5G: Fundamentals and Deployment Considerations

A 5G Tutorial at ISART 2020

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Reference:

Nishith D. Tripathi and Jeffrey H. Reed, “5G Cellular Communications- Journey and Destination,” The Wireless University, https://thewirelessuniversity.com/ , April 2019.

About Us: Dr. Jeff Reed

Willis G. Worcester Professor at Virginia Tech

- Founder of *Wireless @ Virginia Tech and* Fellow to the IEEE
- Founding Faculty member of the Ted and Karyn Hume Center for National Security and Technology
- *Software Radio: A Modern Approach to Radio Design*
- Co-founder of Cognitive Radio Technologies (CRT), Federated Wireless, and PFP Cybersecurity
- International Achievement Award by the Wireless Innovations Forum

About Us: Dr. Nishith Tripathi

Samsung Research America
Adjunct Faculty Member at Virginia Tech

- **The world's FIRST multimedia book on 5G!**
- Textbook on Cellular Communications
- 23 years in wireless communications
- Expertise: 5G, LTE-Advanced Pro, LTE-Advanced, LTE, IMS
- Pioneering work on applications of AI in cellular networks
- Contributor to FCC, GSMA, Scientific American, CTIA, CNN, EE Times University

Tutorial Goals

- Give examples of services targeted by 5G
- Specify the performance goals for 5G in terms of data rates and latency
- Illustrate the overall 5G system architecture
- Explain Network Slicing, Service Based Architecture (SBA), and Multi-access Edge Computing (MEC)
- Summarize key characteristics of the New Radio (NR) air interface
- Differentiate between Standalone (SA) NR and Non-Standalone (NSA) NR
- Discuss the challenges of different spectrum bands
- Mention the roles of Network Functions Virtualization (NFV) and Software Defined Networking (SDN)

5G Fundamentals: Target Services & Performance Goals

Evolution to 5G

Before 5G:

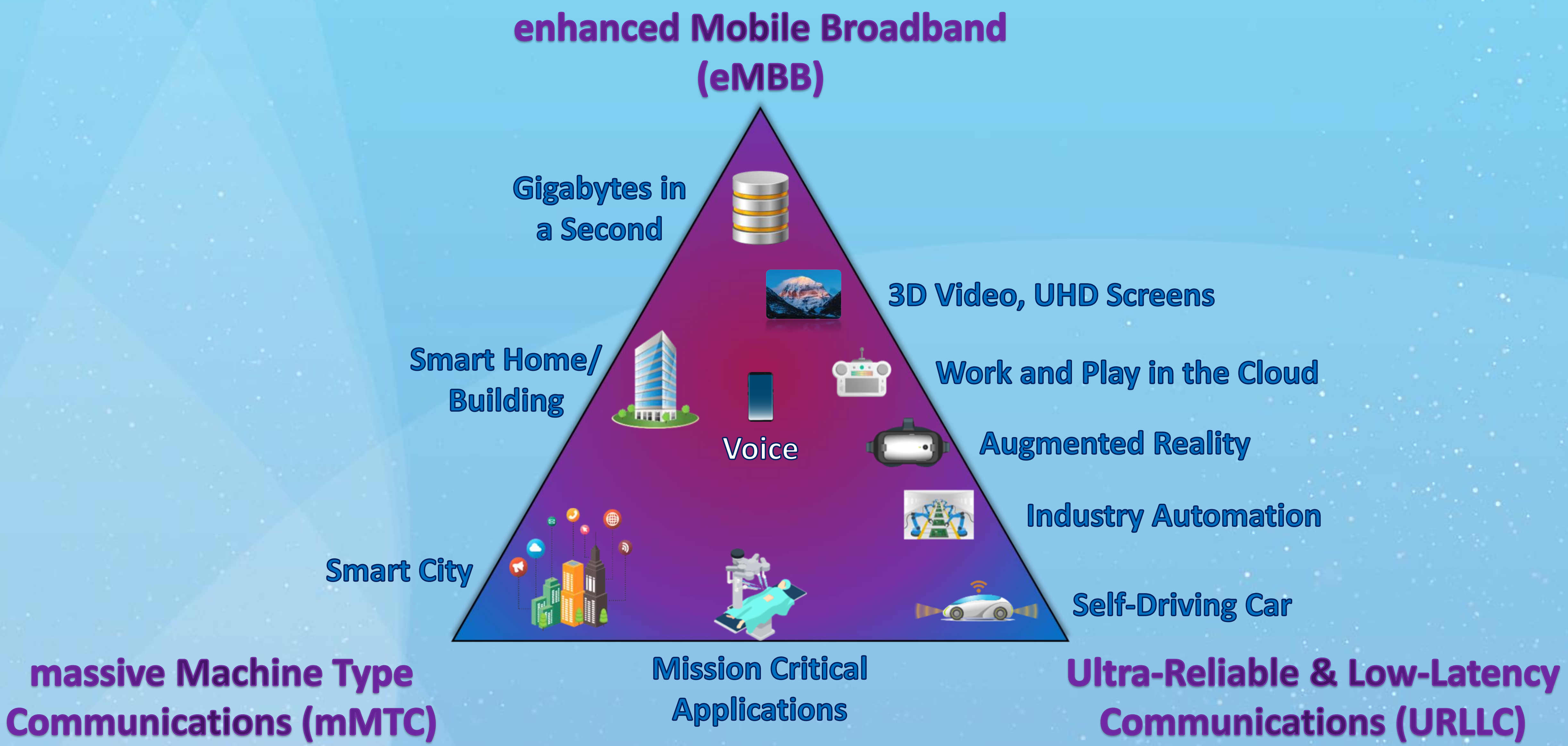
- Cellular technologies have evolved from the first-generation (1G) to the fifth-generation (5G) in about four decades
- 4G Long Term Evolution (LTE) is a globally-deployed mobile broadband technology
- The standards organization, 3GPP (Third Generation Partnership Project), defined 4G LTE in Release 8 in 2008

The 5G Era:

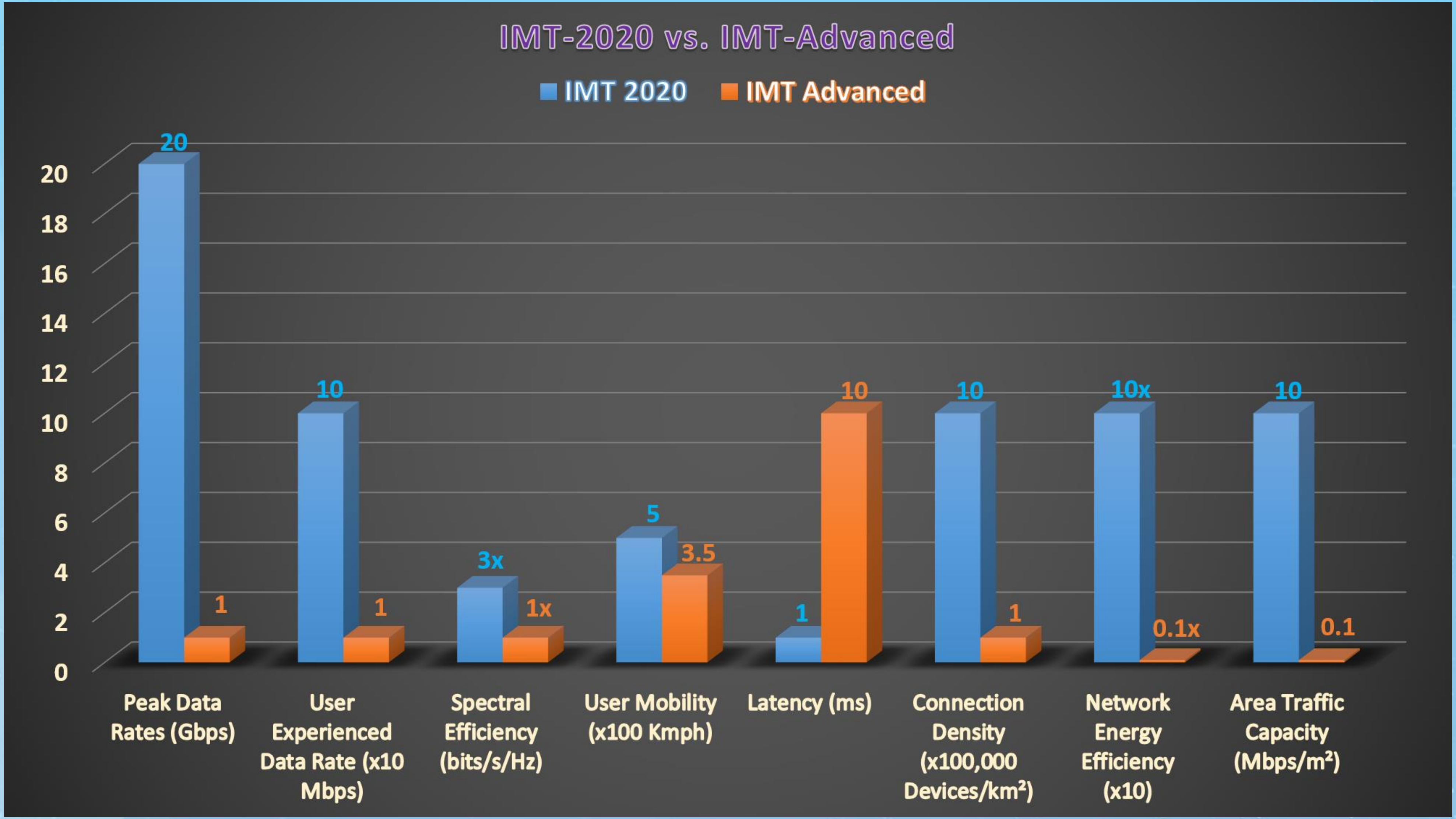
- 5G offers unprecedented performance capabilities and flexibility
- 3GPP defined "5G Phase 1" in Release 15 in 2018
- 3GPP finalized "5G Phase 2" in Release 16 in July 2020

