Network Slicing

in 5G Networks

Muhammad Asif Khan, PhD
Qatar Mobility Innovations Center (QMIC)

Topics

- Definition
- architecture
- Benefits
- Types
- Requirements
- Attributes
- Related Research Work

Network Slicing

- "A network slice is a logical network that provides specific network capabilities and network characteristics." (**3GPP TS 23.501**).

3GPP

- **3rd Generation Partnership Project (3GPP)**
  - the largest telecommunication standards body with 7 member organizations and >500 partners including device and chip makers, service providers, and research institutions. Develop standards in the form of "**Releases**".
  - Notable standards: WCDMA, HSPA, LTE, LTE-Advanced.
- **International Telecommunication Union (ITU)**
  - A United Nations' entity
  - Sets the main visions and goals, provide guidance in the form of "**Recommendations**".

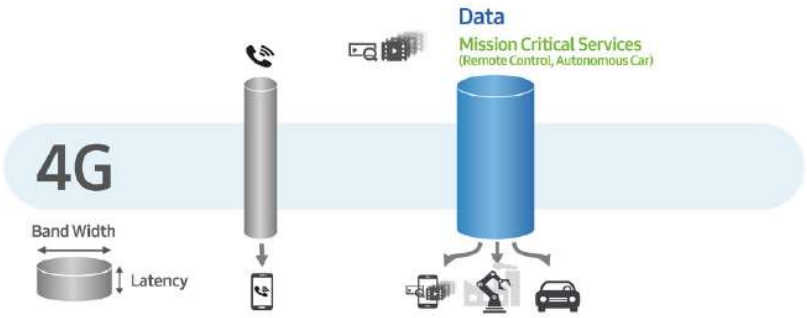
Network Slicing

- "A network slice is a logical network that provides specific network capabilities and network characteristics." (**3GPP TS 23.501**).

- **Network slicing allows the operator to provide customized networks.**
  - Customized functionalities - priority, charging, policy control, security, and mobility.
  - Customized performance - latency, mobility, availability, reliability and data rates.
  - Restricted access - MPS users, public safety users, corporate customers, roamers, or hosting an MVNO.

- Network slicing enables virtual pipelines for each data service to ensure QoS in 5G networks.

Network slicing



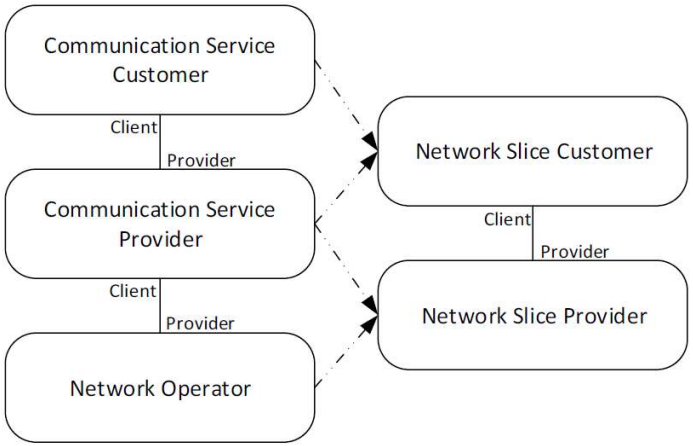
a single pipeline for data services (e.g., video streaming, Internet surfing and navigation).

virtual data pipelines for each data service.

Architecture

- **Two parties:**
  - NSP - Network Slice Provider (can span across multiple domains (access, core, transport)
  - NSC - Network Slice Customer (dedicated and/or shared resources e.g., functionalities, storage, compute)

- **Four Roles:**
  - CSP - Designs, builds and operates its communication services.
  - NOP - Designs, builds and operates its networks.
  - NSC – A CSP or CSC who uses Network Slice as a Service.
  - NSP – A CSP or NOP who provides Network Slice as a Service.



Why network slicing?

