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Introduction: technologies

ICT for Industrial Applications
(ICT4IA)

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SIGNALS AND NETWORKING RESEARCH GROUP

the (short) history of cellular systems

From 1G to 4G

1G - TACS	2G - GSM	3G - UMTS	4G - LTE
			
Cellular network concept & analogue communications	Digital communication and centralized Network Control	• Multi-Rate & Adaptive Modulation and Coding • Scheduling & Fairness • Soft Handover	• Channel Aggregation • Small cells & Network densification • MIMO & Comp

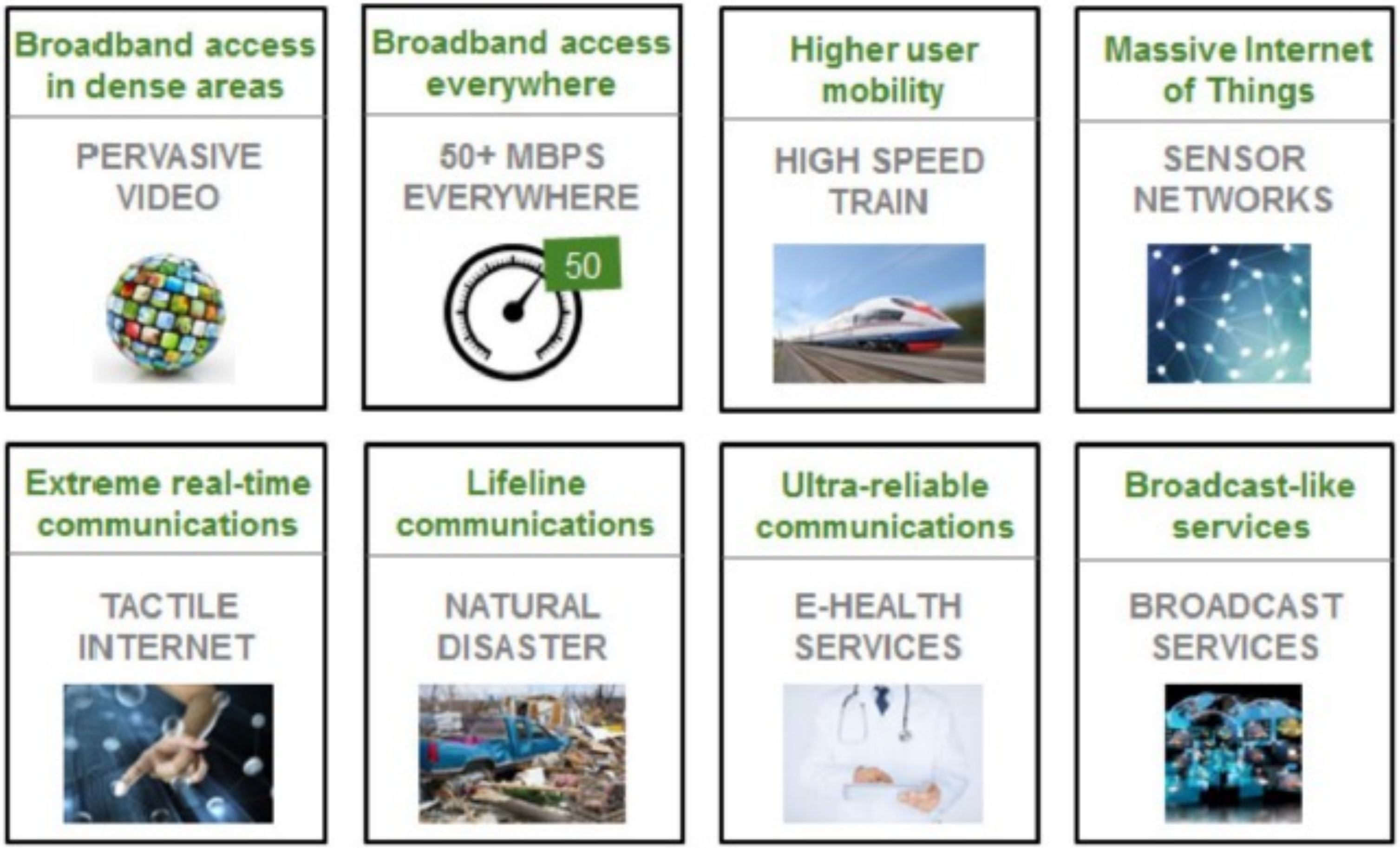
From 1G to 4G

- **1G:** established seamless mobile connectivity introducing mobile voice services
- **2G:** introduced the multi standards (GSM, CDMAone), applied frequency reuse
- **3G:** optimized mobile for data enabling mobile broadband services with faster and better connectivity
- **4G:** more capacity with faster & better mobile broadband experiences

Where does 4G fall short?

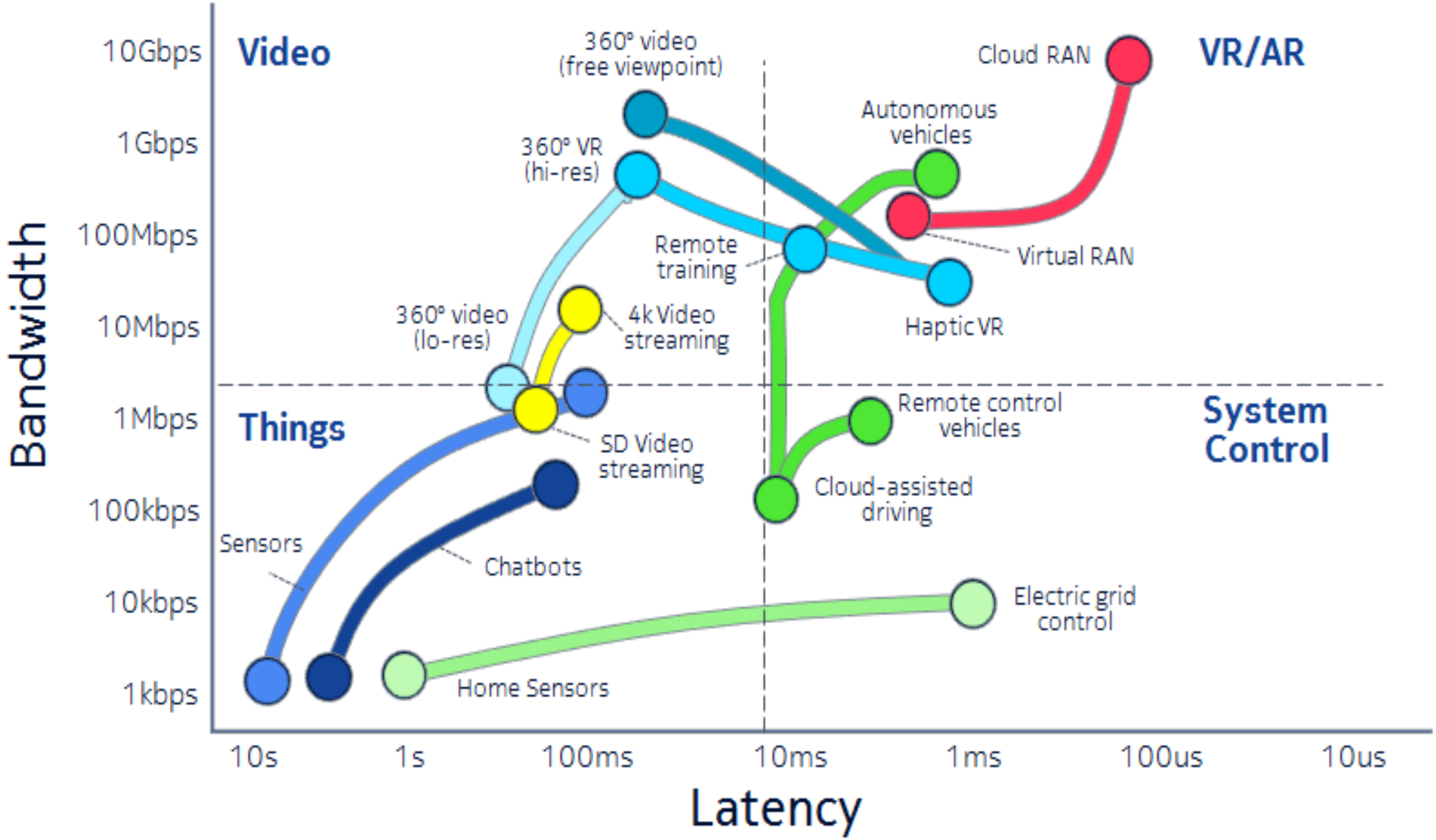
- 4G monolithic ‘one-fit-all’ architecture cannot meet very disparate service requirements
- 4G cannot provide truly differentiated services while maintaining high efficiency
- Latency, capacity & reliability do not match the requirements of most challenging **new applications**

Which applications?



