5G and Beyond: A Systematic View

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Overview

- 5G, IoT and CPS
- SDN and NFV Enabling Technologies
- Fog (Edge) Computing
- Caching
- Conclusion

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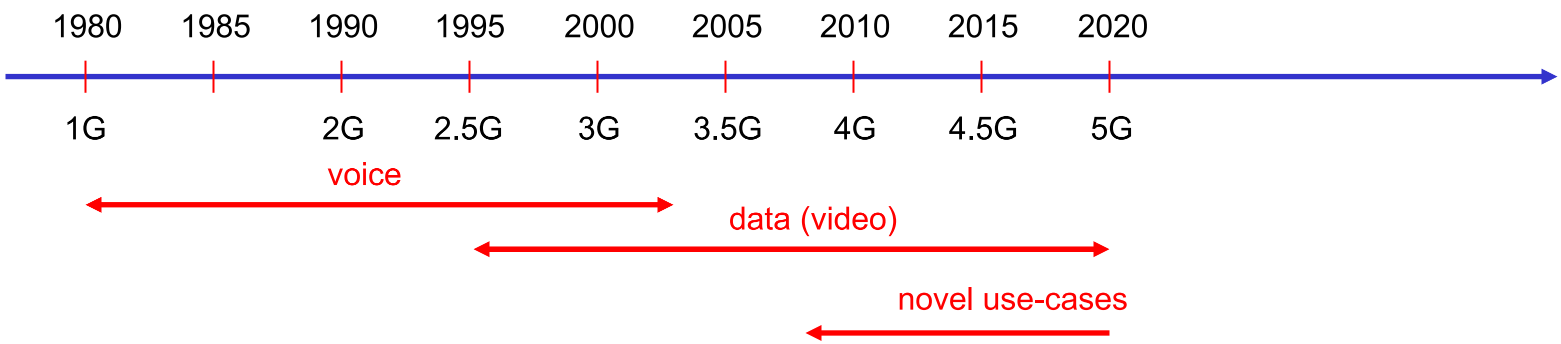
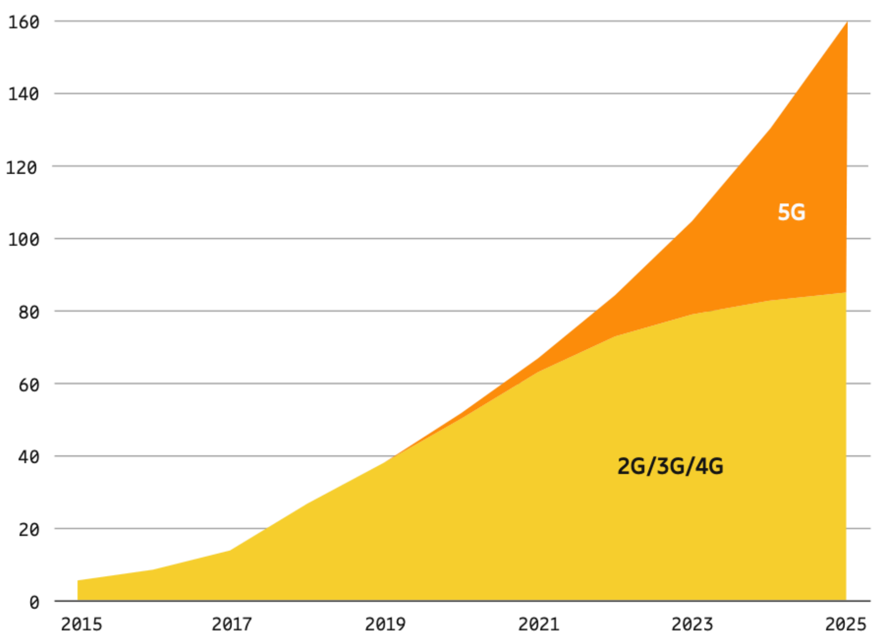
Comparison of 1G-5G Technologies

	1G	2G	3G	4G	5G
Period	1980 – 1990	1990 – 2000	2000 – 2010	2010 – (2020)	**(2020 - 2030)**
Data Rate	2kbps	64kbps	144kbps – 2Mbps	100Mbps – 1Gbps	**> 1Gbps**
Technology	Analog cellular	Digital cellular (GSM)	CDMA, UMTS, EDGE	LTE, WiFi	**WWWW**
Applications	Voice calls	Voice calls, Short messages	Video conferencing, Mobile TV, GPS	Video streaming, Wearable devices	**Remote control of vehicles, robots, and medical procedures**

5G Evolution or Revolution?



Global mobile data traffic (EB per month)



In 2025, 5G networks will carry nearly half of the world‘s mobile data traffic.

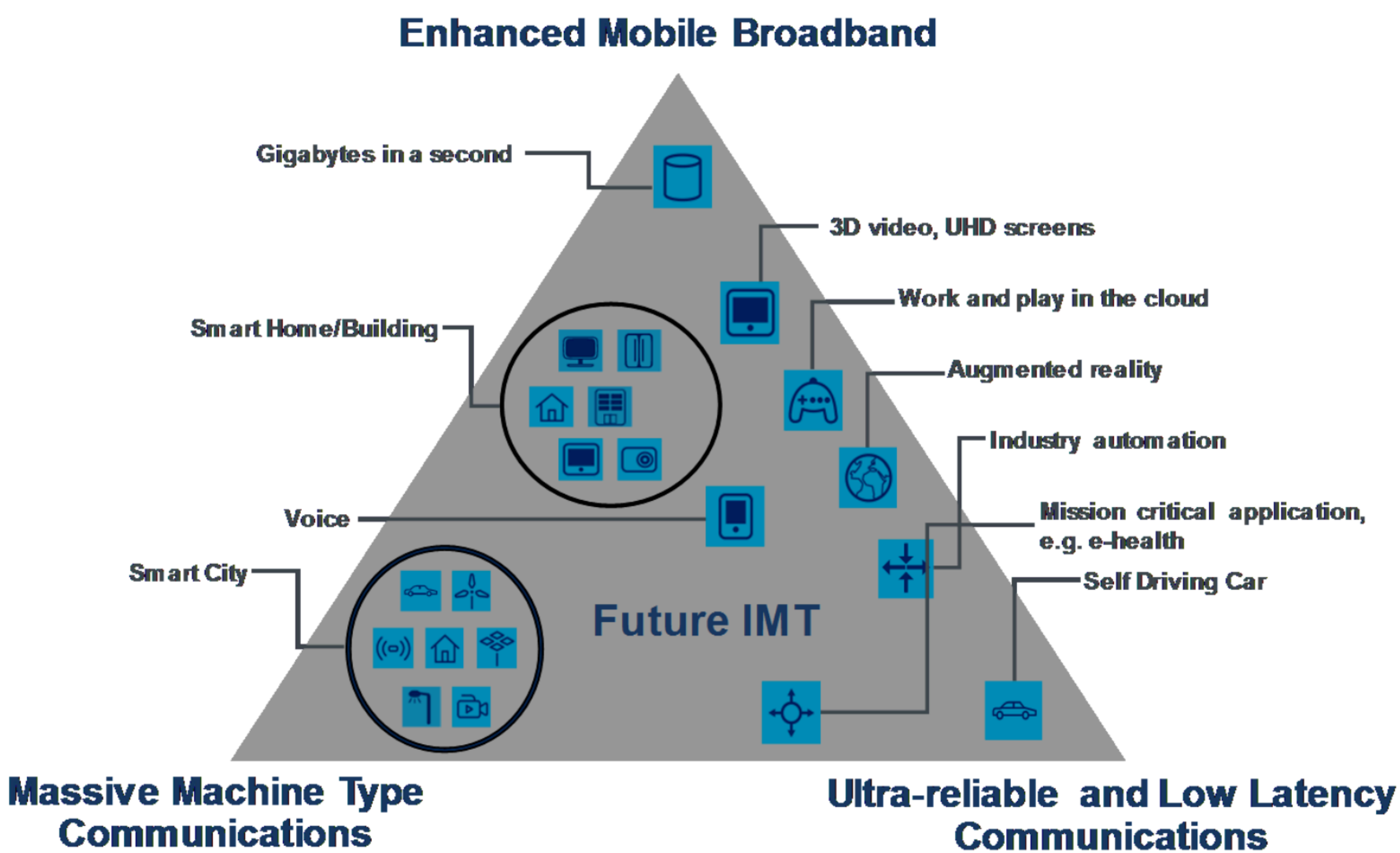
source: Ericsson Mobility Report

Future: 6G? 7G?