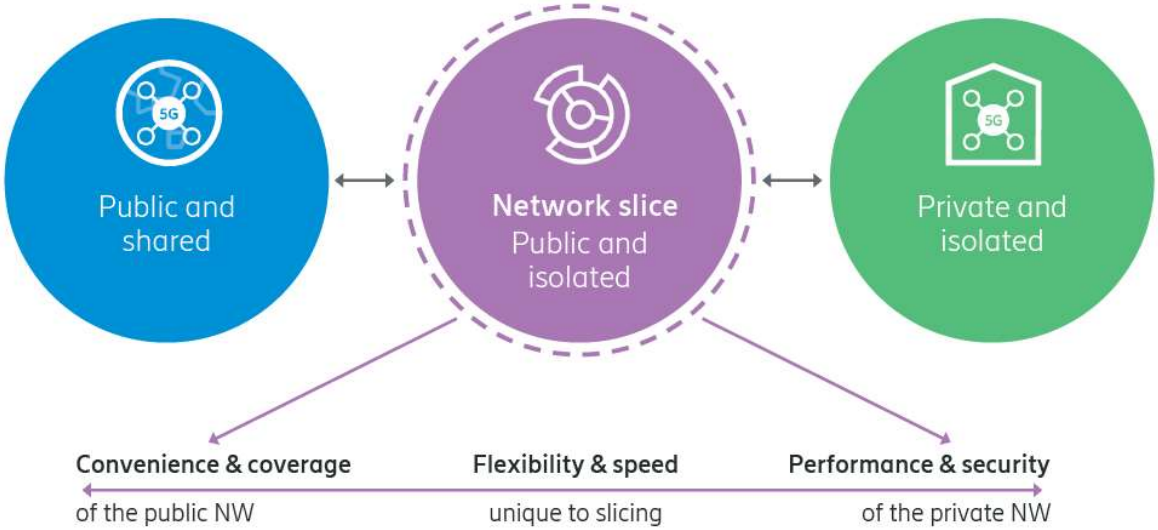
- Stringent KPI requirements in 6G networks (expected to debut by 2030)
  - 2-100 Gbps user data rate
  - 0.1 ms end-to-end latency
  - 10 million devices/km^2
- Support for wide range of devices and services
  - IoT sensors - traffic in a few bits, and network does not need overhead signaling
  - Streaming videos – bulk of data with low latency requirements
  - Cloud applications e.g., robotics - high bandwidth required on the uplink than downlink)

Benefits of network slicing

- **Multi-tenancy**
  - Sharing the common physical network infrastructure by multiple virtual networks (MVN) reduces capital expenditure.
- **Service/Performance Isolation**
  - Network slices are constructed for different services to guarantee service requirements as per SLAs.
- **Flexibility**
  - Slice creation, modification, and deletion can be done anytime to dynamically meet users' requirements.
- **Security**
  - Isolate traffic to and from an organization to avoid data leakage.

Benefits of network slicing

A network slice is a public and isolated network.



Horizontal vs Vertical Slices

- **Horizontal network slicing**
  - resource sharing among different network nodes.
  - over-the-air resource sharing across network nodes.
  - enhance the capabilities of less capable network nodes.

- **Vertical network slicing**
  - resource sharing between different services and applications.
  - enhance QoS.

3GPP Network Slice Types

- 3GPP defines five slice/service types (SSTs). (Release 17 - Section 5.15)
  1. eMBB
  2. URLLC
  3. MIoT
  4. **V2X**
  5. **HMTC**