Source: NGMN Alliance, "NGMN 5G White Paper" - v1.0, 17th February 2015
https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

5G Latency requirements per type of service



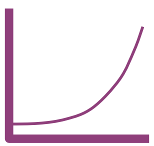
What do we expect from 5G?

5G CHALLENGES

Avalanche of
Traffic Volume

Further expansion of mobile broadband

Additional traffic due to communicating machines



"1000x in ten years"

Massive growth in
Connected Devices
"Communicating machines"

"50 billion devices in 2020"

Large diversity of
Use cases & Requirements

Device-to-Device Communications

Car-to-Car Comm.

New requirements and characteristics due to communicating machines

Source: METIS Project

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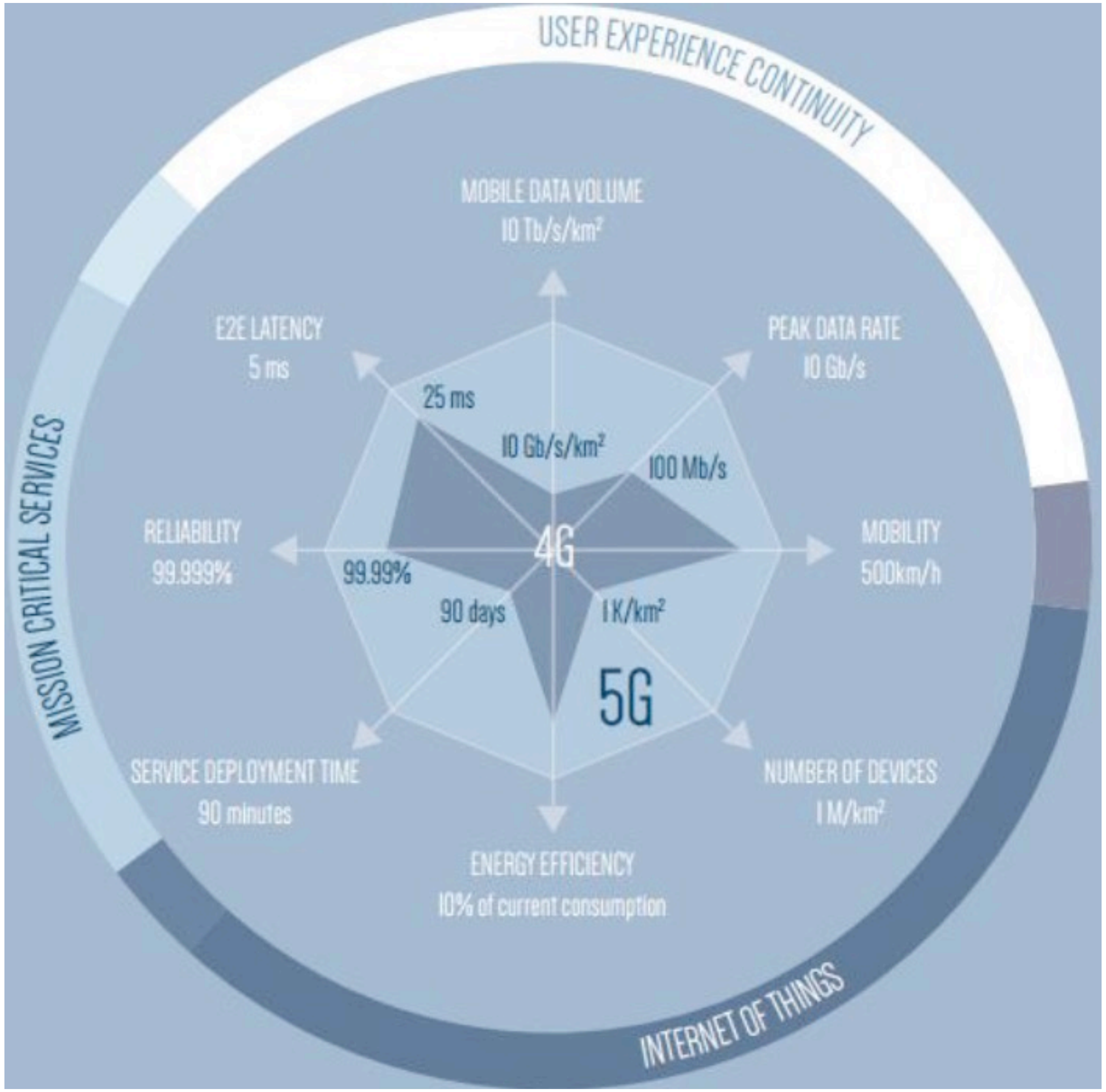
User perspective

- **Infinite capacity**
  - Everyone gets enough to be “happy”!
- **Ubiquitous coverage**
  - No more connectivity gaps
- **Pervasive connectivity**
  - “Every” object is Internet-enabled
- **Customization**
  - Services adapt to the context and the personal requirements
- **Flexibility**
  - Easy development and integration of new services

Requirements on 5G

Source: 5G-PPP (https://5g-ppp.eu/)



1000x more data rates

Towards 0-5ms E2E latency

1M/km^2 devices

500km/h high mobility

99.999% reliability

<90’ service deployment time

90% energy efficiency

MORE CAPACITY

More CAPACITY

- A single user-centric view

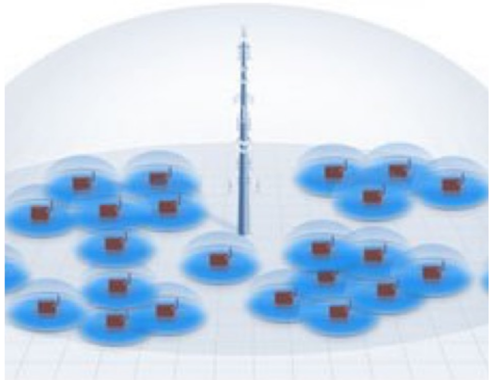
$$C = W \log_2(1 + SINR)$$

- C: Rate per user
- W: Bandwidth per user, antenna degrees of freedom
- $\log_2(1 + SINR)$: Spectral efficiency

- Current coding techniques are **very close** to the theoretical Shannon **spectral efficiency bounds** for single user capacity
- Most techniques for 5G increase the **bandwidth** and **degrees of freedom** to exploit diversity