More info about standards in another ISART tutorial

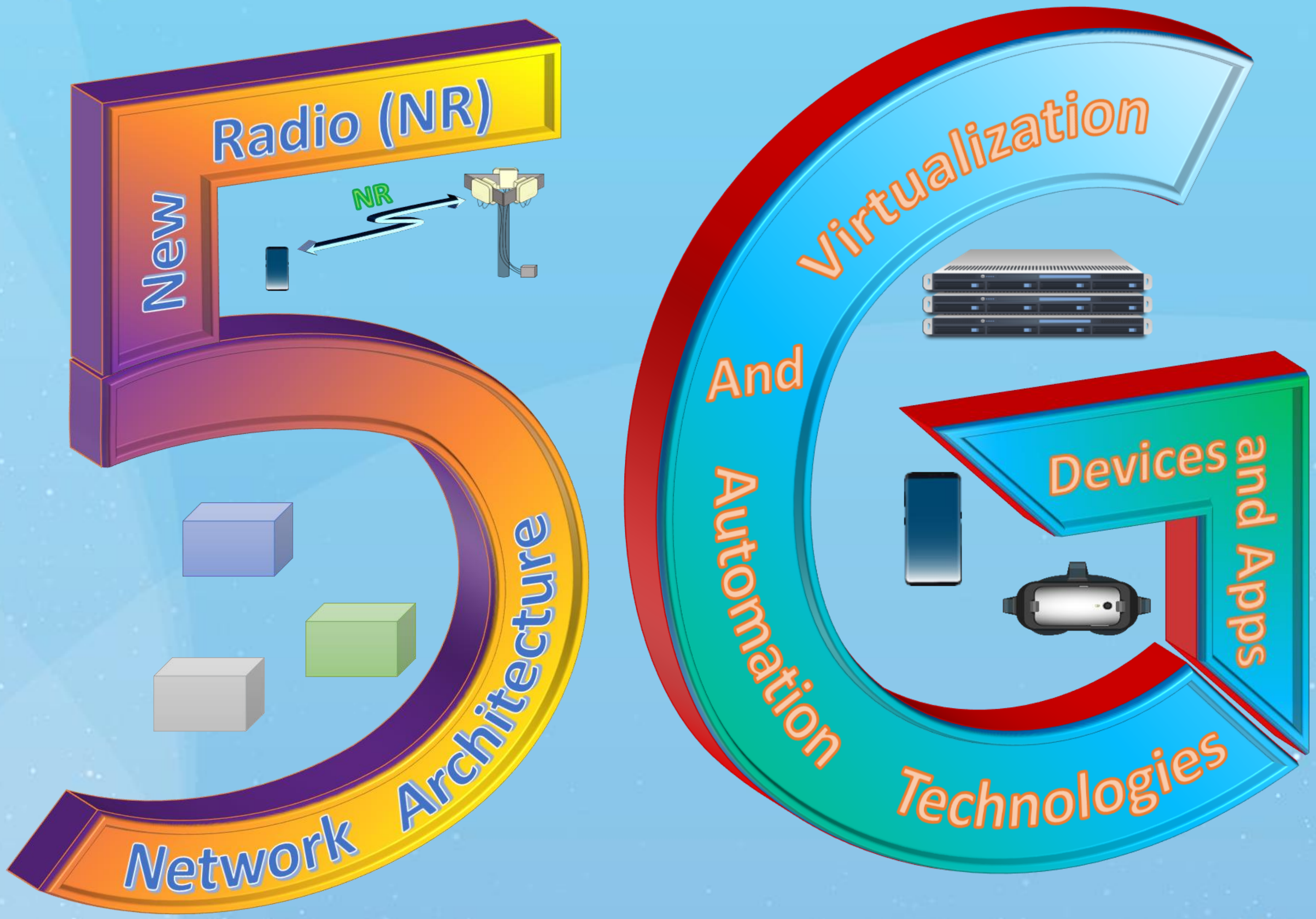
What can 5G Do for Us? The ITU Triangle!



5G vs. 4G: Performance Goals in a Nutshell!



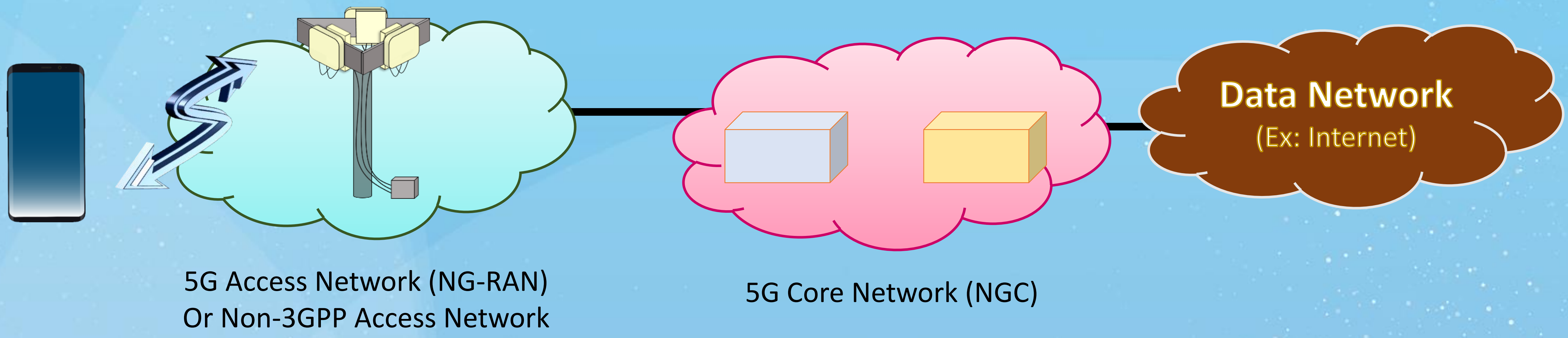
So, How Do We Build 5G?