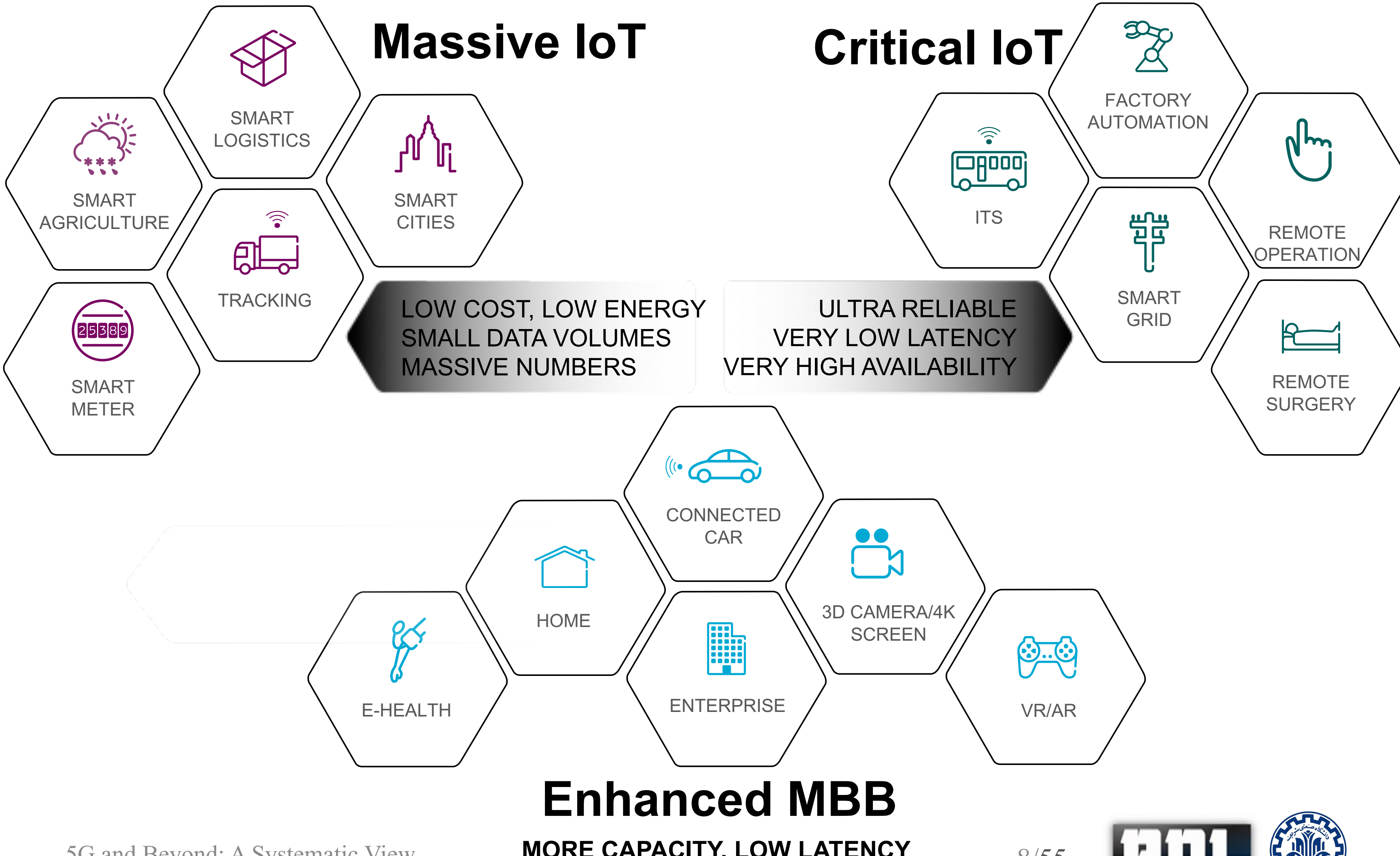
- 6G
  - integrate 5G with satellite network for global coverage
  - ultra fast Internet access
  - ubiquitous AI services from the core to the end devices

- 7G
  - space roaming
  - world completely wireless

5G Usage Scenarios



5G Enables New IoT Use Cases



IoT Market Outlook

24.9 Billion Connections by 2025

new use cases

2019

10.8 Billion Connections

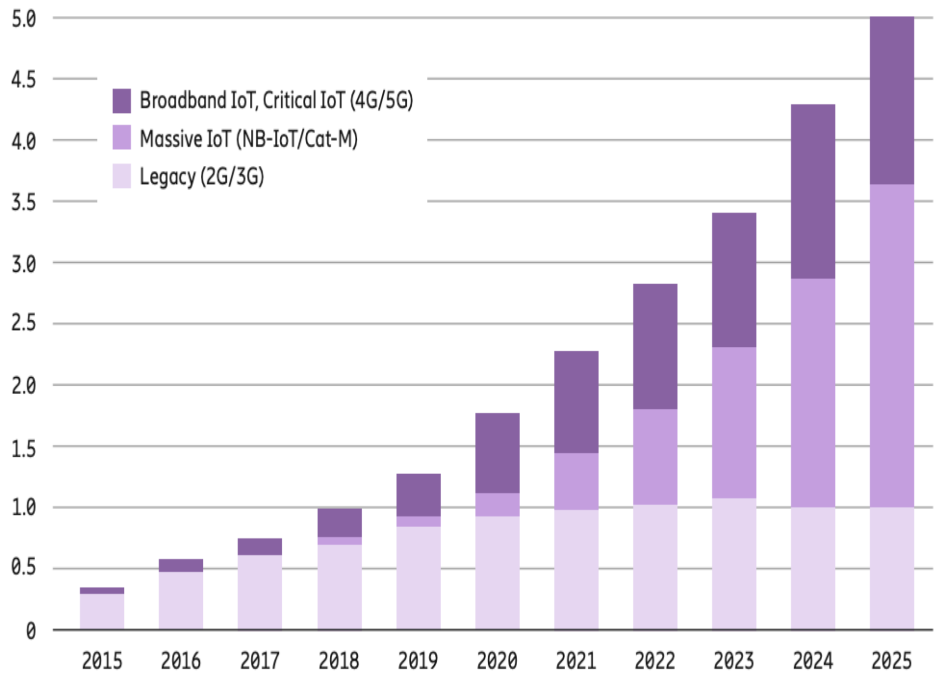
source: Ericsson Mobility Report

Cellular is the foundation for the IoT

Cellular IoT connections are predicted to increase from **1 billion** in 2018 to **4.1** billion in 2024.

Massive IoT is projected to account for more than 50 percent of cellular IoT connections in 2025.

Cellular IoT connections by segment and technology (billion)



By the end of 2025, 28 percent of cellular IoT connections will be broadband IoT, with 4G connecting the majority

Only a small fraction of total cellular IoT connections will be Critical IoT in 2025.

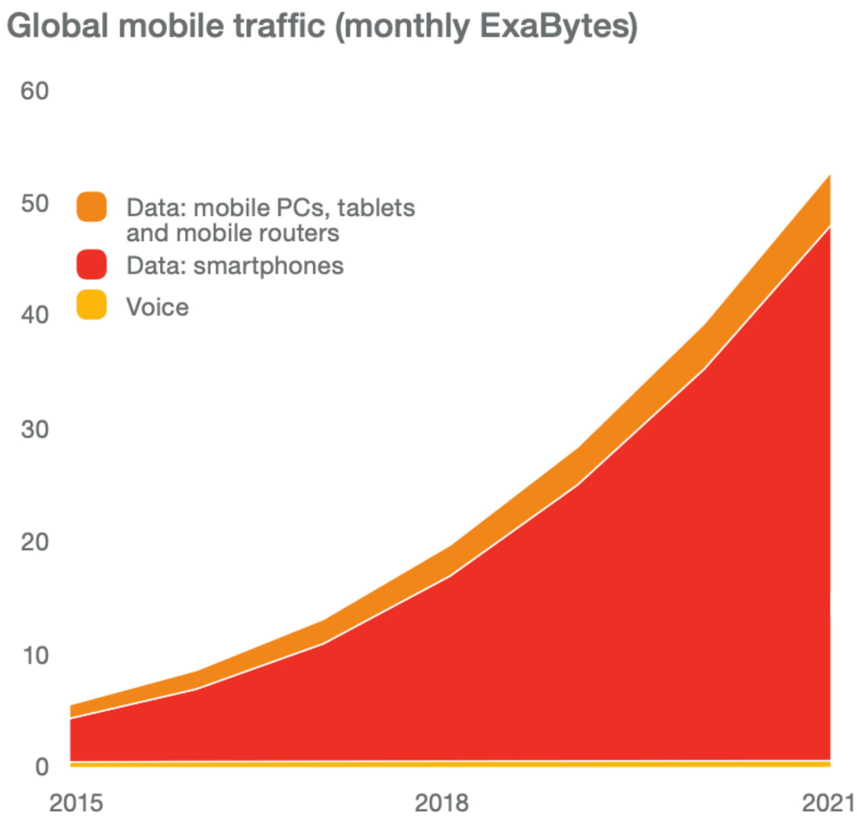
source: Ericsson Mobility Report

Cellular IoT Use case Evolution with Supporting Technology

	Current	On the road to 5G	5G experience
Automotive	On demand information	Real-time information vehicle to vehicle	Autonomous control
Manufacturing	Process automation	Flow management and remote supervision	Cloud robotics and remote control
Energy & Utilities	Metering and smart grid	Resource management and automation	Machine intelligence and real-time control
Healthcare	Connected doctors and patients	Monitoring and medication e-care	Remote operations

5G Diverse Requirements

- Massive traffic volume



~45% CAGR

12X In 2015-2021, there will be a 12X growth in smartphone traffic

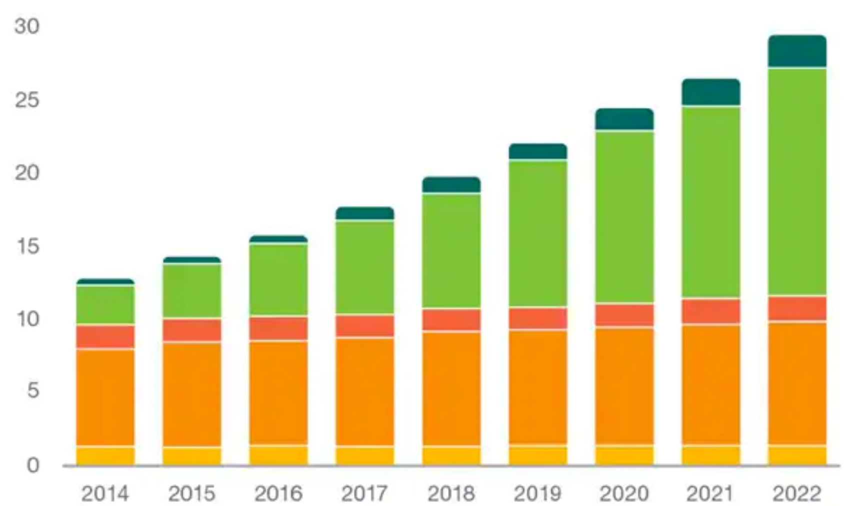
Around 90% of mobile traffic will be from smartphones by the end of 2021

source: Ericsson Mobility Report

5G Diverse Requirements

- Massive number of connected devices

Connected devices(billions)



	2016	2022	CAGR
Wide-area IoT	0.4	2.1	30%
Short-range IoT	5.2	16	20%
PC/laptop/tablet	1.6	1.7	0%
Mobile phones	7.3	8.6	3%
Fixed phones	1.4	1.3	0%
	16 billion	29 billion	10%