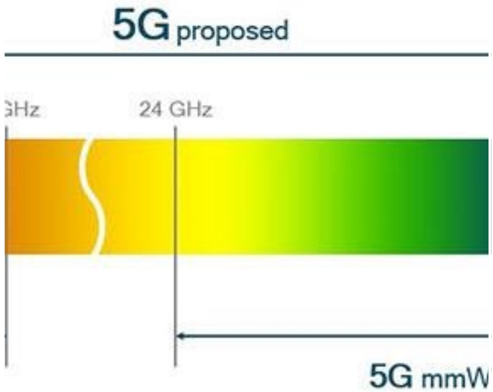
More capacity

Densification



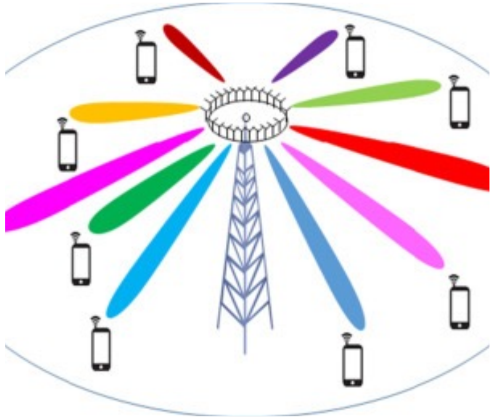
- Small cells, Relays, mobile Relays and Drones
- larger bandwidth per user in each cell

More bandwidth



- new spectrum @ higher frequencies (above 6 GHz)
- mmWave
- Visible Light Communications

More antennas



- Massive MIMO
- Dynamic beamforming
- Spectrum sharing
- Multiple-RATs

Network densification

Classic Challenges:

1. **Interference**
    - **Cross-tier** & **co-tier**
    - Near-far effect
2. **Uncoordinated** operations
    - Inter-cell **interference**
    - **Mobility** management

New Challenges:

3. **Unplanned** deployment
    - **Overlaying** coverage
    - **Over-dimensioned capacity**
4. **Energy** consumption
    - High number of **always on APs**
    - **Traffic unbalance** at APs

Massive MIMO

- Massive MIMO use a large arrays at BSs
  - e.g., $N \approx 200$ antennas, $K \approx 40$ users
- Key: Excessive number of antennas, $N \gg K$
- Very narrow beamforming
- Little interference leakage
- Disruptive for 5G
- Channel Estimation is critical

More spectrum

- New frequency bands
  - mm-Wave communications (3 to 300 GHz)
  - 5 – 9 GHz of unlicensed bandwidth
  - Ever heard of WiGig (IEEE 802.11ad)?
    - 1 Gbps at 60 GHz
    - http://www.wi-fi.org/discover-wi-fi/wigig-certified
- Very sensitive to blockage…

mmW channel intermittency due to blocking

- Causes of blocking
  - **Human body** shadowing
  - **Object** blocking

- Types of blocking
  - **Short term blocking**: shorter than the tolerable time to the service
  - **Long term blocking**: is longer than the tolerable time-to-live of the service

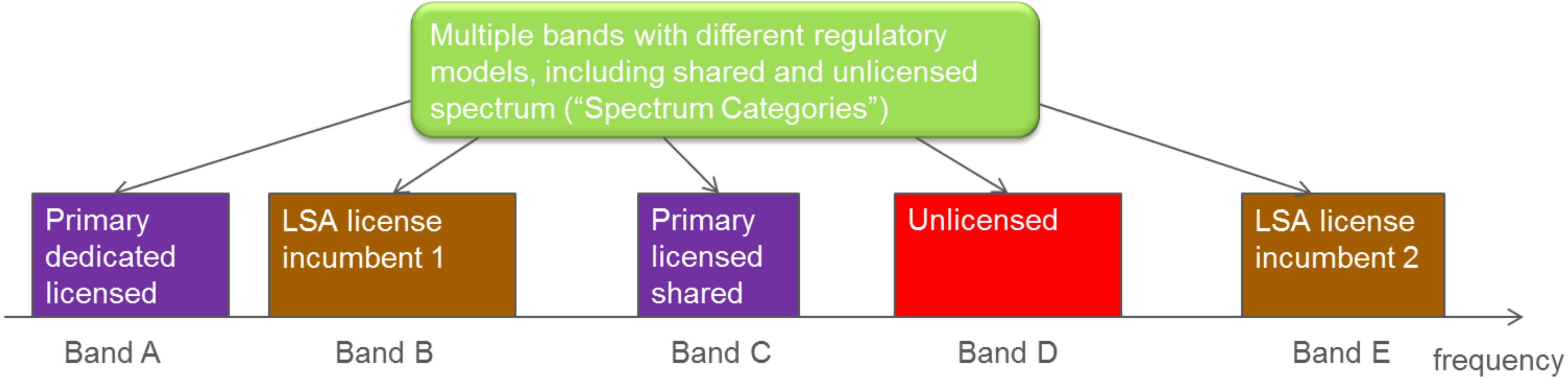
Counteract strategies

- With Short term blockages:
  - ***Catch up approach***: compensate the time lost for blockage with higher average information transmission rate
    - **Multi-link communications** over same or different Radio Access Technologies (RATs) such as LTE, 5G, WiFi,…
    - **Overprovisioning** of resources

- With Long term blockages:
  - Overprovisioning is not sufficient
  - Make **offloading robust** by
    - **Multi-link communications** for spatial error-correcting codes with resource overprovisioning
    - Block erasure **channel code design** over multi-links

Spectrum Scenario: Future Landscape

LSA = Licensed Shared Access



- Multiple frequencies bands: dedicated licensed spectrum complemented with various forms of shared spectrum

"Toolbox" of different sharing enablers required

In order for **5G** system to work under such scenarios

MASSIVE ACCESS

Machine Network Traffic

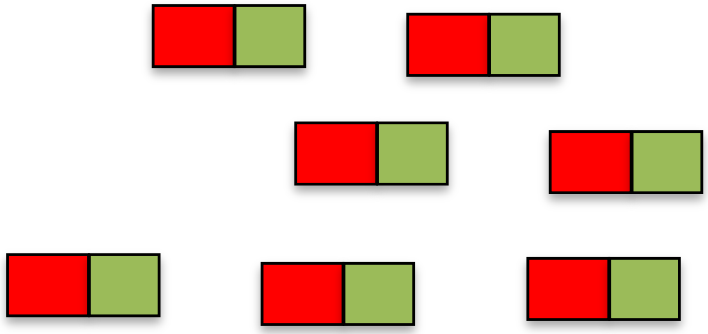
- M2M devices generate traffic of the following types
  - *Periodic*: smart metering application
  - *Event-driven*: emergency event report
  - *Continuous*: surveillance camera

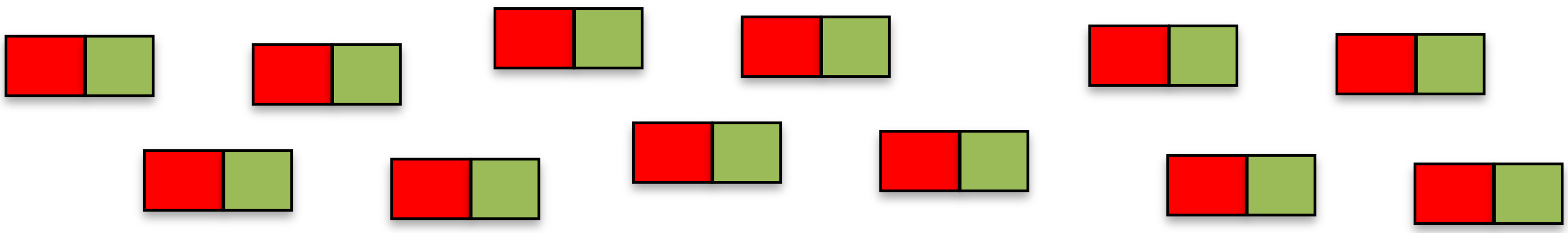
- Large volume of different types of traffic at core network
  - Guarantee of diverse QoS traffic requirements
  - Reliability of both human-to-human and M2M traffic

high-speed wireless vs. M2M

- high-speed systems built from information-theoretic principles with small control info and **large data**