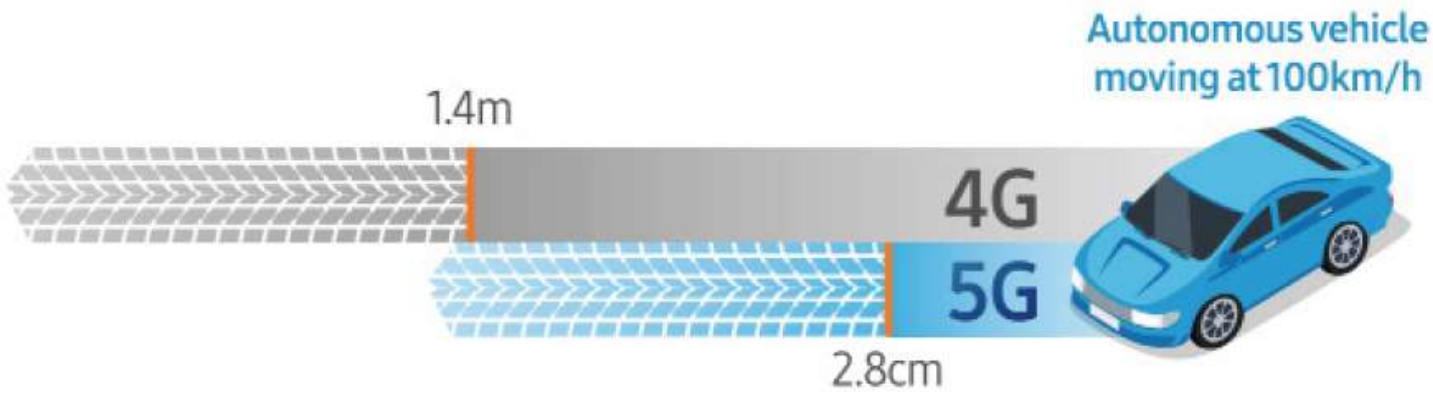
- Same set of features to different groups of users
- A single users can be part of one or more network slice instances simultaneously, regardless of if the user is 3GPP/N3GPP user.

Explaining "eMBB"

- **eMBB** - enhanced Mobile BroadBand
- Typical data rates from 100Mbps up to 20Gbps per user
- 100Mbps data speed at the cell edge (where user receive a weak signal).
- **Application:** High definition (HD) videos, virtual reality (VR), and augmented reality (AR).

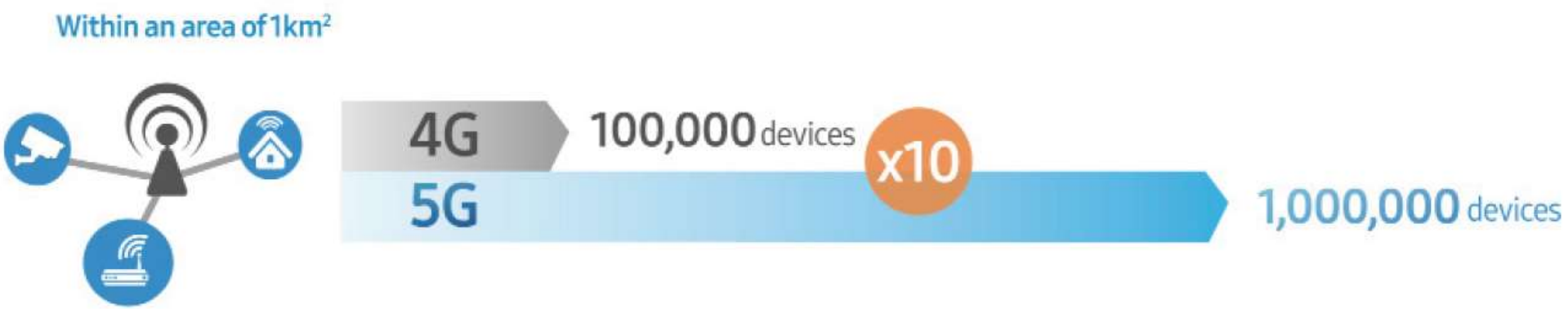
Explaining "URLLC"

- **URLLC** - Ultra Reliable and Low Latency Communications
- 1 millisecond latency (10ms in 4G)
- 99.99% reliability
- **Applications:** Remote robot control, smart health, autonomous vehicles, etc.



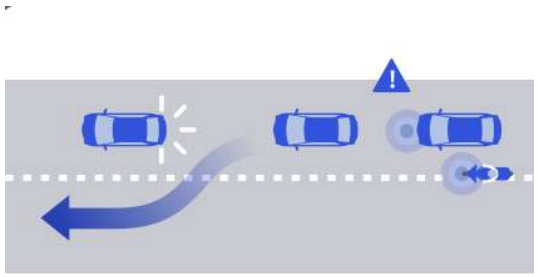
Explaining "mMTC"