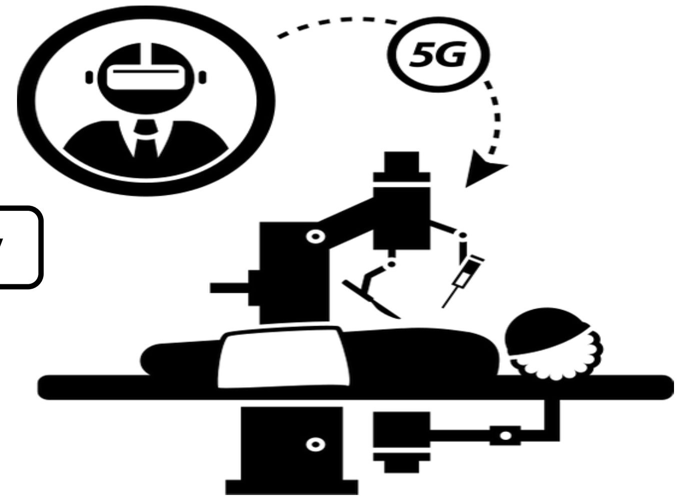
IoT connected devices have surpassed mobile phones

source: Ericsson Mobility Report

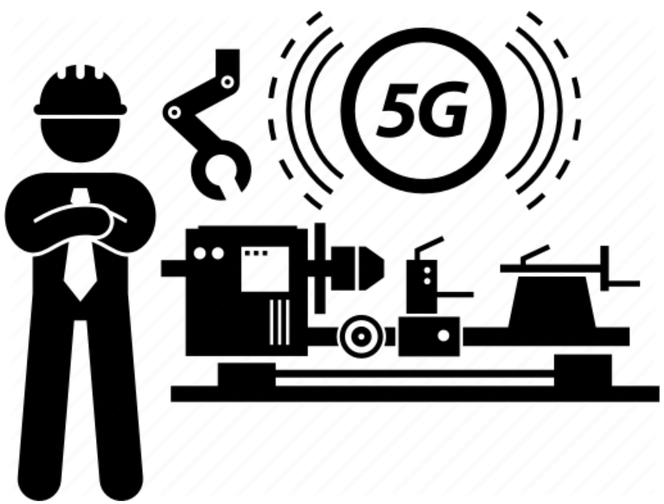
5G Diverse Requirements

- Ultra-low latency
- Reliability
- Security

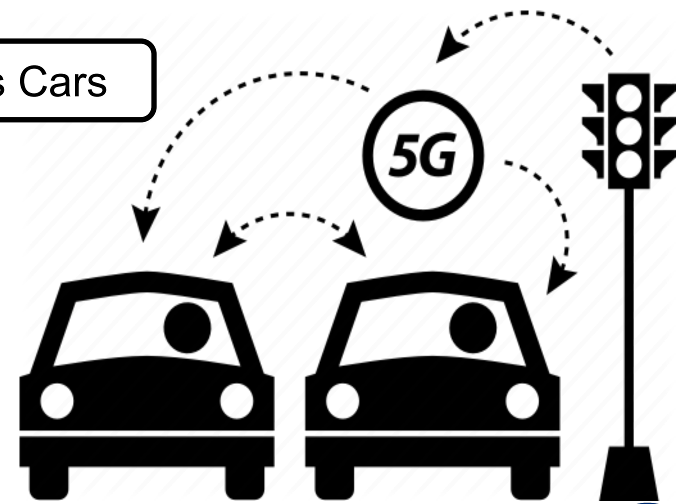
Remote Surgery



Remote Control of Vehicles



Autonomous Cars

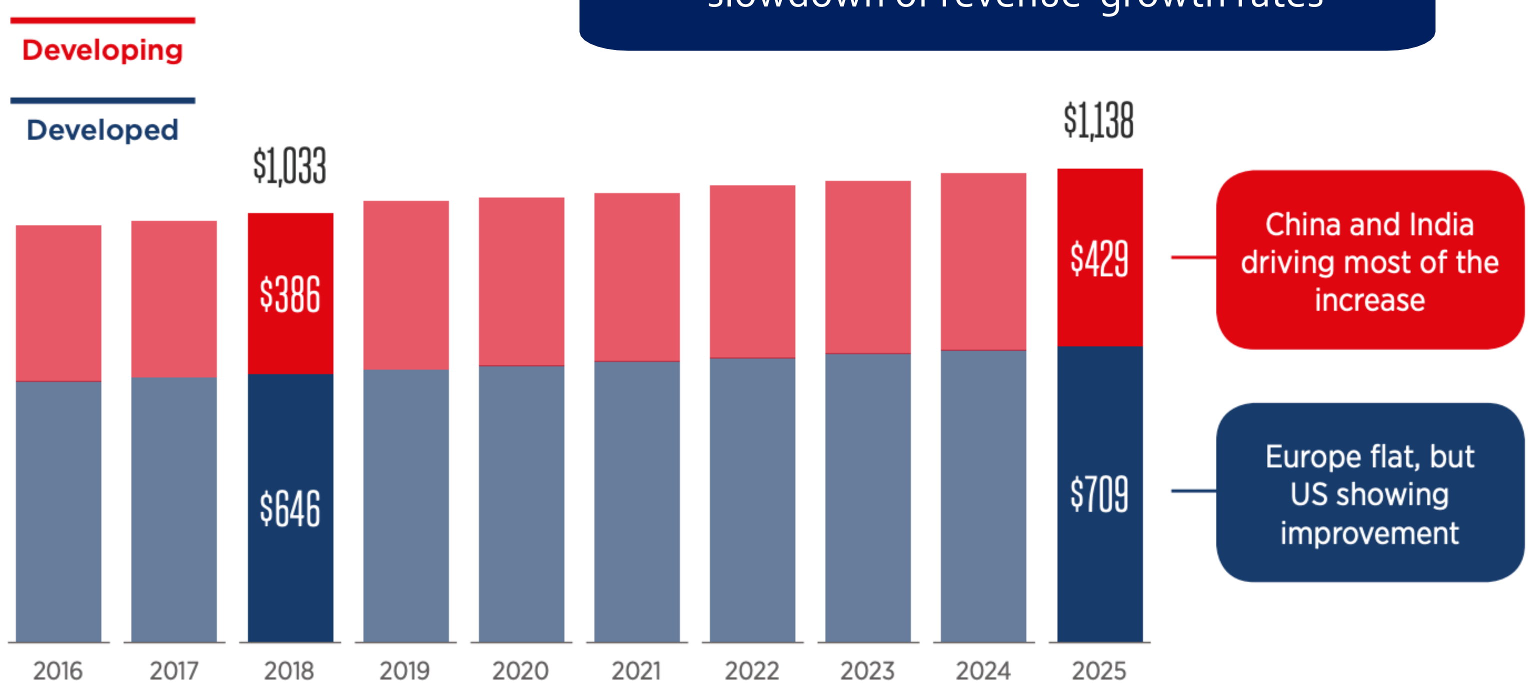


5G Diverse Requirements

- Cost Efficiency

Mobile Revenue ($ billion)

