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A high level perspective on 5G technologies and applications

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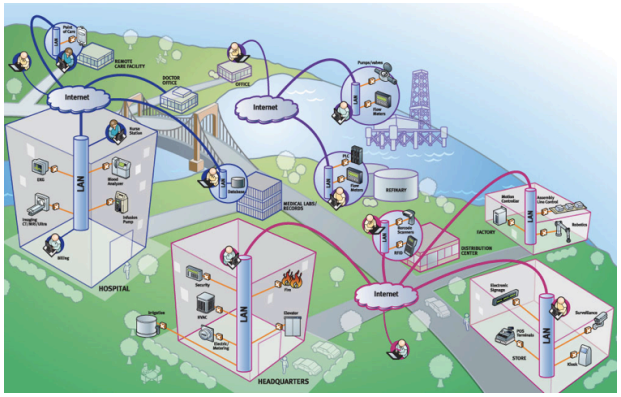
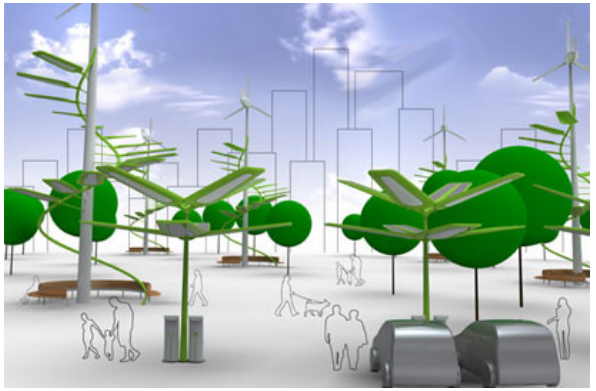
Signet