5G Fundamentals:
System Architecture

Some Definitions…

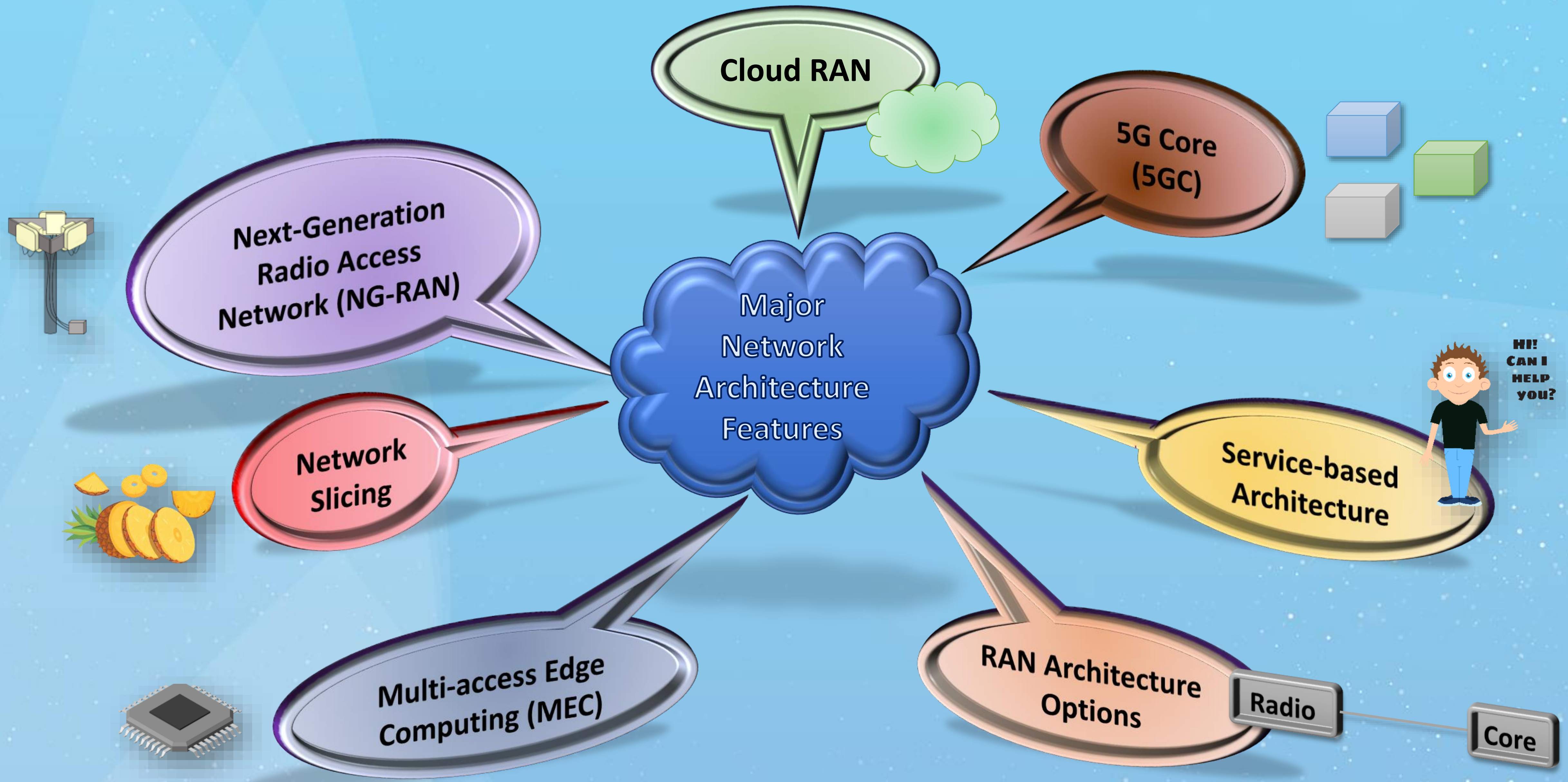
5G Architecture Related Terms



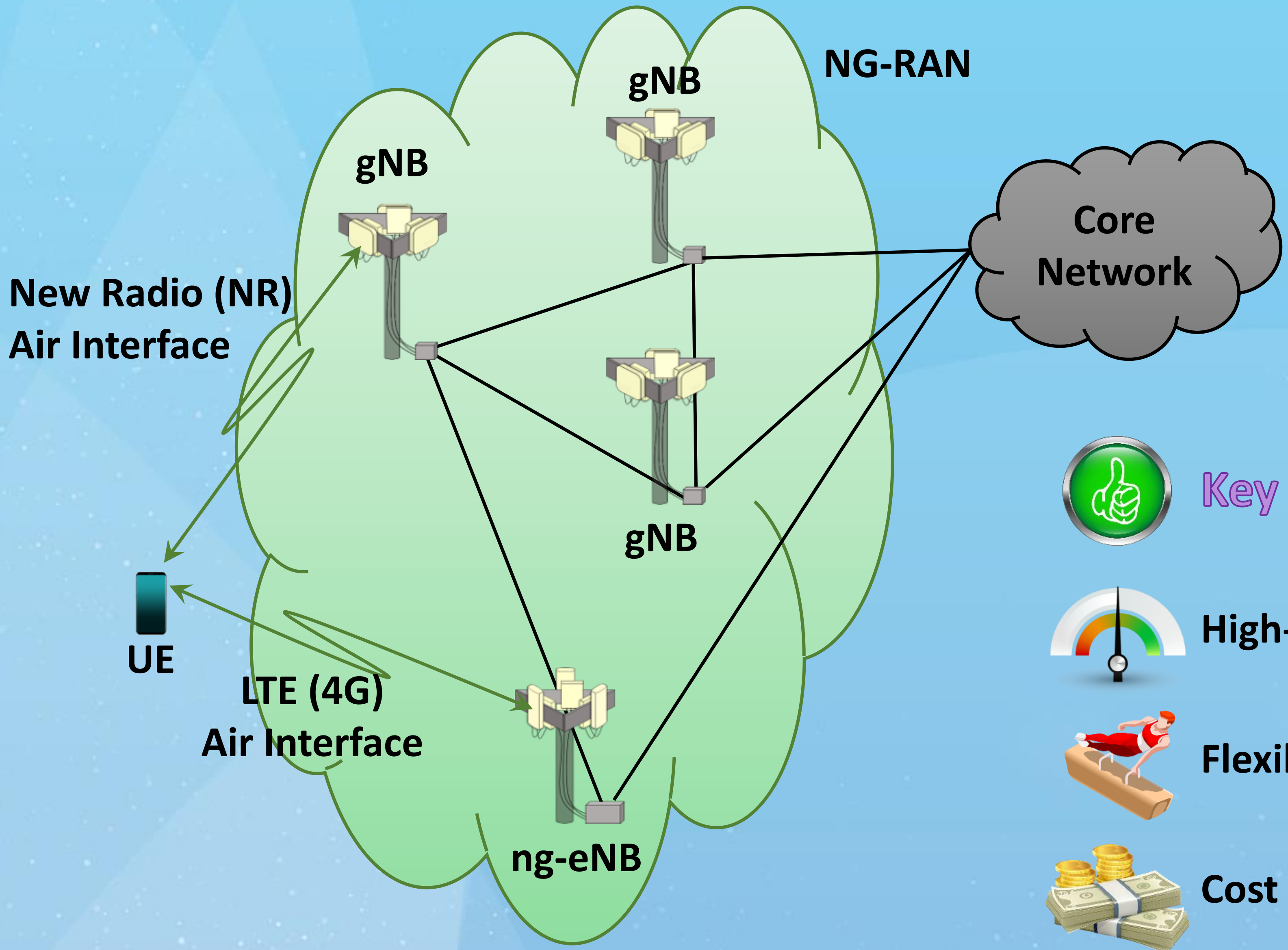
UE + 5G Access Network + 5G Core Network = 5G System

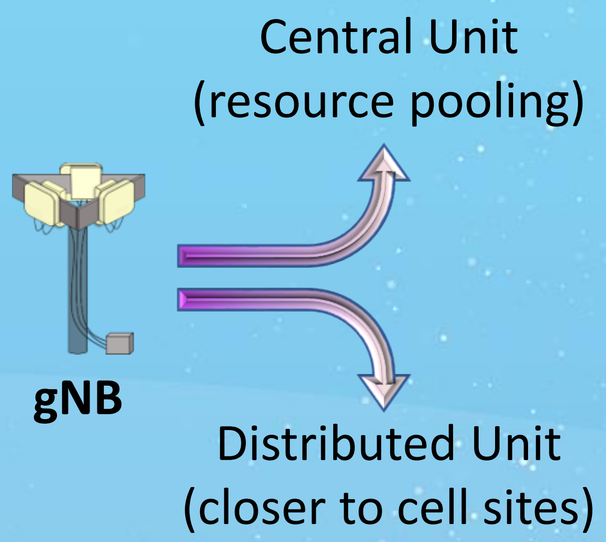
Network Function: 3GPP-defined/adopted processing function in the network

Network Features



Next-Generation Radio Access Networks (NG-RAN)