- M2M requires short data packets from massive number of devices each transmitting sporadically





The issue of short packets

- Today's cellular systems are designed mainly for broadband traffic sources
  - Can easily accommodate 5 clients transmitting at 2 Mbit/s each, but not 10.000 clients transmitting at 1kbit/s
  - Coding and control overhead may become predominant
  - Preambles for channel estimation may be longer than data payload!

wireless M2M

- some **challenges**:
  - highly reliable connections despite coverage problems
  - low latency
  - long battery lifetime
  - massive number of nodes with sporadic use
- some **opportunities**:
  - correlation of machine-type data across space and time
  - predictability and/or periodicity of data/control traffic
  - header compression using implicit/context information
  - advanced PHY/MAC techniques

Three main approaches

Short-range multihop

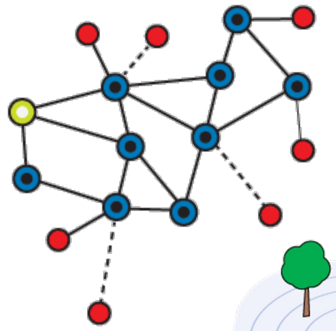
- ZigBee
- WiFi low energy
- RFID

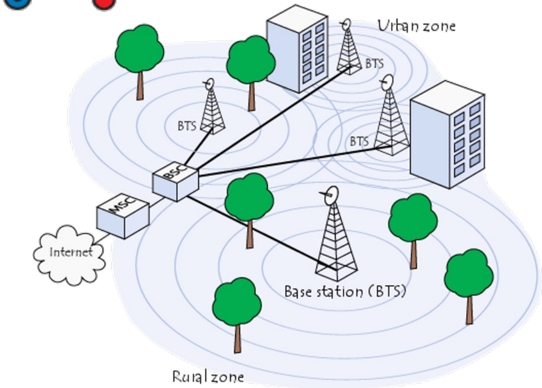
Cellular

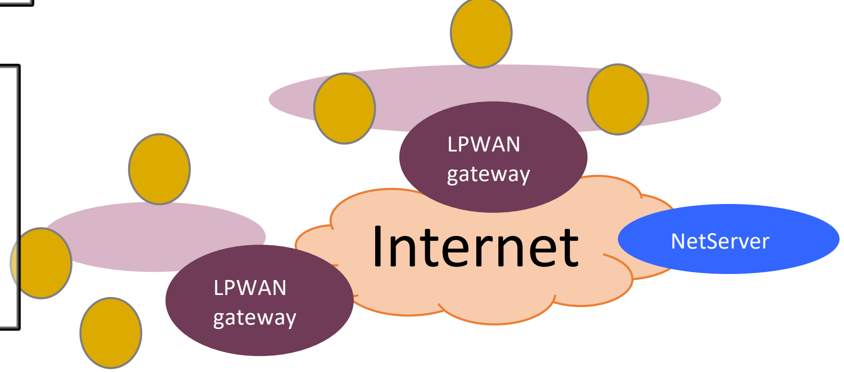
- GSM
- LTE-A/NB-IoT
- 5G

Low Power Wide Area Networks (LPWAN)

- SIGFOX
- LoRa
- NB-IoT







PROGRAMMABLE NETS

Networking planes

- **Data Plane**
  - All activities involving as well as resulting from data packets sent by the end user, e.g.,
    - Forwarding
    - Fragmentation and reassembly
    - Replication for multicasting
- **Control Plane**
  - All activities that are necessary to perform data plane activities but do not involve end-user data packets
    - Making routing tables
    - Setting packet handling policies (e.g., security)
    - Base station beacons announcing availability of services

Ref: Open Data Center Alliance Usage Model: Software Defined Networking Rev 1.0,"
http://www.opendatacenteralliance.org/docs/Software_Defined_Networking_Master_Usage_Model_Rev1.0.pdf

Data vs control planes

Data plane runs at line rate

- e.g., 100 Gbps for 100 Gbps Ethernet → Fast Path
- Typically implemented using special hardware
- Few activities handled by CPU in switch → Slow path
  - e.g., Broadcast, Unknown, and Multicast (BUM) traffic

All control activities are generally handled by CPU

OpenFlow key idea

- Separation of control and data planes
- Centralization of control
- Flow based control
  - Control logic is moved to a controller
  - Switches only have forwarding elements
  - One expensive controller with a lot of cheap switches
  - **OpenFlow** is the protocol to send/receive forwarding rules from controller to switches

Ref: N. McKeown, et al., ``OpenFlow: Enabling Innovation in Campus Networks," ACM SIGCOMM CCR, Vol. 38, No. 2, April 2008, pp. 69-74.

OpenFlow basics

- One packet arrives to the switch
- Switch logic compares header fields with flow entries in a table
  - if any entry matches → take indicated actions
  - If no header match →
    - packet is queued and **header** is sent to the controller
    - Controller sends a new rule to the switch
    - subsequent packets of the flow are handled by this rule
- Doesn't all of this sound somehow familiar?

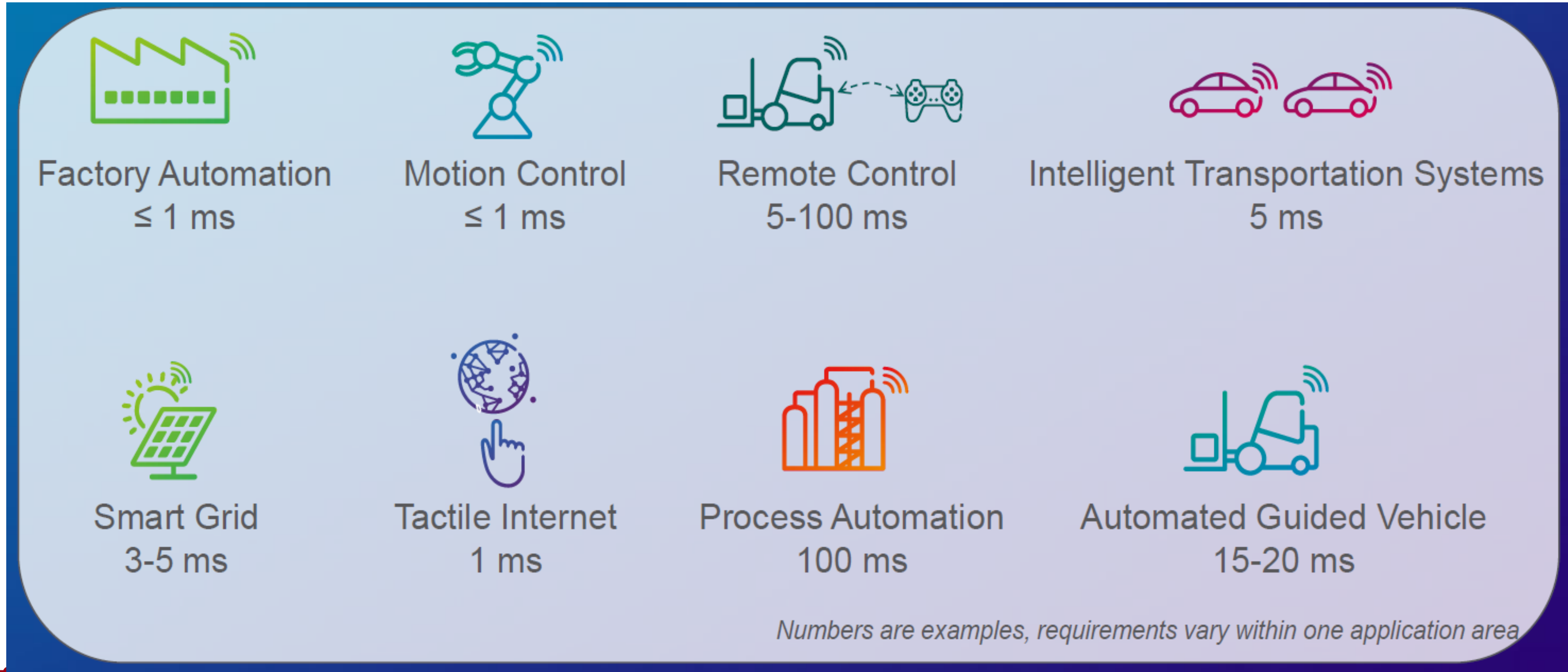
Ref: N. McKeown, et al., ``OpenFlow: Enabling Innovation in Campus Networks," ACM SIGCOMM CCR, Vol. 38, No. 2, April 2008, pp. 69-74.

