan
Lin Han, Futurewei Technologies, USA
Zhicheng Yang, PingAn Tech, US Research Lab, USA

- Extreme capacity xHaul
- Extended Reality (XR)
- Autonomous vehicle mobility & Smart transportation
- Device-to-device communications
- Connectivity to remote areas
- Integrating intelligence in the network
- eHealth
- Industry 4.0 and robotics

Challenges & questions for discussion
Starting points for the panelists

Brian Kelley, University of Texas at San Antonio, USA

What does security at the network edge look like and how do we insure ultra-reliability and resiliency? Is wireless an extension of the wired Internet or is the Internet an increasingly and extension of wireless?

Eugen Borcoci, University POLITEHNICA Bucharest, Romania

What are the challenges for Edge, Fog, and cloud computing in the context of 6G?

Dirceu Cavendish, Kyushu Institute of Technology USA/Japan

What challenges do strong security and privacy regulations pose in medical devices?

Lin Han, Futurewei Technologies, USA

New Spectrum is not a panacea. Why is wireless technology not enough? Are we reaching the technical ceiling for Internet?

Zhicheng Yang, PingAn Tech, US Research Lab, USA

Challenges of mobility and human blockage of 60 GHz millimeter-wave networks. Are these challenges under control?

Topics from the panelists

Brian Kelley, University of Texas at San Antonio, USA
Security at Layer 1 of the protocol stack

Eugen Borcoci, University POLITEHNICA Bucharest, Romania
Elements of Network Slicing and fox/edge computing in the 6G context

Dirceu Cavendish, Kyushu Institute of Technology USA/Japan
Medical devices hacking (and ransomware) may prevent the adoption of advanced medical systems

Lin Han, Futurewei Technologies, USA
The Future Internet will consist of a combination of terrestrial networks + non-terrestrial networks + services beyond best-effort

Zhicheng Yang, PingAn Tech, US Research Lab, USA
Vital sign and sleep monitoring in healthcare and estimating sugar content of fruits in smart agriculture through millimeter-wave sensing

Panellist Position

Communications of the Future: Hot Topics in Internet

Prof. Brian Kelley
JBSA 5G Program Management Office
Associate Profess of ECE. University of Texas at San Antonio, USA, Brian.Kelley@utsa.edu

- Network-Slicing-as-a-Service
- High Performance Computing at the Edge
- Mobile Internet as a Service
- Mobile Services as an Application
- Mobile 6G versus Wired Internet

→ Autonomous vehicle will revolutionize society

→ Transformation in robotics and intelligent automation lead to Industry 4.0

→ Combined low latency and security enabling safe telepresence

Panellist Position

6G - Enabling Technologies for Advanced Network Architectures

Eugen BORCOCI, Eugen Borcoci, University POLITEHNICA Bucharest, Romania

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- General architectural concepts
- Network slicing in 6G context
- Software Defined Networking and Network Function Virtualization (SDN/NFV)
- Service Based Architectures (SBA)
- Cognitive Service Architectures (CSA)
- Cell-free (CF) Architectures
- Cloud/fog /edge computing

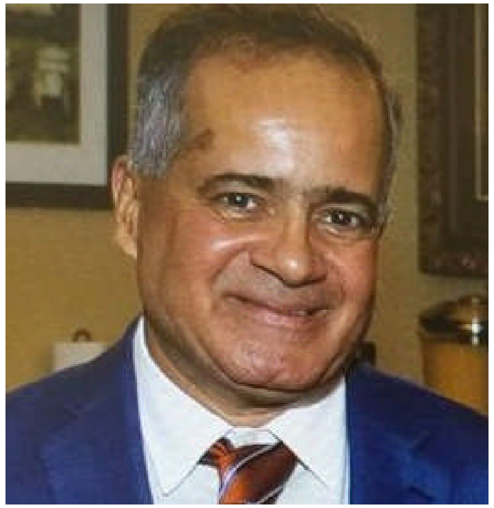
INTERNET Experts Panel
Communications of the Future: Hot Topics in Internet
((speed, 5G/6G, streaming, mmwave networks; network slicing, high data processing, industrial protocols, mobility, security, monitoring etc.)

InfoWare 2021

Panellist Position

Security/Privacy in IoT Medical Devices

Dirceu Cavendish, Kyushu Institute of Technology USA/Japan cavendish@ndrc.kyutech.ac.jp



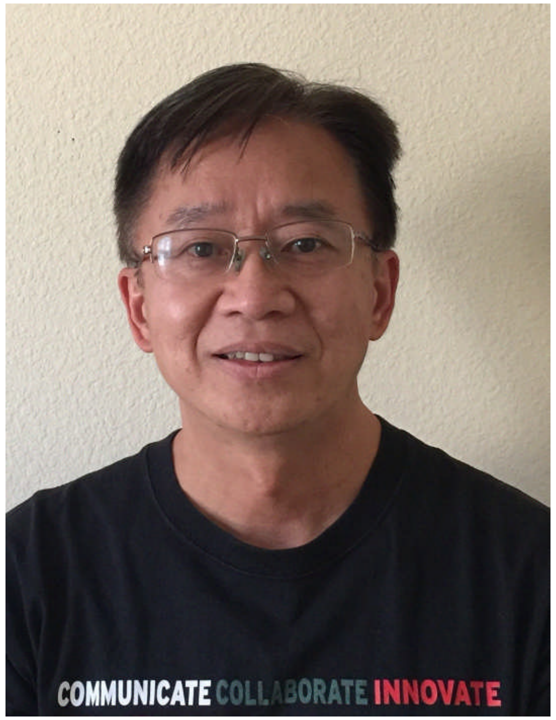
- 5G networking
- IoT Medical Systems
- Security in IoT Medical Systems
- Medical IoT Privacy Regulations
- Privacy Challenges

→ Deep personal data mining is coming

→ Strong Security/Privacy regulations in Medical Devices raise challenges

→ Medical devices hacking (and ransomware) may prevent the adoption of advanced medical systems

Panellist Position



Future Internet: Challenges and Potential Technology

Lin Han, Futurewei Technologies, USA, lin.han@futurewei.com

- Are we reaching the technical ceiling for Internet?
- Forever topics: Better service and More coverage
- Traditional technologies vs Emerging technologies

→ New Spectrum is not panacea; Wireless is not enough

→ Emerging Technologies are needed for Services beyond Best-Effort and Super coverage

→ Future Internet: Terrestrial network + Non-terrestrial network + Services beyond Best-Effort

Panellist Position

Managing Fleets of Drones and Driverless Cars

Zhicheng Yang; Senior Research Scientist; PingAn Tech, US Research Lab, USA zcyangpingan@gmail.com

- Challenges of 60 GHz mmWave networks
  - Human Blockage
    - 60 GHz access point deployment
  - Node Mobility
    - 60 GHz phased array codebook design
- Applications of 60 GHz mmWave sensing
  - Healthcare
    - Vital sign and sleep monitoring
  - Smart Agriculture
    - Estimation of sugar content in fruits

Panellist Position

6G - Enabling Technologies for Advanced Network Architectures

Eugen Borcoci, University POLITEHNICA Bucharest, Romania

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- **6G Vision**
- **General architectural concepts**
- **Software Defined Networking and Network Function Virtualization (SDN/NFV)**
- **Network slicing in 6G context**
- **Service Based Architectures (SBA)**
- **Cognitive Service Architectures (CSA)**
- **Cell-free (CF) Architectures**
- **Cloud/fog /edge computing**
- **Conclusions**

- **Eugen Borcoci : professor**
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  - **Electronics, Telecommunications and Information Technology Faculty**
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  - **E- mail address: eugen.borcoci@elcom.pub.ro**
- **Expertise:** teaching and research in specific domains of telecommunications and computer networks architectures, technologies and services:
  - network architectures and services, management/control/data plane, protocols, 4G/5G, QoS assurance, multicast and multimedia services over IP networks and heterogeneous access
- **Recent research interest :** Software Defined Networking (SDN), Network Function Virtualization (NFV), Fog/edge computing, 5G/6G networking and slicing, vehicular communications
- Publications: 6 books, 4 textbooks and over 200 scientific or technical papers and scientific reports.
- UPB team leader in many national and int'l European research projects

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- **6G Vision**

Why 6G?

- **Today- 5G is a strong technology intensively developed; however, it has limitations, w.r.t. future needs**

- ***6G Vision for 2030: the society will be data driven, served by near instant, unlimited wireless connectivity***
  - **6G goals:**
    - meet **novel network demands** (e.g., ultra-high reliability, high capacity and efficiency, and low latency) in a holistic fashion, answering the new needs of economic, social, technological, and environmental context of the 2030 era
    - **integration** of the space, aerial, terrestrial, and maritime communications into a robust network
    - **large range of applications and services**:
      - AR/VR, Holographic tele-presence (teleportation), eHealth, pervasive connectivity, Industry 4.0 and robotics, unmanned mobility, new devices replacing smart phones
      - Telepresence -high resolution imaging and sensing, wearable displays, mobile robots and drones, specialized processors, distributed AI, haptic communication
      - Autonomous connected vehicles, massive URLLC (mURLLC), human-centric services, bio-Internet of Things (B-IoT), nano-Internet of things (N-IoT), mobile broadband reliable and low-latency communication **-**

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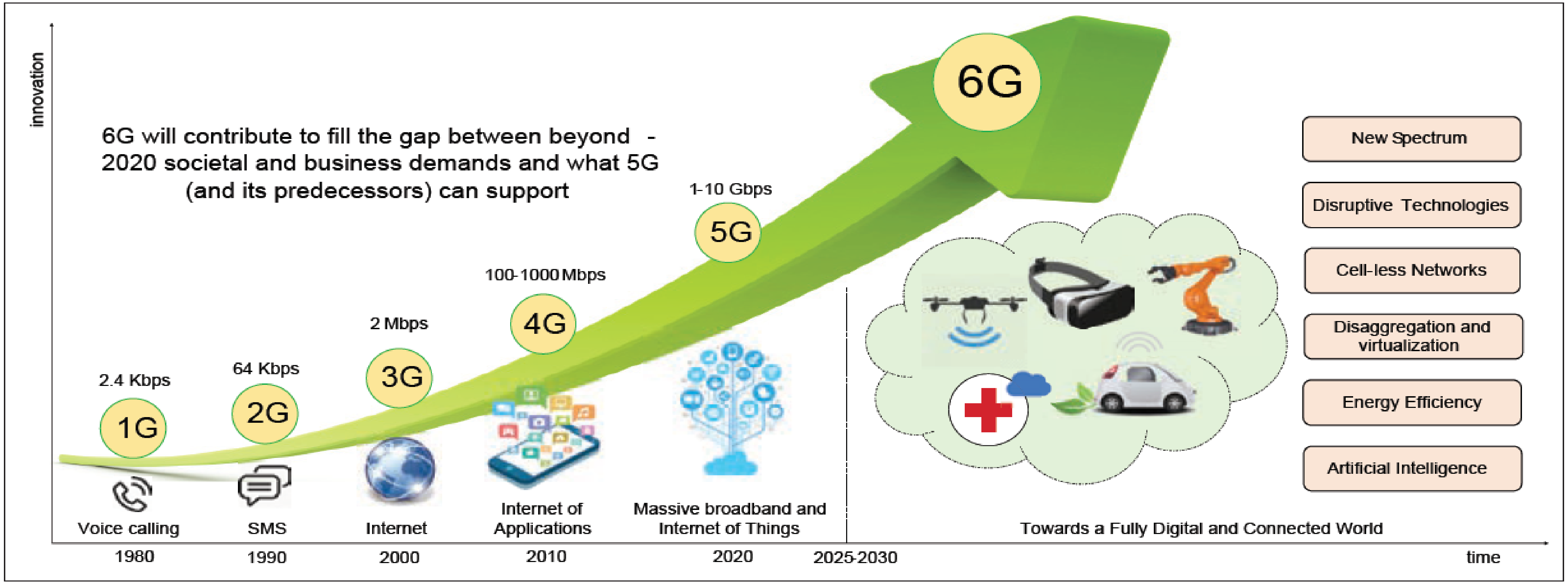
- **General architectural concepts**
  - **1G ….6G evolution**



Source: M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

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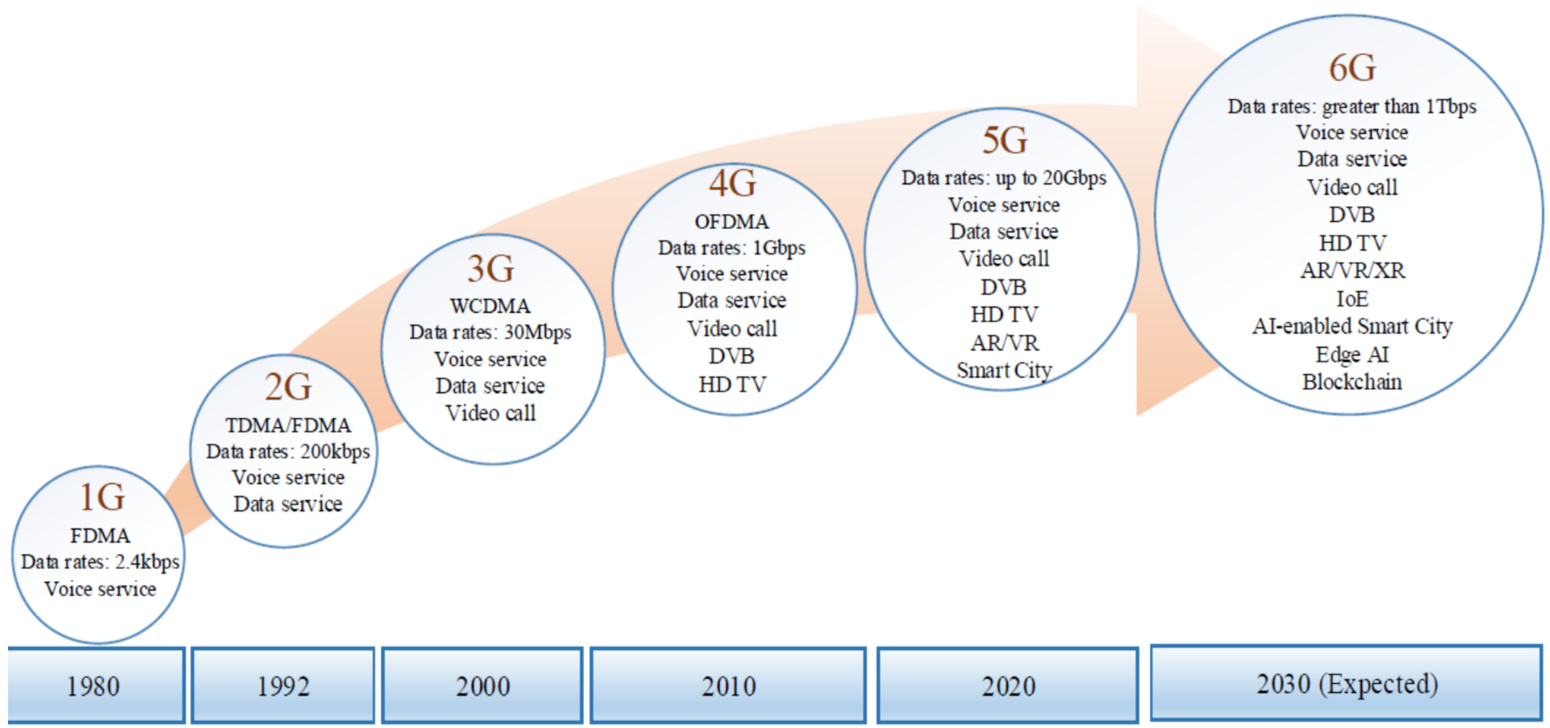
- **General architectural concepts**
- **1G..6G evolution**

Parameter	5G	6G
Peak data rate	10 – 20 Gb/s	> 1Tbps
Spectrum efficiency	3 ∼ 5x relative to 4G	> 3x relative to 5G
Receiver sensitivity	About −120dBm	< −130dBm
Latency	ms level	< 1ms
Mobility	350 km/h	>1000km/h
Traffic density	$10Tb/s/km^2$	$>100Tb/s/km^2$
Energy efficiency	1000x relative to 4G	10x relative to 5G
Processing delay	100ns	10ns
End-to-end reliability requirements	99.999 percent	99.99999 percent
Radio only delay requirements	100ns	10ns



Source: L.U. Khan, et al., "6G Wireless Systems: A Vision,Architectural Elements, and Future Directions", 10.1109/ACCESS.2020.3015289, IEEE Access, 2020, https://www.researchgate.net/publication/343565534