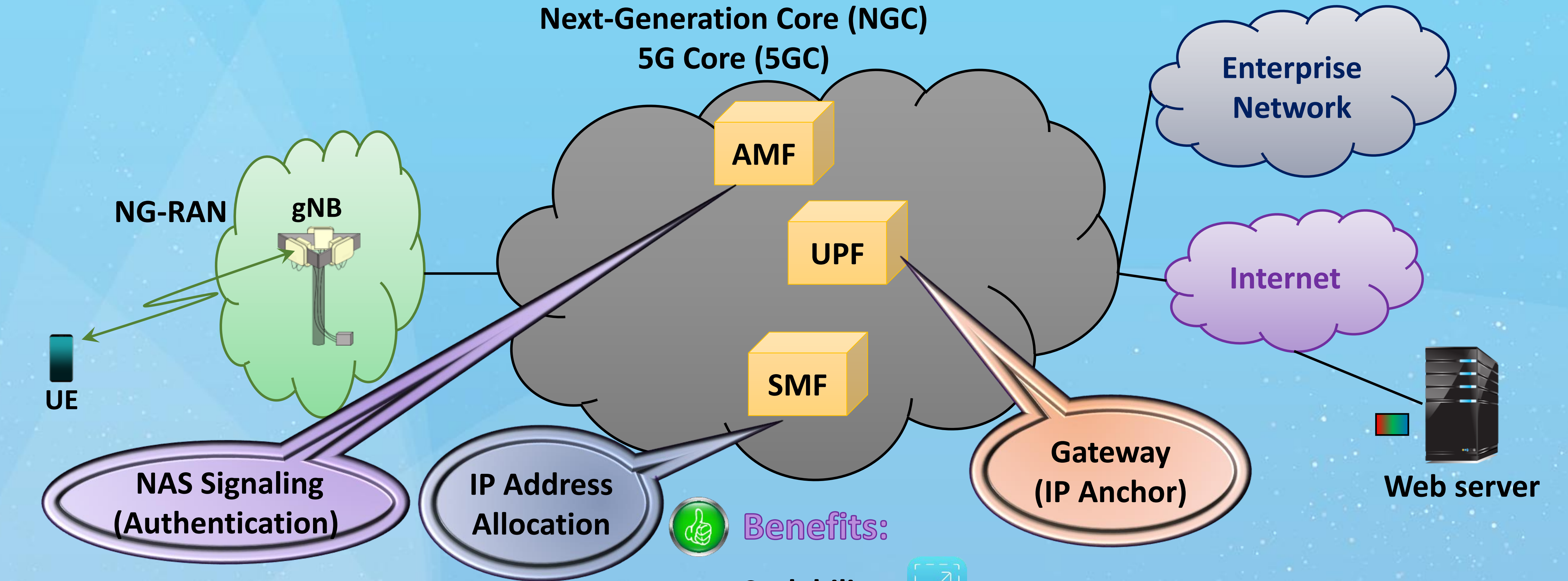




Key Benefits:

- **High-performance air interface**
- **Flexibility of deployment**
- **Cost Savings**

5G Core (5GC)



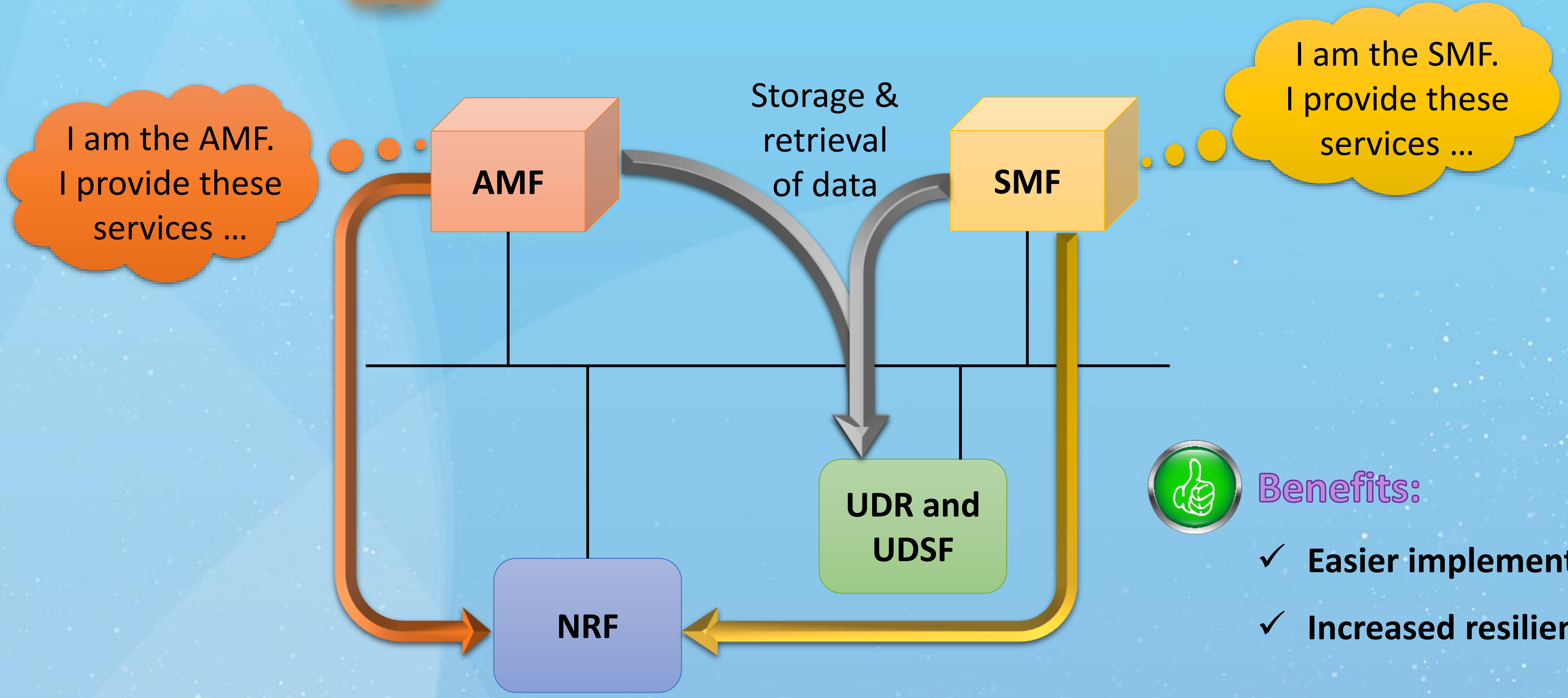
Modularization: More than a dozen different elements ("network functions")

Benefits:

- **Scalability**
- **Flexibility- network slicing, unknown services, ...**
- **Cost savings**

Service-based Architecture (SBA)

Each network element or node ("network function"):
A set of services

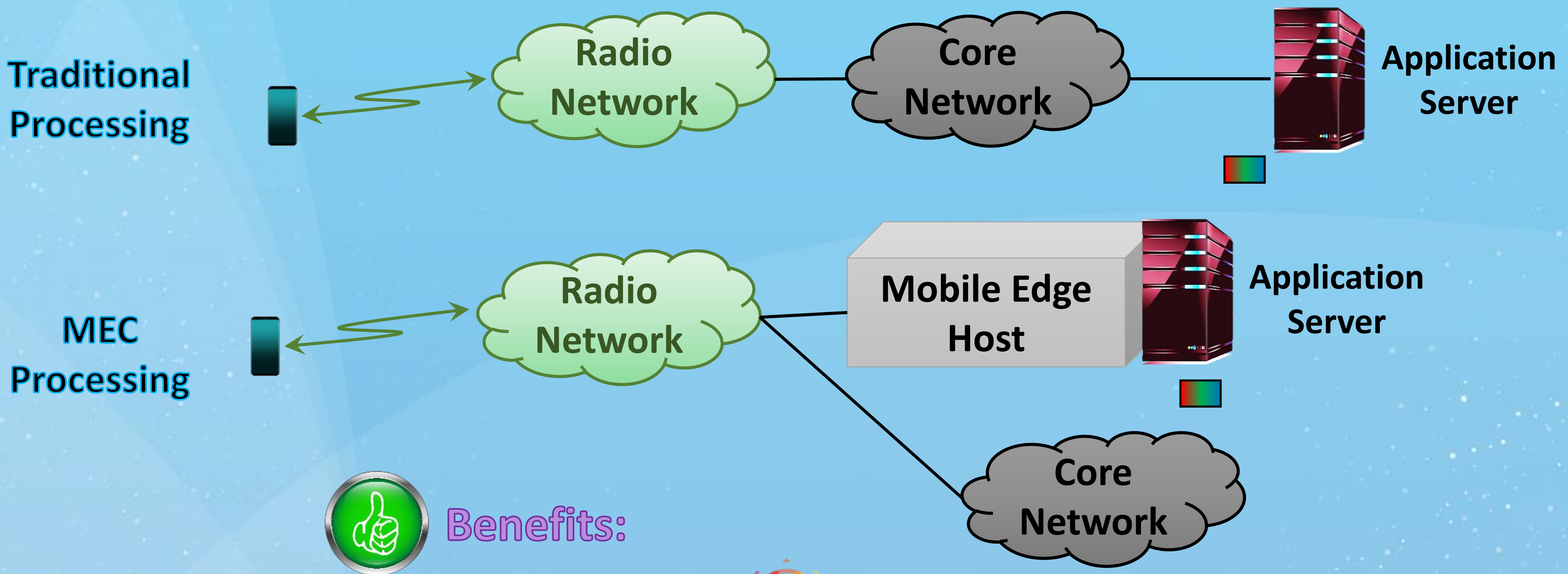


Benefits:

- ✓ **Easier implementation**
- ✓ **Increased resilience**

Multi-access Edge Computing (MEC)

Bring the processing closer to the end user/device

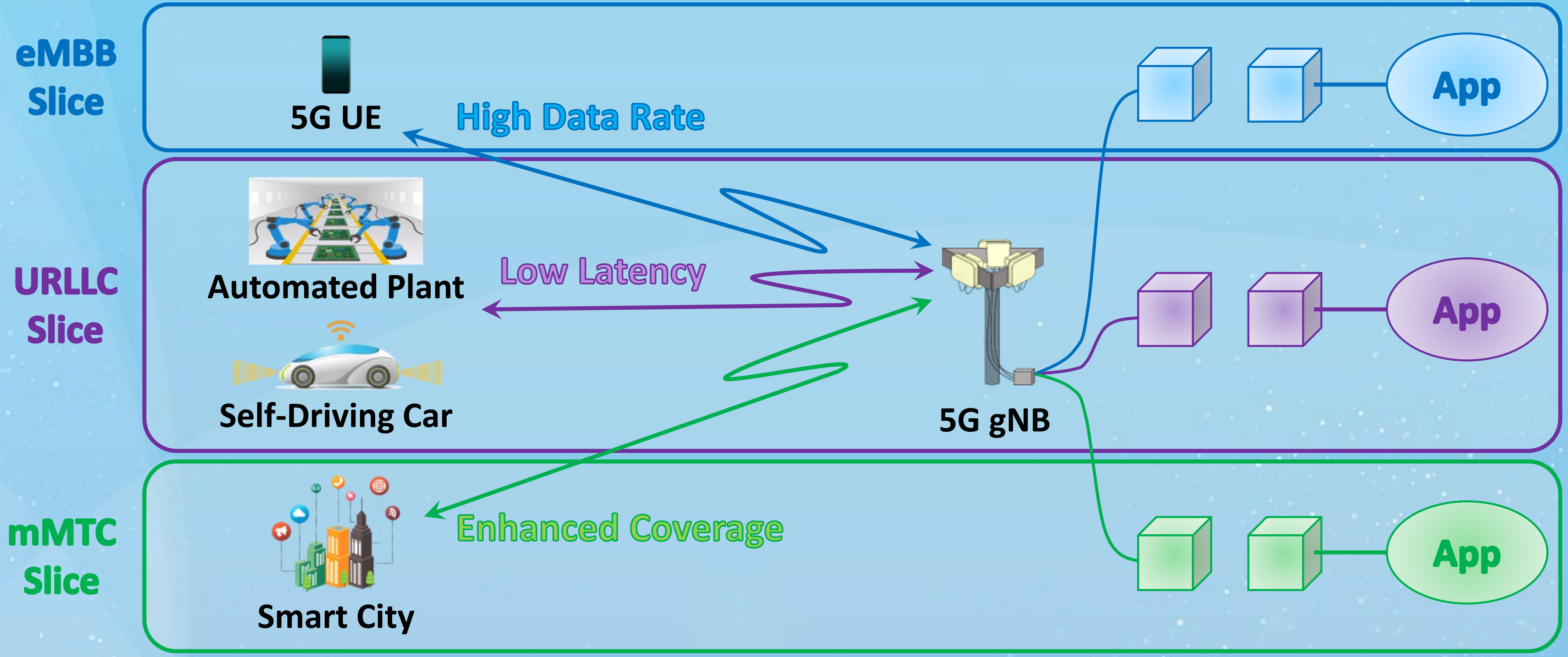


Benefits:

- Reduced latency
- Less traffic in the backhaul and core networks
- Location-aware and RAN-aware services

Network Slicing

Provide custom QoS for a variety of services and users/customers



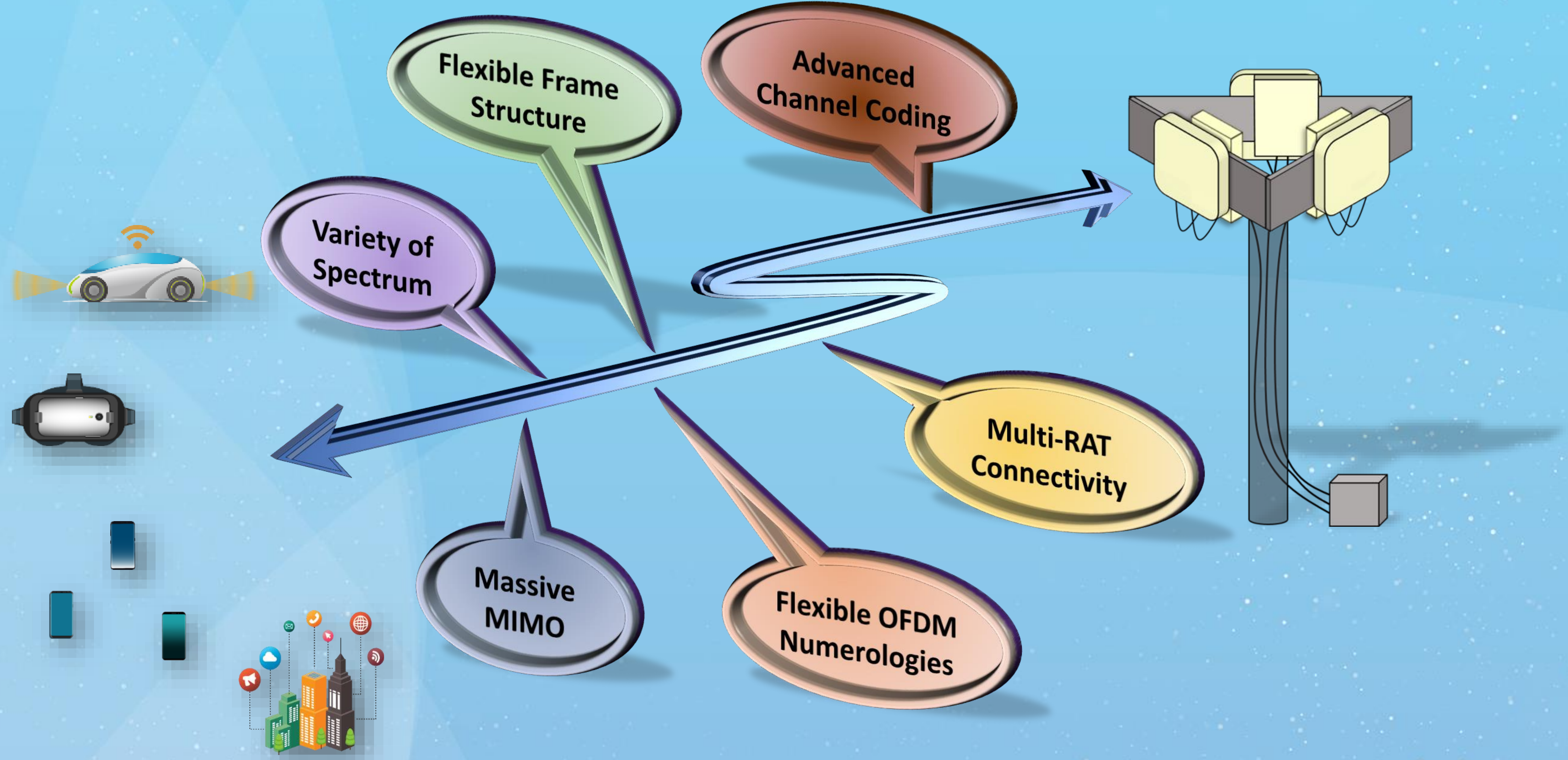
Create different logical networks by using the same physical infrastructure

Benefits:

- **Custom QoS**
- **Cost savings- use only required functions**
- **Rapid deployment of services**

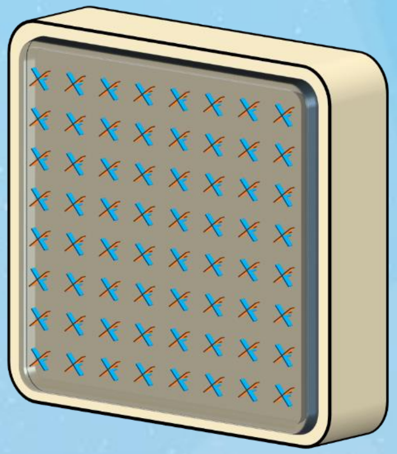
5G Fundamentals:
New Radio (NR) Air Interface