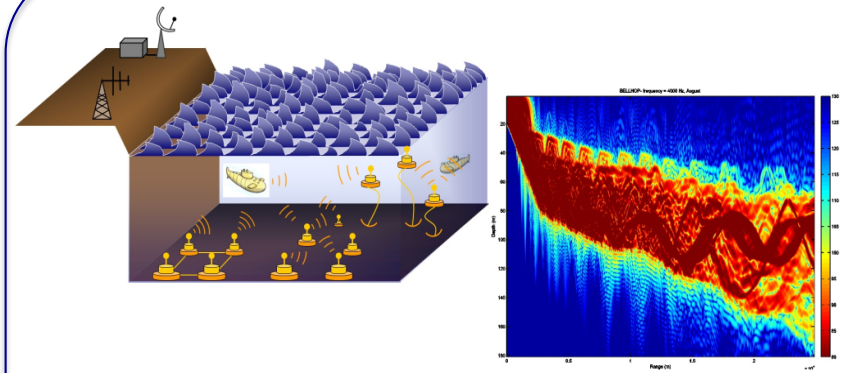
Main research areas…



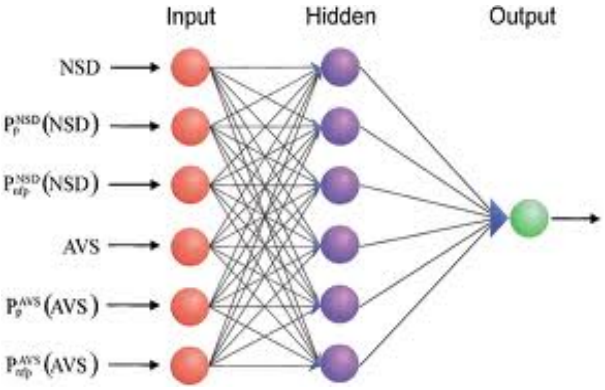
Next generation mobile & IoT



Energy harvesting & smart grids

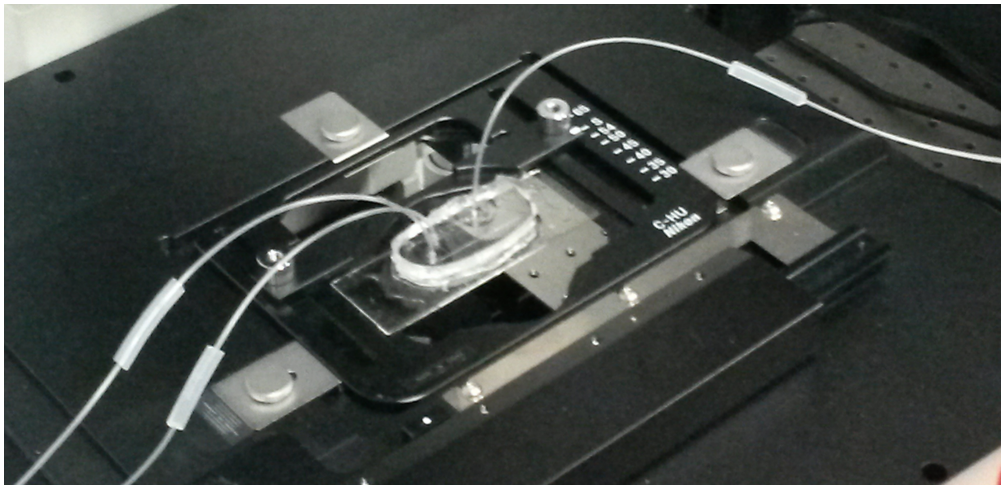


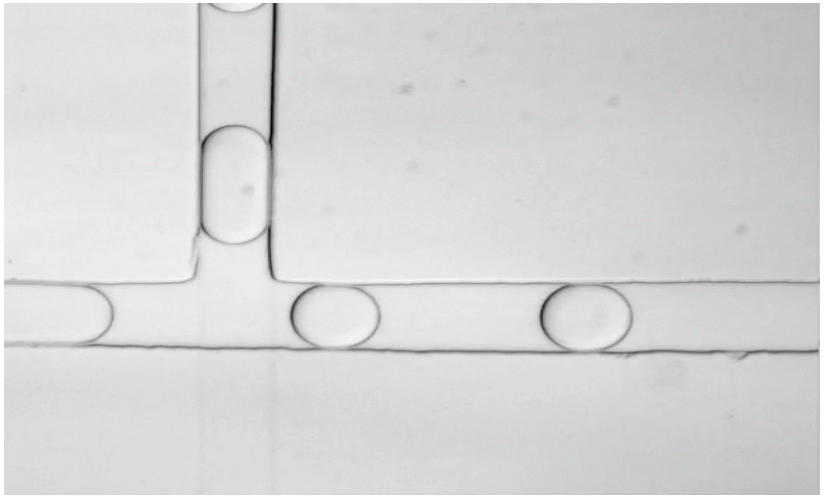
Underwater communications

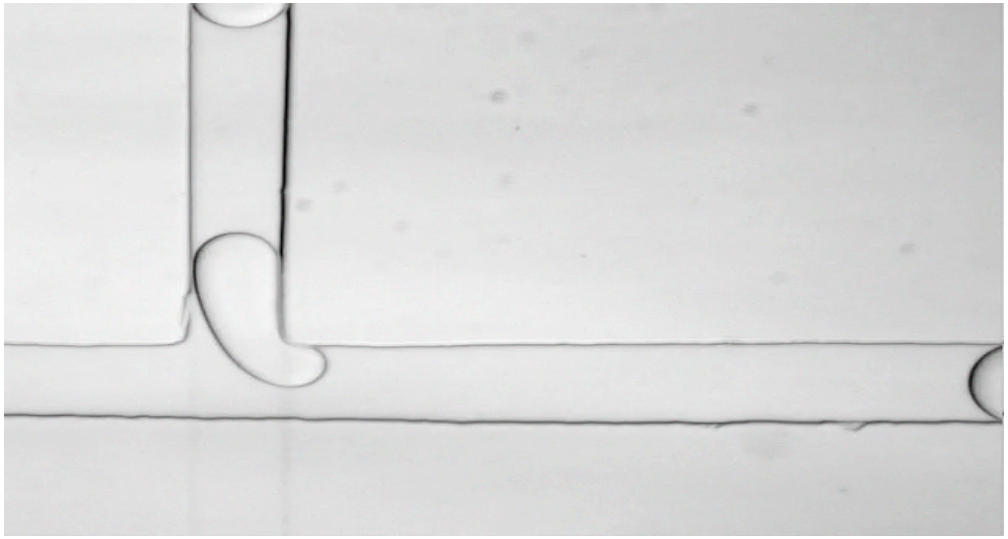


Cognitive Networks

Plus more exotic stuff…







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THE (SHORT) HISTORY OF CELLULAR SYSTEMS

From 1G to 4G

1G - TACS

Cellular network concept & analogue communications

2G - GSM

Digital communication and centralized Network Control

3G - UMTS

- Multi-Rate & Adaptive Modulation and Coding
- Scheduling & Fairness
- Soft Handover

4G - LTE

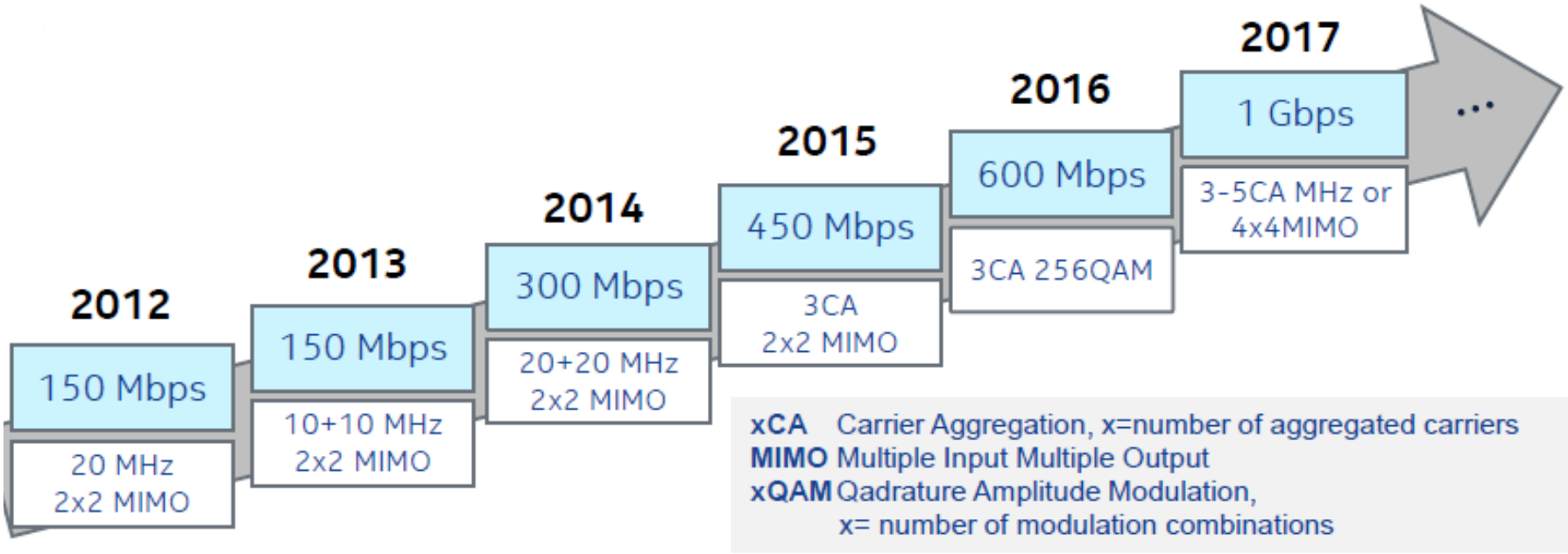
- Channel Aggregation
- Small cells & Network densification
- MIMO & Comp

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

4G capacity evolution

- 4G started with 150 Mbps with contiguous 20 MHz band
- Latest devices supports already 600 Mbps
- Chipset capability allows 1 Gbps devices already in end 2017 which requires typically 80-100 MHz spectrum



Where does 4G fall short?

- 4G monolithic 'one-fit-all' architecture cannot actually 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**