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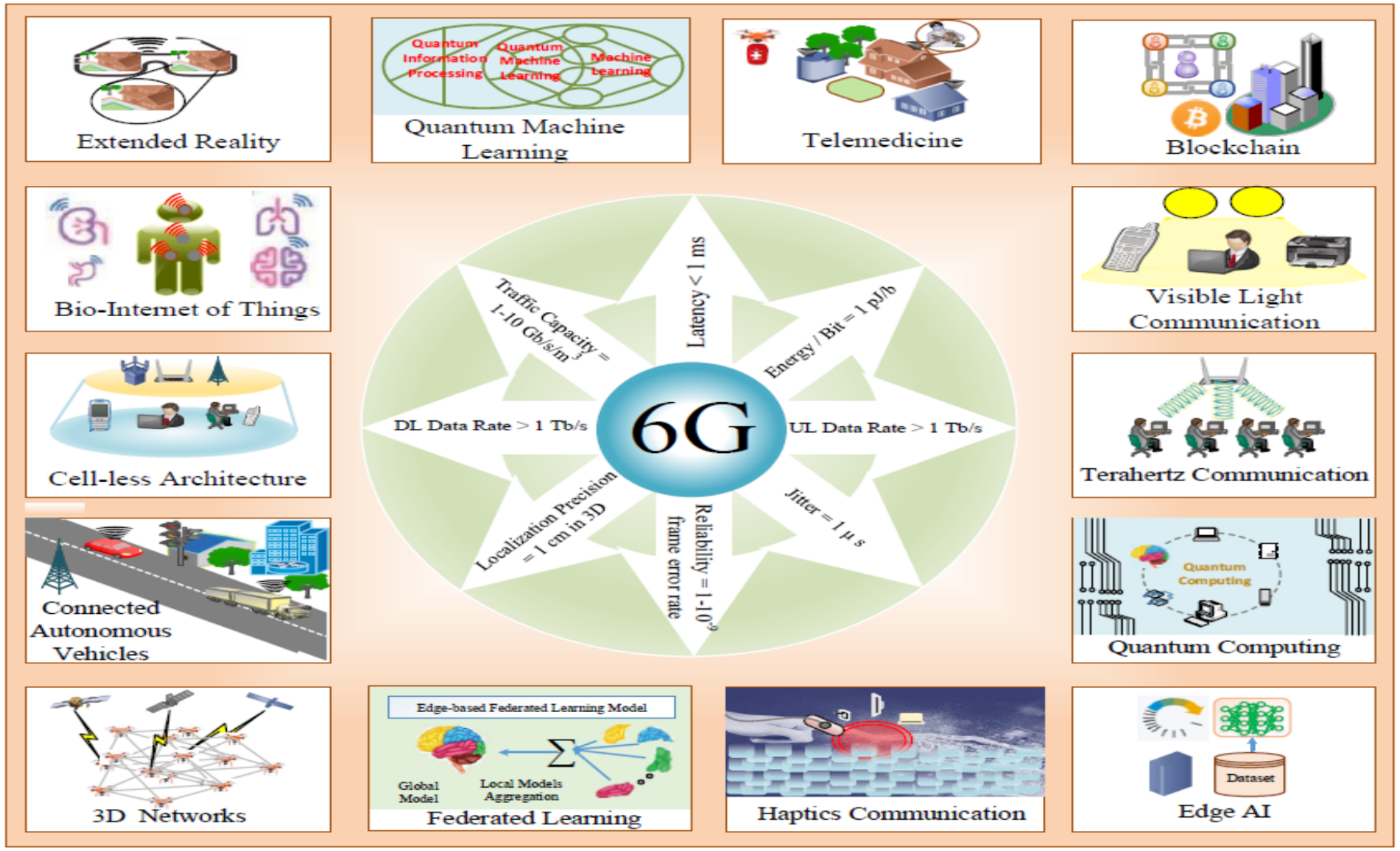
- **General architectural concepts**
  - **Overview of 6G system**
    - key requirements:
    - capacity, UL/DL data rate
    - localization precision, reliability
    - latency, jitter, energy per bit
  - **Several enabling technologies**
    - Machine learning (quantum), federated learning
    - Computing (quantum)
    - 3D networking
    - Edge Artificial Intelligence
    - Cell-less architecture
    - Blockchain
    - Haptic communication
    - Terahertz communication
  - **Use cases – examples**
    - Connected autonomous vehicles
    - Telemedicine
    - Extended reality
    - Internet of Things



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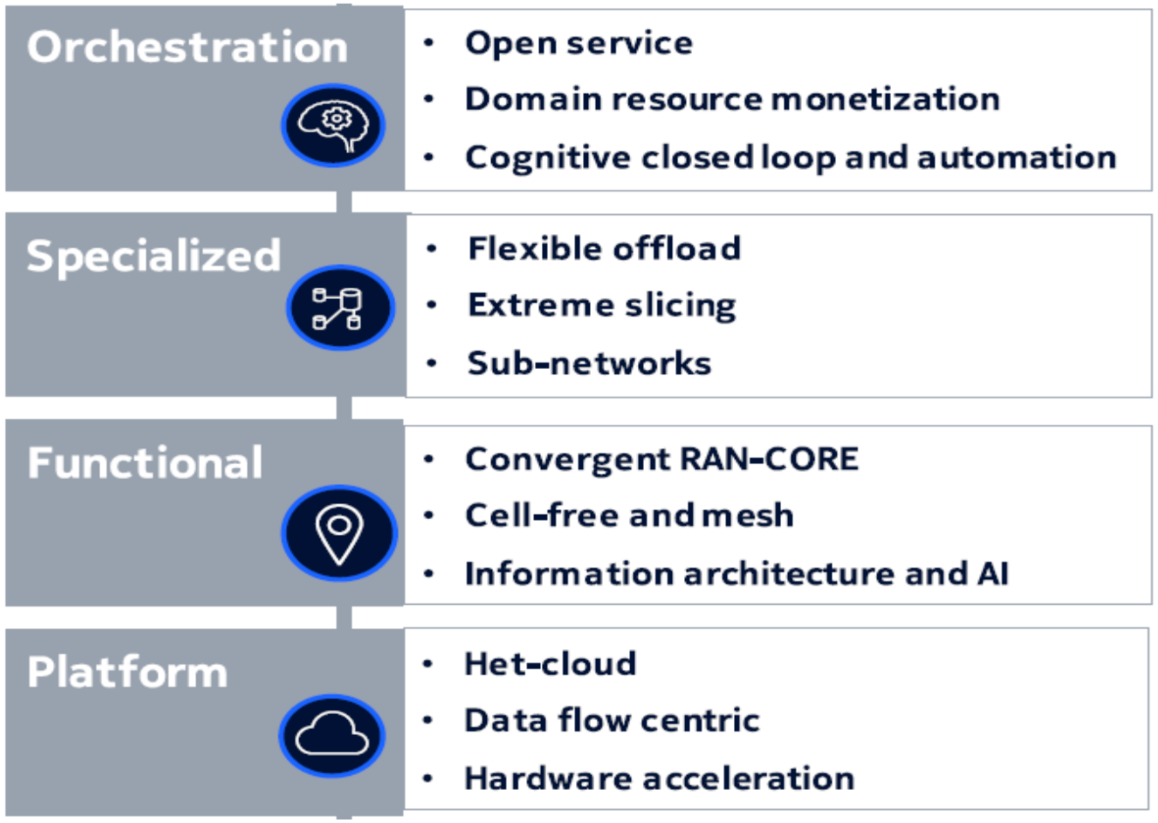
- General architectural concepts
- 6G Architectural framework – building blocks example
- Four major interworking components, to provide an open and distributed reference framework

- Platform infrastructure:
  - "het-cloud", open, scalable and agnostic run-time environment
  - data flow centricity, hardware acceleration
- Functions (functional architecture)
  - RAN- CORE convergence
  - cell free and mesh connectivity
  - information architecture and AI

- Specialized networks and architectural enablers for
  - flexible off-load, extreme slicing, sub-networks

- Orchestration component
  - assures open service enabling and ecosystem play
  - domain resource monetization
  - cognitive closed loop and automation



Source: V.Ziegler et al., "6G Architecture to Connect the Worlds", IEEE Access, Sept 2020, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9200631

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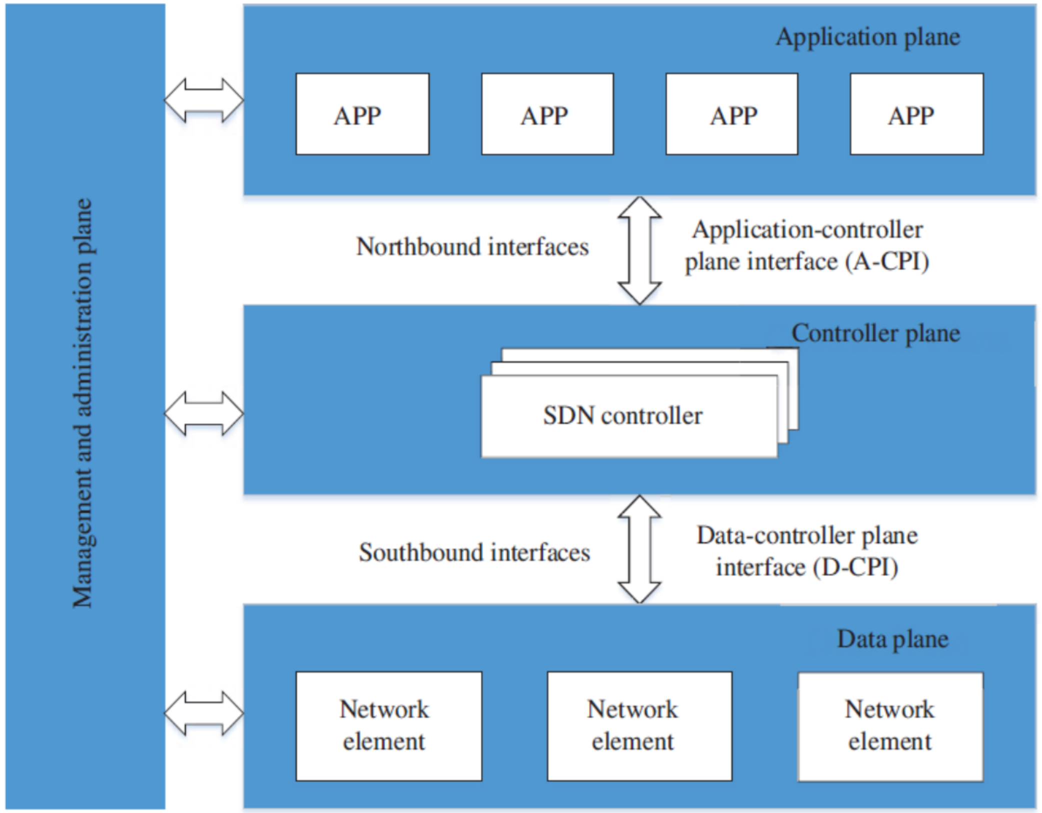
- **Software Defined Networking (SDN) and Network Function Virtualization (NFV) in 6G**
- **SDN high level architectural view**
  - **SDN provides the flexibility to program the network**
  - **It separates the Control plane (CPl) and the Data plane (DPl)**
  - **CPl function is logically centralized (SDN controllers)**
  - **DPl – distributed, (network nodes) but abstracted for network apps. and services requesting, through the SDN controllers**



- **Functional Architecture: four planes**
  - data plane
  - controller plane
  - application plane
  - management and administration plane

Source: Open Networking Foundation. SDN architecture overview. https://www.opennetworking.org/images/stories/downloads/sdn-resources/technical-reports/SDN-architecture-overview-1.0.pdf

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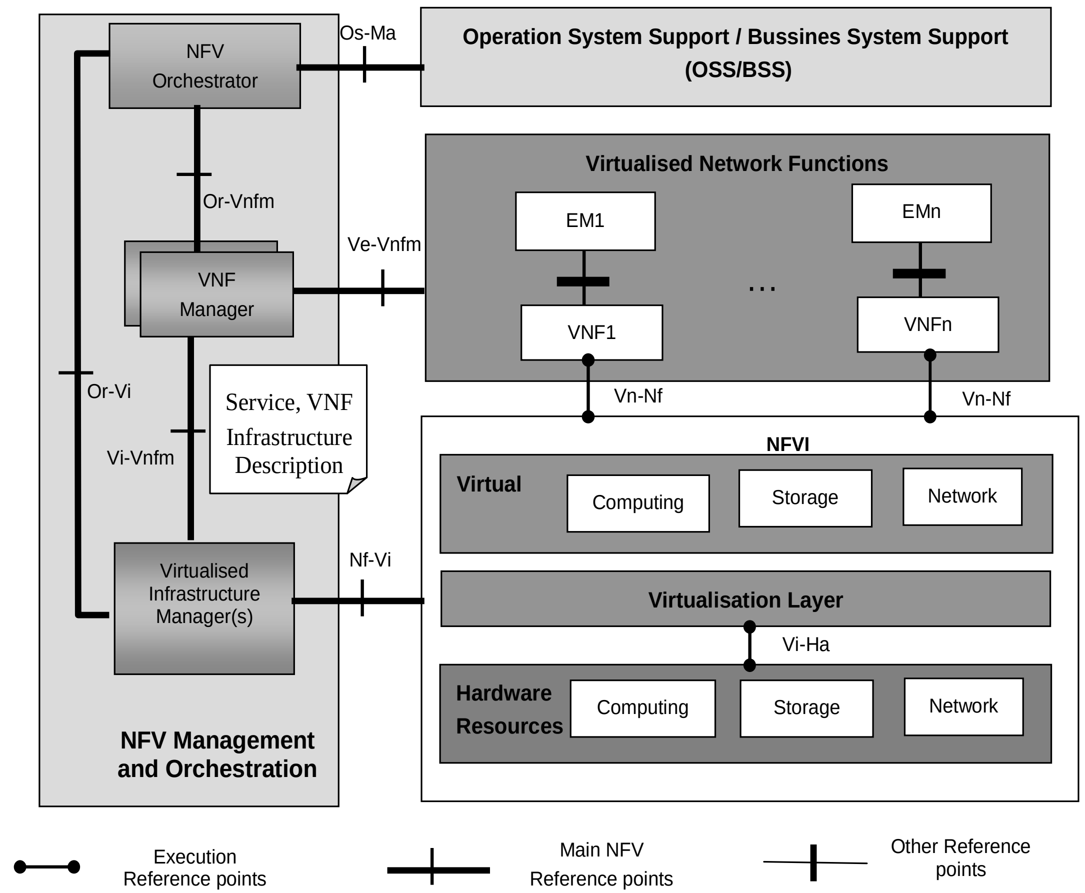
- **Software Defined Networking (SDN) and Network Function Virtualization (NFV)**
- **NFV high level architectural view**

- **Working domains**
  - **Virtualized Network Functions (VNF)**
    as the SW implementation of a NF
  - **NFV Infrastructure (NFVI)** includes the PHY resources and how these can be virtualized
    NFVI supports the execution of the VNFs
  - **NFV Management and Orchestration (NFV-MANO)**
    - orchestration and lifecycle management of physical and/or SW resources
    - NFV MANO focuses on all virtualization-specific management tasks



Source: ETSI GS NFV 002 v1.2.1 2014-12, NFV Architectural Framework

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- **Software Defined Networking and Network Function Virtualization (SDN/NFV) in 6G**

- **SDN and NFV cooperation in 6G**
  - **Hybrid SDN - concept**
    - both centralized and decentralized paradigms coexist and communicate together to different degrees to configure, control, change, and manage network behavior for optimizing network performance and user experience
    - the effective management of heterogeneous paradigms and interaction between several networks is important
    - introduction of AI allows increased automation of SDN networks
  - **NFV**
    - is a key enabler for 5G (virtualize the various appliances in the network, RAN, Core)
    - provide infrastructure for network slicing (multiple virtual networks to support different RANs or various services)
    - enable the 5G networks to support serviced-based architecture by dynamically creating **service chains**
    - makes the 5G networks elastic and scalable, improves the agility and simplifies the management

    - **All the above NFV features are also valid in 6G**

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- **Software Defined Networking and Network Function Virtualization (SDN/NFV) in 6G**

- **SDN and NFV cooperation in 6G**

- M&O of SDN and NFV is still an open challenge in 5G and 6G
  - Complexity, reliability, security, multi-operator, multi-domain and multi-tenant issues
  - The management responsibility for the various parts of the network and service provisioning is well defined in the SDN and NFV
    - however, the M&O complexity will increase: the separation of control and management, multivendor system needs, improved functionalities desired, real-time resources allocation, dynamic network conditions, and network slicing
  - The network may have unexpected and unforeseen type of failures → increased complexity of the M&O
  - SDN and NFV face issues in terms of reliability and security
  - The 5G and 6G network is multi-tenant, where network operators and service providers share the same physical infrastructure
    - the network M&O must deal with the corresponding multitenant issues

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- **Network slicing in 6G context**

- **General network slicing concepts**:
  - **E2E concept** covers all network segments: radio, wire access, core, transport, and edge networks
  - **concurrent deployment of multiple E2E logical, self-contained and independent shared or partitioned networks** on a common infrastructure platform
  - **Slices**
    - created **on demand**, running on a common underlying (PHY/V) network, mutually isolated with independent M&C
    - **composition** of adequately configured NFs, network apps, and the underlying cloud infrastructure (PHY/virtual/ emulated resources, etc.)
    - **resources are bundled together** to meet specific UC reqs. (e.g., bandwidth, latency, processing, resiliency) coupled with a business purpose
- **SDN and NFV** – support technologies providing virtualisation, programmability, flexibility, and modularity to create **multiple network slices** each tailored for a given UC

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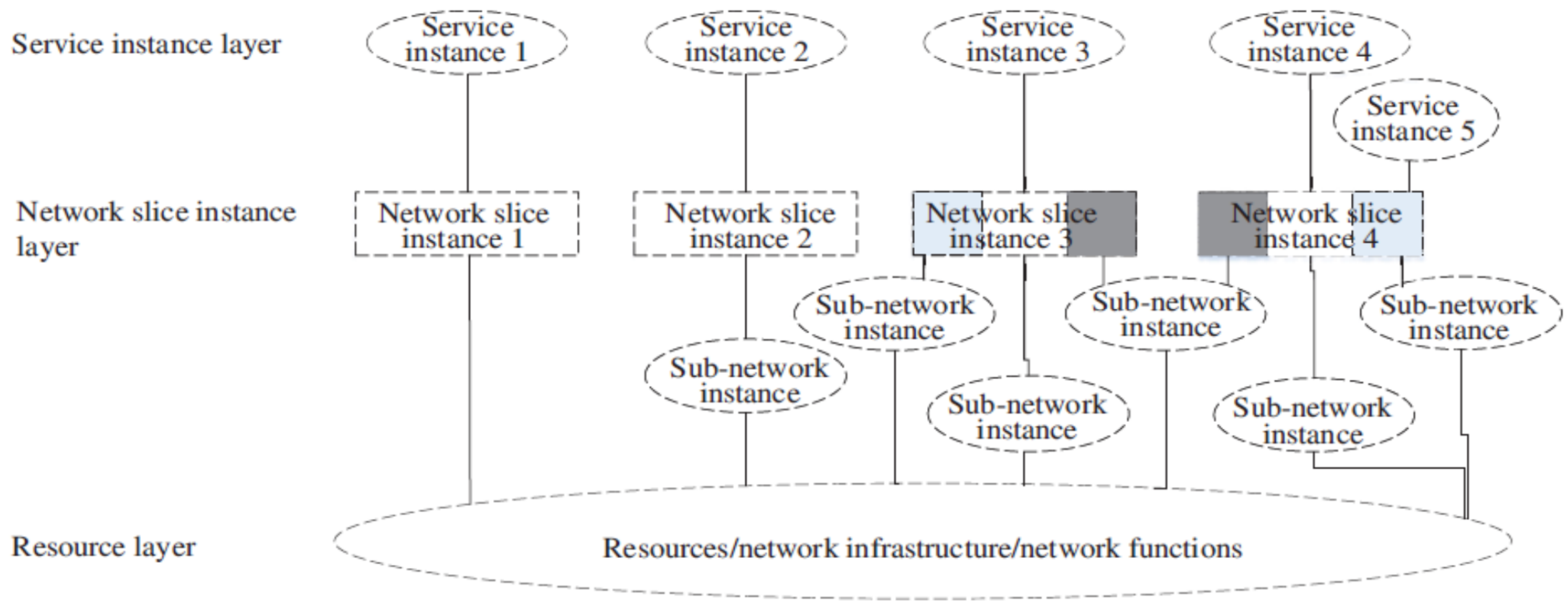
- **Network slicing in 6G context** (cont'd)
- **General network slicing concepts**



Source: NGMN Alliance. Description of Network Slicing Concept, NGMN 5G P1 Requirements & Architecture, Work Stream End to-End Architecture, Version 1.0. 2016