Creating a 5G NR Air Interface



Massive MIMO

Use hundreds of antenna elements at the gNB to enhance overall performance



5G gNB

High-gain narrow beams

Space Division Multiple Access

Spatial Multiplexing

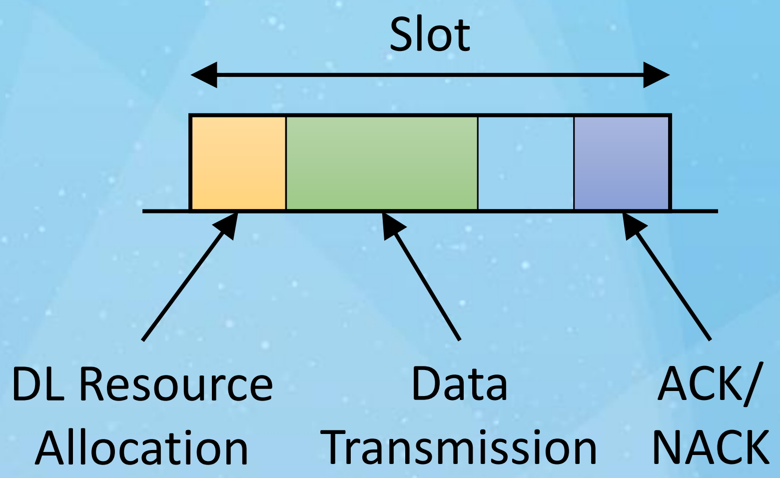
High Throughput!

High Capacity!

Flexible Frame Structure

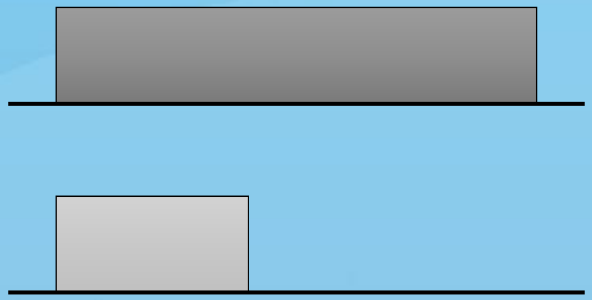
Frame quite flexible!

Self-contained Slot



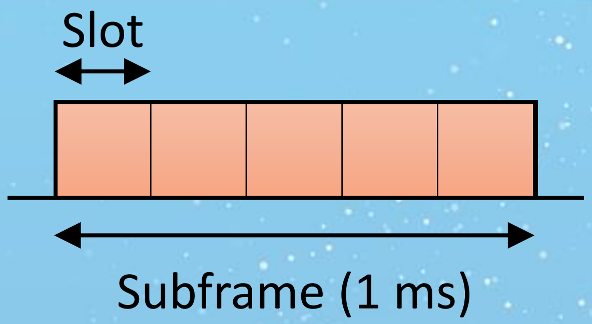
- ✓ Independently decodable slots
- ✓ No static timing dependency across slots

Variable Slot Length



- ✓ Adapt to QoS requirements

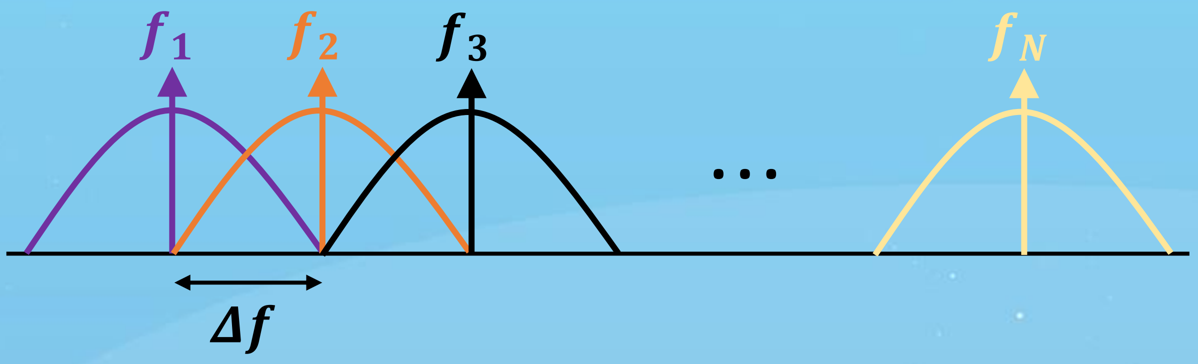
Backward and Forward Compatibility



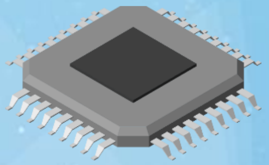
- ✓ Resource sharing with legacy LTE and future enhancements

Flexible OFDM Numerologies

Numerology: Configuration with a given subcarrier spacing (Δf)



Δf: 15 kHz (LTE); 15 x 2 = 30 kHz; 30 x 2 = 60 kHz; 60 x 2 = 120 kHz



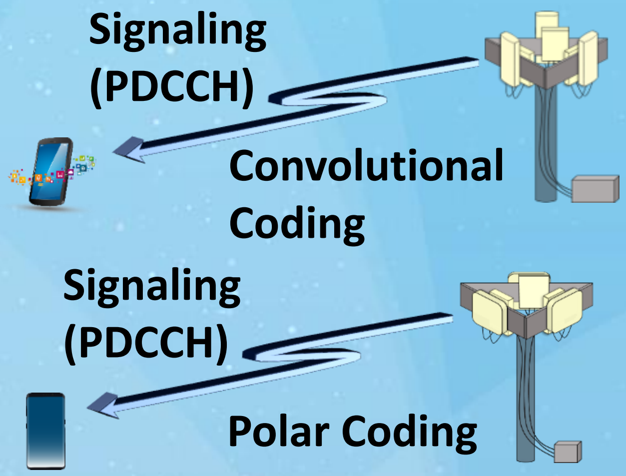
Lower-complexity processor for diverse spectrum bands (FFT)

Service QoS requirements (Ex: URLLC)