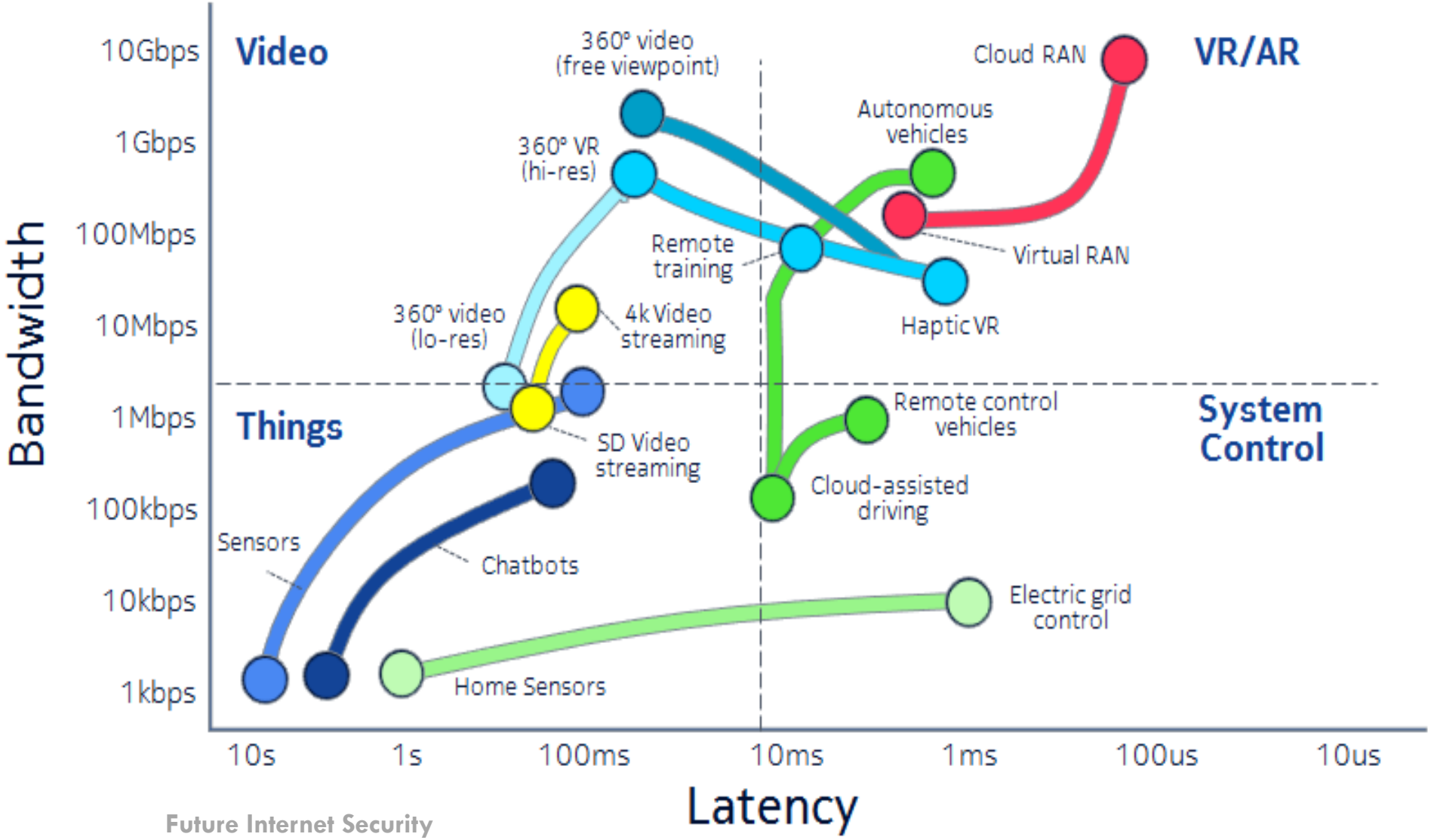
Which applications?

Broadband access in dense areas PERVASIVE VIDEO 	**Broadband access everywhere** 50+ MBPS EVERYWHERE 	**Higher user mobility** HIGH SPEED TRAIN 	**Massive Internet of Things** SENSOR NETWORKS 
Extreme real-time communications TACTILE INTERNET 	**Lifeline communications** NATURAL DISASTER 	**Ultra-reliable communications** E-HEALTH SERVICES 	**Broadcast-like services** BROADCAST SERVICES 

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

ngmn
the engine of broadband wireless innovation

5G Latency requirements per type of service



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WHAT DO WE EXPECT FROM 5G?

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

Technical requirements

User demands

- **Infinite capacity**
  - Everyone gets enough to be happy

Engineers answer…

- More data rate
- Higher spectrum efficiency
- More spatial reuse
- **QoE-based RRM**
- Dynamic content caching
- …

Technical requirements

User demands

- **ubiquitous coverage**
  - No more connectivity gaps!

Engineers answers

- multiple RATs
- new frequency bands
- multiple antennae & beamforming
- cell densification
- higher sensitivity
- better handover
- …

Technical requirements

User demands

- **pervasive connectivity**
  - "Every" object is Internet-enabled

Engineers answers

- protocols protocols protocols!
  - 6LowPAN, RPL, CoAP,…
- **massive access management**
- energy efficiency
- security
- …

Technical requirements

User demands

- **customization**
  - Services adapt to the context and the personal requirements

Engineers answers

- software adaptability
- quality of experience
- service differentiation
- **context awareness**
  - Machine learning
  - Unsupervised learning
  - Emergent behavior, …

Technical requirements

User demands

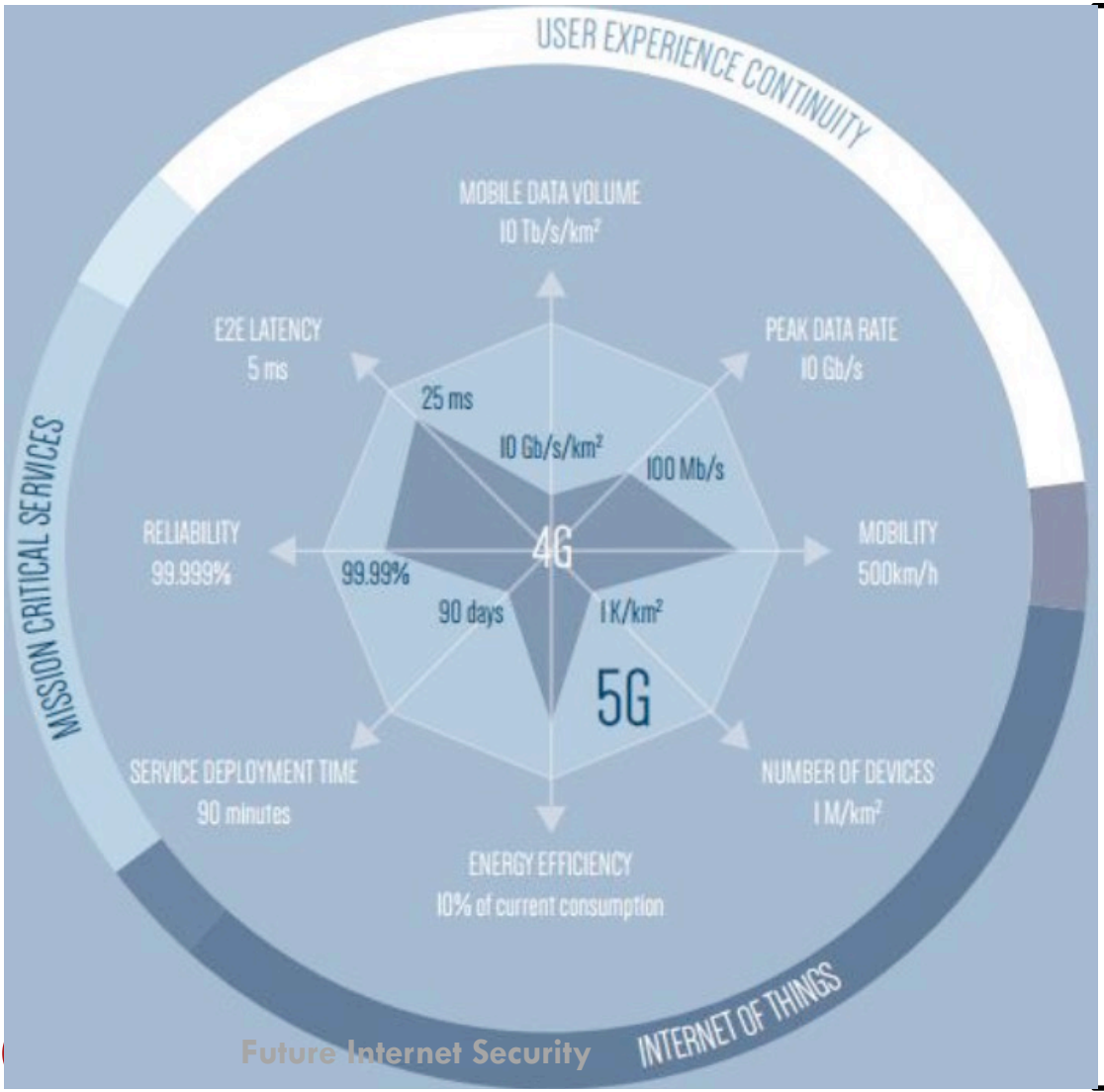
- **flexibility**
  - Easy development and integration of new services