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- **Network slicing in 6G context** (cont'd)

- **Additional challenges for Network slicing in 6G**
  - **(1) Slice isolation- important property of network slicing**
    - to guarantee the service quality of each slice: different areas of isolation should be realized, including traffic, bandwidth, processing, and storage
    - the main challenge is the M&C ; it needs to accommodate different isolation techniques in different domains
    - there is not yet a final standardized network slice architecture
    - the isolation techniques significantly rely on the SDN and NFV technologies, which are not yet fully mature
  - **(2) Dynamic slice creation and management**
    - efficient dynamic slice creation and deletion is necessary
    - challenge to create or delete slices ; it must have no effect on the currently running slices, which involves the isolation and security issues
    - the network slices should be able to scale dynamically with the varying load
    - efficient sharing is needed → issues like isolation and security
    - the lifecycle management (LCM) of network slices is a critical problem
    - LCM in multi domain, multi-tenant and multi-operator environment is still a challenge

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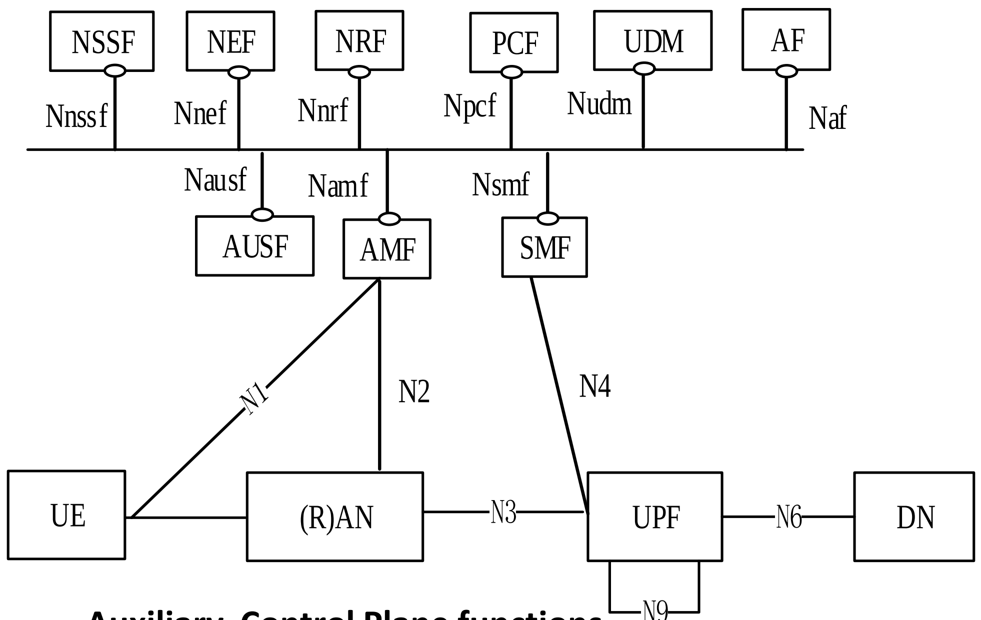
- **Service Based Architecture (SBA) - 3GPP 5G functional architecture**
  - **Non-roaming reference arch. Service-based interfaces are used within the Control Plane**



Source: 3GPP TS 23.501 V15.2.0 (2018-06), System Architecture for the 5G System; Stage 2, (Release 15)

Notations:
Data Path

UE User Equipment
(R)AN (Radio) Access Network
UPF User Plane Function
DN Data Network e.g., operator services, Internet access or 3rd party services

Control Plane
Main Control Plane functions

AUSF Authentication Server Function
AMF Access and Mobility Mgmt. Function
SMF Session Management Function

Auxiliary Control Plane functions

UDSF Unstructured Data Storage Function
NEF Network Exposure Function NRF Network Repository Function NSSF Network Slice Selection Function
PCF Policy Control Function UDF Unified Data Management UDR Unified Data Repository
SEPP Security Edge Protection Proxy NWDAF Network Data Analytics Function

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- **Service Based Architecture (SBA) - usage in 6G**
  - The SBA is based on: cloud computing, virtualization, microservice, stateless service, etc.
    - Cloud computing provides on-demand computing to the SBA
    - Virtualization realizes more flexible and efficient resource management and usability
    - Microservice is an emerging and useful architectural design pattern, where the network is divided into small-granularity, highly cohesive, and loosely coupled services
      - Each service can realize a specific functionality
      - A microservice can enable the SBA with flexibility, granularity, and independent scaling
  - **SBA challenges in 5G and 6G**
    - The SBA enables network functions of the SBA to securely communicate within the serving network domain and with other network domains
      - E.g., for: network function registration, discovery and authorization security aspects, and protection for service-based interfaces
    - SBA domain security is a new security feature in 5G and 6G
    - To ensure security between UEs in the SBA, security mechanisms such as transport layer security and open authorization are needed

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- **Cognitive Service Architectures (CSA)**
  - The SBA of 5G core network is based on coarse-grained configuration
    - It lacks real-time perception and dynamic adaptation to the change of service demand
  - The SBA of 6G core network should be significant **cognitive function**, i.e., CSA.
  - **CSA features**
    - it can accurately recognize target behaviors, scene semantics, and user characteristics
    - it can adaptively adjust the network services and dynamically through the unified service description method
  - **Needed: a cognitive interface, a lightweight learning agent, and a distributed service analyzing module**
    - The cognitive interface, supports the ability of situation cognition and can perceive the change of service demand in a fine-grained way
    - The lightweight learning agent makes the decision according to gained information by rule matching or approximate reasoning
    - Simultaneously, the distributed service analyzing module evaluates the service running state and provides a reference for the decision making of a lightweight learning agent
  - CSA implements a **complete cognitive closed loop of perception, decision-making, and evaluation**
  - **CSA can get strong support from AI**

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- **Cognitive Service Architectures (CSA)** (cont'd)
  - **6G core network functions will further sink to the edge of the network (i.e., edge core)**
  - 6G core network (CN) will leverage edge computing to form a multi-center architecture to provide efficient, flexible, ultra-low delay, and ultra-large capacity network services
  - The original 5G CN running in the cloud will no longer directly participate in the control of the network
    - It just helps edge cores to communicate with each other
    - The network response delay is reduced
    - The flexibility of network management is improved
    - The CSA will realize the whole network coverage from the core network to the UE
      - So, the UE can adopt a variety of communication modes and can switch seamlessly if needed
      - Edge core supports service adaptation, migration, collaboration, and evolution through distributed service agents running in edge core
  - Edge core discovers migration requirements and completes migration decisions through service cognition and invokes various modules through the north interface of the network layer to realize various processes such as state data transmission, cell handover, and user session switching
  - The whole process ensures low delay and transparency for users

Source: X. You, et al., "Towards 6G wireless communication networks: vision, enabling technologies, and new paradigm shifts":, SCIENCE CHINA, Information Sciences, January 2021, Vol. 64 110301:1–110301:74, https://doi.org/10.1007/s11432-020-2955-6

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- **Cell-free (CF) Architectures- why cell free?**
  - A cellular topology limitation : **boundary effect-** the users at the cell boundary receive weak signal (due to path loss) and experience strong interference from other cells (that was acceptable in the past and current mobile networks)
  - In beyond **5G and 6G systems**, the **high data rate** demand causes **ultra-densified and heterogeneous BSs/APs deployment**
  - The cell coverage is smaller and the distance between BSs/APs is ~ tens of meters
  - Such **densification → more interference**; the boundary effect is a main bottleneck of cellular systems; it cannot be solved by any technology
  - Despite techniques as MIMO, CoMP with joint transmission and distributed antenna systems, the ability to overcome this bottleneck is limited
  - **Possible solution:**
    - The CF (or cell-less) massive MIMO networks s a practical and scalable version of network MIMO (next slide figure)
    - many APs jointly serve many user terminals in the same time frequency resources
    - All APs are distributed in a large area (e.g., the whole city) and connected to one or several CPUs.
    - In such a network, a terminal can decide to access several BSs/APs via different Uls and DLs and downlinks depending on the wireless channel status and its demands.
    - The BSs/APs do not need to maintain a list of associated terminals; Instead, the associate control in a SDN controller will decide which BSs/APs the terminals should be associated via the control link

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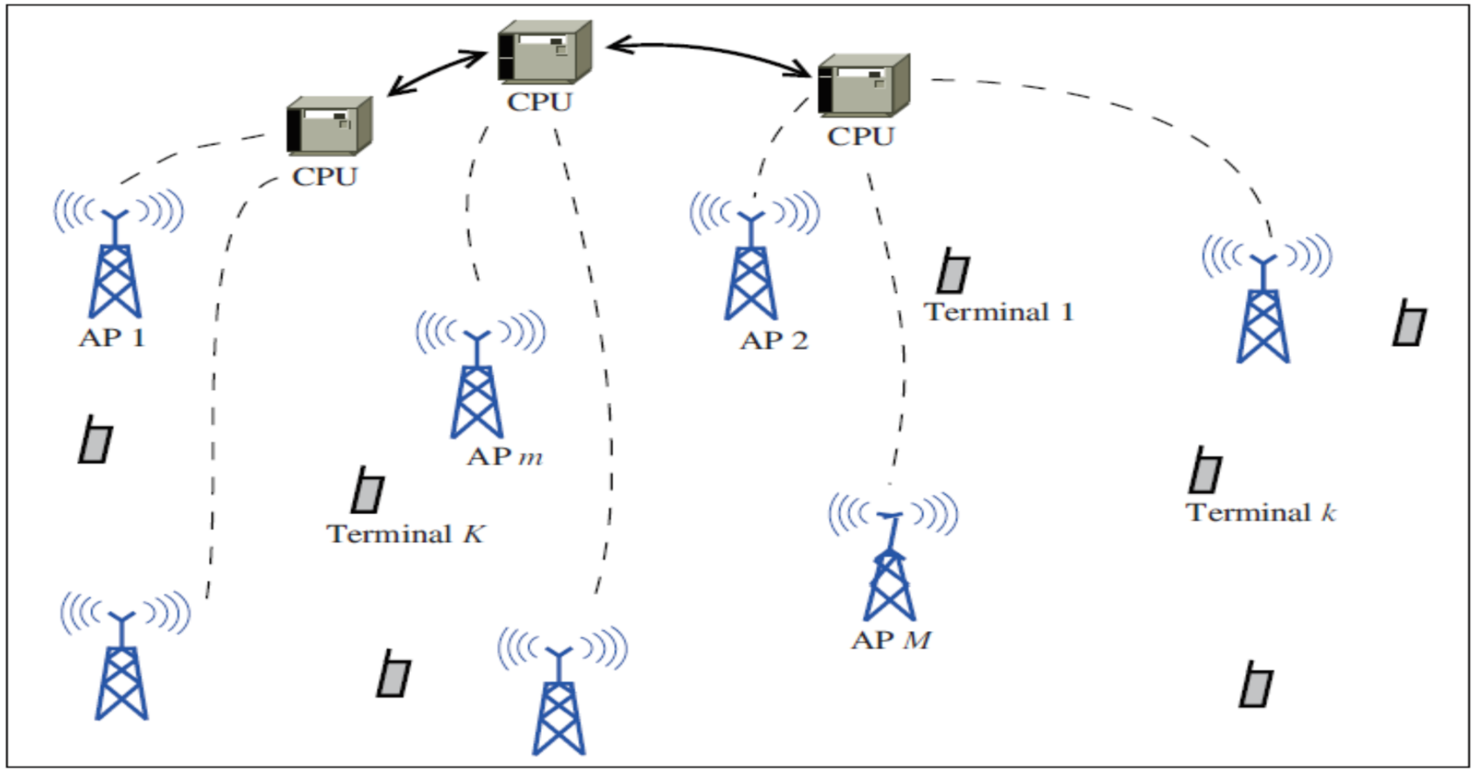
- **Cell-free (CF) Architectures-** (cont'd)

- The Tx control in the SDN controller can create dynamic UL/DLs and backhaul links to support the joint Tx/Rx between terminals and BSs/Aps
- the BSs/APs in the same group can inter-cooperate to realize the joint Tx/Rx for a specified terminal
- **CF massive MIMO benefits:**
  - High network connectivity (coverage probability)
  - Huge spectral and energy efficiency
  - Simple linear signal processing and low-cost devices
- **Open research issues:**
  - Scalable signal processing
  - Scalable power control



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- **Cloud/fog /edge computing**
- **Cloud computing (CC)** : architecture with centralized resources and management in the data centers, backbone Internet protocol (IP) networks and cellular core networks
  - centralized resources and management; end devices and consumers may have with elastic on-demand resource allocation, reduced management efforts, flexible pricing model and easy applications and services provisioning
  - long physical distance → limited communication bandwidth, intermittent network connectivity, etc., → CC cannot meet the requirements of many delay-sensitive applications in 5G(e.g., automatic driving)
- **Mobile Edge computing (MEC)** - defined by ETSI (2014) - provides IT and CC capabilities within the RAN in proximity to mobile subscribers
  - ETSI expanded (2017) the MEC scope into "multi-access"
- **Fog computing (FC)** (Cisco- 2012), and further promoted by **OpenFog consortium** extends and generalizes edge computing
  - The OpenFog consortium defines FC as "a system-level horizontal architecture that distributes resources and services of computing, storage, control, and networking anywhere along the continuum from cloud to things"
- Combination of AI and edge computing was introduced for dealing with several emerging future communication issues
- Novel integrated **multi-tier computing** paradigm involving collaborations between CC edge computing, and FC computing is the solution in the future- **solution to be integrated in 6G**

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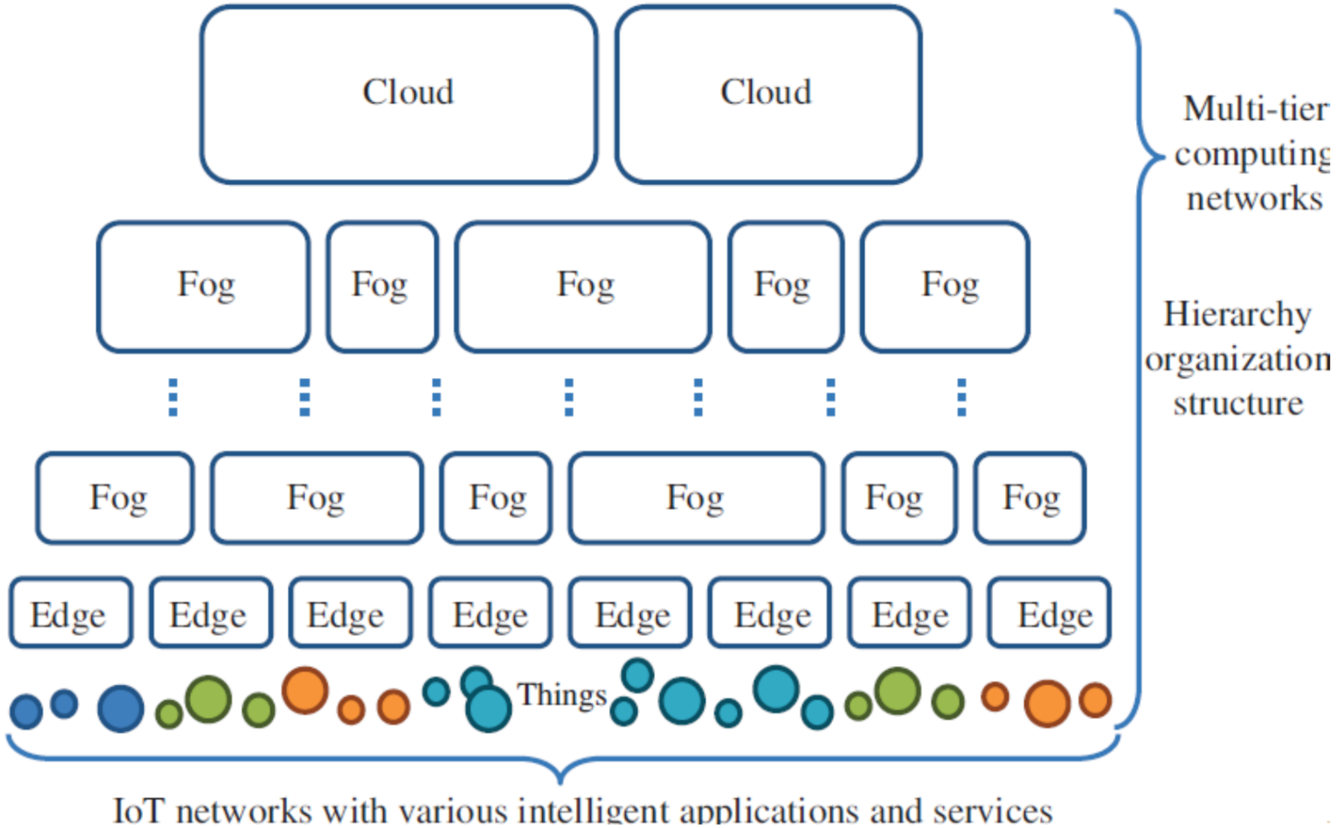
- **Cloud/fog /edge computing**
- Cloud/fog edge hierarchy



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- **Conclusions**

  - Commercial and accelerated 5G deployment in most markets worldwide is on-going or will start soon
  - The architectural evolution of 5G is still running, as it will likely continue for eight more years or so
  - Many opportunities from real-time communication and synchronization between the physical, digital and biological worlds → new human experience.

  - **6G architectural research has been successfully initiated**
    - Objectives: flexibility, simplicity, reliability, security, efficiency and automation required to realize the variety of future applications of 6G to consumer and vertical industries.
    - The het-cloud platform with new cloud computing capabilities – important component the 6G network
    - Convergent RAN-CORE implemented as micro services and facilitates new cell free and mesh architectures
    - A new data and information architecture will be an essential part of 6G
      - important role that data and AI/ML optimization will play in the design and operation of the 6G network

Thank You!