slowdown of revenue growth rates

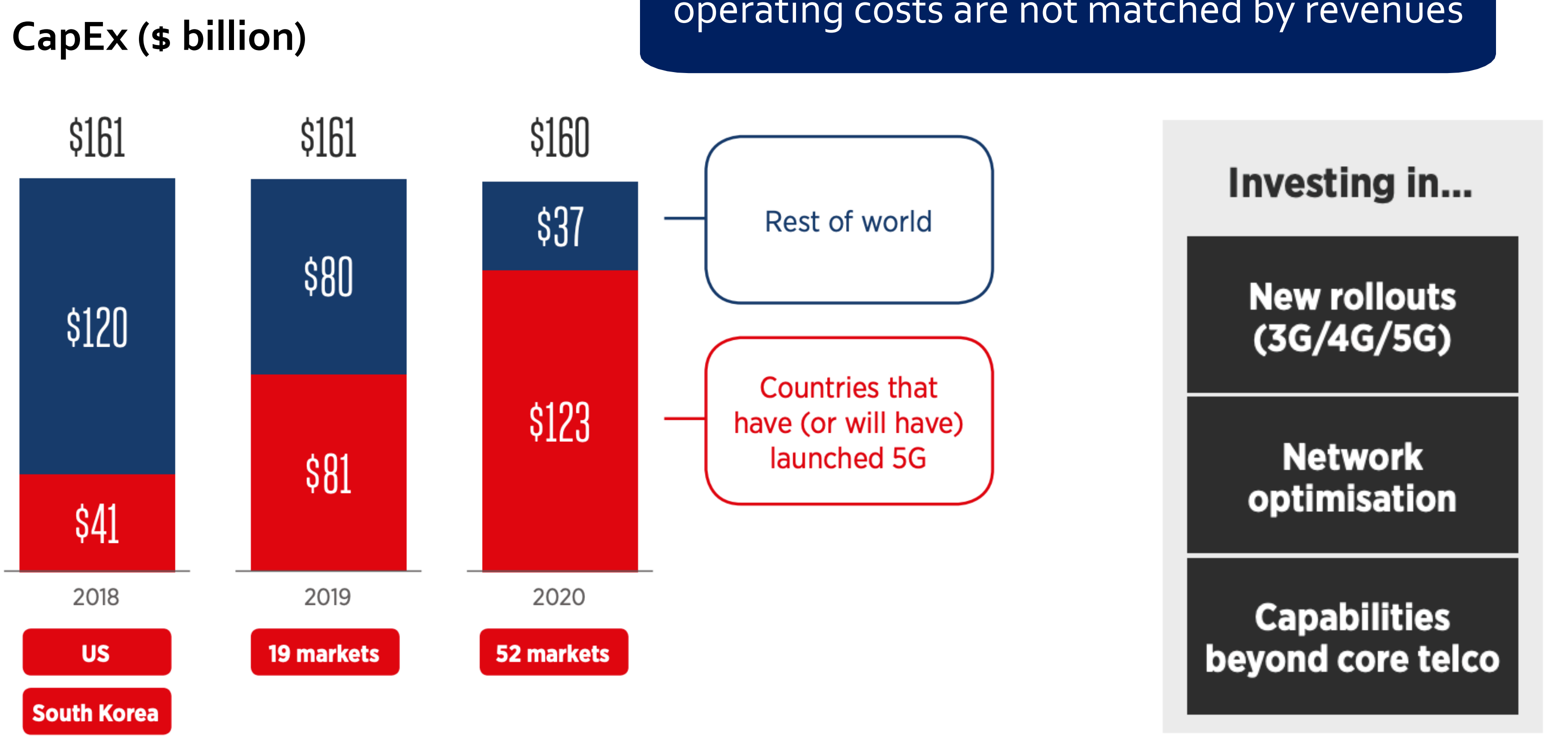


Source: GSMA Intelligence

5G Diverse Requirements

- Cost Efficiency

operating costs are not matched by revenues



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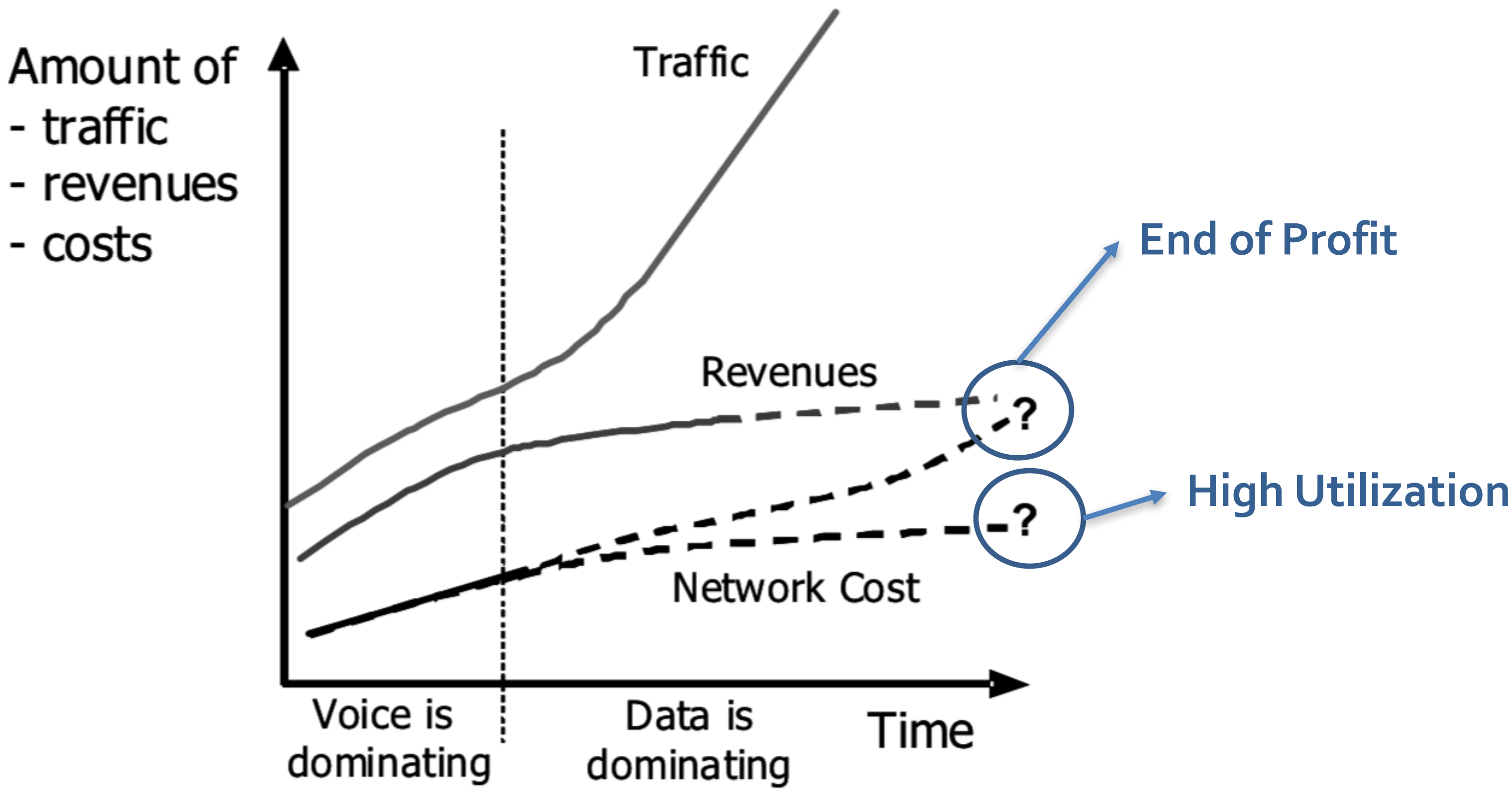
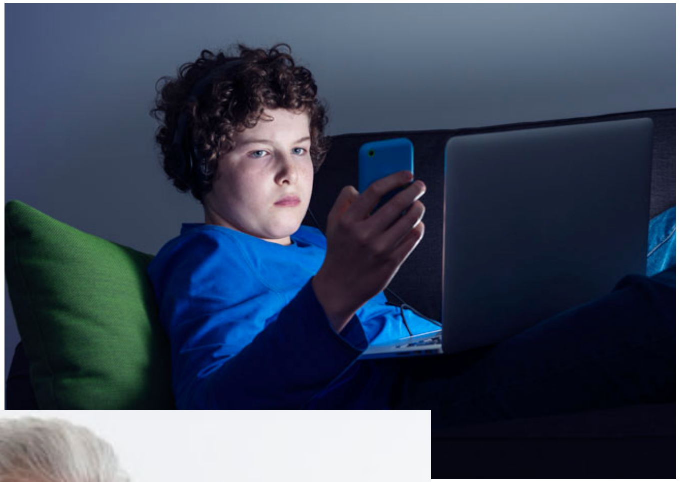
5G Diverse Requirements

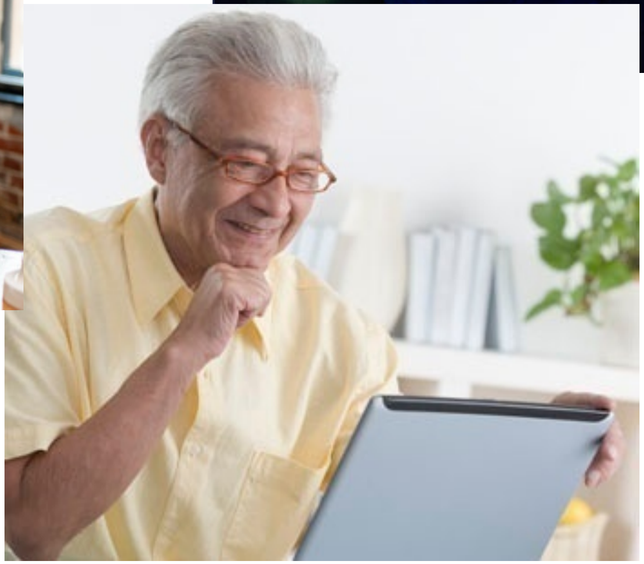
- Cost Efficiency



5G Diverse Requirements

- Support complex users





5G Diverse Requirements

- Support vertical markets
  - automotive machinery, energy, healthcare, etc.

- Novel advanced architecture
  - more than just bigger and better mobile broadband
  - extreme network flexibility and elasticity

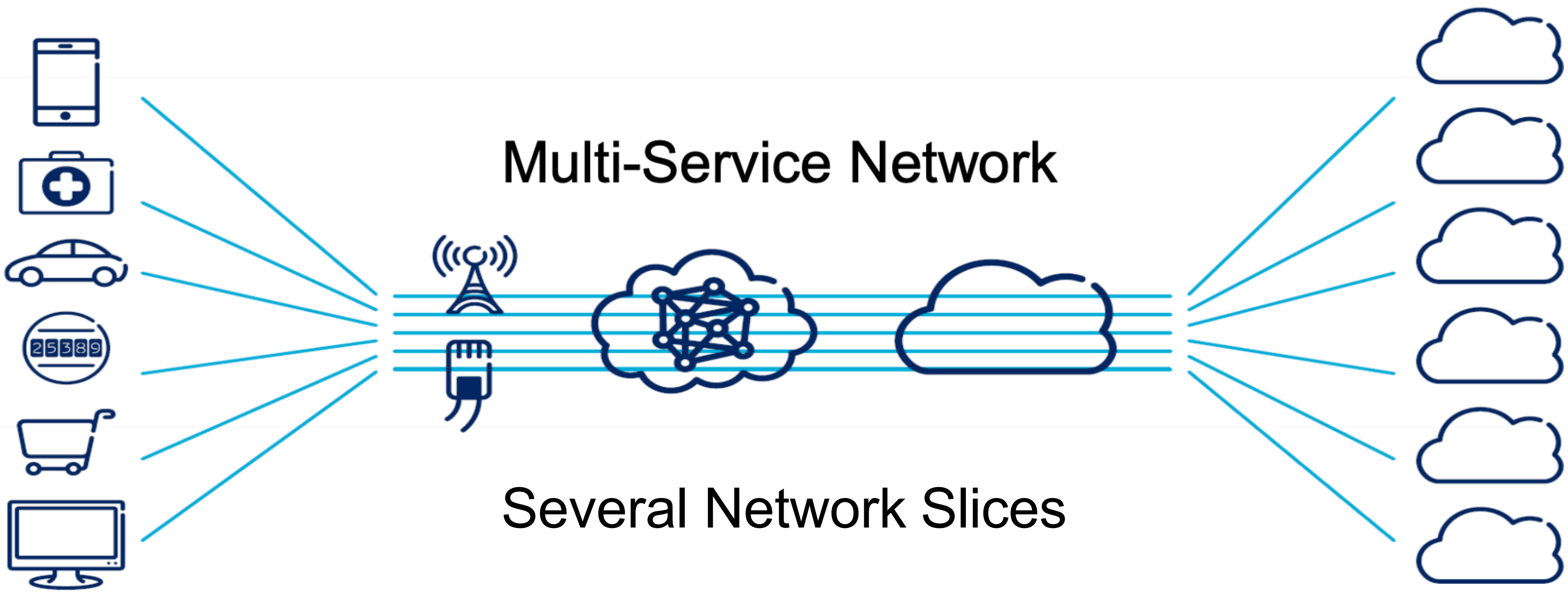
5G System Requirements

- Performance
  - 1000x higher mobile data volumes
  - 10x – 100x higher number of connected devices
  - 10x – 100x typical end-user data rates
  - 5x lower latency
  - 10x battery life for low power devices