Engineers answers

- semantic web
  - Ontologies
- data accessibility
- heterogeneous sources
  - wideband services (voice, video, web,…)
  - machine-type devices
  - Highly mobile users (VANET, trains,…)

Requirements on 5G

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



1000x more data rates

Towards 0-5ms E2E latency

1M/km^2 devices

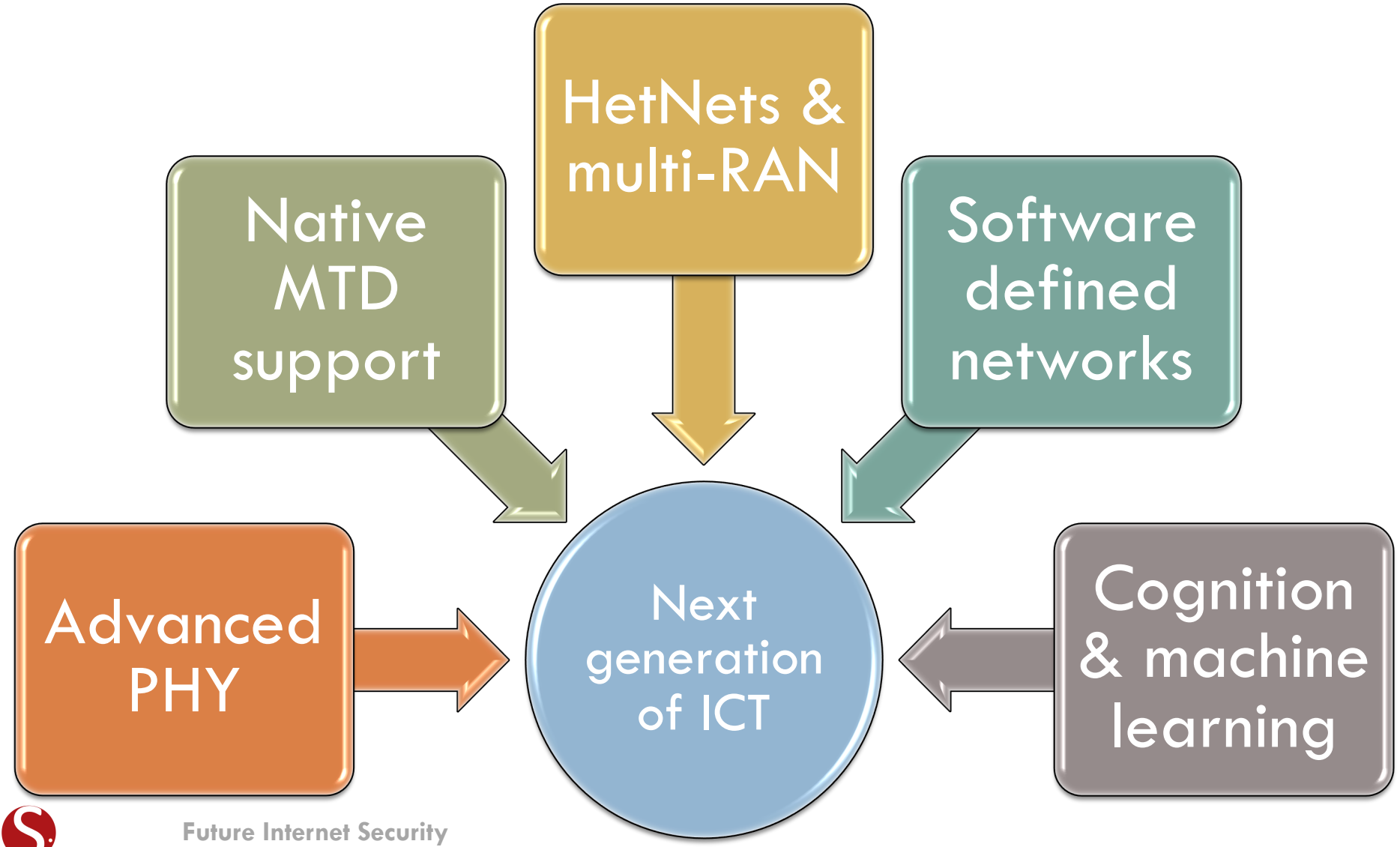
500km/h high mobility

99.999% reliability

<90' service deployment time

90% energy efficiency

The basic ingredients



More CAPACITY

- A single user-centric view

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

Rate per user

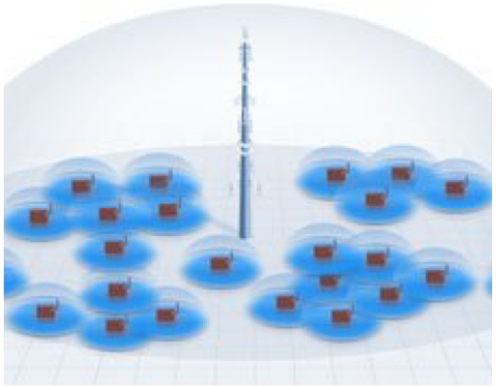
Bandwidth per user, antenna degrees of freedom