References

[1] M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

[2] V.Ziegler et al., "6G Architecture to Connect the Worlds", IEEE Access, Sept 2020, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9200631

[3] L.U. Khan, et al., "6G Wireless Systems: A Vision,Architectural Elements, and Future Directions", 10.1109/ACCESS.2020.3015289, IEEE Access, 2020, https://www.researchgate.net/publication/343565534

[4] X. You, et al., "Towards 6G wireless communication networks: vision, enabling technologies, and new paradigm shifts":, SCIENCE CHINA, Information Sciences, January 2021, Vol. 64 110301:1–110301:74, https://doi.org/10.1007/s11432-020-2955-6

[5] ETSI NFV ISG. Network functions virtualization, white paper. https://portal.etsi.org/nfv/nfv white paper.pdf

[6] Open Networking Foundation. SDN architecture overview. https://www.opennetworking.org/images/stories/downloads/sdn-resources/technical-reports/SDN-architecture-overview-1.0.pdf

[7] NGMN Alliance. Description of Network Slicing Concept, NGMN 5G P1 Requirements & Architecture, Work Stream End to-End Architecture, Version 1.0. 2016

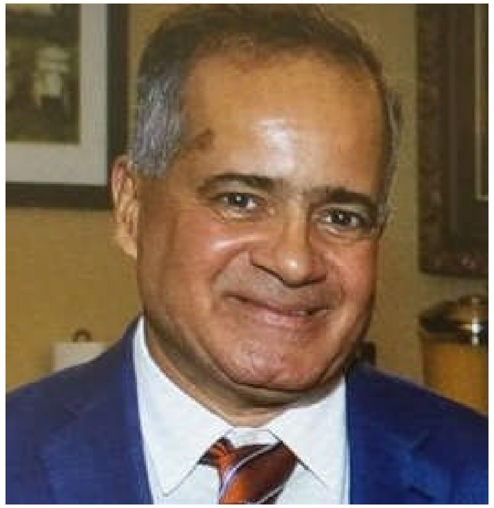
[8] Brown G. Serviced-based architecture for 5G core network. White Paper, Huawei Technology Co. Ltd. 2017 https://www.3g4g.co.uk/5G/5Gtech 6004 2017 11 Service-Based-Architecture-for-5G-Core-Networks HR Huawei.pdf

[9] ETSI GS MEC 003 V1.1.1 (2016-03), ”Mobile Edge Computing (MEC); Framework and Reference Architecture”

Panellist Position

Security/Privacy in IoT Medical Devices

Dirceu Cavendish, Kyushu Institute of Technology USA/Japan cavendish@ndrc.kyutech.ac.jp



- 5G networking
- IoT Medical Systems
- Security in IoT Medical Systems
- Medical IoT Privacy Regulations
- Privacy Challenges

→ Deep personal data mining is coming

→ Strong Security/Privacy regulations in Medical Devices raise challenges

→ Medical devices hacking (and ransomware) may prevent the adoption of advanced medical systems

Internet 2021 Panel

Communications of the Future: Hot Topics in the Internet

Security/Privacy in IoT Medical Devices

Dirceu Cavendish, Kyushu Institute of Technology, Japan

Network Design Research Center

5G Networking

5G Salient Characteristics

- Flexible and efficient spectrum usage (including millimeter wave)
- Efficient data transport: control/emergency/low latency
- New IoT use cases
  - Automotive: connected and ADAS cars
  - **Healthcare: smart medical devices**
  - Smart homes: surveillance, home automation

IoT systems architectures

- Small edge devices (sensor, appliance, combination)
- Cloud intelligent services
- Smartphone command and control

Network Design Research Center

IoT Medical Systems

Architecture

- Small edge device: sensor, actuator
    - Short range communication: battery/security
- Cloud infrastructure
    - Data gathering and analysis
    - System security control
- Command and control device: smartphone

Interaction with service verticals

- Home management: home health care
- Transportation: Emergency services
- Manufacturing: provisioning and security

Security in IoT Medical Systems

Secure IoT requirements

- Firmware tampering verification
- Firmware/software compatibility (Versioning)
- Configuration/calibration verification
-

IoT Authentication and Authorization

- Short range authentication: secure BLE (IoT whitelisting)
- System Multifactor authentication
- Oauth2.0: explicit resource authorizations via security tokens
- Cloud Hardware Security Module (HSM): management of security credentials
- System multicomponent authentication: distributed ledgers
    - E.g., Connected home via IP security

Network Design Research Center

Medical Systems Privacy Regulations

Strong regulatory mandates

- FDA Code of Federal Regulations: Part 11 Medical devices
  - SSL encryption (at rest, in transit);
  - Restricted access;
  - Access control;
  - Data audit trail;
  - Version control;
  - Digital signature
- GDPR: General Data Protection Regulation
  - Right to data report
  - Right to data correction
  - Right to be forgotten
  - Right to opt-out data storage/processing/sharing

Medical IoT Privacy challenges

Unreadable/unenforceable EULAs

- Cumbersome End-User License Agreements
- Click through services

Controlled data sharing

- Health personal data sharing with medical personnel only
- Massive data gathering (unprocessed medical data)

Third party medical data gathering

- Primary care physician/nurse computer systems
- Point of care security (hospital outdated systems)
- Cloud partners: Medical data gathering companies

.

Technology failures

- IoT device hacking: cheap HW, small SW footprint
- Cloud system miss-management
- Cryptographic material leaks

Panellist Position

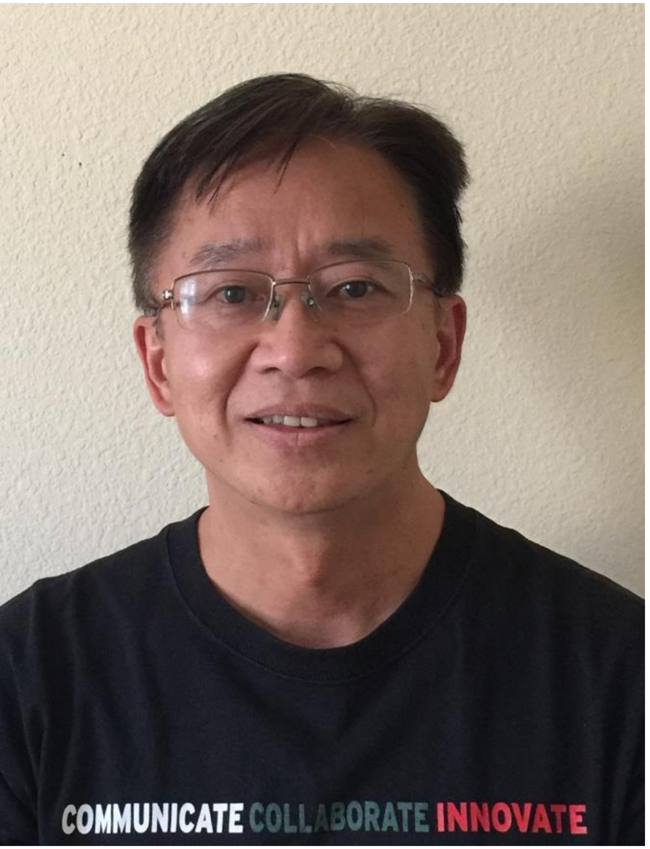
Future Internet:
Challenges and Potential technology

Lin Han

Futurewei Technologies, USA

lin.han@futurewei.com

Lin Han



- Professional Experience
  - Distinguished Engineer, Futurewei Technologies (2019-Present)
  - Principal Engineer, Huawei U.S.A (2011-2019)
  - Technical Leader, Cisco Systems (1999-2011)
  - Software Engineer, Newbridge Network, Canada (1996-1999)
- Activities and publications
  - Work for “Focus Group on Technologies for Network 2030” in ITU, 2019
    - Member to write “Towards a New Internet for the Year 2030 and Beyond”
    - Member of SubG1: “Network 2030 Architecture Framework for FG-NET2030”,
  - Rapporteur of ETSI NGP “Network Layer Multi-Path” WI, 2018
  - Rapporteur of ETSI NGP “New Transport Technology” WI, 2017
  - IEEE WCNC 2020 - “New IP Enabled In-Band Signaling for Accurate Latency Guarantee Service”
  - EuCNC 2020 - “In-Network Knowledge Reasoning with New IP”,
  - IEEE INFOCOMM 2020 Workshop on NewIP – “A Framework for Bandwidth and Latency Guaranteed Service in New IP Network”,
  - “Support Precise Latency for Network Based AR/VR Applications with New IP”, Proceedings of the 13th EAI International Conference on Mobile Multimedia Communications, Mobimedia 2020,
  - IEEE WOCC 2018 – “Flow-Level QoS Assurance via IPv6 In-Band Signaling”
  - AFIN 2018, The Tenth International Conference on Advances in Future Internet – “A New Congestion Control Algorithm for Bandwidth Guaranteed Networks”
  - More than 20 USA Patents

Agenda

- Are we reaching a technical ceiling for Internet?
- What is New IP
- Use case 1 (for better service): In-Vehicle-Network (IVN) and V2X
- Use case 2 (for super coverage): Non-terrestrial network (ongoing work)

Are we reaching a technical ceiling for Internet

- Billion cell phones + Billion computers
- Almost every countries can access Internet
- Pandemic has proved the robustness of Internet
- What next?
  - Wireless: 6G
  - IP: ?
  - App: AI/ML/Autonomous networking, Self-driving car, many others

Future Internet

- Two forever topics
  - Constraint in Service
    - E2E Latency/Jitter/Packet loss – new requirements
      - Industry control
      - AR/VR
      - V2X, Robert car, Self-driving car
    - Bandwidth – never enough
      - AR/VR
      - Holographic communication
    - Many things not connected
  - Constraint in Coverage
    - Ocean
    - Airplane
    - Hi-speed train
    - Many areas in developing countries
- Others
  - Security, cost, features, power consumption…

High Precision Communication
Ultra high through put
All things connected

More fiber, more base station?
Satellite

Cheaper/better/more-powerful silicon
White box, Open source

Future Internet driven by Emerging Technologies

→New Spectrum is not panacea, Wireless is not enough

→Emerging Technologies are needed for Services beyond Best-Effort and Super coverage

→Future Internet: terrestrial network + non-terrestrial network + Services beyond Best-Effort

- New IP - New network protocol for future internet
- Reference:
  - Sheng Jiang, et.al, "New IP, Shaping Future Network: Propose to initiate the discussion of strategy transformation for ITU-T", TSAG C-83
  - R. Li, A. Clemm, U. Chunduri, L. Dong and K. Makhijani, "A New Framework and Protocol for Future Networking Applications," ACM Sigcomm NEAT workshop, 2018.
  - R. Li, K. Makhijani, "New IP: A Data Packet Framework to Evolve the Internet : Invited Paper"

Agenda

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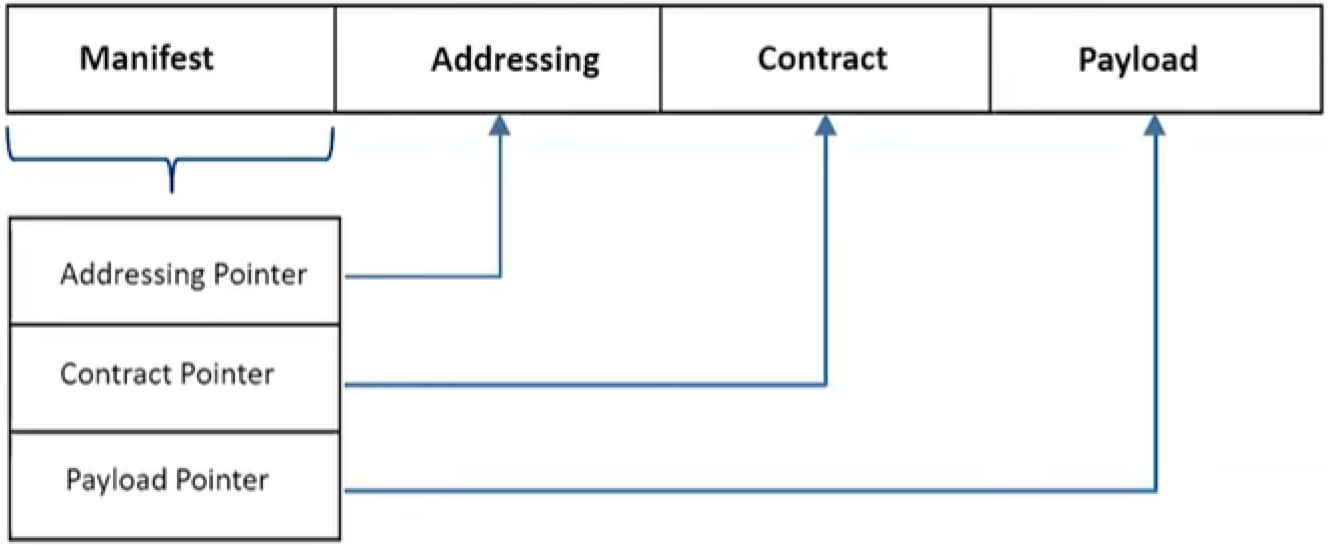
New IP for network side ≈ 5G NR for radio side
Similar approach to solve similar problem

	5G	Future Internet (5G and beyond)
Purpose and Requirements	eMBB mMTC uRLLC	Ultra high through put All things connected High Precision Communication
Solutions	New Radio (5G NR) (+ SBA)	New IP
Technologies	New spectrum, MIMO New protocol stack at UE 5G NR QoS Grant Free Dynamic Scheduling	Flexible addressing Network Layer Multiple path New protocol stack at host and UE In-band signaling New queuing and scheduling Qualitative communication Network programmability Intrinsic Security Automation and autonomous networking

True E2E uRLLC = 5G+New IP

New IP Packet Encoding Proposal



<Contract> := <Contract Clause> | <Contract Clause> AND <Contract>
<Contract Clause> := <Contract Item> | <Contract Item> OR <Contract Clause>
<Contract Item> := <Meta Data>
| <Event, Condition, Action> |
| <Event, Condition, Action> <Meta Data>
<Event, Condition, Action> := <Action> | <Condition> <Action> | <Event><Condition><Action>

- Final format is up to IETF standard

Addressing

- Free-Choice Addressing
  - Flexible Addressing System
  - Semantic Addresses
  - Existing IPv4, IPv6
  - Any others
- Mix and Match

Contract

- KPI (latency, packet loss, etc)
- Sender's Intent
- In-Band OAM and Telemetry
- Network Programmability

Payload

- Native Stream of Bits and Bytes
- Structure of Bits and Bytes
  - Entropy-Based
  - Semantics-Based

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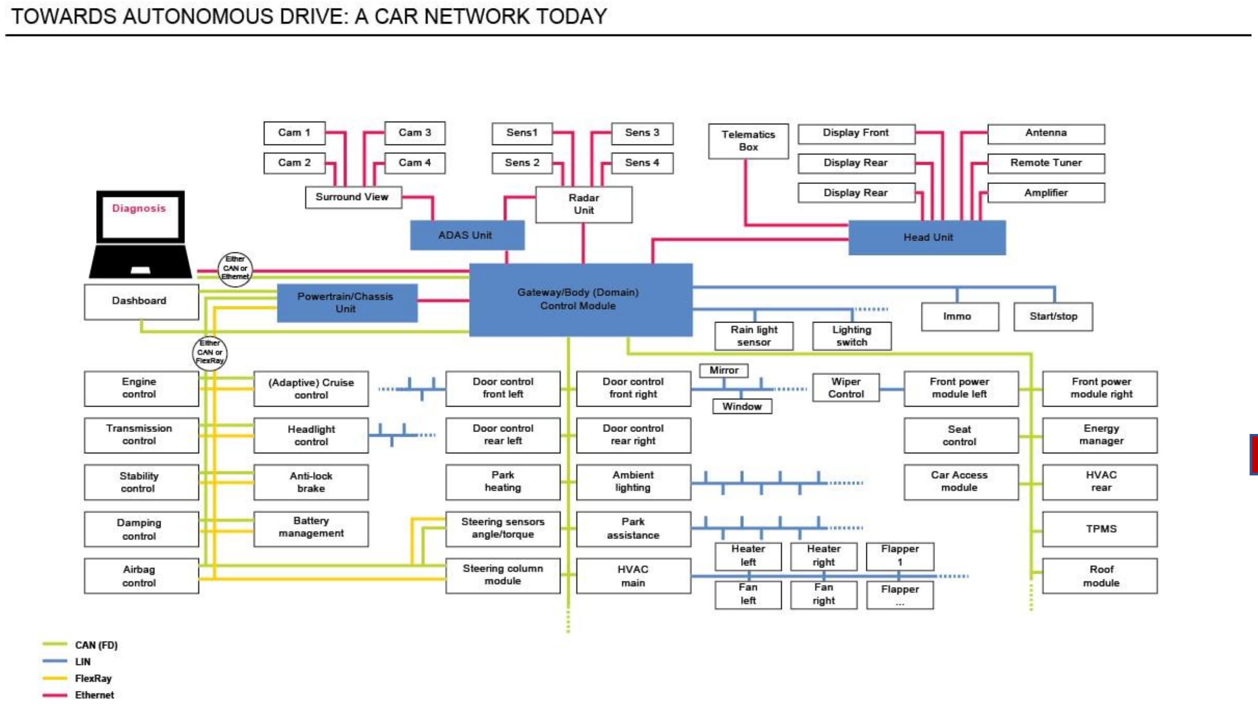
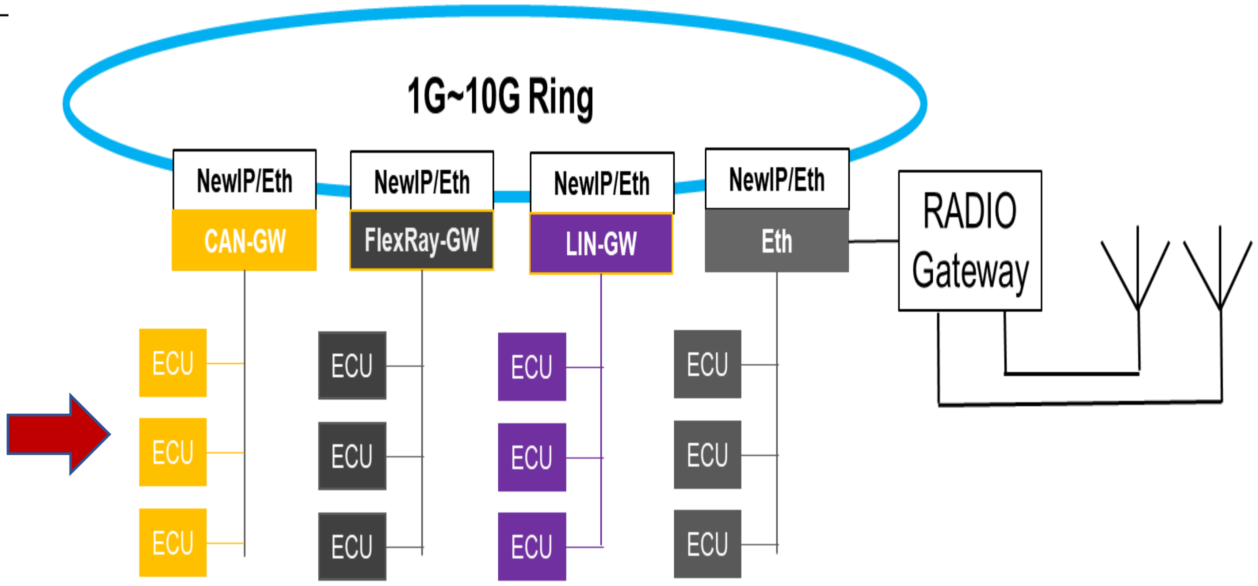
Use case 1 (for better service): In-Vehicle-Network (IVN) and V2X