- Flexibility
  - network programmability
  - affordable and sustainable

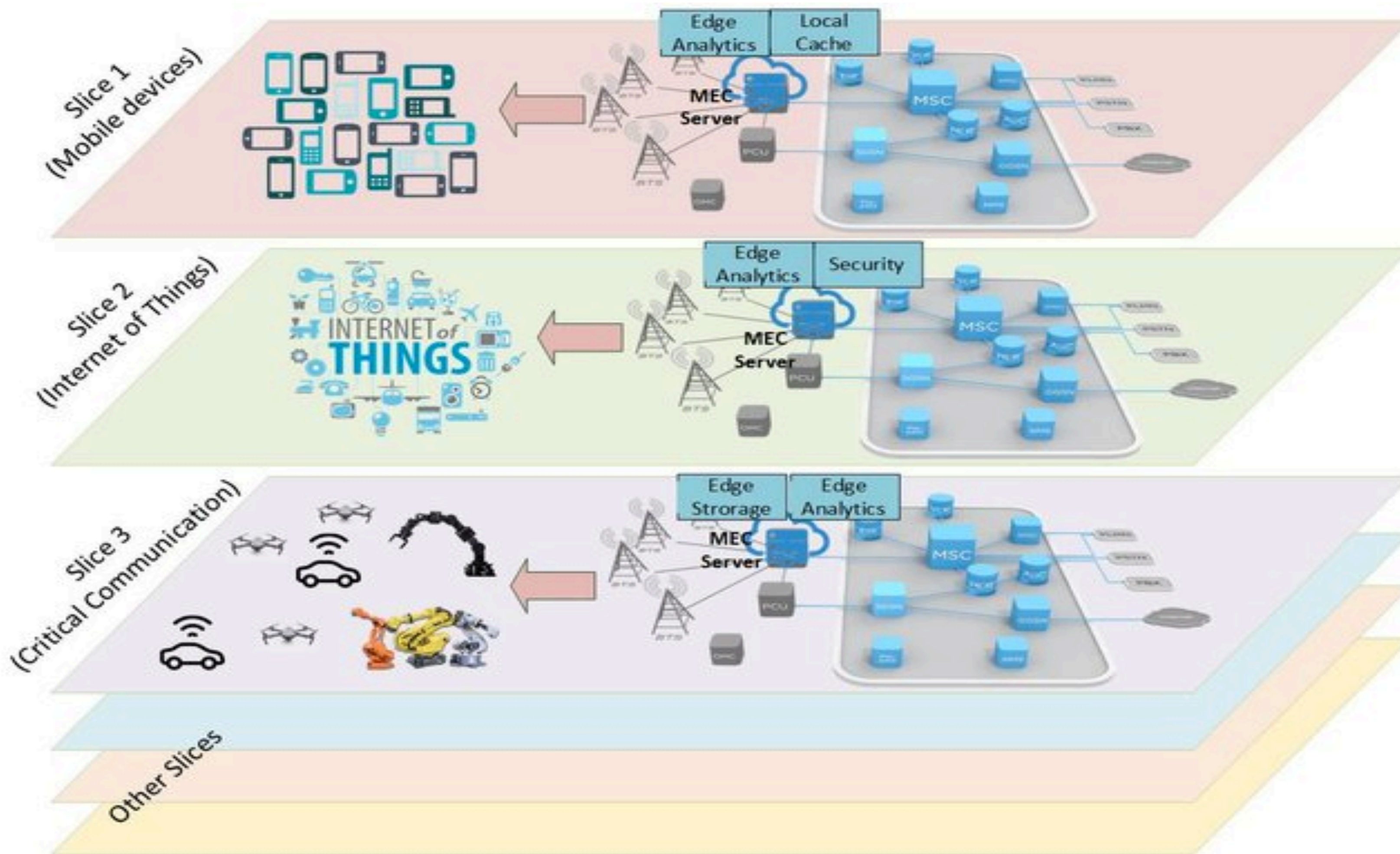
››› Design the Network?

One network: Multiple Industries



Source: Ericsson WP. on 5G Systems

5G Architecture: Network Slicing



Source: Liyanage, Madhusanka & Porambage, Pawani & Ding, Aaron Yi. (2018). Five Driving Forces of Multi-Access Edge Computing.

What is a Slice?

- A network slice
  - is an E2E logical network
  - supports one type of industry
  - has an infrastructure resources partition (either physical or virtual)
    - computation, storage, networking
- Slices
  - are on top of a shared infrastructure
  - are isolated from each other
  - have independent control and management

5G Enablers

- Leverage emerging techs of both optical and wireless technologies
  - **e.g.**, advanced MIMO, advanced waveforms, heterogeneous networking, ultra dense network, etc.

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- 5G will be driven by software ingredients
  - Software Defined Networks (SDN)
  - Network Functions Virtualization (NFV)
  - Fog Computing (FC)

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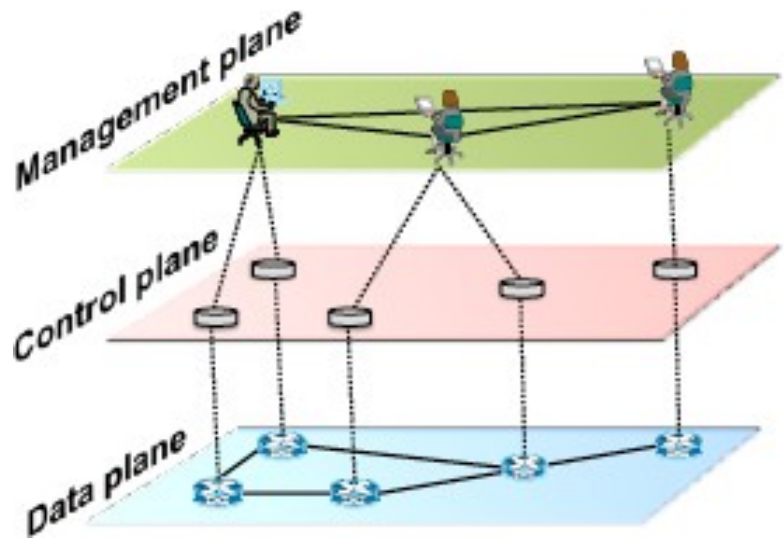
SDN- Software-Defined Networking

- **Main Principle:** data plane is decoupled from control plane



Goal:

- Make the network programmable
- Simplify networking and enable new applications
- History: IETF ForCES (2004), ONF OpenFlow (2010)

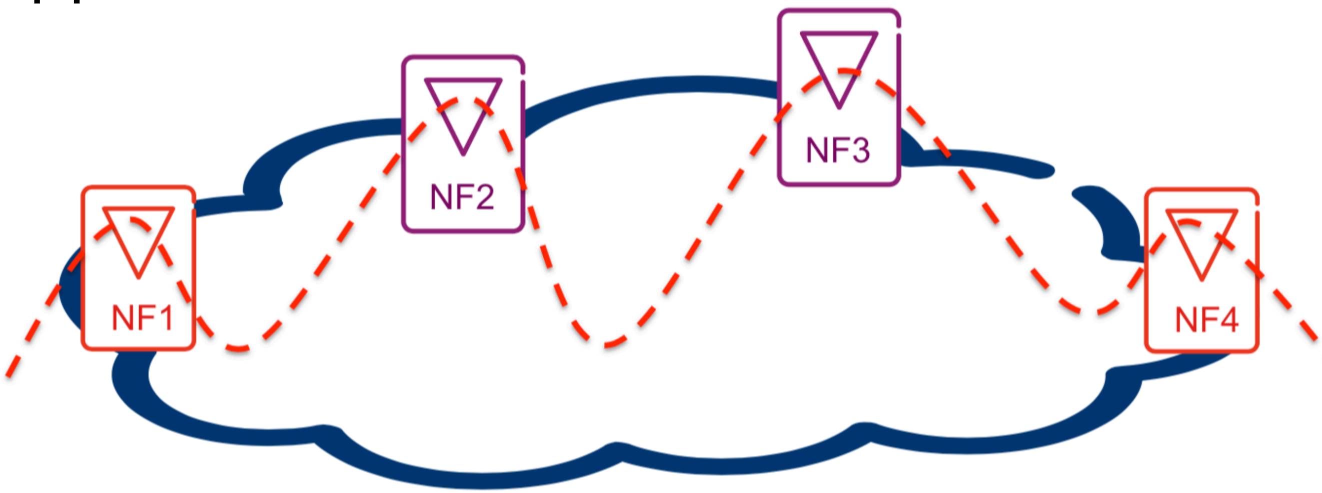
Source: “Software-Defined Networking: A Comprehensive Survey”, Kreutz et al., https://arxiv.org/pdf/1406.0440.