What do we need SDN for?

1. **Virtualization**: Use network resource without worrying about where it is physically located, how much it is, how it is organized, etc.
2. **Orchestration**: Manage thousands of devices
3. **Programmable**: Should be able to change behavior on the fly
4. **Dynamic Scaling:** Should be able to change size, quantity
5. **Automation**: Lower OpEx
6. **Visibility**: Monitor resources, connectivity
7. **Performance**: Optimize network device utilization
8. **Multi-tenancy**: Sharing expensive infrastructure
9. **Service Integration**
10. **Openness**: Full choice of Modular plug-ins
11. **Unified management** of computing, networking, and storage

5G is changing ‘the Equation’

- The issue of 5G is not only more capacity but also more reactive, smart and connected devices

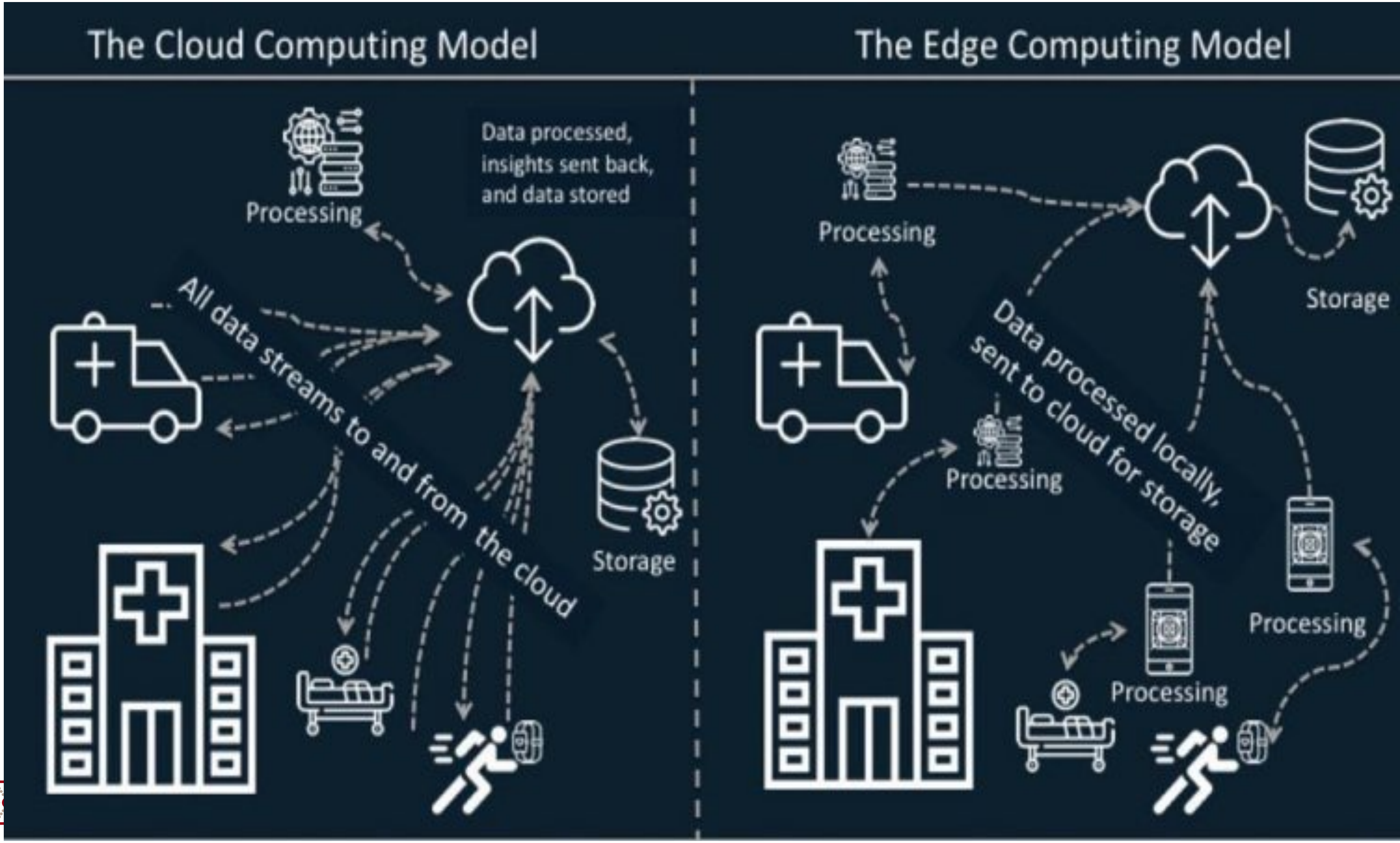


5G is changing ‘the Equation’

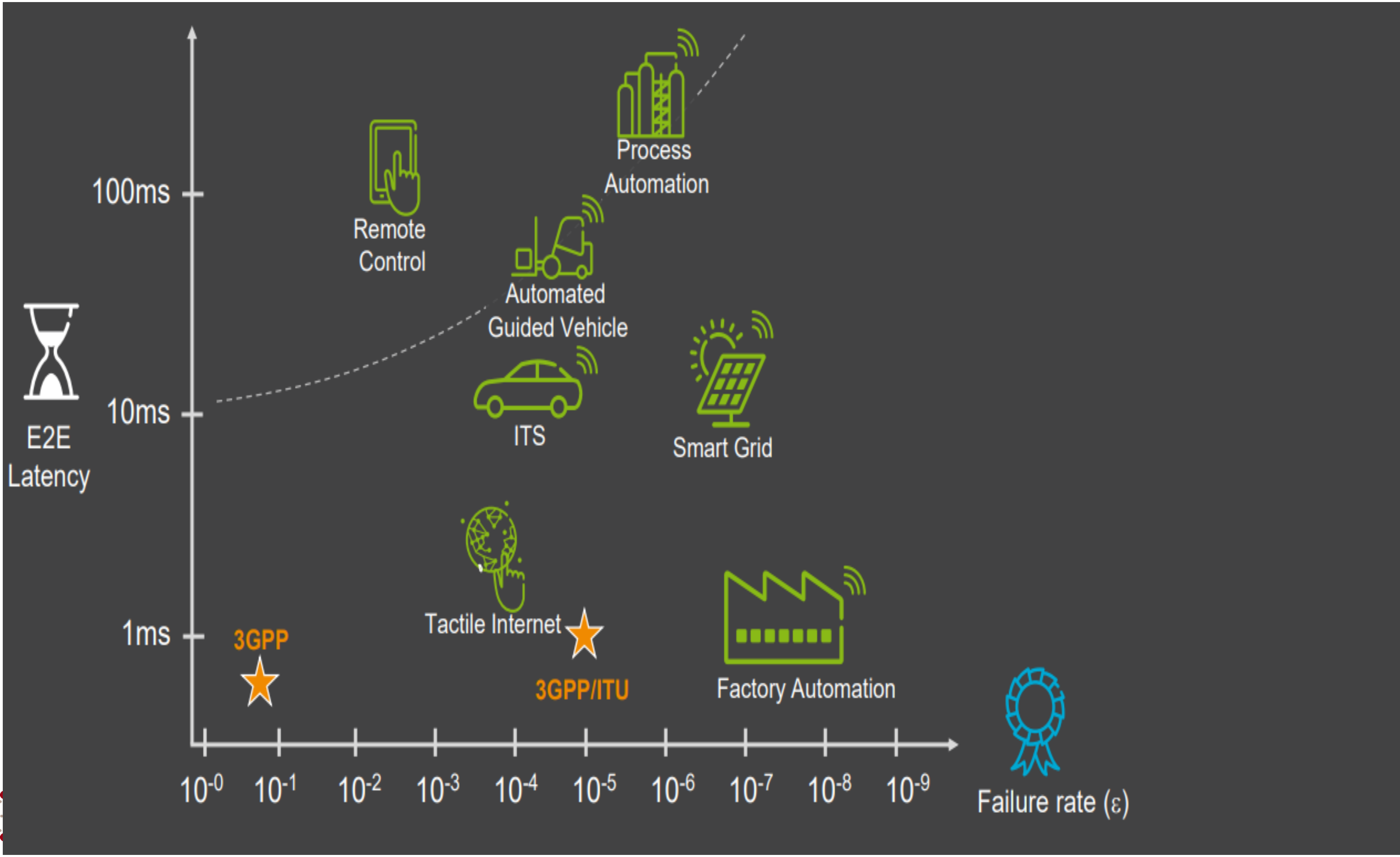
- “Latency” is based on 3 major component:
- transmission delay + routing and switching + IT response time