- Current status for IVN
  - Legacy technologies: CAN(Controller Area Network), LIN(Local Interconnect Network), FlexRay,
  - IEEE802.1: TSN
  - AutoSar propose to move all to IP.
- New IP solution
  - "A Study of In-Vehicle-Network by New IP"
  - Unify protocol for IVN, V2X to IP
  - Much flexible and easier for application and new feature development
    - Control of Sensor, Feeding of Radar and Lidar, MEC, ML, Autonomous drive, etc
  - E2E latency and bandwidth guarantee, congestion free, no packet loss
  - L2 independent, more flexible topo, higher link utilization
  - IVN integrated with V2X and Internet

Unified IP network for better service

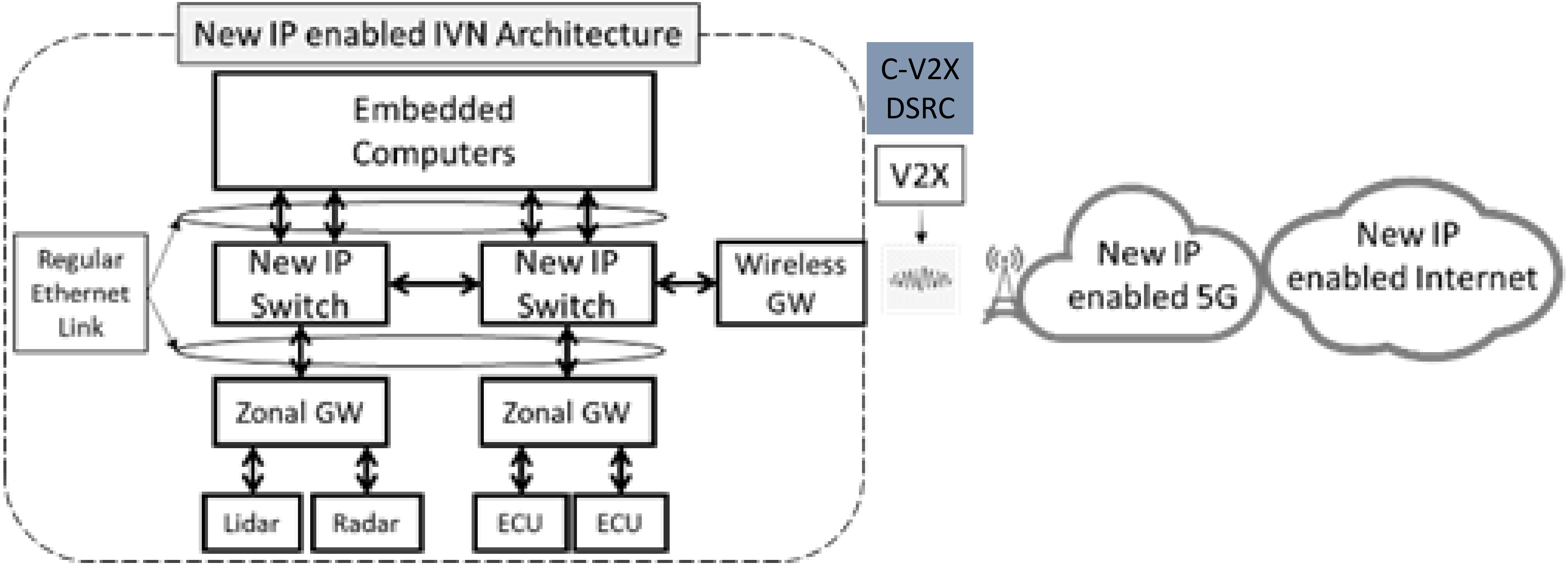


TOWARD-AUTONOMOUS-DRIVE.jpg (1200×712) (nxp.com)

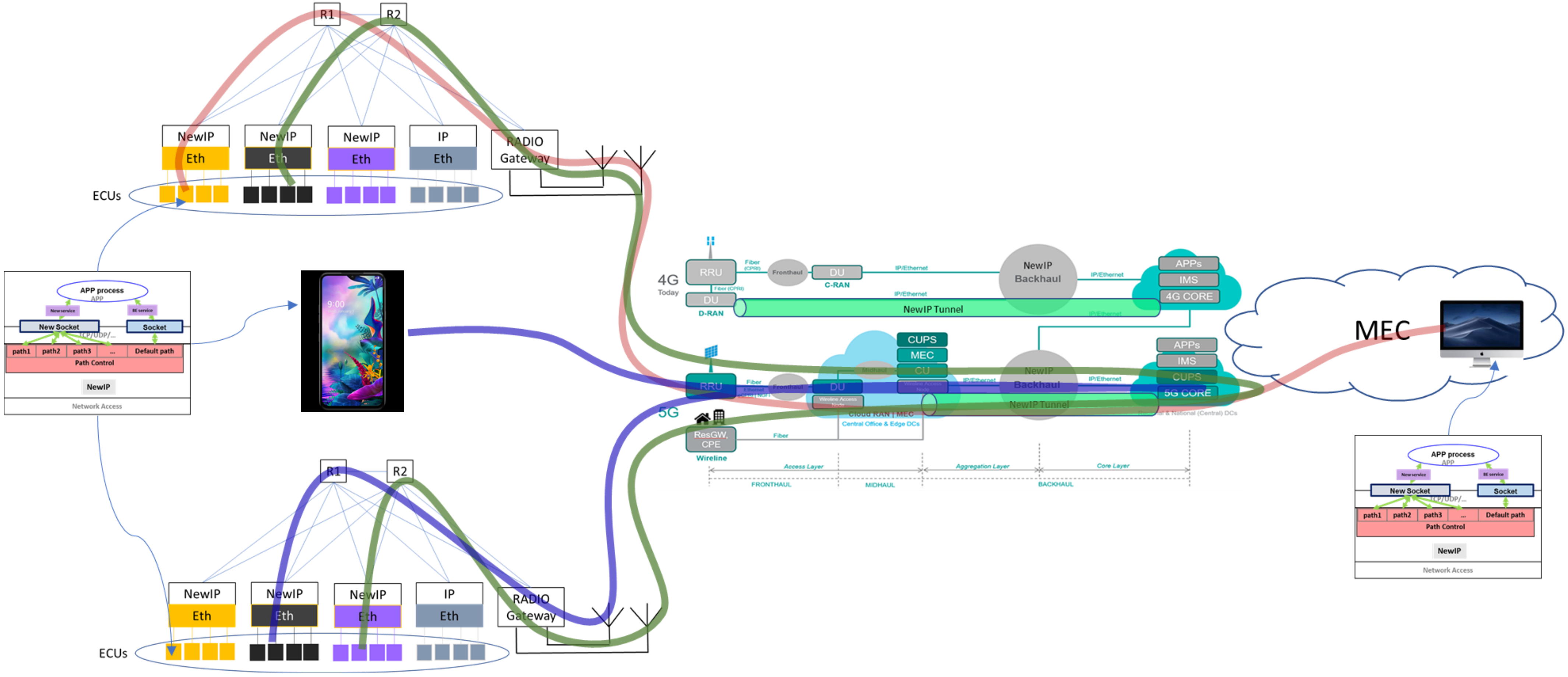


New IP based IVN

New IP enabled IVN architecture in future Internet



NewIP + 5G: Enable true E2E uRLLC for V2X



Agenda

- Are we reaching a technical ceiling for Internet?
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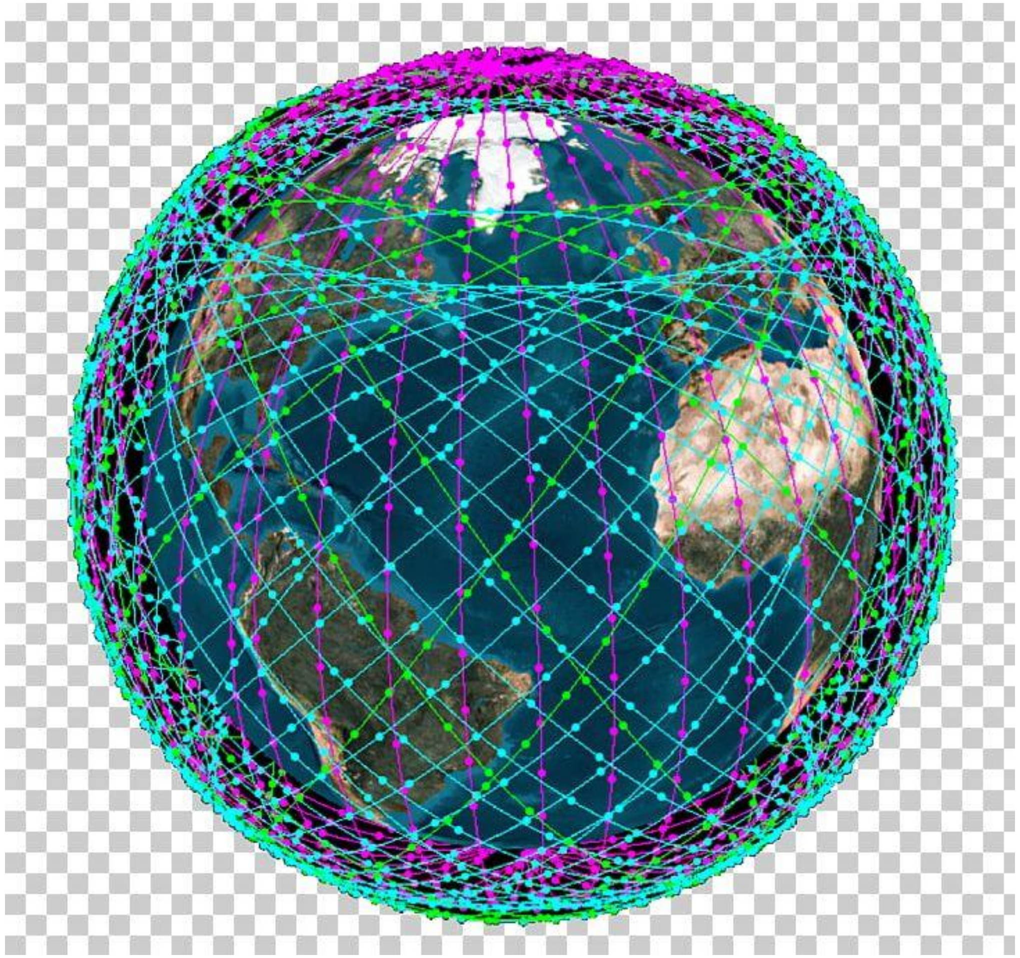
Use case 2 (for super coverage): Non-terrestrial network (ongoing work)

- 4G->5G->6G
- New Spectrum is not panacea
  - Higher frequency -> Higher bandwidth -> shorter distance -> smaller coverage
  - Energy consumption
  - Cost of more base stations
- Moving objects form a network
  - Balloons, airships, airplanes, satellites
- Benefits
  - Extensive coverages (remote areas, ocean, airplanes…)
  - 4g(~10km) -> 5g (<1km) -> satellites (x100km – x1000km)
  - Shorter latency (200km/s -> 300km/s)

LEO Orbits, StarLink Satellite



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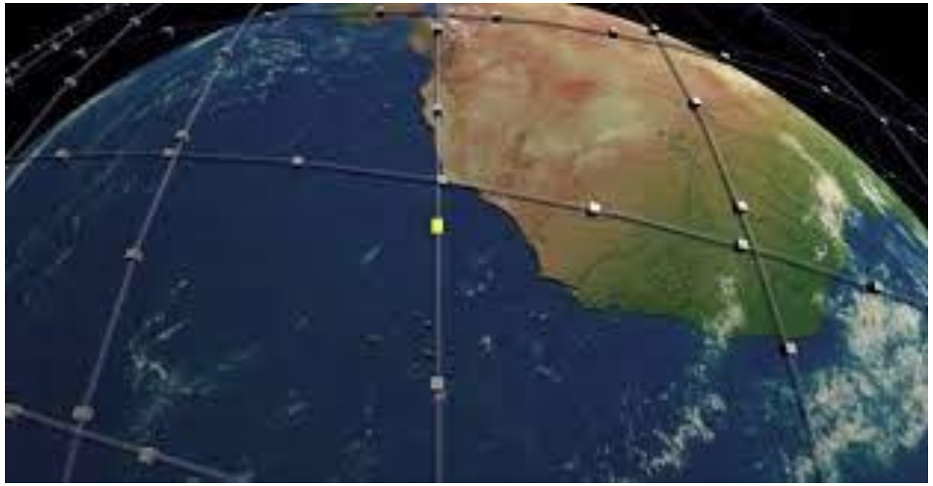
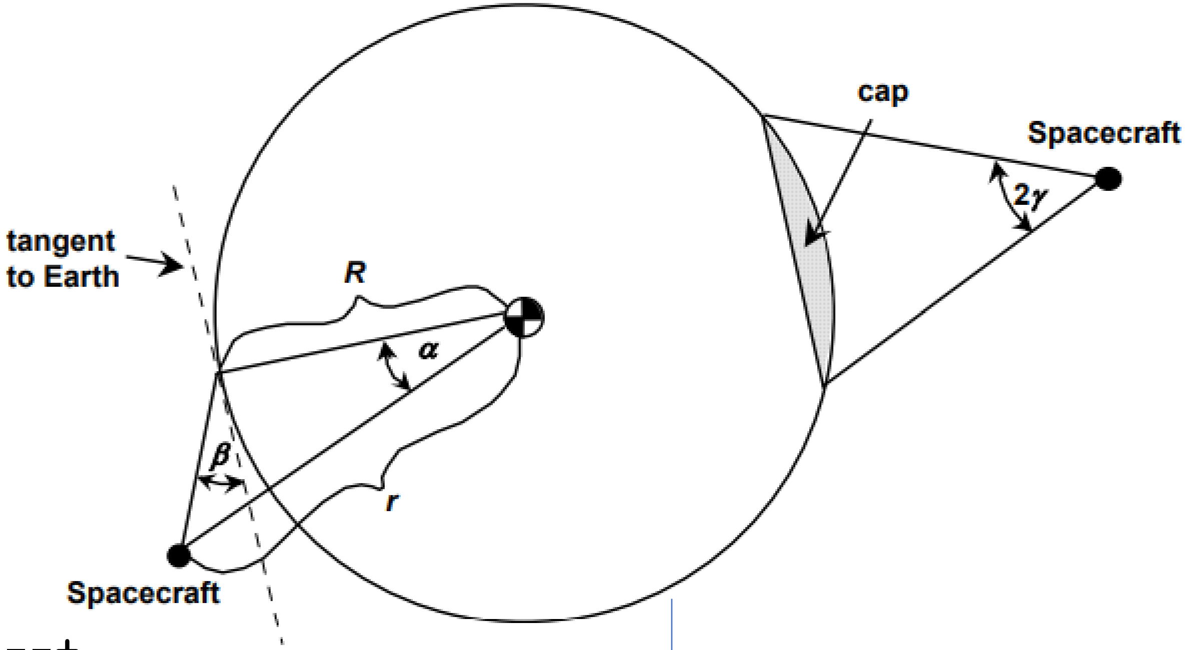
https://www.teslarati.com/spacex-next-starlink-launch-worlds-largest-constellation/



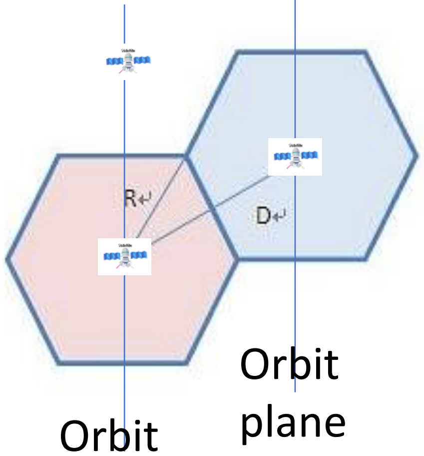
https://www.satellitetoday.com/launch/2019/04/29/fcc-approves-lower-orbit-for-spacex-starlink-satellites/

Satellite network: Coverage

As: The altitude of a satellite; **Re**: The radius of earth
Rc: The radius (arc length) of the covrage, or, the arc length of hexagon center to its 6 vertics. Rc=Re*(a*pi)/180
alpha: The view angle for the coverage area from earth center (the RC arc).
alpha = arccos((Re/(Re+As))*cos(b))-b.
beta: The least elevation angle that a ground station or a terminal can communicate with a satellite, b = 35 degree.
Ns: The minimum number of satellite on one orbit plane, it is equal to the number of the satellite's vertical projection on Earth, so, Ns=180/(a*cos(30))
No: The minimum number of orbit (with same inclination), it is equal to the number of the satellite orbit's vertical projection, so, No = 360/(a*(1+sin(30)))



Parameters	VLEO1	VLEO2	LEO1	LEO2
As(km)	335.9	450	1100	1150
alpha(degree)	3.907	5.078	10.681	11.051
Rc(km)	435	565	1189	1230
Ns	54	41	20	19
No	62	48	23	22



Satellite network: Limited Communication time

- Fast Mobility (>7km/s) caused two problems
  - Limited time for satellite-to-ground-station communication
  - Limited time for Inter-satellite communication

Parameters	VLEO1	VLEO2	LEO1	LEO2	LEO3
As(km)	335.9	450	1100	1150	1325
a(degree)	3.907	5.078	10.681	11.051	12.293
AL(km)	793	1048	2415	2515	2863
SD(km)	792.5	1047.2	2404	2503.2	2846.1
V(km/s)	7.7	7.636	7.296	7.272	7.189
T(s)	103	137	331	346	398

The time for the station-satellite communication

Parameters	VLEO1	VLEO2
As(km)	335.9	450
V (km/s)	7.7	7.636

Table 3: Two VLEO with different altitude and speed

A (degree)	0	10	45	90	135	180
|V| (km/s)	0.065	1.338	5.869	10.844	14.169	15.336
T(s)	61810	2984	680	368	282	260

Table 4: Two VLEO intersecs with different angle and the life of communication

Parameters	LEO1	LEO2
As(km)	1150	1325
V (km/s)	7.272	7.189

Table 5: Two LEO with different altitude and speed

A (degree)	0	10	45	90	135	180
|V| (km/s)	0.083	1.263	5.535	10.226	13.360	14.461
T(s)	47961	3155	720	390	298	276