Benefits of SDN

- Control plane can be directly programmed
  - customized control logics
  - rapid creation of new services
- Vendor independent network control
  - using a standard API between forwarding & control
- Simplified forwarding elements
  - support only a generic API instead of many protocols
- Data & control planes can evolve independently
  - higher rates of innovations

NFV- Network Function Virtualization

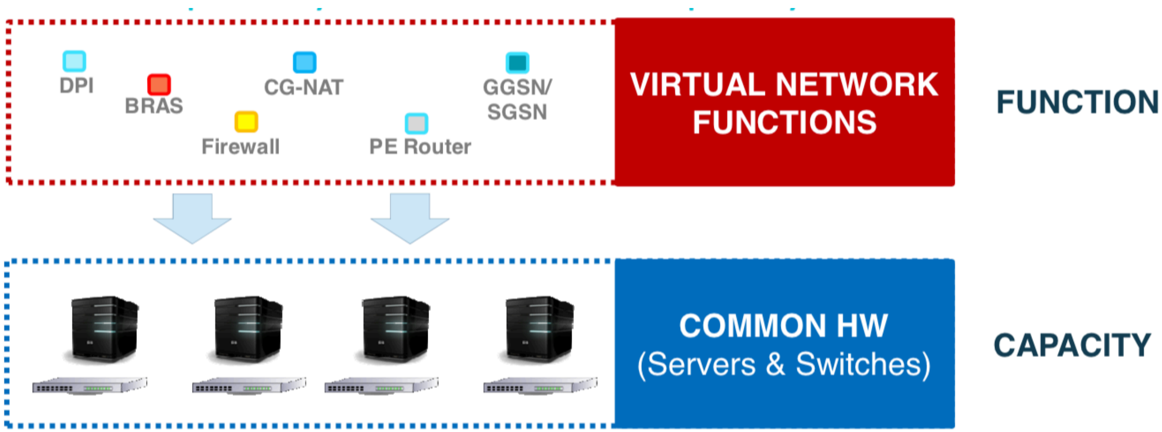
- Today's network services are highly dependent on HW appliances



- An end-to-end network service usually comprises several network functions (NFs) distributed over fixed locations
- NF Examples: Firewall, Fixed and Mobile Gateways, AAA, DPI

NFV- Network Function Virtualization

- **Main Principle:** network functions decoupled from the supporting hardware

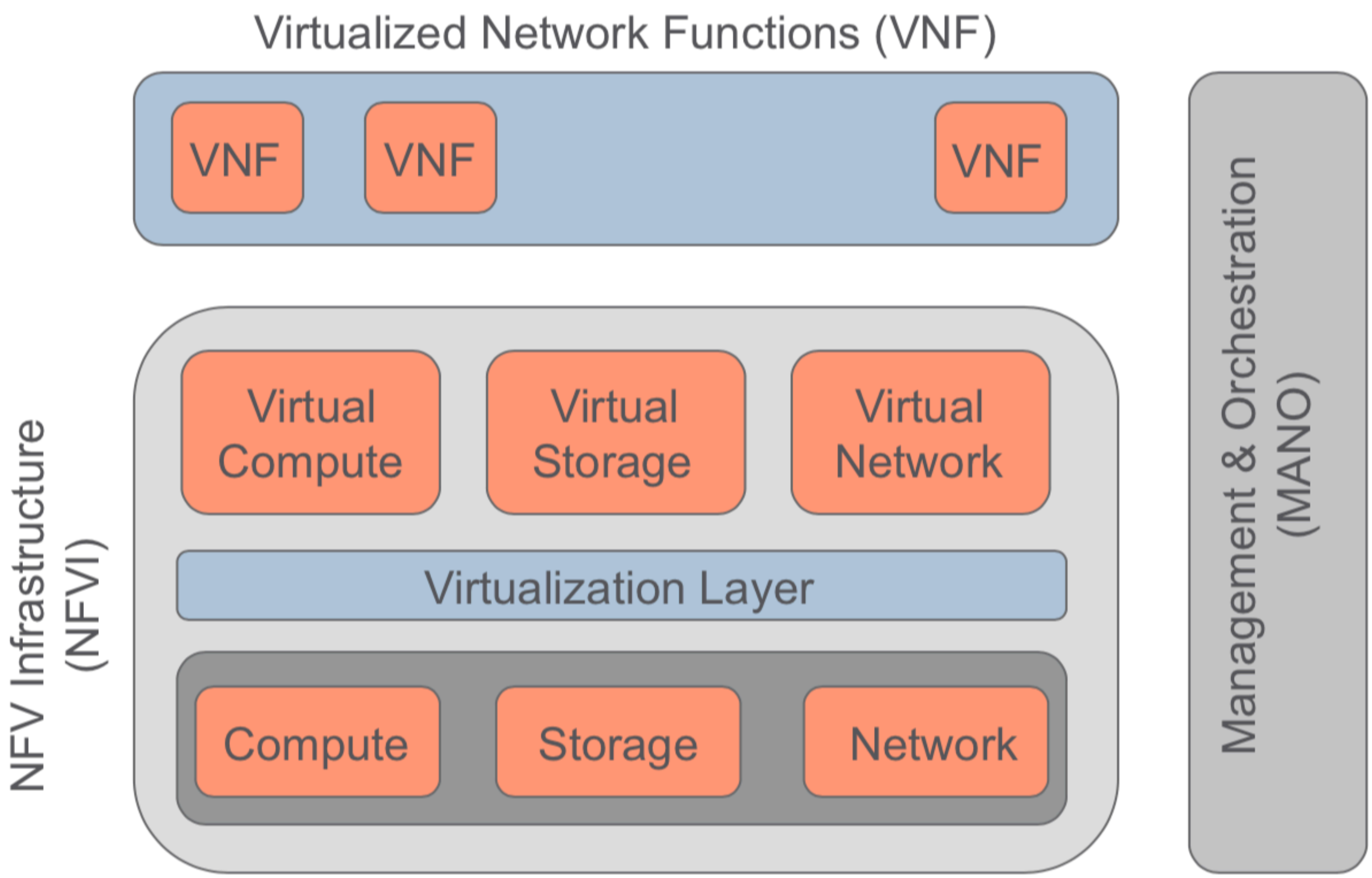


- **Goal:** rapid and flexible deployment of services on general purpose HWs
- History: ETSI Whitepaper (2012)

Benefits of NFV

- Efficient resource utilization
- Agile creation of new networking services
- Decoupling the evolution of network functions (services) from underlying platforms
- Reduced Cost (CapEx & OpEx)

NFV Architecture (ETSI View)



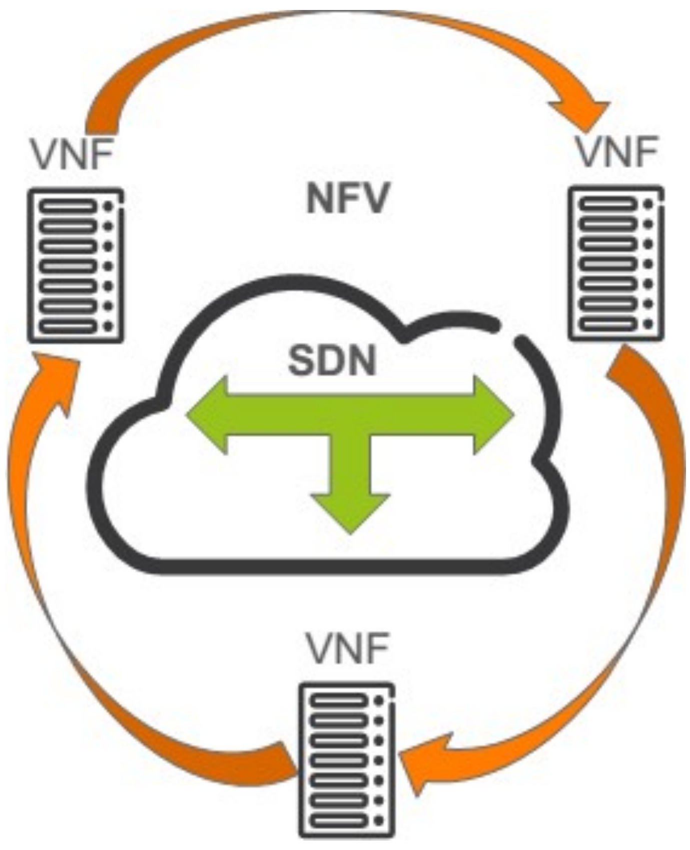
NFV vs. SDN

SDN ››› flexible forwarding & steering of traffic in a physical or virtual network environment
[Network Re-Architecture]

NFV ››› flexible placement of virtualized network functions across the network & cloud
[Appliance Re-Architecture]

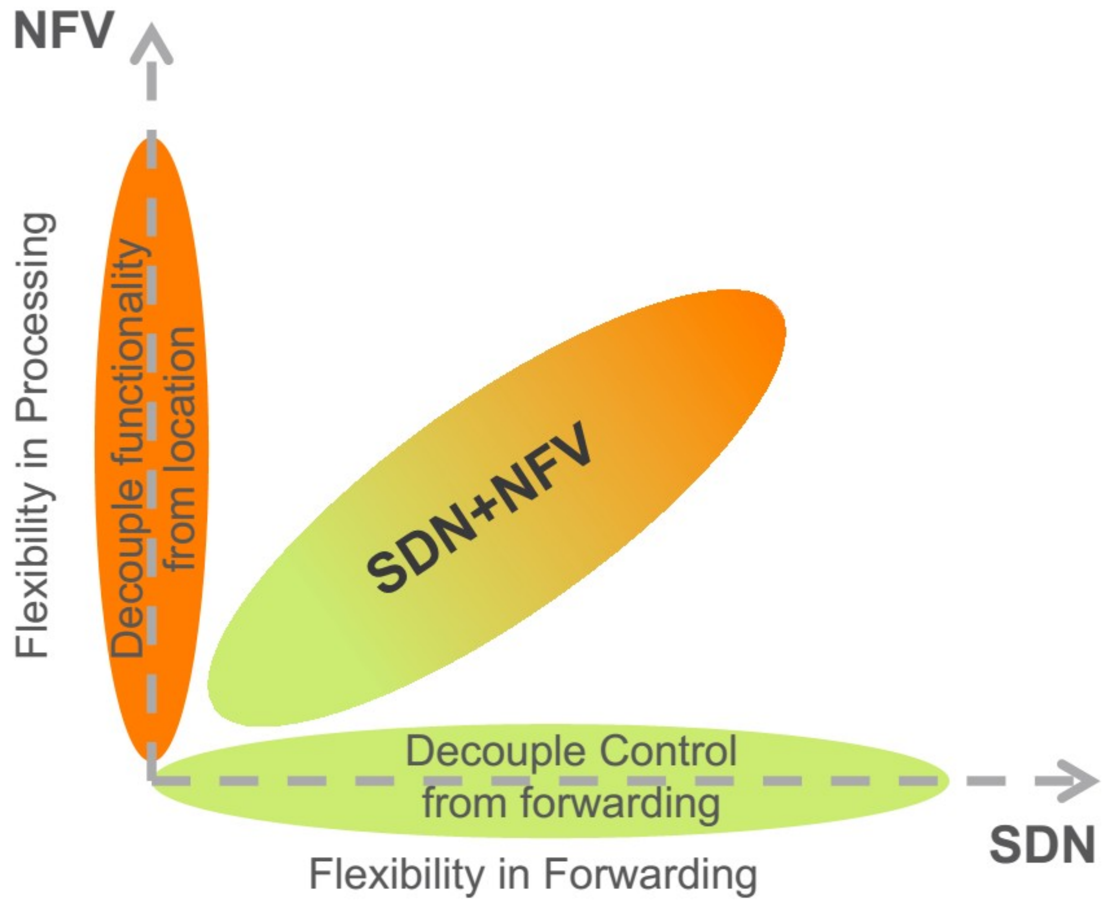
››› SDN & NFV do NOT depend on each other