Wireless / Wired **Processing and Storage**

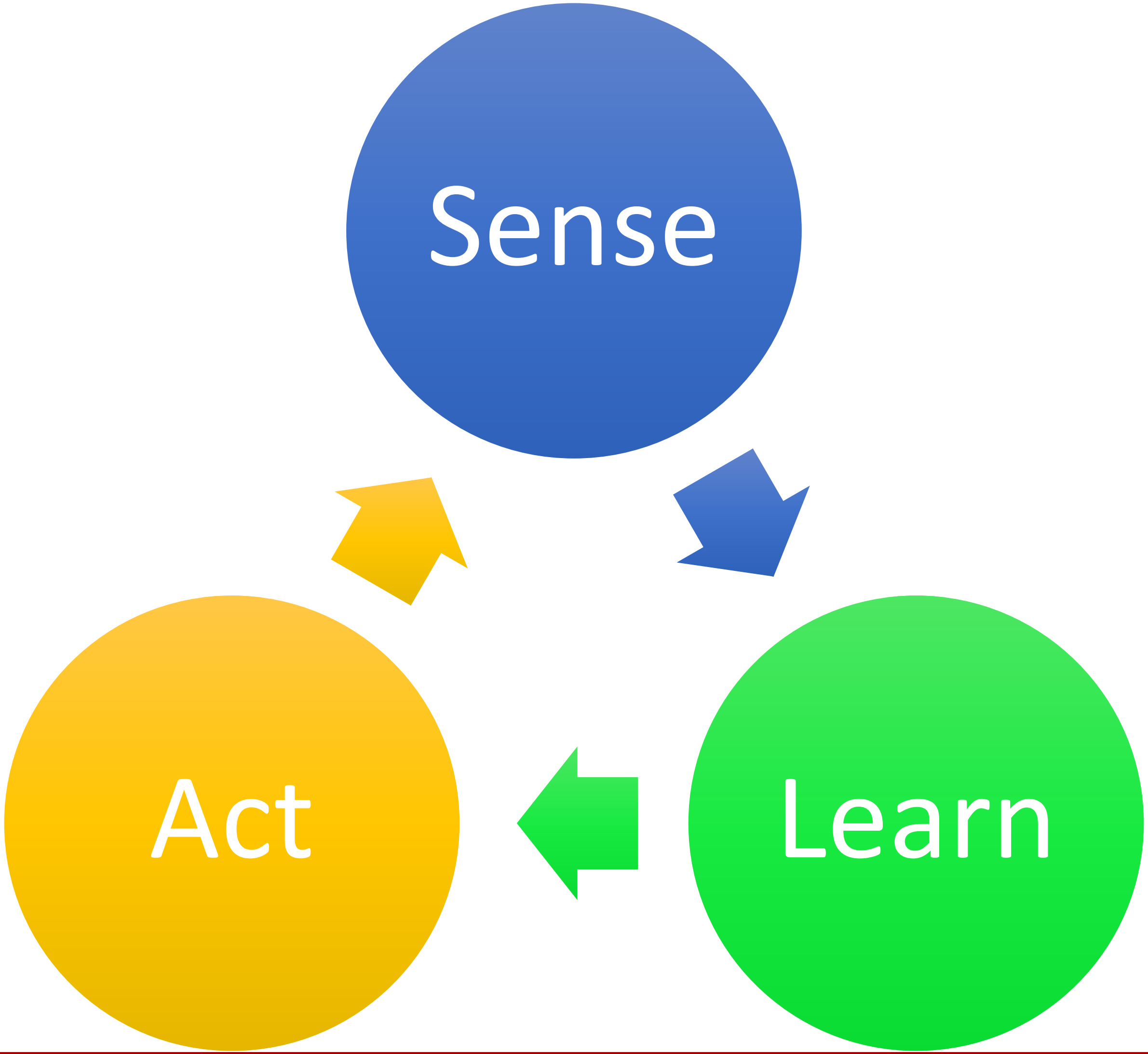
Local processing to reduce the latency: the ECM



Latency reduction versus reliability



The cognition cycle



True for human, true for networks

- **Sense**: nowadays devices are crammed with transducers/sensing apparatuses
  - needs efficient data handling
- **Learn**: optimization algorithms can be run at each node individually
  - needs (i) efficient algos (ii) harmonization
- **Act**: network modifies the environment
  - requires convergence of multiple devices

Cognition-based Network

Each node of the network:

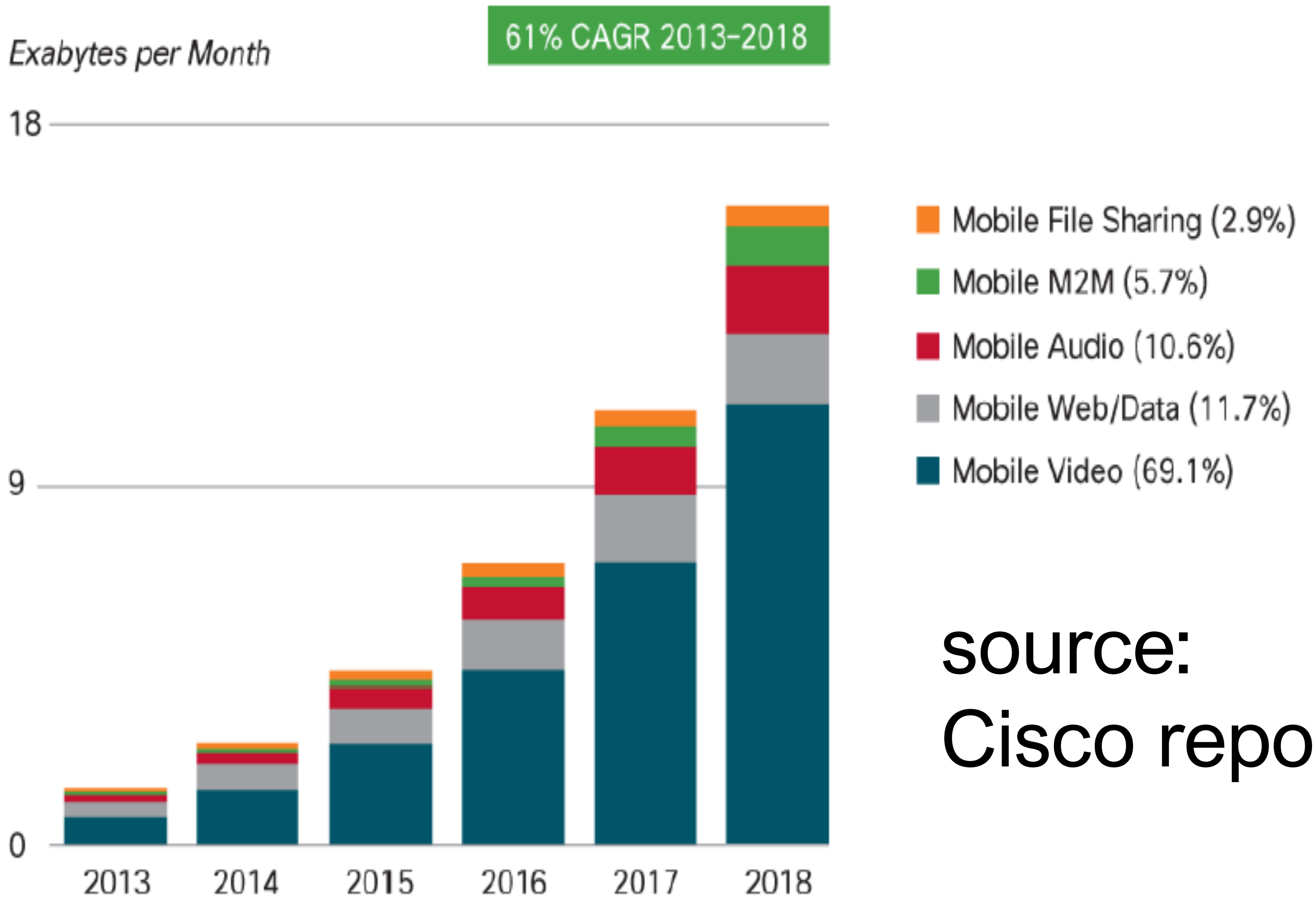
- exploits local information to achieve its goal
- shares it with its neighbors

↓

Self-adaptation to the environment to achieve network wide goals

Cognition applied to the **entire network**

Multimedia growth

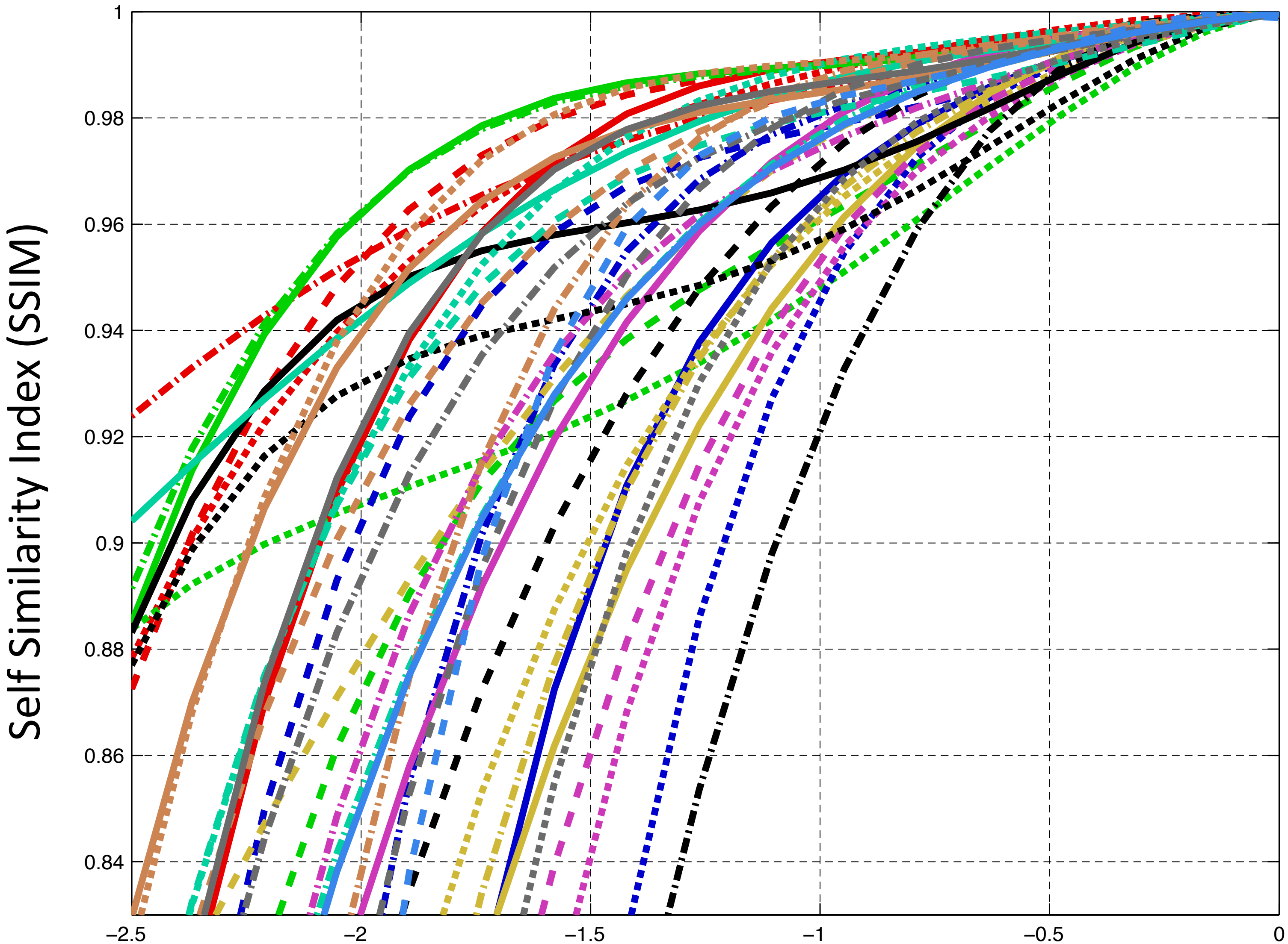


source:
Cisco report (2014)

Analysis

- We consider a test set of 38 video clips, all encoded in an H.264-AVC format
- All the videos are encoded with a 16-frame structure (1 I-frame, 15 P-frames) and compressed with 18 different rates
- Depending on the content, the perceived quality of a compressed version changes
  - We used the SSIM indicator to capture it