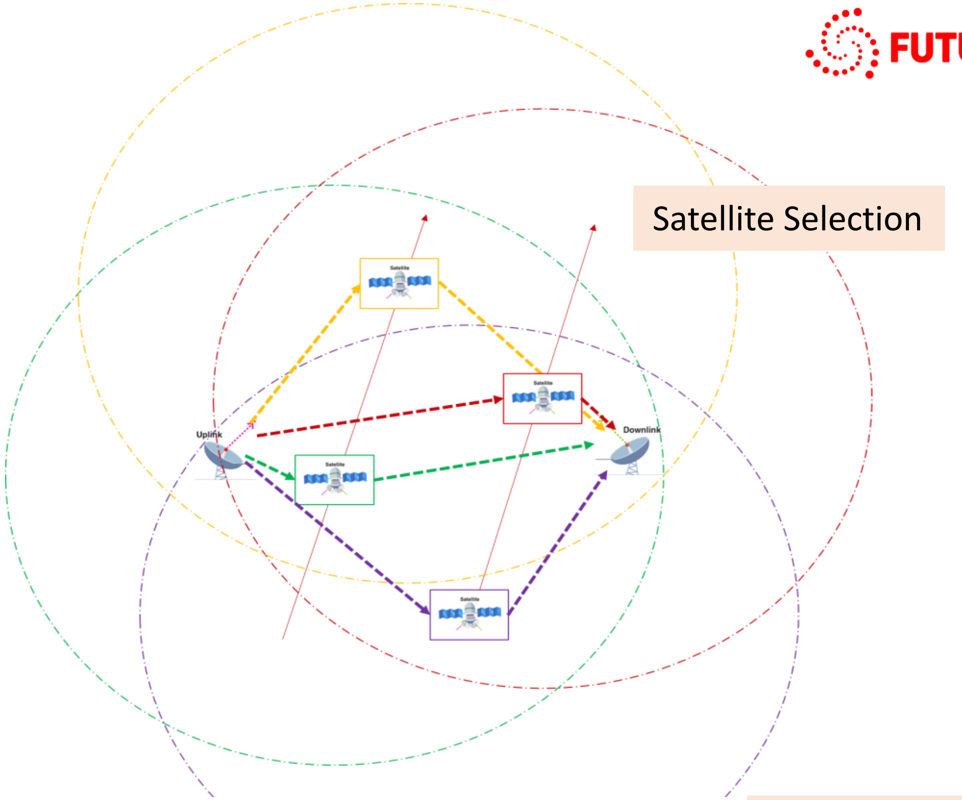
Table 6: Two LEO intersecs with different angle and the life of communication

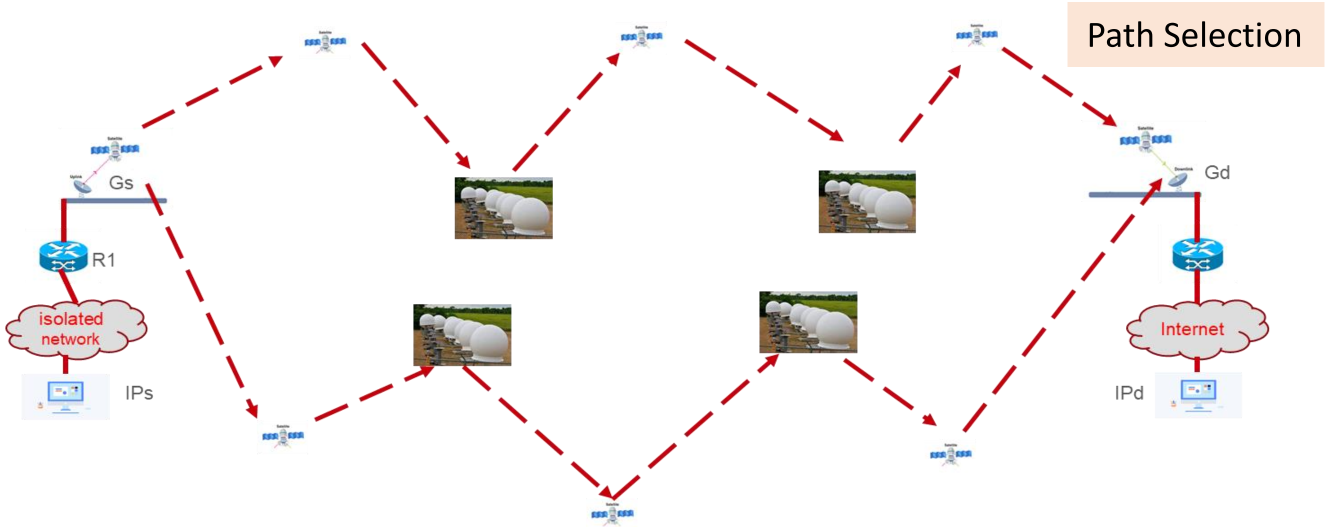
LEO/VLEO satellite network

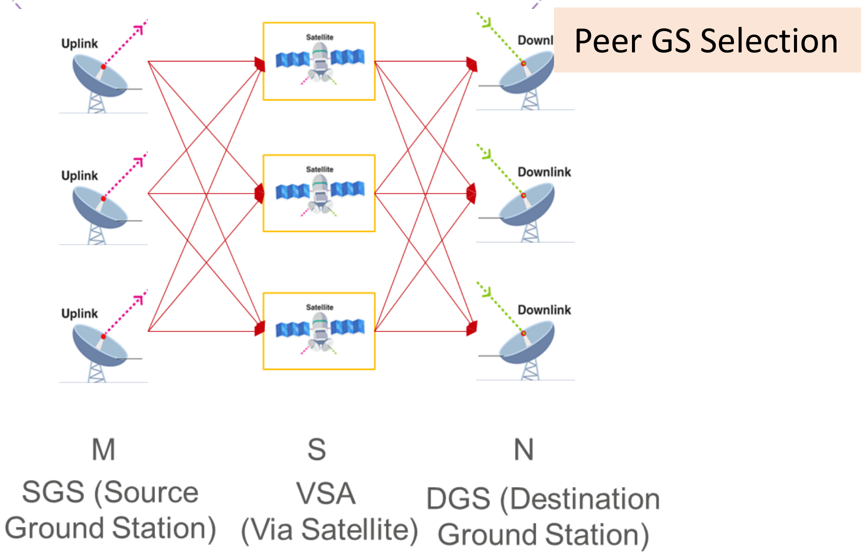
- Two Operational Mode
  - Satellite Relay
  - Satellite network by inter-satellite link (ISL)
- Limited communication time:
  - Satellite to ground station communication: 100 ~ 500s
  - Inter-Satellite (different altitude) communication: <24Hr.
- Dynamic topology, Frequent Hands over
- Traditional IP wont work well, network not steady
- Addressing, routing, packet lookup and forwarding
  - Routing convergency
  - Routing and forwarding process
  - Satellite energy constraint

Satellite Relay

- One satellite relay is same as traditional GSO communication
- Multiple satellite Relay
  - Practical Solution for global coverage before Inter-Satellite Networking is available
- More complicated than One Satellite Relay
  - Networking is required
  - Satellite, Peer, Path selection
  - Protocols
  - Packet forwarding





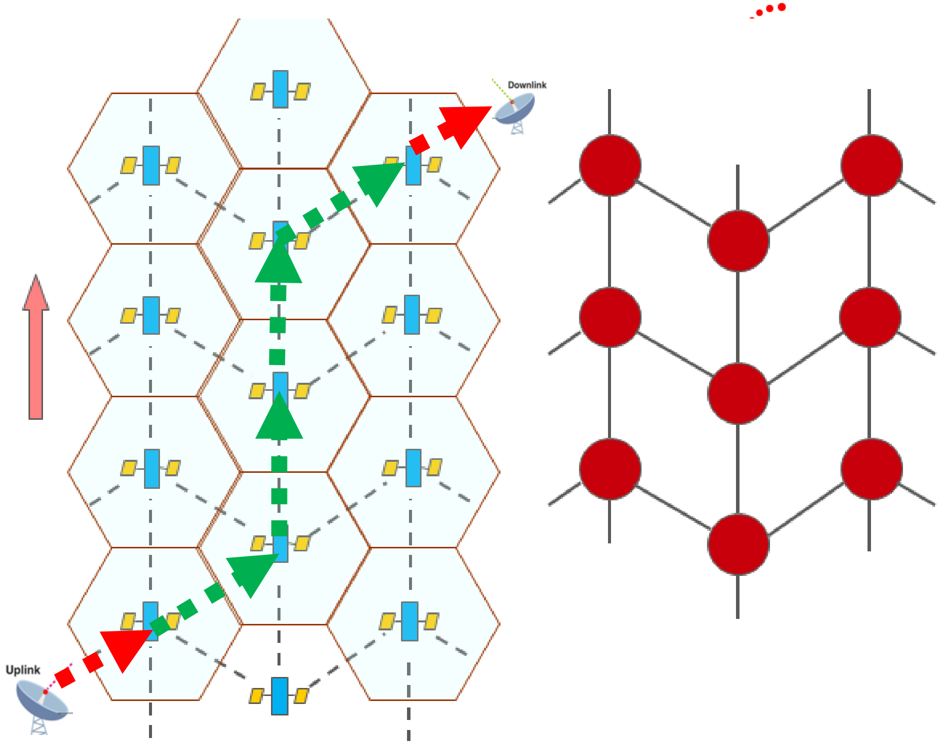


Satellite Networking – By Inter-satellite Link

```
               S1-----S2-----S3--\           /----------\
              /                   \         /            \
   T---GW--GS1--S4----S5---S6---GS2-------PE   Internet    +
              \                   /         \            /
               \---S7----S8----S9/           \----------/
```

```
  /-----------\           S1-----S2-----S3---\          /-------\
 /             \         /                    \        /         \
+ Local network CE------GS1--S4----S5---S6---GS2-------PE Internet +
 \             /         \                    /        \         /
  \-----------/           \---S7----S8----S9/           \-------/
```

- Huge amount of satellite
  - Satellite - >10k for one provider
- Huge amount of ground stations
  - Ground stations > 1m
    - ❑ StarLink has requested 1m ground station license
      - ❖ Each continent > 100 gateway ground stations
      - ❖ Others are terminal ground stations



Two routing issues
- Massive IGP flooding
- BGP convergency

Consequences
- Satellite routing device is costly and consume a lot power due to the heavy tasks for routing protocols
- ISL link consume bandwidth for control
- Network state is not steady
- Service is not steady

What New IP can do

- Addressing:
  - Semantic address for satellite
- Routing
  - Intelligent routing by meta data
  - Semantic routing by new address
- New protocols for
  - Satellite selection
  - Peer selection
  - Hands over
  - Satellite discovery

Conclusions

- Current Internet is not perfect and is not reaching the ceiling
  - Service and Coverage are forever topics
  - Service has a lot room to improve
  - Many application’s requirements are not satisfied
  - Satellite networking has a lot challenges to the current technologies
- New technologies have to consider the whole network
  - New Spectrum is not panacea, Wireless is not enough
  - True E2E solution is needed.
- New IP is a potential technology for future Internet
  - For whole network except wireless, it is Similar to 5G NR for radio side
  - Demonstrated the capability to provide same service as legacy protocols for In-Vehicle-Network that the traditional IP cannot provide.
  - Provide solution for satellite-networking as analyzed.

Thank You!

Panellist Position

Challenges and Applications of 60 GHz mmWave Communications

Zhicheng Yang; PAII Inc. (PingAn Tech, US Research Lab), USA zcyangpingan@gmail.com

- **Challenges of 60 GHz mmWave networks**
  - **Human Blockage**
    - 60 GHz access point deployment
  - **Node Mobility**
    - 60 GHz phased array codebook design
- **Applications of 60 GHz mmWave sensing**
  - **Healthcare**
    - Vital sign and sleep monitoring
  - **Smart Agriculture**
    - Estimation of sugar content in fruits

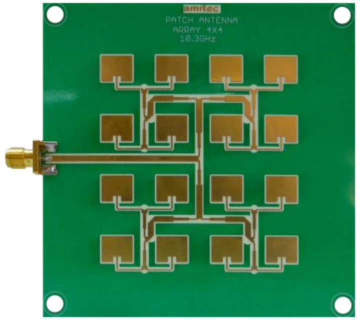
- **Zhicheng Yang**
  - Senior Research Scientist @ PAII Inc. (PingAn Tech, US Research Lab), USA
  - E- mail: zcyangpingan@gmail.com

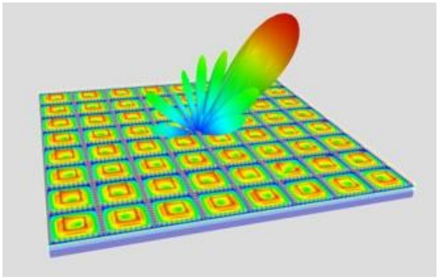
- Research Interests
  - 60 GHz mmWave networks
  - 60 GHz sensing application design
  - Internet of Medical Things
  - Medical Image Analysis
  - Mobile and Pervasive Computing

- Publications: over 35 scientific or technical papers
- TPC members: IARIA INTERNET 2020-2021, IFIP NETWORKING 2019-2021, IEEE IPCCC 2019-2021, etc.

- Background of 60 GHz millimeter-wave
  - 60 GHz millimeter-wave (mmWave) unlicensed spectrum -> multi-Gbps throughput -> IEEE 802.11ad/ay
  - Wireless 4K/8K AR/VR video streaming, Telemedicine and remote surgery, …

  - Signal attenuation at 60 GHz frequency is considerable
  - Much close to the vibration frequency of oxygen atom
  - 60 GHz communications are required to be highly directional
  - To compensate for such high loss, the signal need to be concentrated in some certain direction
    - Horn antenna
    - Phased antenna array -> Beamforming





- Challenges of 60 GHz mmWave networks
  - Human Blockage
    - 60 GHz access point deployment
  - Node Mobility
    - 60 GHz phased array codebook design

- Applications of 60 GHz mmWave sensing
  - Healthcare
    - Vital sign and sleep monitoring
  - Smart Agriculture
    - Estimation of sugar content in fruits

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- Applications of 60 GHz mmWave sensing
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    - Vital sign and sleep monitoring
  - Smart Agriculture
    - Estimation of sugar content in fruits

- Challenges of 60 GHz mmWave networks
  - Coverage and blockage issue
    - 60 GHz mmWave signals attenuate significantly while penetrating walls and other indoor objects such as metal cabinets, indoor furniture
    - This means that one 60 GHz AP is required in each room (or enclosed indoor space) to provide sufficient coverage
    - Blockage of an mmWave link from a human body results in a loss of 20 to 30 dB
  - Design a blockage-aware deployment of 60 GHz WLANs, which focuses on intelligently placing the 60 GHz access point (AP) in a room to maximize the coverage and the robustness under human blockage
  - Mobility issue
    - When one or both endpoints are mobile, such beamforming is extremely challenging
    - The nodes have to constantly perform beam searching, requiring sector level sweep to re-establish the link in seconds
  - Design a sensor-assisted multi-level codebook-based beamwidth adaptation and beam switching to address the mobility challenges in 60 GHz WLANs

- Blockage-aware access point deployment of 60 GHz WLANs[1]
  - AP placement in 60 GHz WLANs requires redefining coverage in terms of blockage
  - *Coverage metric for spatial diversity*: A new coverage metric ASC (Angular Spread Coverage) is defined
  - *Sensing indoor reflection profile*: A small set of pilot measurements to sense and construct the indoor layout which includes the relative positions of blocking and reflective objects
  - *Link reliability under multiple human blockages*: We show that the MACAR (MAximum Coverage using single AP and minimum Relays) problem is NP-hard and provide a greedy strategy for AP and relay placement

[1] Yang, Z., Pathak, P. H., Pan, J., Sha, M., & Mohapatra, P. (2018, October). Sense and deploy: Blockage-aware deployment of reliable 60 ghz mmwave wlans. In 2018 IEEE 15th International Conference on Mobile Ad Hoc and Sensor Systems (MASS) (pp. 397-405). IEEE.

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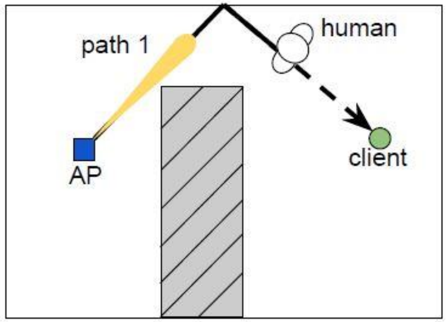
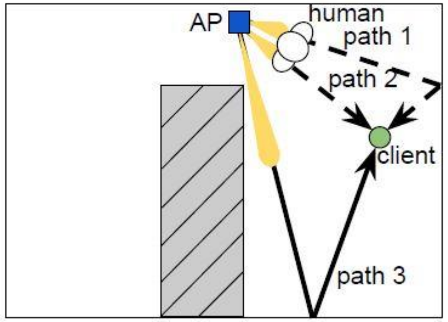
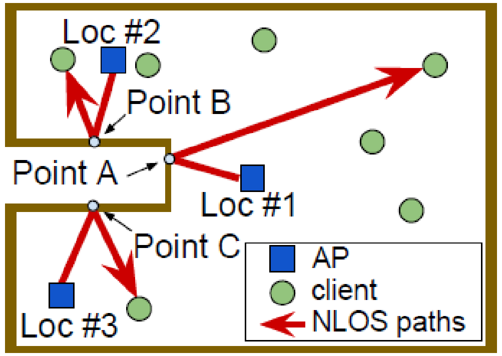


(a) Example of an AP placement where the client has only one path from the AP



(b) Example of an AP placement which has three spatially diverse paths between AP and client



  - *Coverage metric for spatial diversity*: A new coverage metric ASC (Angular Spread Coverage) is defined
  - *Sensing indoor reflection profile*: A small set of pilot measurements to sense and construct the indoor layout which includes the relative positions of blocking and reflective objects
  - *Link reliability under multiple human blockages*: We show that the MACAR (MAximum Coverage using single AP and minimum Relays) problem is NP-hard and provide a greedy strategy for AP and relay placement

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- Blockage-aware access point deployment of 60 GHz WLANs[1]
  - AP placement in 60 GHz WLANs requires redefining coverage in terms of blockage
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$$\Lambda = \frac{P' + \sqrt{|F_0|^2 - |F_1|^2}}{P''}$$