Efficient support for diverse deployment scenarios

Advanced Channel Coding

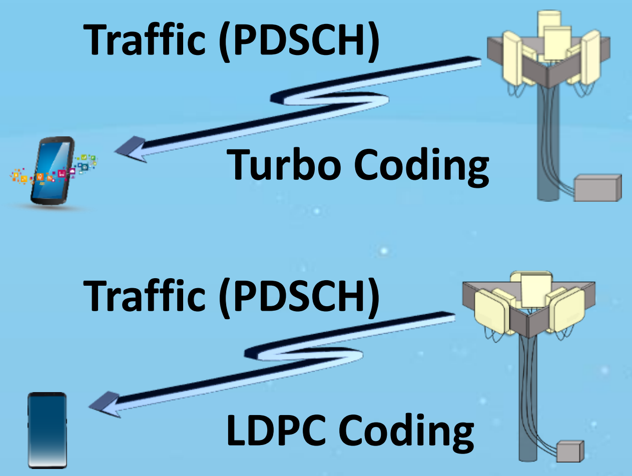
Resource Allocation



Benefits

- ✓ Better error protection
- ✓ More efficient to decode

Data Transmission

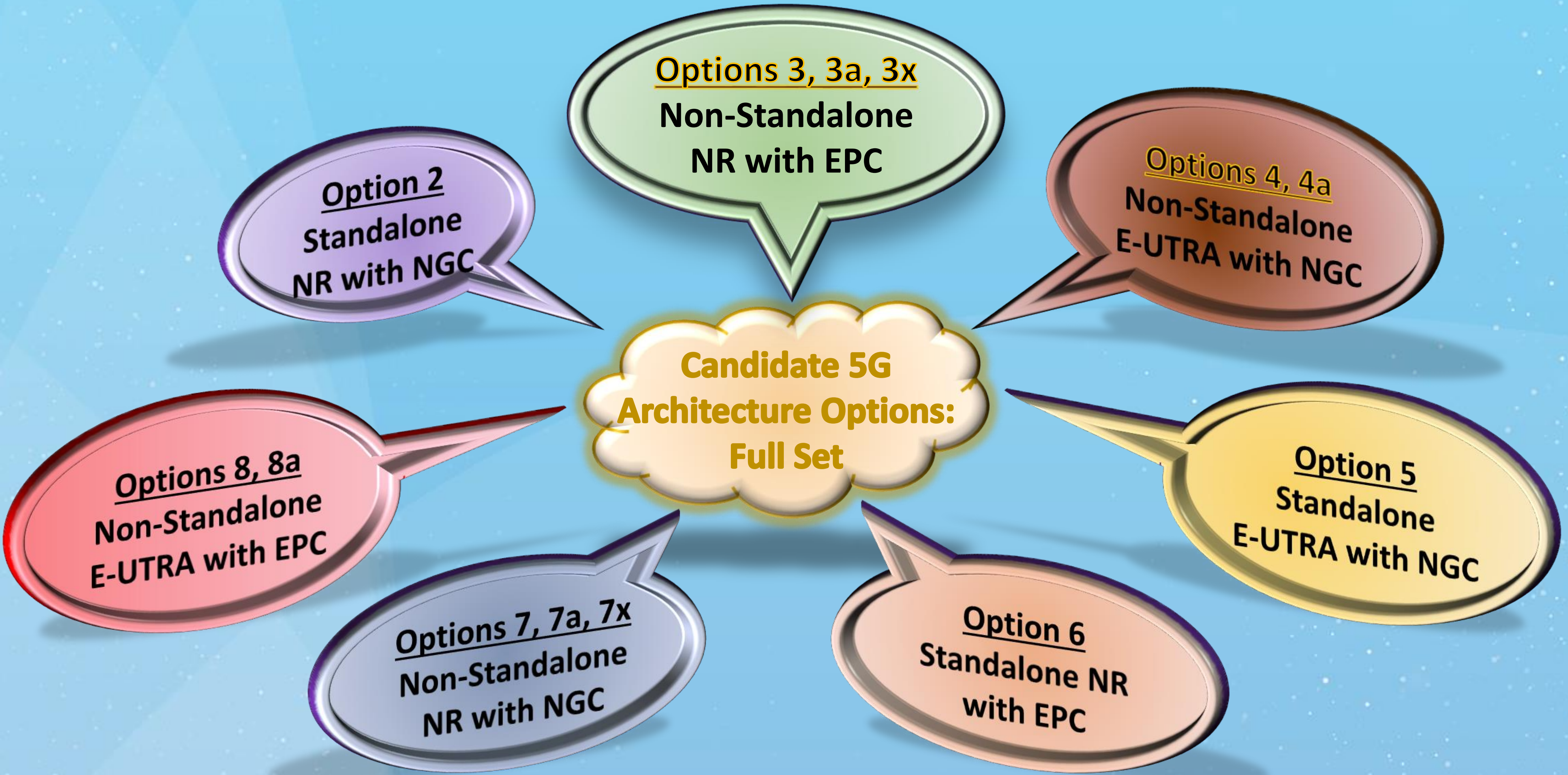


Benefits

- ✓ Higher throughput for large packets
- ✓ Lower complexity and reduced power consumption

5G Deployment Considerations

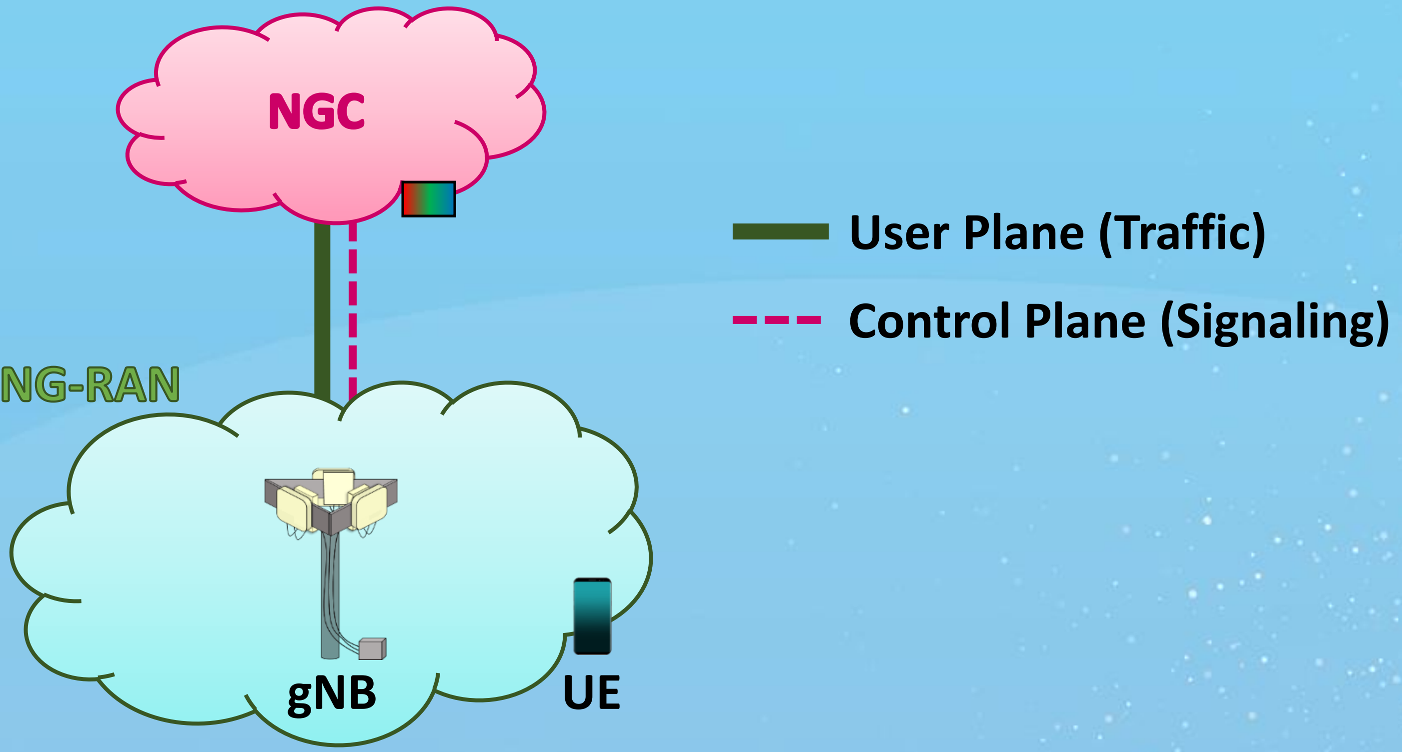
Architecture: Options Galore!



A mystery … **Option 1 Baseline LTE Architecture: E-UTRA with EPC!** 🙂

Architecture Option 2

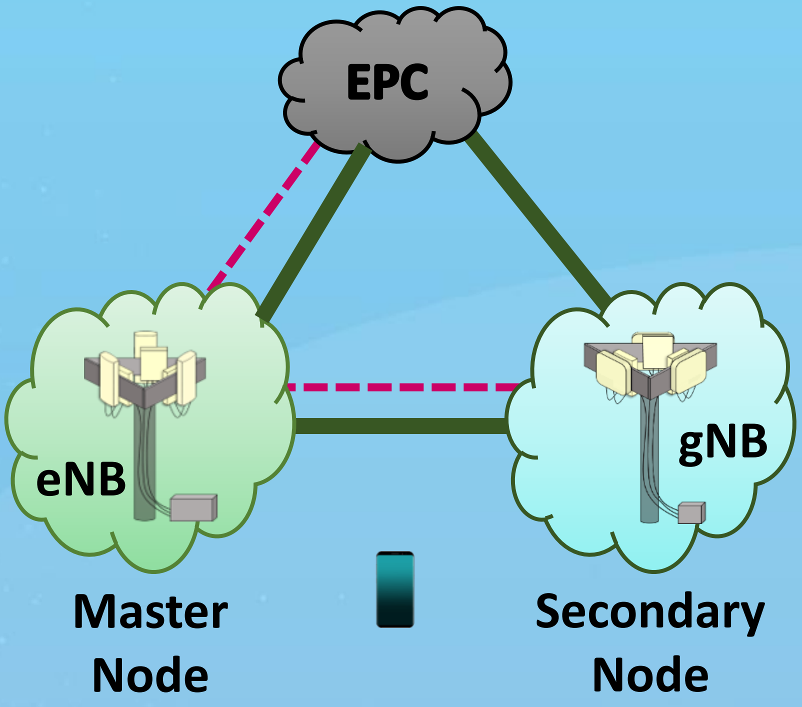
Standalone (SA) NR with NGC



- ✓ Realize the full potential of 5G
- ✓ Requirements of the new core network as well as the new radio network

Architecture Option 3x

Non-Standalone (NSA) NR with EPC
EN-DC: E-UTRA (LTE) NR Dual Connectivity



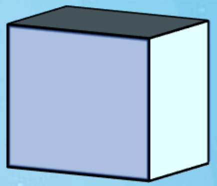
- ✓ Faster time-to-market (no NGC)
- ✓ Benefits of the high-performance 5G air interface
- ✓ Good overall coverage due to LTE

Network Functions Virtualization (NFV)

Network Functions Virtualization Software Implementation on Generic Hardware

Physical Network Function (PNF)

MME



AMF

- ✓ Purpose-built!
- ✓ Proprietary software
- ✓ Custom hardware
- ✓ Tightly coupled software & hardware