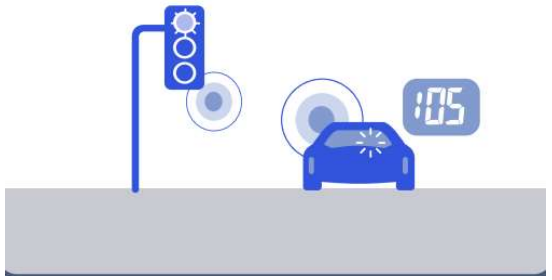
- **mMTC** - massive Machine Type Communications
- small packets, low-rate, uplink-centric transmission, tolerate high latency (~10s)
- 1 million IoT devices per Km^2 (10X more than 4G).
- **Applications**: smart buildings, smart HVAC, smart lighting, environmental monitoring, fire detection.



Explaining "V2X"

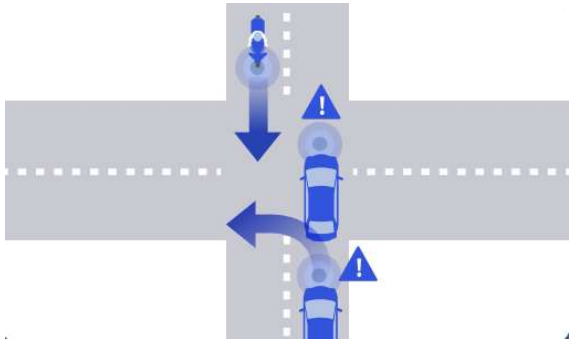
- **V2X** – Vehicle-to-everything (e.g., V2V , V2I, V2P, V2N)
- A customized slice for V2X services
- Distance-based multicast communication
- **Applications**: cooperative traffic management, electronic toll system, road safety, UAV communication





Explaining "HMTC"

- **HMTC** – High performance Machine-Type Communication
- Mixed requirements that do not fit into any of the particular slices e.g., large data (~eMBB), low latency (~URLLC), high density (~mMTC)
- delay <10ms, fixed position devices, density < 1000/km2, mission-critical support
- **Applications**: industrial automation, public safety, remote robotic surgery



Network Slicing Requirements in 5G

The 5G system allows an MNOs (mobile network operators) to:

- create, modify, and delete a network slice.
- define and update the set of services and capabilities in the slice.
- assign a user to a slice, move it to another slice, and remove it from a slice.
- assign a user to a network slice with the needed services or to a default network slice.
- assign a user to more than one slices simultaneously in the same operator network.
- scale a network slice without impacting the “minimum available capacity” of other network slices.
- define a priority order between different multiple competing (for resources) network slices on the same network.
- restrict geographical boundaries for a slice.
- limit a user to only receiving service from an authorized slice.
- traffic and services in one network slice shall have no impact on traffic and services in other network slices in the same network.
- creation, modification, and deletion of a network slice shall have no or minimal impact on traffic and services in other network slices in the same network.

Slice Attributes Categories

- **Character attributes**
  - Performance related: Specify KPIs e.g., throughput, latency, etc.
  - Function related: e.g., positioning, prediction
  - Core & management related: how to control and manage the slice.
- **Scalability attributes**
  - e.g., number of UEs, area of service.
- **Exposure attributes**
  - KPI – provide performance capabilities.
  - API – provide an API to NSC to access slice capabilities.

Slice attributes

- Availability - amount of time the end-to-end communication service is delivered according to an agreed QoS.
- Area of service – e.g., country, states, altitude (UAS)
- Maximum no. of UEs and UE density (devices per Km^2)
- Delay tolerance – applies to 3GPP access types.
- Deterministic communication – FFS (reserved).
- Periodicity – To support periodic communication E.g., temperature sensor (600s)
- Throughput Per slice - aggregated data rate in downlink/uplink for all UEs in the slice.
- Throughput per UE
- Energy efficiency – defined in 3GPP Release 17 TS 28.554 Section 6.7
- Group communication support – Single cell P-MP, Broadcast, Multicast, Unicast
- Isolation level – FFS (reserved).