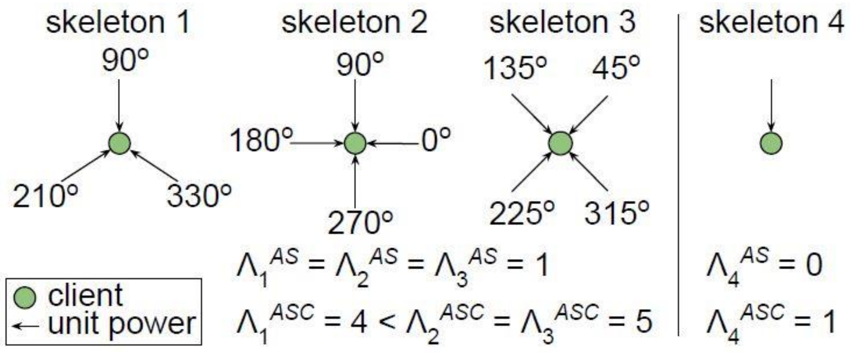
where

$$F_q = \int_0^{2\pi} p(\theta)\exp(jq\theta)d\theta$$

$$p(\theta) = P_1\delta(\theta - \alpha) + P_2\delta(\theta - \beta) + \ldots$$

$$\Lambda^{AS} = \sqrt{1 - \frac{|F_1|^2}{|F_0|^2}}$$

P' and P'' are set as P_{max}
$\{P_1, P_2, \ldots\}$ are the individual powers arrive at the corresponding angle at the azimuth plane



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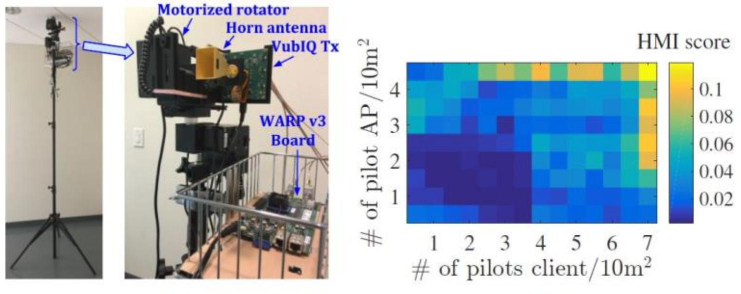

Fig. 5: (a) 60 GHz transmitter setup to imitate a ceiling mounted AP; (b) HMI score with different pilot AP and client densities

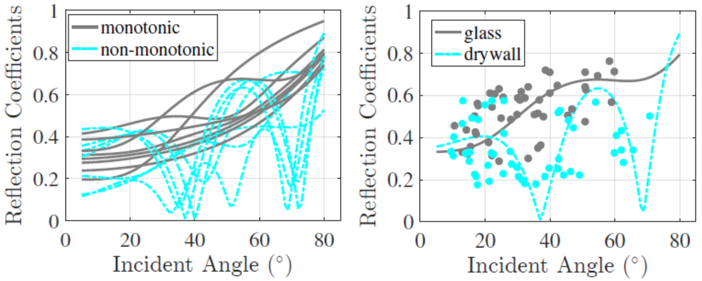

Fig. 4: (left) Reflection coefficients of various indoor materials (one line represents one material); (right) Using k-means clustering to categorize the reflection points in strong or moderate reflectors

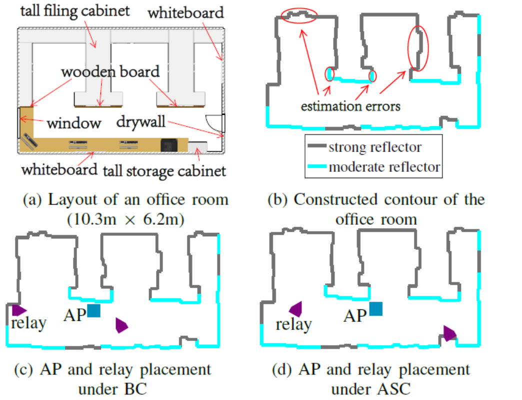

Fig. 6: ASC and BC based deployments result in different placement of AP and relays because ASC aims at covering clients with more spatially diverse paths

  - *Link reliability under multiple human blockages*: We show that the MACAR (MAximum Coverage using single AP and minimum Relays) problem is NP-hard and provide a greedy strategy for AP and relay placement

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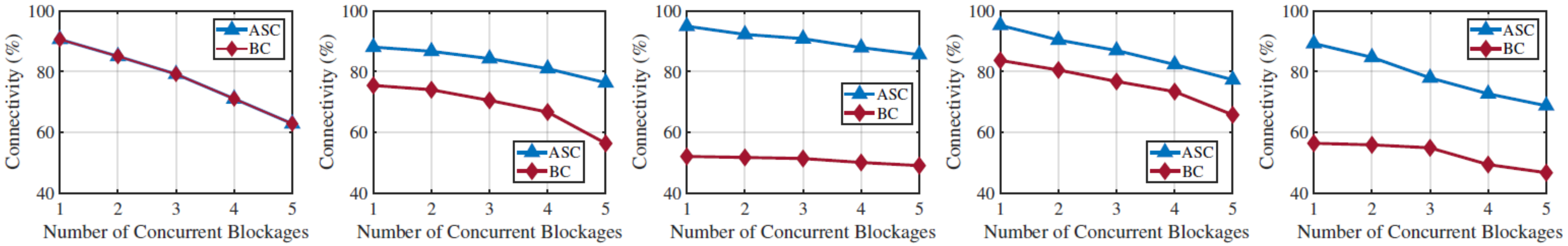

(a) Conference room (b) Office room (c) Lab room (d) Home living room (e) Home master bedroom

Fig. 7: Percentage of connected clients (% connectivity) under the two metrics in five rooms with concurrent blockages; As number of concurrent blockages increase, ASC-based deployment provide substantially better tolerance to blockages

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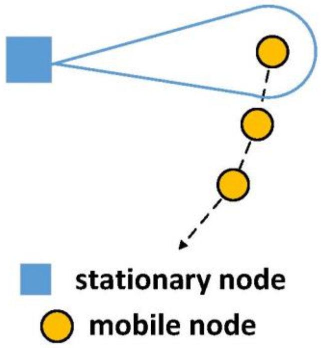
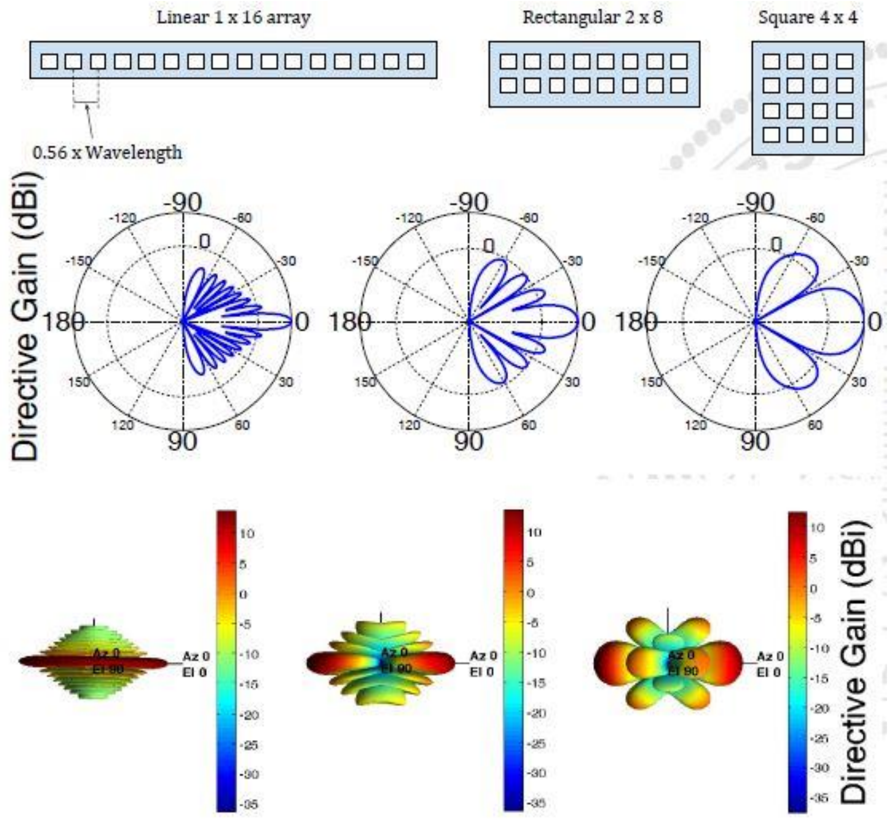
- Sensor-assisted multi-level codebook design[2]
  - Limitations:
    - Sector level sweep is time consuming
    - Endpoints need to keep stationary

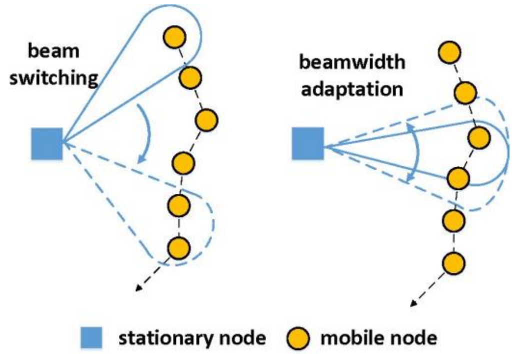


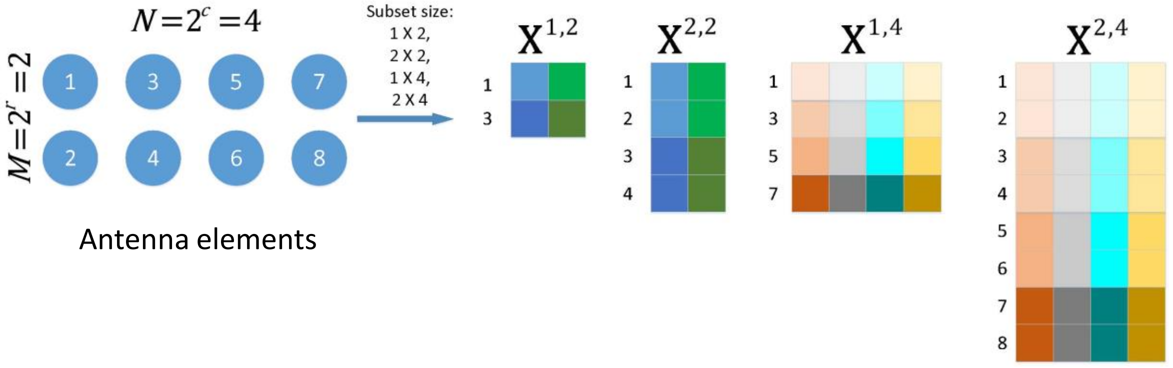


  - Phase antenna array
    - Small size embedded in wireless devices
    - Digital beamforming
    - Codebook design for controlling sub array or even single element

[2] Yang, Z., Pathak, P. H., Zeng, Y., & Mohapatra, P. (2015, October). Sensor-assisted codebook-based beamforming for mobility management in 60 ghz wlans. In 2015 IEEE 12th International Conference on Mobile Ad Hoc and Sensor Systems (pp. 333-341). IEEE.

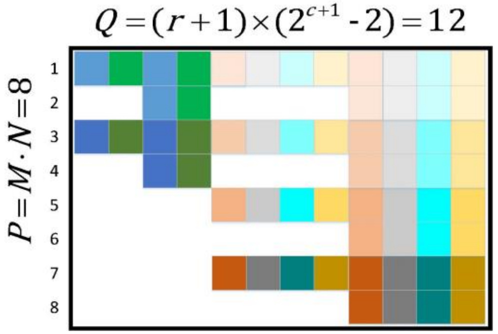
- Sensor-assisted multi-level codebook design[2]
  - Design a beam adaptation technique that can retain the codebook's efficiency and scalability while keeping a robust link even in the presence of client mobility
    - Multi-level Codebook Design: Multiple beamwidths in multiple directions
    - Sensor-Assisted Beamforming: Leverage client's sensors to know its mobility

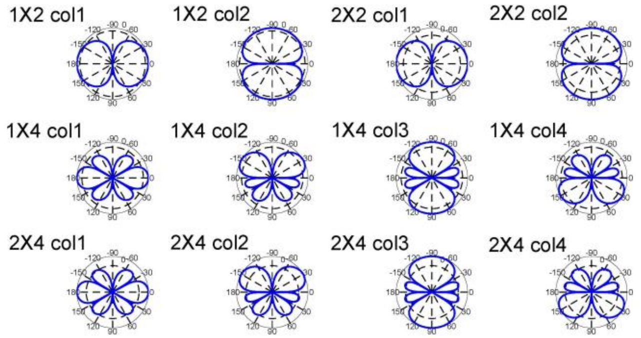




Antenna elements

(different colors indicate different weights)





Multi-level codebook
which can cover different beamforming angles using a variety of beamwidths and directive gain

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    - Multi-level Codebook Design: Multiple beamwidths in multiple directions
    - Sensor-Assisted Beamforming: Leverage client's sensors to know its mobility
      - Predicting Client's Mobility
        - Estimating the AP-client distance
        - Estimating the heading direction
        - Estimating the distance travelled by the mobile node
      - Pre-defined trajectories
      - Calculate heading direction and distance travelled
        - accelerometer, magnetometer (sampling frequency of 20 Hz)

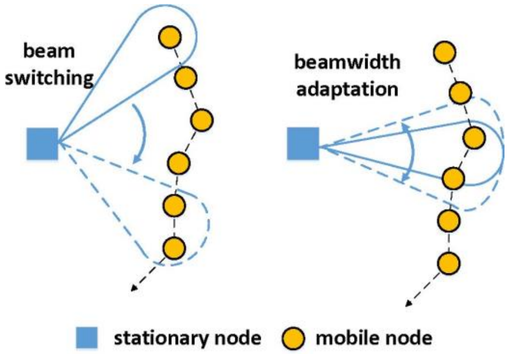
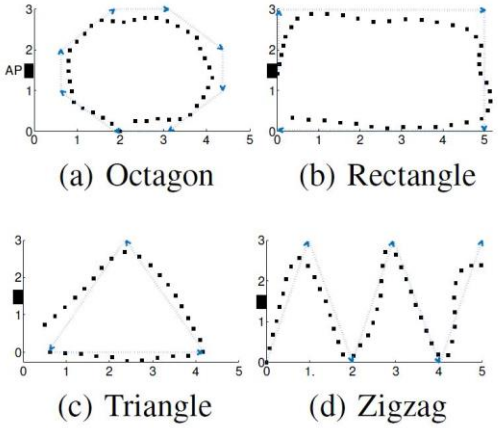


TABLE I: Percentage of connected time for real mobility traces

Trace shape	True location	Sensor-predicted location
Octagon	84.47%	89.38%
Rectangle	87.7%	89.33%
Triangle	85.83%	86.38%
Zigzag	71.42%	72.92%



Sensor data (black dotted line) and ground truth (blue dotted arrow) of four pre-defined trajectories

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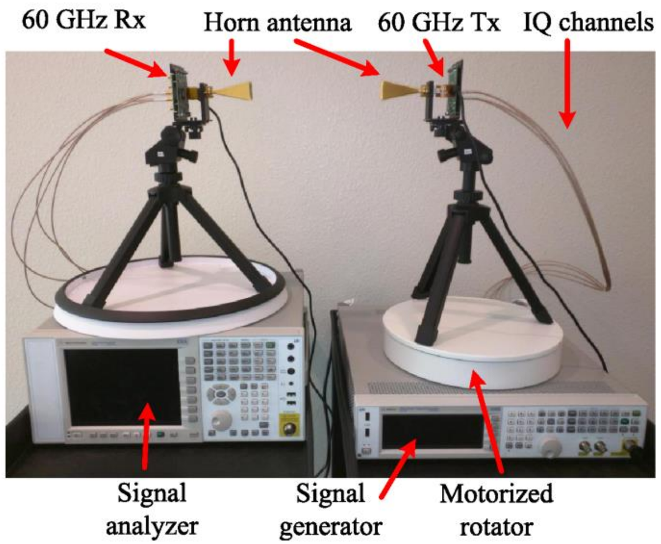
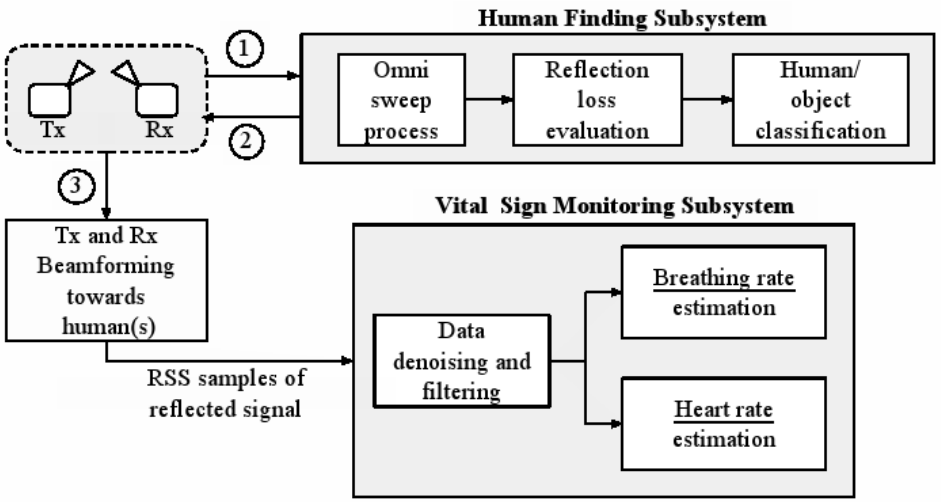
- Challenges of 60 GHz mmWave networks
  - Human Blockage
    - 60 GHz access point deployment
  - Node Mobility
    - 60 GHz phased array codebook design

- Applications of 60 GHz mmWave sensing
  - Healthcare
    - Vital sign and sleep monitoring
  - Smart Agriculture
    - Estimation of sugar content in fruits

- Applications of 60 GHz mmWave sensing
  - Healthcare
    - Continuous and ubiquitous monitoring of person's vital signs
    - Wearable devices are required to be connected to the human's body at all times
    - mmWave signals reflected off a human body can accurately represent minute chest motion necessary to estimate human's breathing and heart rate
    - The directional nature allows higher spatial reuse where multiple human subjects can be monitored in parallel within a room
  - Design a system that uses 60 GHz mmWave signals for vital sign and sleep monitoring (mmVital)
  - Smart Agriculture
    - The rapid advancements in the Internet of Things (IoT) technologies have paved the way for smart agriculture
    - Significant efforts have been made to develop new approaches to monitor the fruit quality, such as Near Infrared (NIR) spectroscopy, laser imaging, etc.
    - Estimating the quality of a fruit and predicting the precise time of consumption are also important for consumers
    - The existing approaches either rely on specialized, expensive devices or require invasive testing, making them infeasible to be used by consumers
  - Investigate the feasibility of using 60 GHz mmWave signal for non-invasive estimation of sugar content in fruits

- Vital sign and sleep monitoring using mmWave[3]
  - The reflection-based monitoring is robust to different incident angles of signal onto the human body and different postures
  - Before starting the vital signs monitoring, it is first required to find the human in the vicinity of Tx and Rx
  - Regarding monitoring multiple people in parallel, relative position of multiple humans result in many complex reflection scenarios





[3] Yang, Z., Pathak, P. H., Zeng, Y., Liran, X., & Mohapatra, P. (2017). Vital sign and sleep monitoring using millimeter wave. ACM Transactions on Sensor Networks (TOSN), 13(2), 1-32.