››› SDN & NFV are complementary tools for achieving full network programmability



Source: Ahmad Rostami, Ericsson Research (Kista): http://www.itc26.org/fileadmin/ITC26_files/ITC26-Tutorial-Rostami.pdf

Flexibility with SDN & NFV



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SDN/NFV Research challenges

- Service orchestration
  - Service composition (e.g. chaining)
- Resource orchestration
  - VNF placement
  - resource allocation (e.g. CPU, networking, storage)
  - traffic routing
  - network optimisation is far from trivial!

››› AI/ML concepts for network optimisation and automation!

Ongoing work …

- *Dynamic* and *joint* VNF placement, resource allocation, and traffic routing in 5G
  - **Goal**: maximizing operators' revenue
  - main key performance indicators (KPIs)
    - end-to-end latency
    - throughput

Morteza Golkarifard
- Ph.D. candidate
- Visiting researcher at TNG, Politecnico di Torino, Turin, Italy in 2018-2019.
- Visiting researcher at SyMLab, HKUST, Hong Kong, in 2014.

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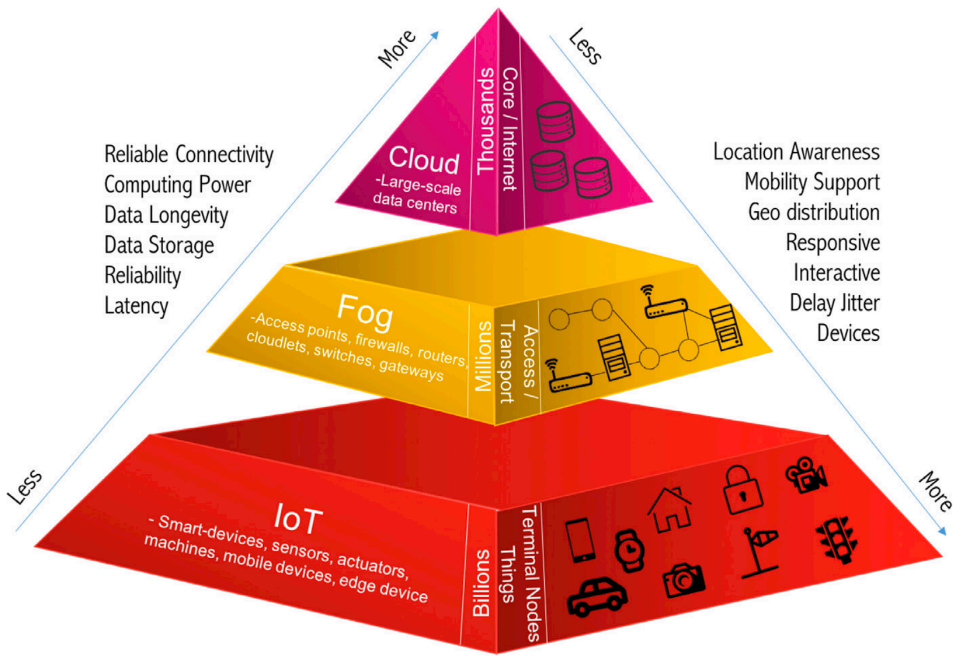
FC- Fog Computing

- Initially the term has been coined by CISCO (2012)
  - Open Fog Consortium (OFC) created in 2015



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- Related Project
  - Multi-access (previously Mobile Edge) Computing (MEC)
    - MEC Reference architecture – ETSI (2014)

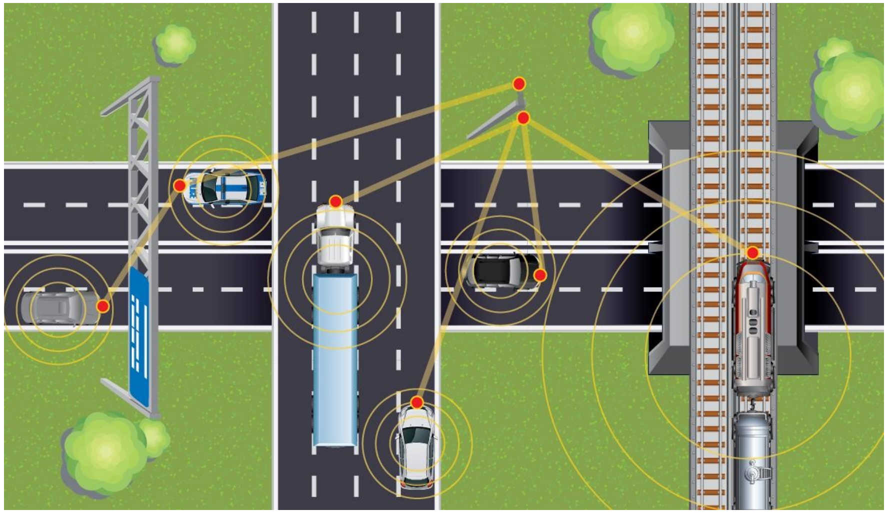
FC- Fog Computing

- **Move cloud computing** capabilities close to the data sources/sinks
  - distributed architectures
  - fast responses
  - minimization of the data transfer to the centralized data centers

- **A Key Technology** to enable evolution to 5G
  - satisfying the demanding requirements for sub-milliseconds latency and reduced infrastructure bottlenecks

FC Applications in 5G

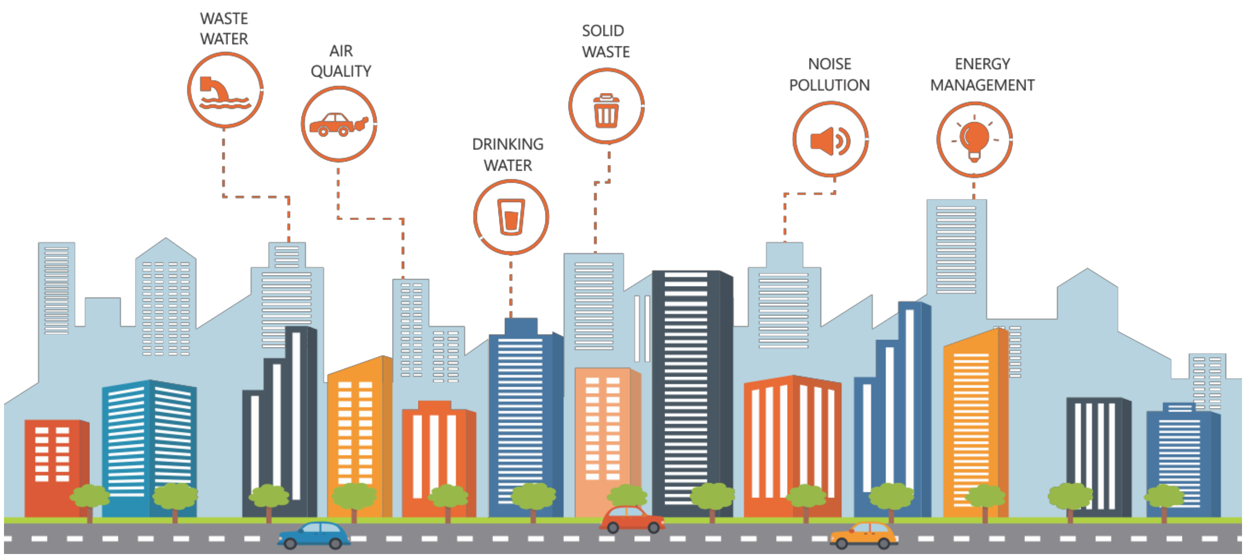
- **Connected Cars**
  - Fog computing is ideal for Connected Vehicles because real-time interactions will make communications between cars, access points and traffic lights as safe and efficient as possible