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

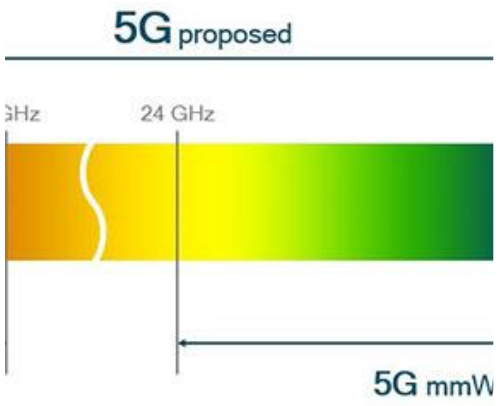
More capacity

Densification



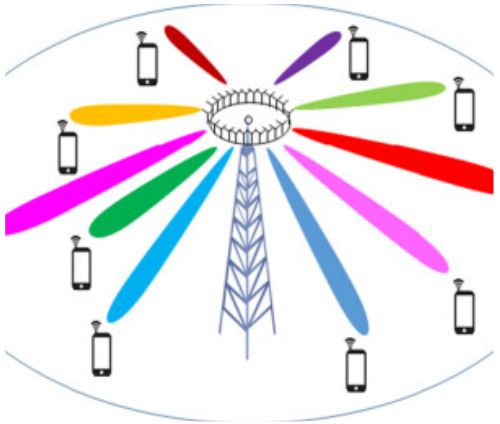
- Small cells, Relays, mobile Relays and Drones
- larger bandwidth per user in each cell

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

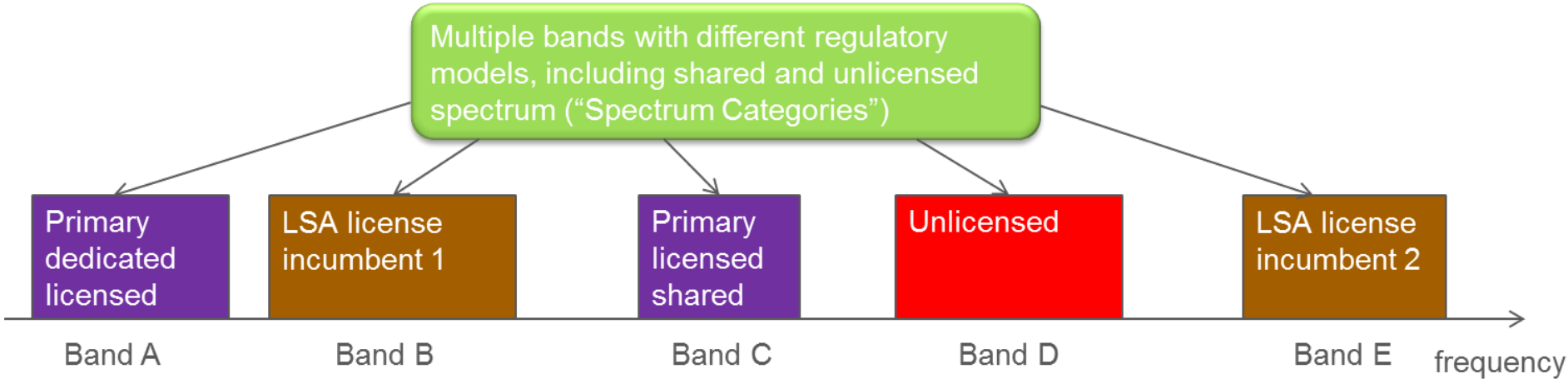
- Types of blocking
  - **Short term blocking**: shorter than the tolerable time live of the service
  - **Long term blocking**: is longer than the tolerable time to live of the service