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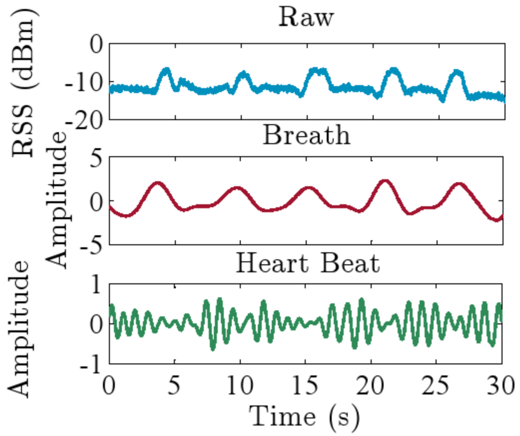

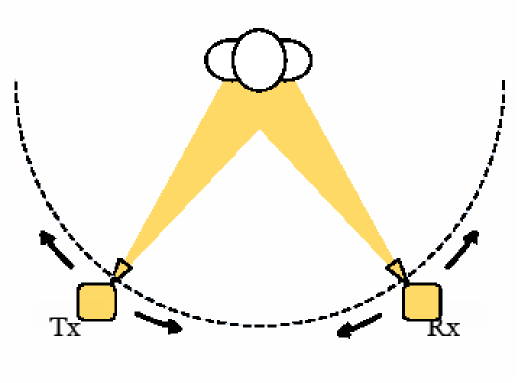

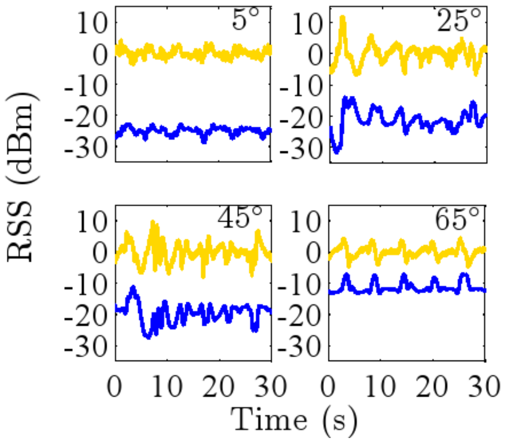

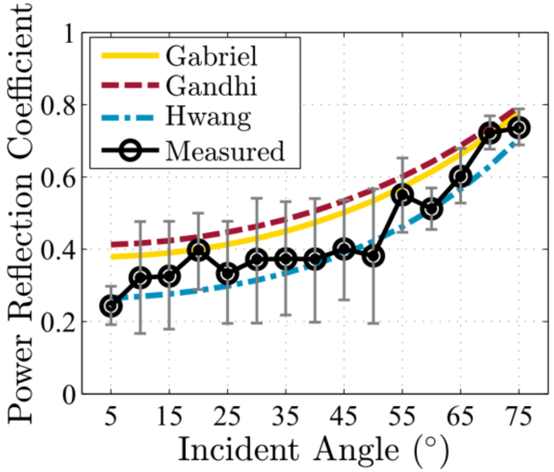

Reflection Coefficient

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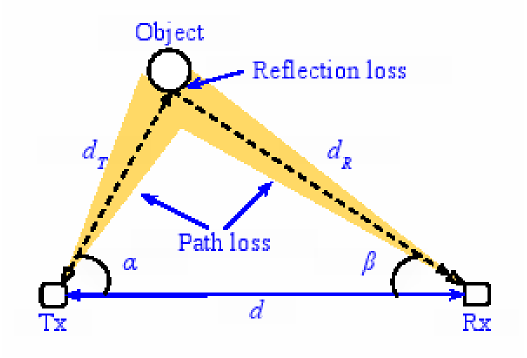

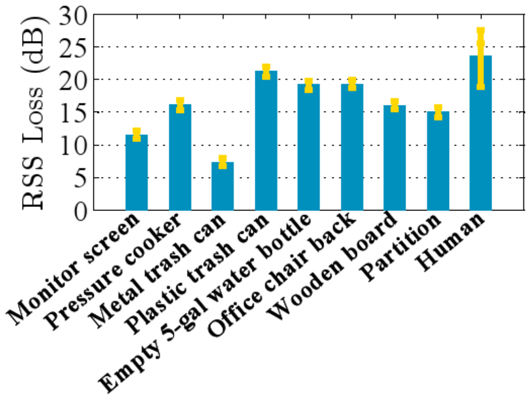

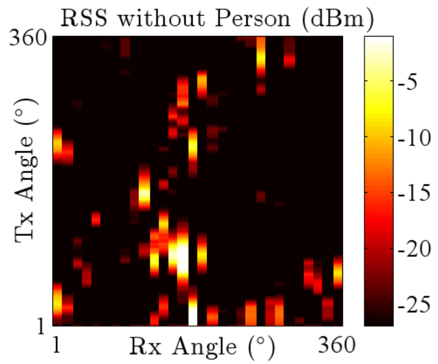

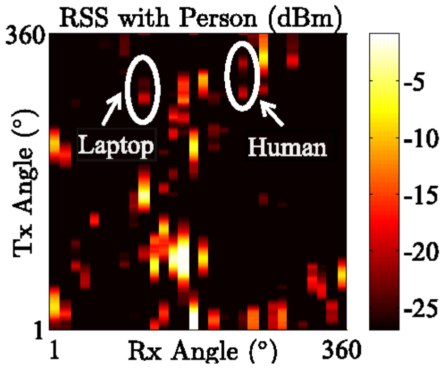

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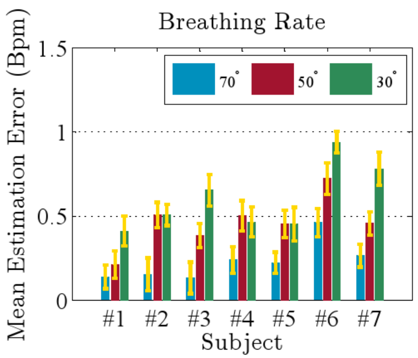

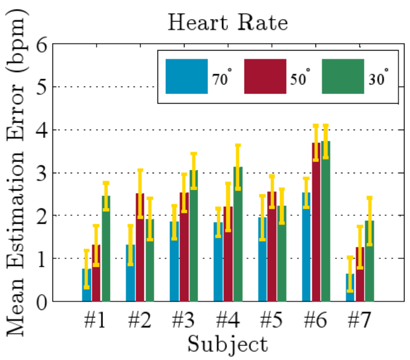

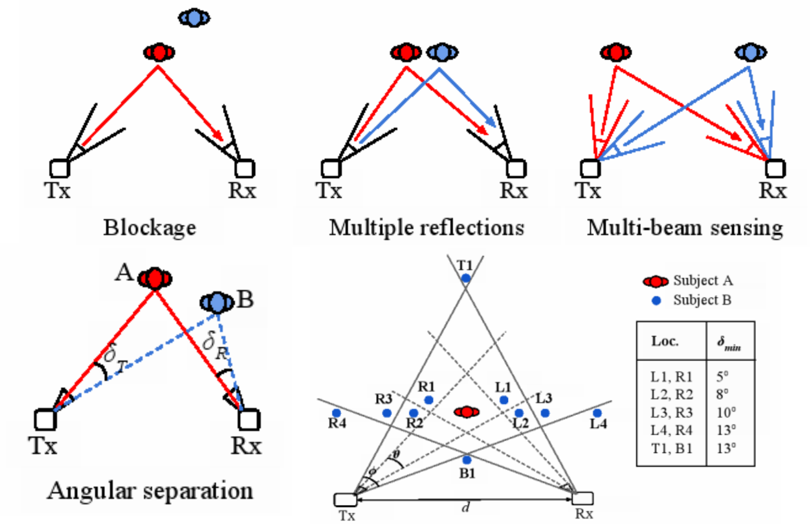

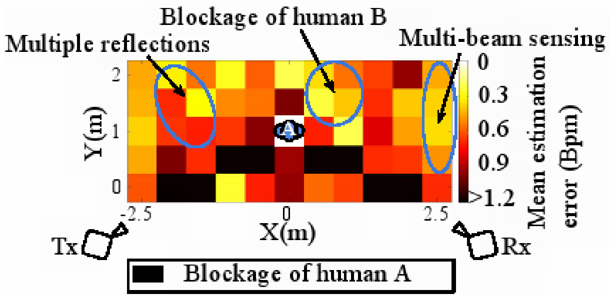

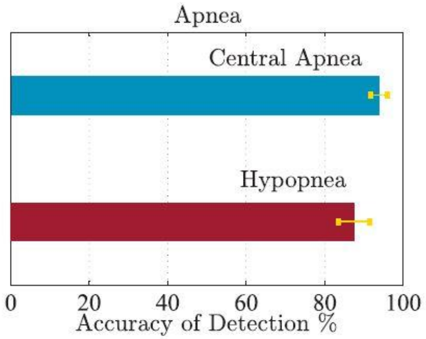

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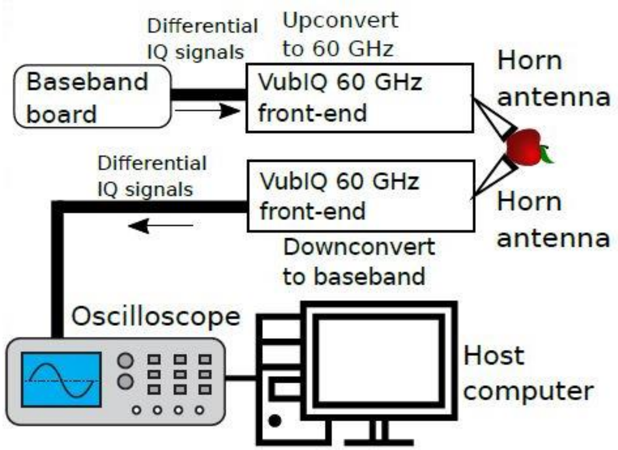
- Non-invasive estimation of sugar content in fruits[4]
  - It is feasible to use 60 GHz mmWave signal reflection to estimate sugar content
  - How varying levels of SSC affect the signal permittivity and in turn change the reflection
  - An extensive evaluation of our proposed technique using different fruit samples



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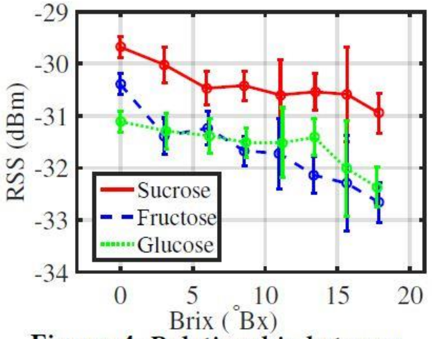

Figure 4: Relationship between Brix and RSS for three simple sugar solutions

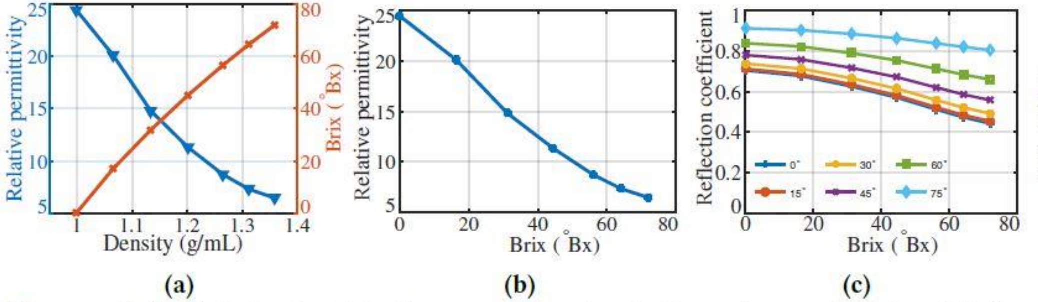

Figure 6: (a-b) Relationship between density, Brix and permittivity (c) The relationship between Brix and reflection coefficient remains unchanged for different incident angles

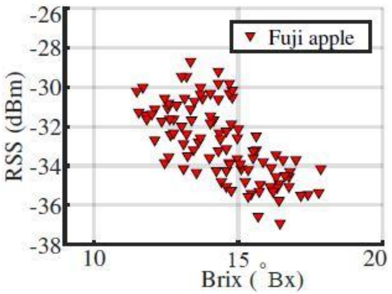

Figure 7: RSS variation for Fuji apple samples with different Brix values

- How varying levels of SSC affect the signal permittivity and in turn change the reflection
- An extensive evaluation of our proposed technique using different fruit samples

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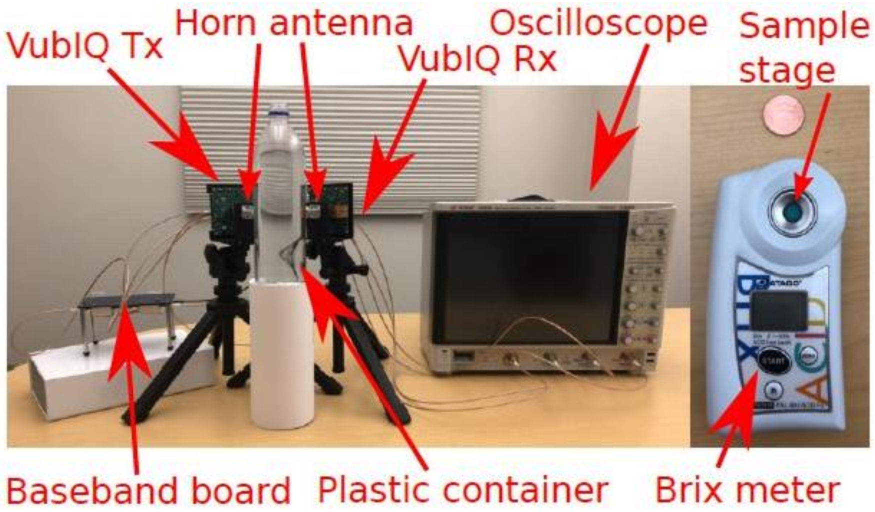

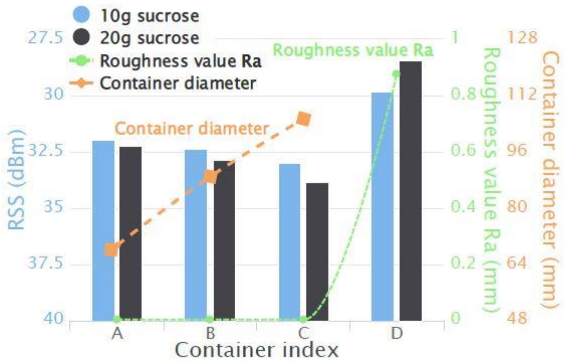

Figure 8: Impact of diameter and roughness on RSS

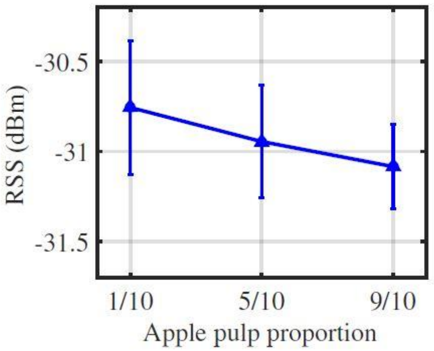

Figure 9: Relationship of different pulp portion and RSS (Brix set to 13.2)

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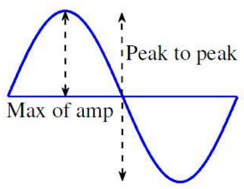
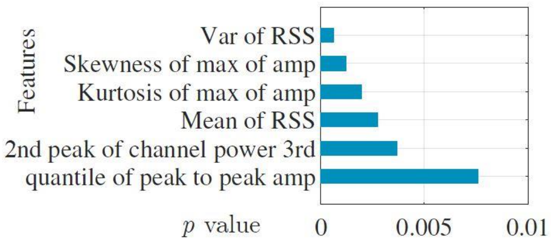
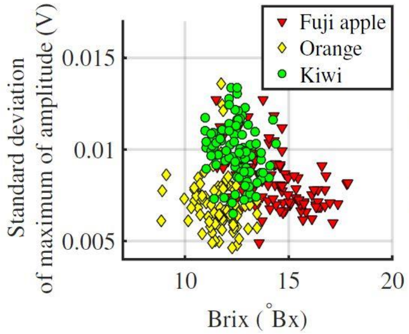
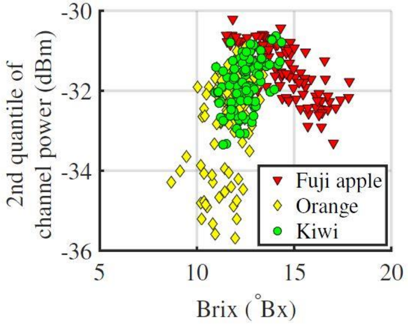


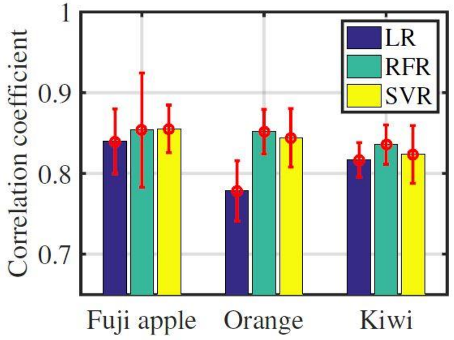
(a) Maximum and peak-to-peak amplitude of raw signal



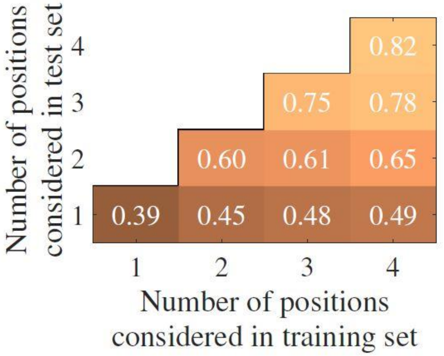
(b) Selected statistical features calculated over raw signal and *p*-values using the Firefly search method







(a) Results of correlation coefficients using different regression algorithms



(a) Correlation coeff. with varying number of measured positions considered in training and testing

[4] Yang, Z., Pathak, P. H., Sha, M., Zhu, T., Gan, J., Hu, P., & Mohapatra, P. (2019, April). On the feasibility of estimating soluble sugar content using millimeter-wave. In Proceedings of the International Conference on Internet of Things Design and Implementation (pp. 13-24).

Thank You!