Virtual/Virtualized Network Function

- ✓ Proprietary/Open Source software
- ✓ Commercial-Off-The-Shelf (COTS) hardware
- ✓ Software and hardware independence

Cost Savings

Scalability

Agility

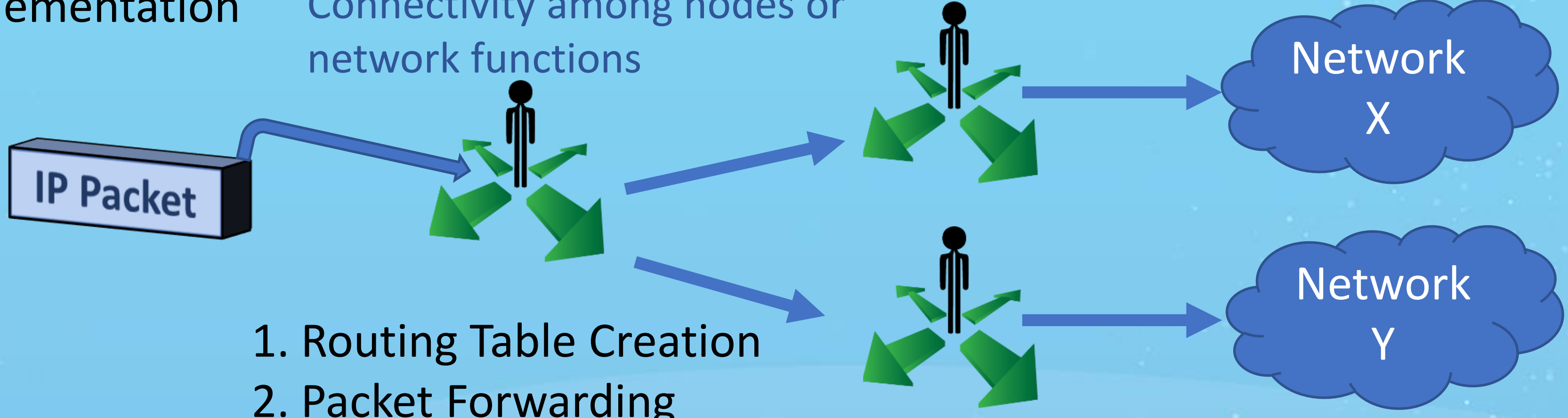
Q: What does the software run on?
A: Cloud infrastructure
(Compute, Storage, Networking)

Software Defined Networking (SDN)

Software-Defined
Software implementation

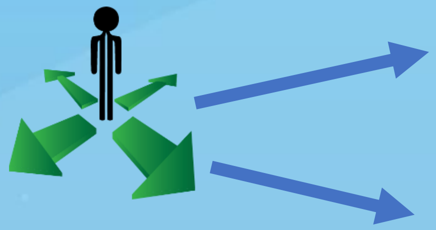
Networking
Connectivity among nodes or network functions

Traditional Approach



1. Routing Table Creation
2. Packet Forwarding

SDN Approach



Control Plane — Centralize intelligence for optimal paths (SDN controller)

Data Plane — Simplify- just packet forwarding (SDN switch or network device)

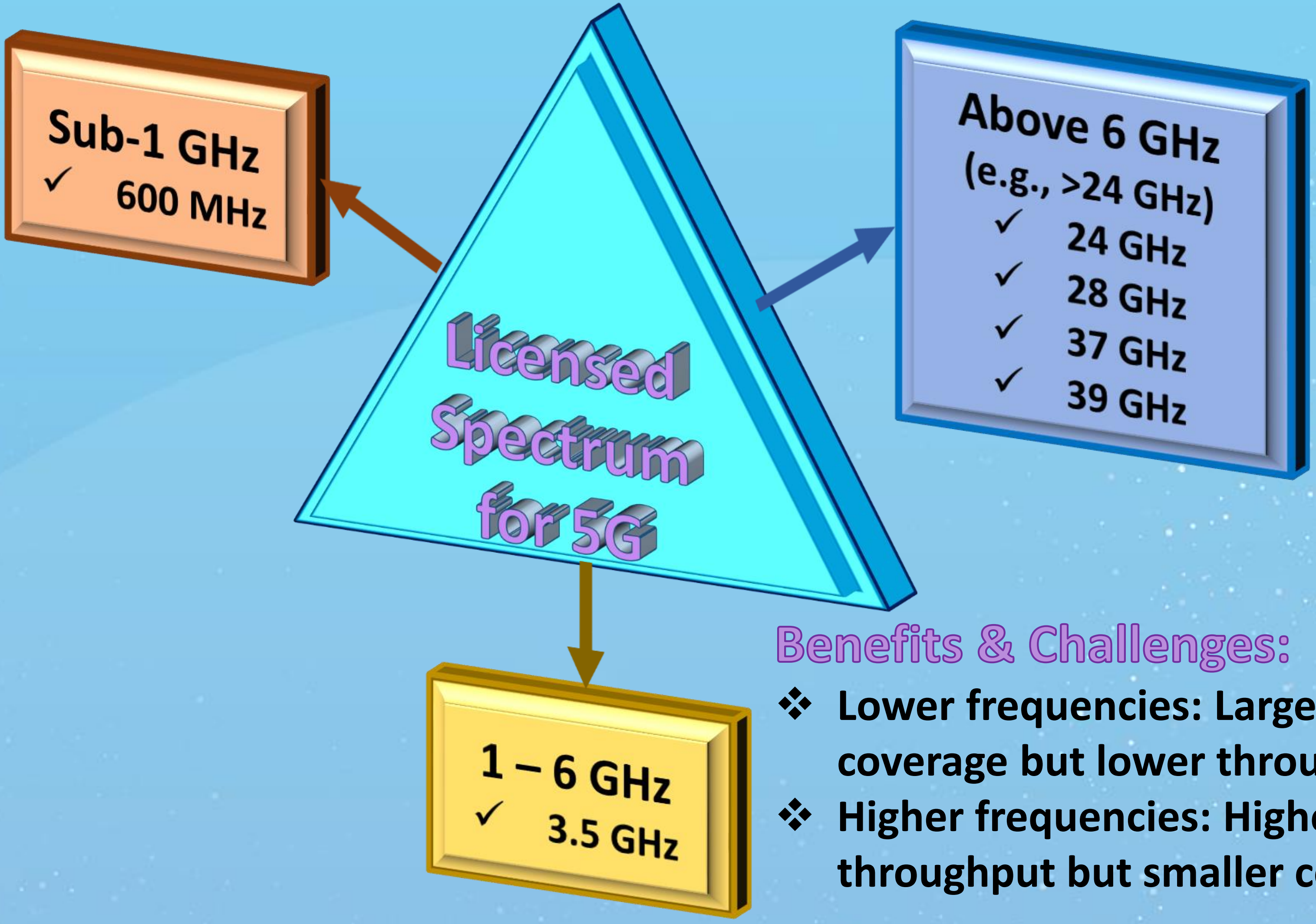
Divide and Conquer!

- ✓ The more we know, the better the decisions we make
- ✓ Minimize manual configurations
- ✓ Simple Data Plane devices…reduced costs (“Countless” RFCs in a traditional IP router!)

Spectrum: Benefits and Challenges

5G Phase 1 Spectrum

- ➢ Frequency Range 1 (FR1): Sub-6 (or 7) GHz
- ➢ Frequency Range 2 (FR2): 24 GHz- 53 GHz
- ➢ Millimeter Wave (mmW) Spectrum: > 30 GHz (or, 24 GHz!)



Benefits & Challenges:

- ❖ **Lower frequencies: Larger coverage but lower throughput**
- ❖ **Higher frequencies: Higher throughput but smaller coverage**

Key Takeaways

- 5G supports eMBB, URLLC, and mMTC
- 5G aims for 20 Gbps peak data rate, 1 ms radio network latency, and 10 Mbps/m^2 area throughput
- A 5G NG-RAN includes gNBs and a 5GC includes NFs such as AMF, SMF, and UPF
- Network Slicing creates custom logical networks to support a variety of QoS and customer requirements
- The NR radio interface includes features such as massive MIMO, OFDM numerologies, flexible frame structure, diverse spectrum, and advanced channel coding
- The SA NR with the 5GC does not rely upon an LTE eNB, while the NSA NR with the EPC needs the support for the LTE eNB that acts as the Master Node.
- Lower frequencies provide larger coverage, while higher frequencies provide higher throughput
- MEC places Applications close to users to reduce delays and transport requirements
- The SBA defines service-based interfaces and facilitates modularization and virtualization
- SDN centralizes the networking intelligence for better routes and reduces costs
- NFV enables software implementation of an NF using generic COTS hardware