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

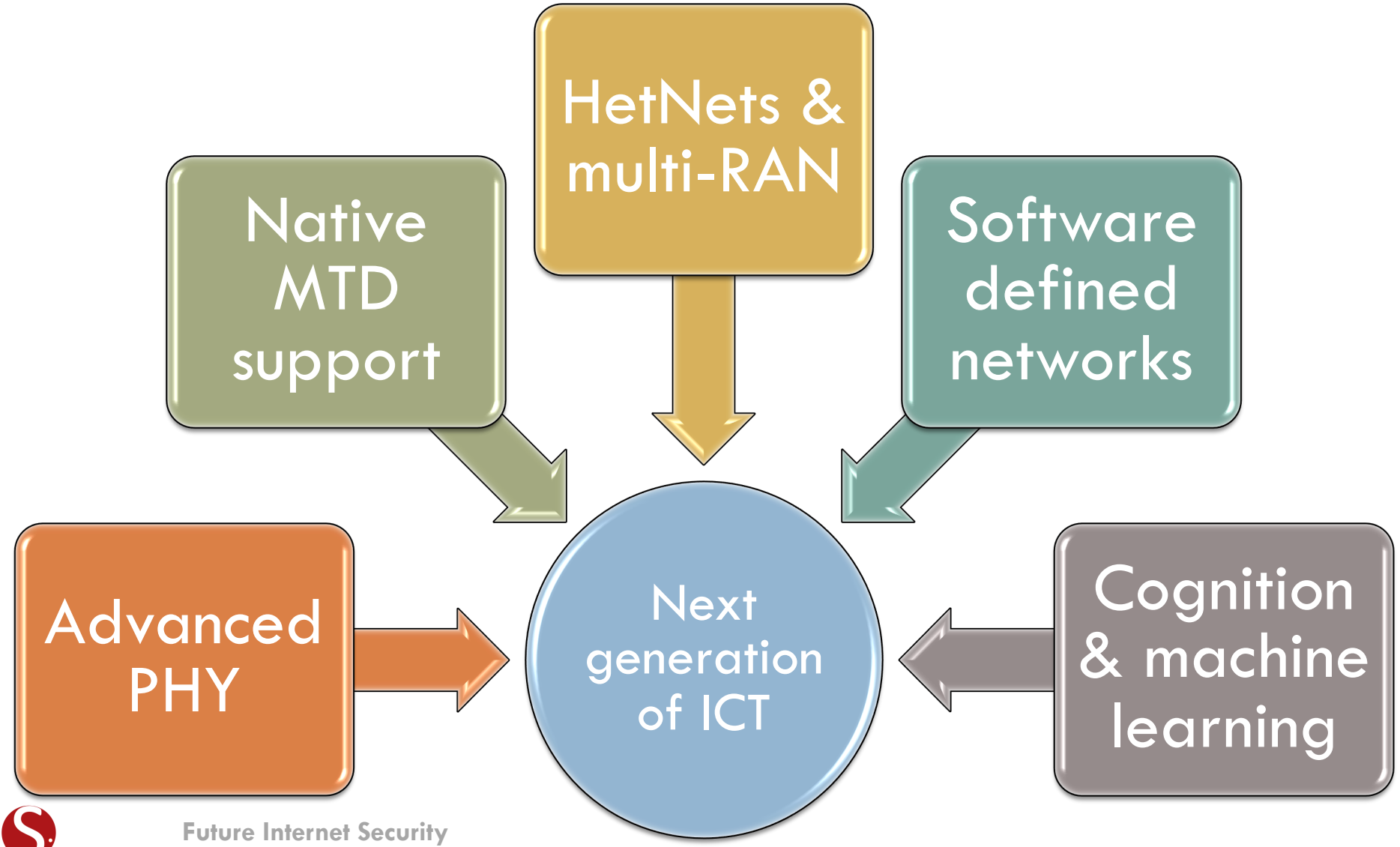


- Multiple frequencies bands: dedicated licensed spectrum complemented with various forms of shared spectrum

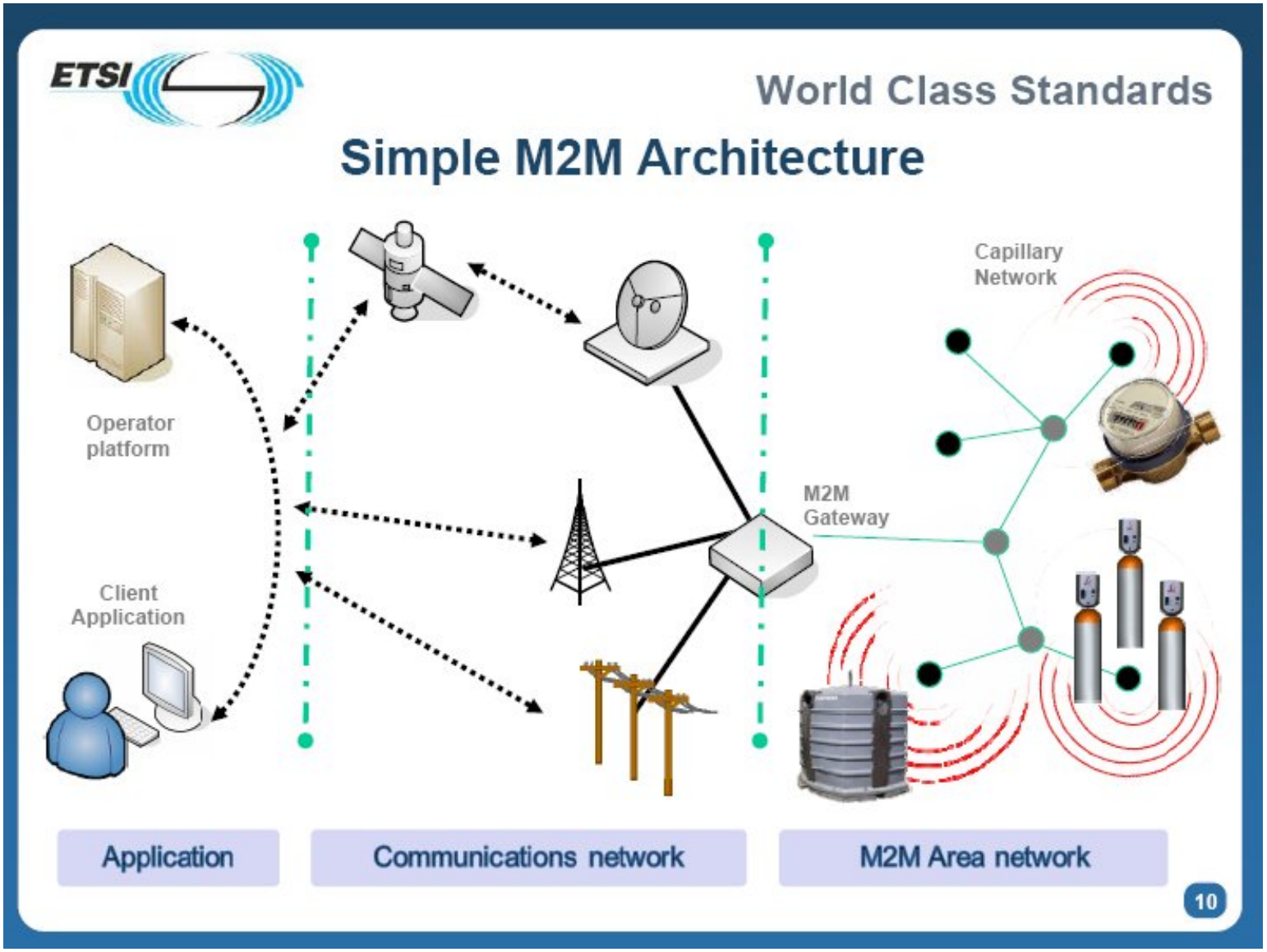
"Toolbox" of different sharing enablers required