SSIM versus rate

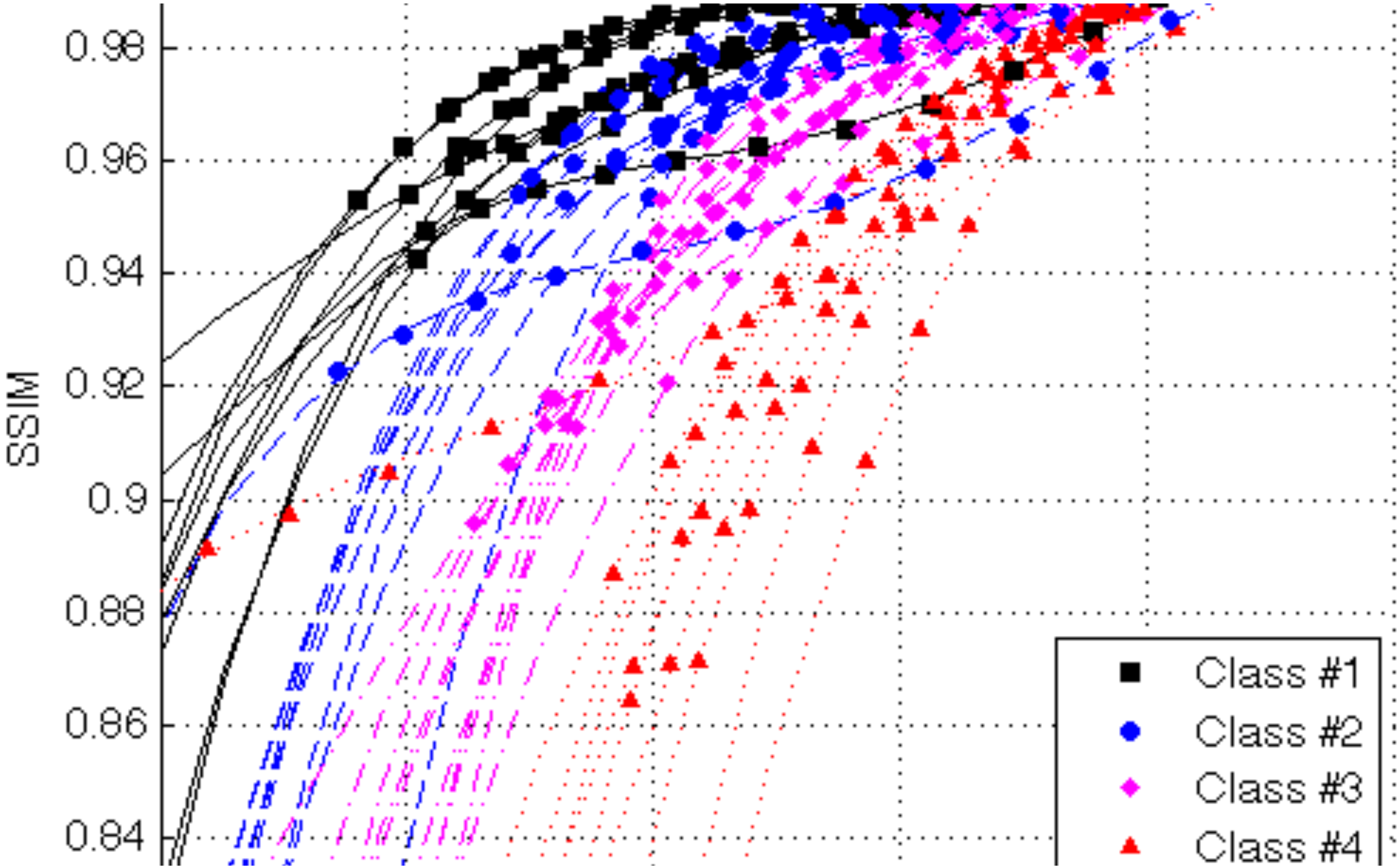


ρ=log(actual rate/original rate)

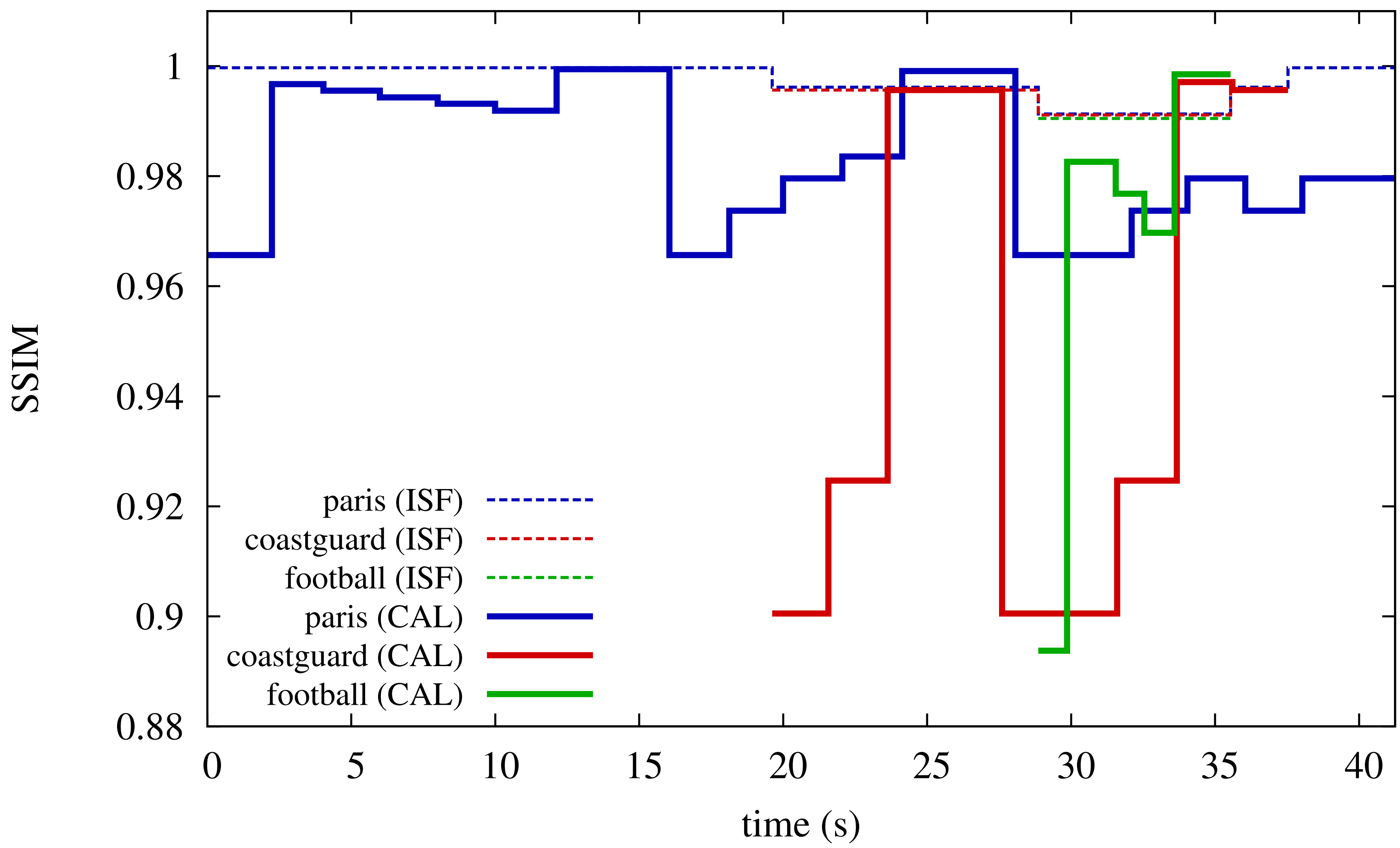
Requirements for video delivery

- QoE-based and content-aware resource allocation
  - Rate-distortion curve depends on video content
  - Video content affects size of the encoded video frames
  - RBM can be used to infer rate-distortion curve of a video by observing the **size** (not the content) of video frames

“Our” Video Classes



QoE-aware proxy vs legacy video clients



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Some useful Links

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- Amazon AWS: www.amazon.com/iot
- Apple HomeKit: www.apple.com/lae/ios
- Google Cloud IoT: https://cloud.google.com/iot/
- MicroSoft Azure: https://azure.microsoft.com
- Qualcomm AllJoyn: https://developer.qualcomm.com/software/alljoyn
- OneM2M: https://www.onem2m.org
- ThingSpeak: https://thingspeak.com
- Connected Home over IP: https://www.connectedhomeip.com