Connected Vehicles communicating each other

FC Applications in 5G

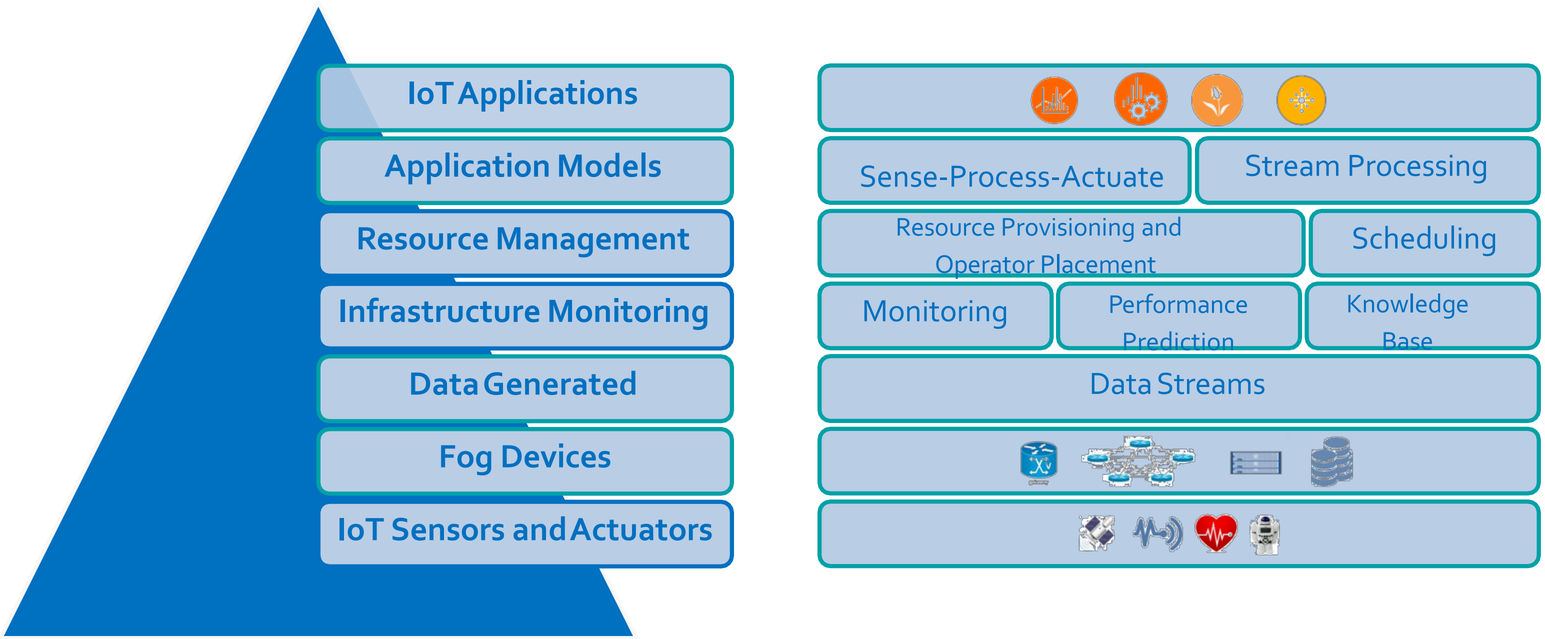
- **Smart Cities**
  - Fog computing would be able to obtain sensor data on all levels, and integrate all the mutually independent network entities within city



FC vs. Cloud

Requirement	Cloud Computing	Fog Computing
Latency	High	Low
Delay Jitter	High	Very Low
Location of Server Nodes	With in Internet	At the edge of local n/w
Distance between the client and server	Multiple Hops	One Hop
Security	Undefined	Can be Defined
Attack on data enrouter	High Probability	Very Less Probability
Location Awareness	No	Yes
Geographical Distribution	Centralized	Distributed
No. of server nodes	Few	Very Large
Support for Mobility	Limited	Supported
Real time interactions	Supported	Supported
Type of last mile connectivity	Leased line	Wireless

FC- Architectures



FC- Research Challenges

- While fog computing provides several benefits, it is still an emerging technology with details yet to be fully flushed out such as :

  - Mobile fog computing
  - Fog resource monitoring
  - Fog node security
  - SDN support for fog
  - Efficient Resource allocation

Ongoing work …

- Efficient resource allocation to IoT services on dynamic Fog environment
  - **Goal**: Efficient resource allocation using machine learning algorithms

Pouya Tahmasbpour Omran

- MS.c. Students
- Collaborating on research projects with Carnegie Mellon University and University of Oslo in 2019

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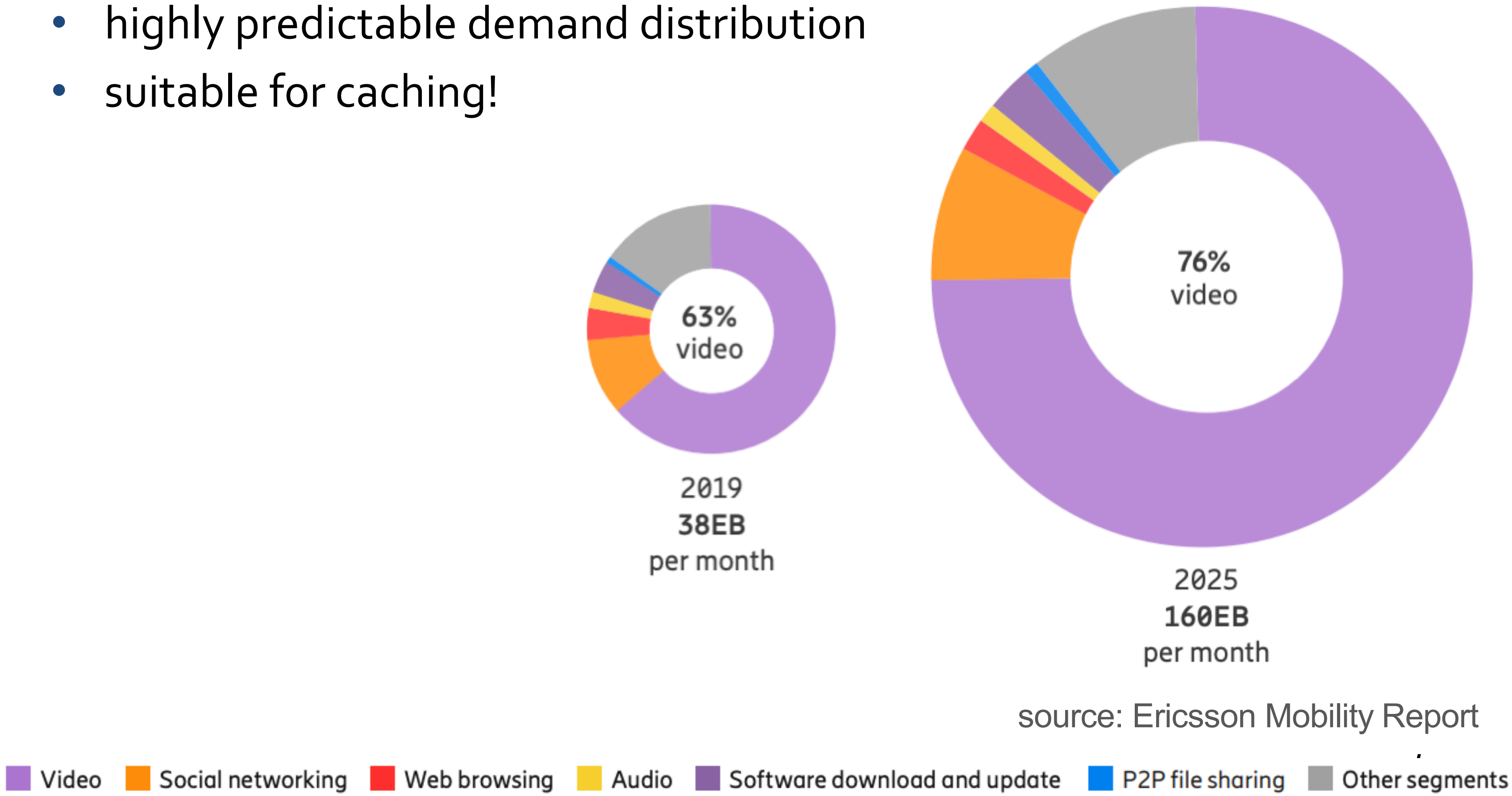
Caching

- **Principle:** caching contents/services at the network edge

- **A Key Technology of the 5G**
  - Reduce **latency**
  - Reduce **costs**

From Connecting Endpoints to Content Delivery

- More than 80% of traffic is content
  - video, Web, File Sharing, Social media, etc.
  - highly predictable demand distribution
  - suitable for caching!



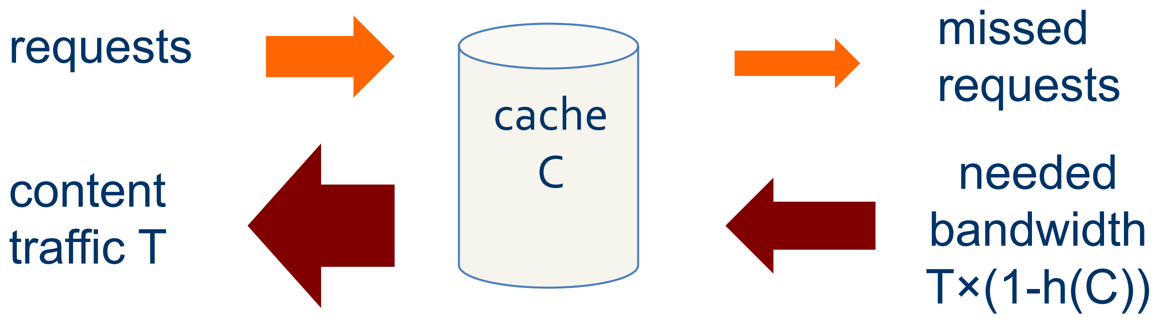
source: Ericsson Mobility Report

Caching in 5G: opportunities and challenges

- Computation caching
  - caching services and related libraries/databases at the edge
- Small cell challenges
  - coverage overlap
  - mobility
- Encrypted Traffic
  - fraction of traffic delivered through HTTPS has already passed 50%

The role of Caching in Reducing Costs

- Demand depends on content placement
  - caching can be used to realize memory for bandwidth trade-off
  - for a cache of size C and hit prob. h(C)
    - only missed requests will need upstream bandwidth



Ongoing Work …

- How big Are the savings and how to realize that?
  - performance evaluation of caching
  - business model to enable the optimal caching by content providers and mobile network operators

Mahdieh Ahmadi
- Ph.D. candidate
- Visiting researcher at Telecom ParisTech, Paris, France, in collaboration with Cisco in 2018-2019.
- Visiting researcher at SyMLab, HKUST, Hong Kong, in 2015.

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Conclusion

- Starting as a mobile evolution, 5G will become a revolutionary enabler
- 5G will enable new functionalities for people, societies, business & industries
- Programmability is the key features of future networking
- SDN, NFV and FC (EC) are enabling technologies toward 5G
- Caching as a means to realize cost efficiency plays a crucial role in future content centric network

- **Thank you!**
- **Any Questions…?**