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

Massive Access



M2M reference architecture



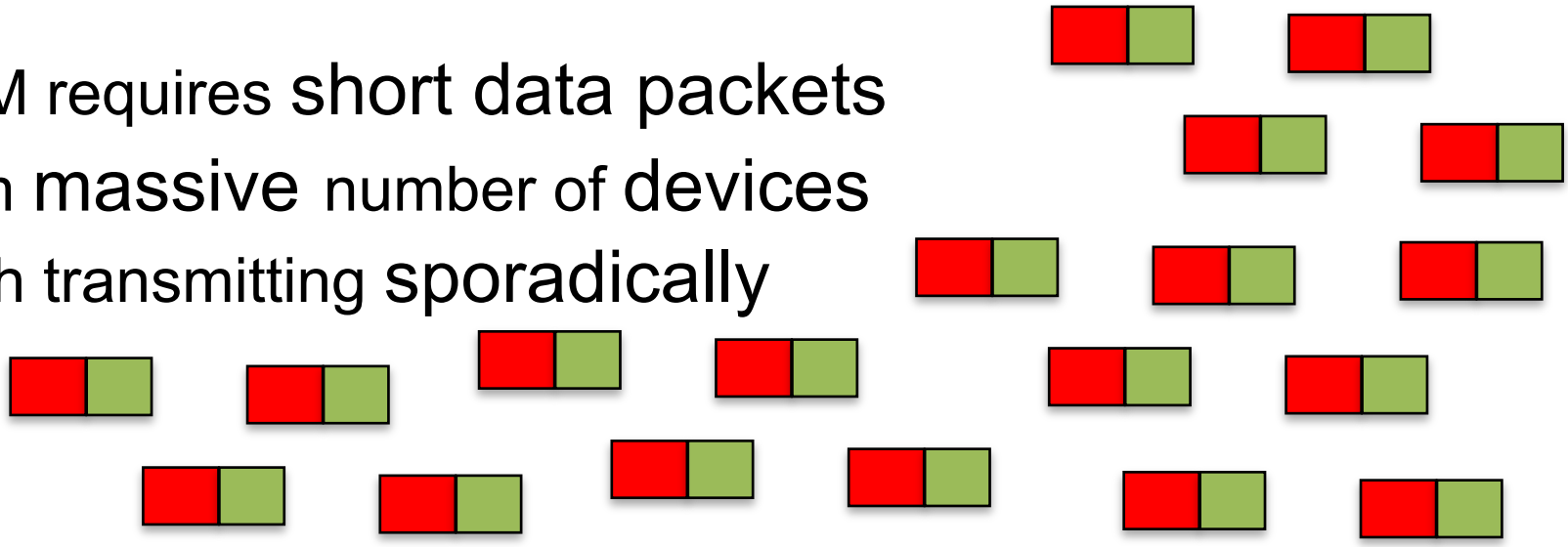
Machine Network Traffic

- 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



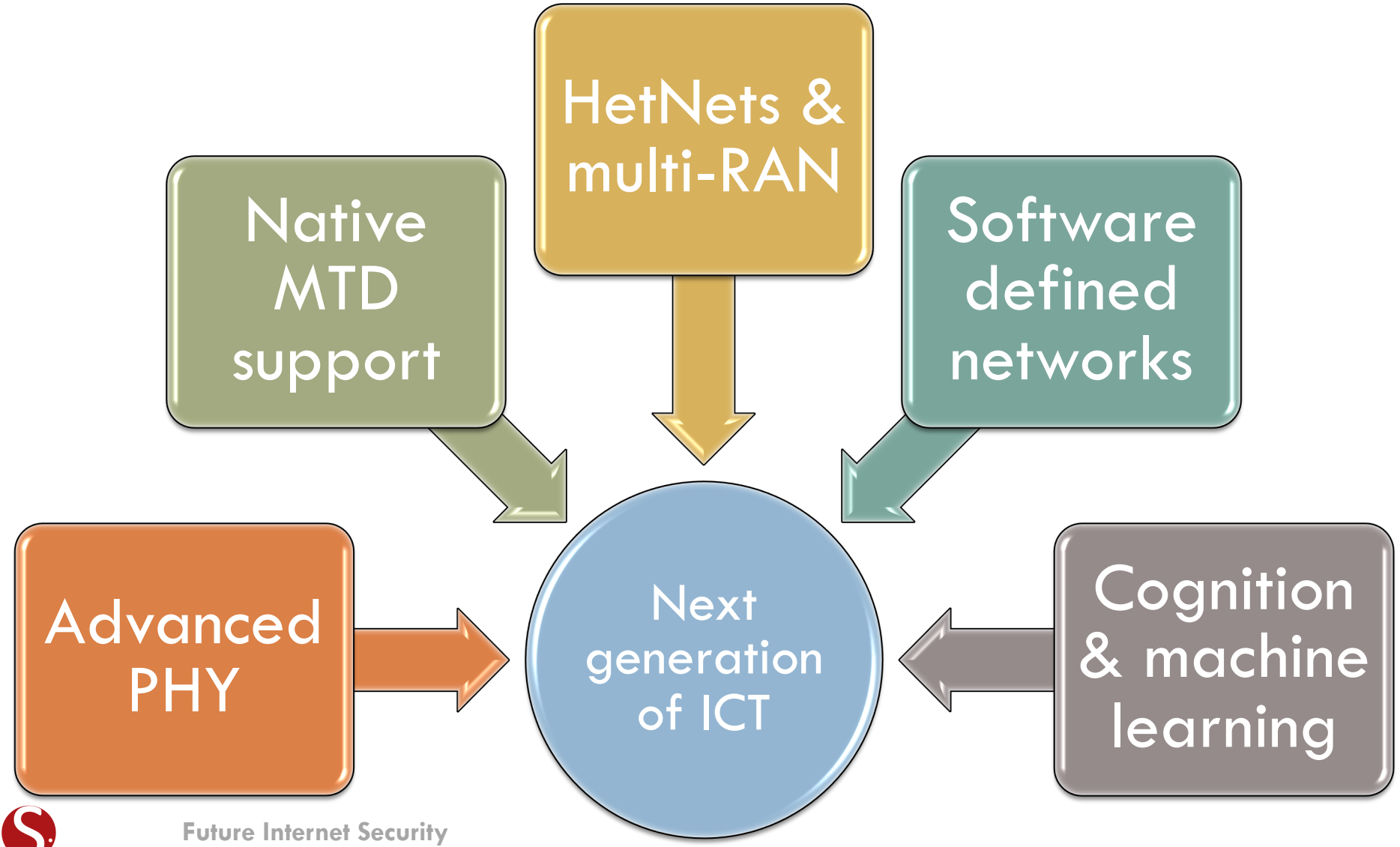
The issue of short packets

- 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

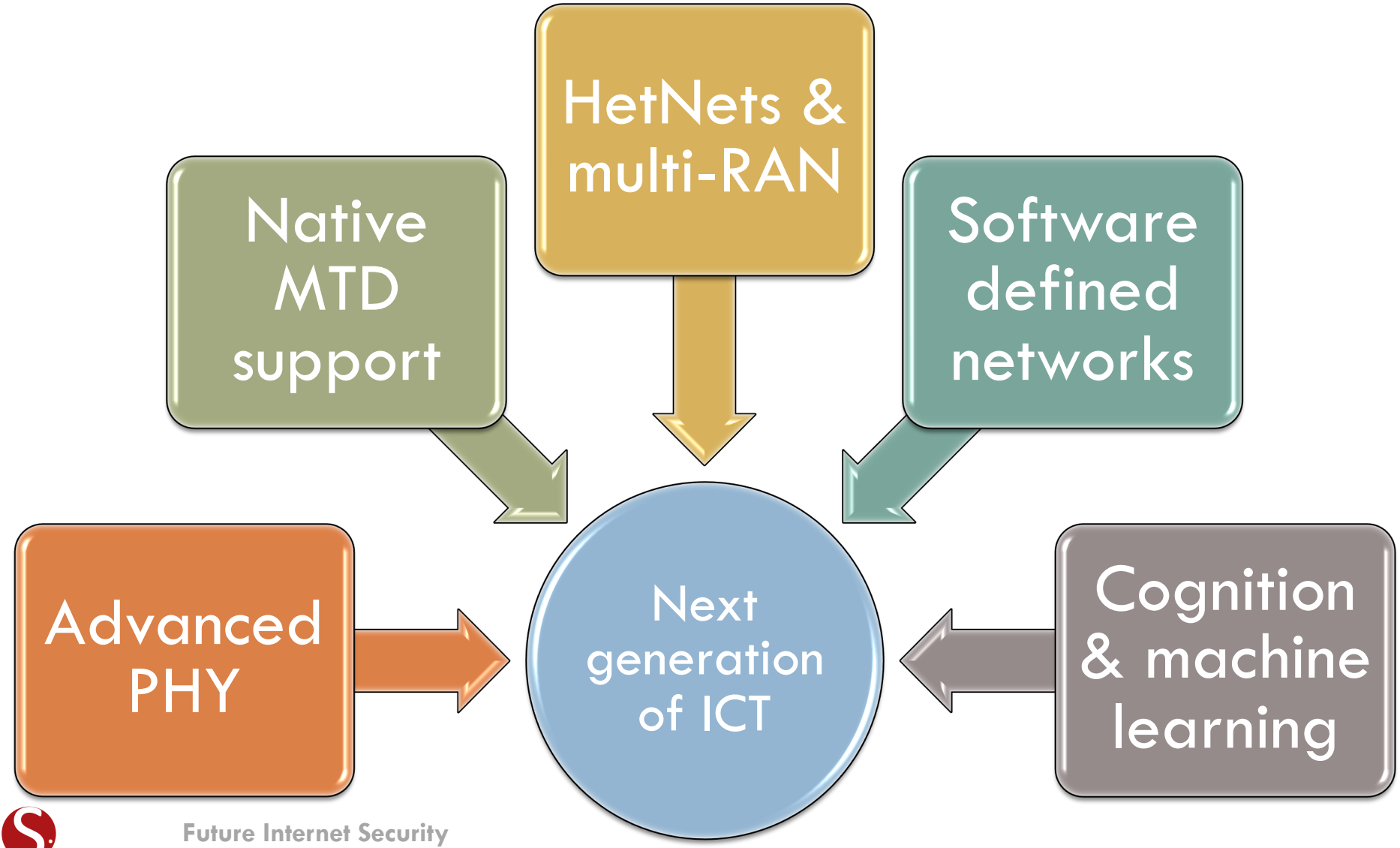
Densification and diversification



HetNets & multi-RAN

- Heterogeneous networks (HetNets):
  - Small cell networks including macrocells and small cells of all types
  - Provide improved spectrum efficiency (bps/Hz/km^2), capacity, and coverage