Slice attributes

- Maximum packet size – To achieve latency, supporting large no. of devices in URLLC and MIoT.
- Mission Critical Support - priority of the network slice relative to others
- Performance Monitoring – Capability for NSC and NOP to monitor KQIs and KPIs.
- Performance prediction – Predictive QoS of services offered by NSP. (More by 5GAA and ITU-T FG ML5G).
- Positioning Support – Geolocalization (via CID, E-CID, OTDOA, RF fingerprinting, AECID).
- Radio Spectrum – Spectrum in which the NS should operate.
- Simultaneous slice usage – if a UE can be part of this and another slice at the same time.
- Slice QoS – applies to 3GPP 5QIs.
- Supported Device velocity – Maximum supported at which the QoS can be achieved.
- V2X Communication – support V2X or not? applies to 3GPP access type only
- NSSAA (NS authentication and authorization) - devices need to be also authenticated and authorized?

Network Slicing Enablers

- Network slicing requires end-to-end implementation i.e., RAN to Core network (CN).
- Slicing at RAN:
  - resource allocation to users based in slice not on the physical cell e.g., admission control, load balancing
  - Slice on/off at each BS.
  - Network operation more service/traffic/user oriented instead of physical cell oriented.

- Slicing at CN - Software Defined Networks (SDN) and Network Functions Virtualization (NFV).
  - **SDN** separate control and data planes and control plan can be programmed via APIs to deploy, operate and manage networks.
  - **NFV** virtualize network functions into software applications running on servers or VMs.
  - **SDN+NFV** virtualize the network elements and functions to enable network slicing.

Literature Review

- Network slicing and edge computing

Network slicing and edge computing

- Sladana et al., Joint Wireless and Edge Computing Resource Management With Dynamic Network Slice Selection, IEEE/ACM Transactions on Networking, 2022
- Minimize the aggregate completion time of computational tasks across all WDs.
- Joint Slice Selection and Edge Resource Management (JSS-ERM)

- **Inter-slice radio allocation policy** - AP resource shared by all slices.
- **Intra-slice radio allocation policy** - Slice resources shared by WDs.

- The problem is Mixed Integer Program → NP-hard
- Approximation → **Choose Offloading Slice (COS)** algorithm.

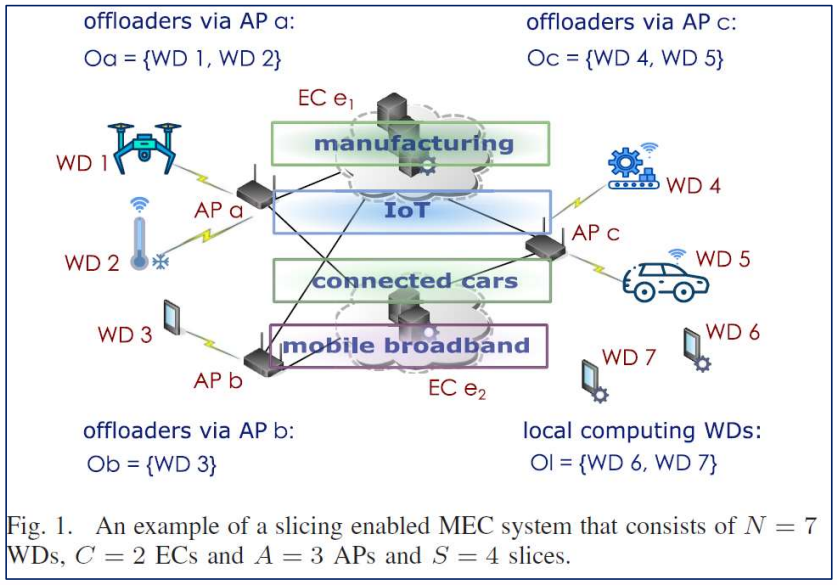


Fig. 1. An example of a slicing enabled MEC system that consists of $N = 7$ WDs, $C = 2$ ECs and $A = 3$ APs and $S = 4$ slices.

References

- Who & How: Making 5G NR Standards, Samsung White paper https://images.samsung.com/is/content/samsung/p5/global/business/networks/insights/white-paper/who-and-how_making-5g-nr-standards/who-and-how_making-5g-nr-standards.pdf
- Ericsson and Arthur D. Little, Network slicing: A go-to-market guide to capture the high revenue potential, Ericson White paper

The END

Questions?