  - Small cells can support wireless applications for homes and enterprises as well as metropolitan and rural public spaces
  - Require solutions for **cell selection**, **handover**, **dynamic content caching**, …

Softwarization & Cloudification



Planes of Networking (1/2)

- 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-

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

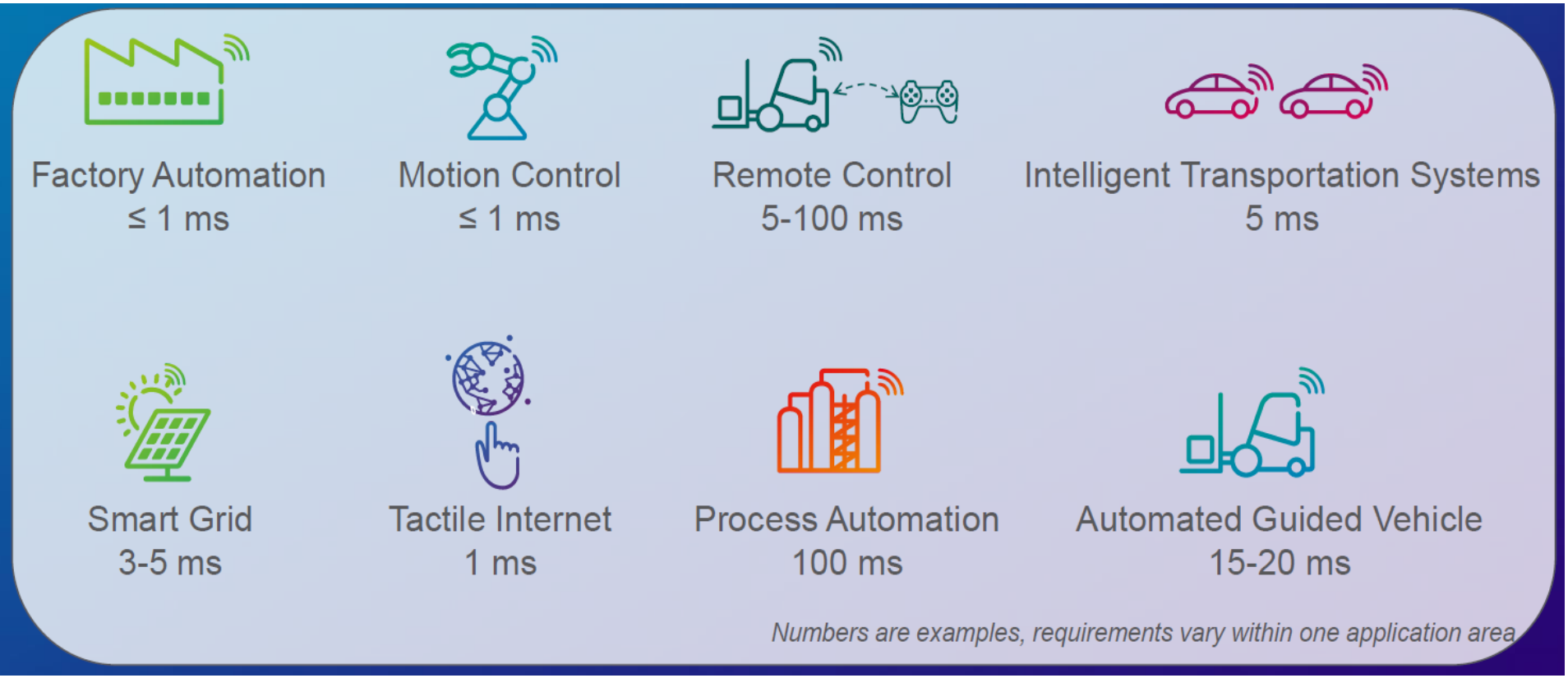
What do we need SDN for?

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

http://www.cse.wustl.edu/~jain/tutorials/icc14.htm

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'

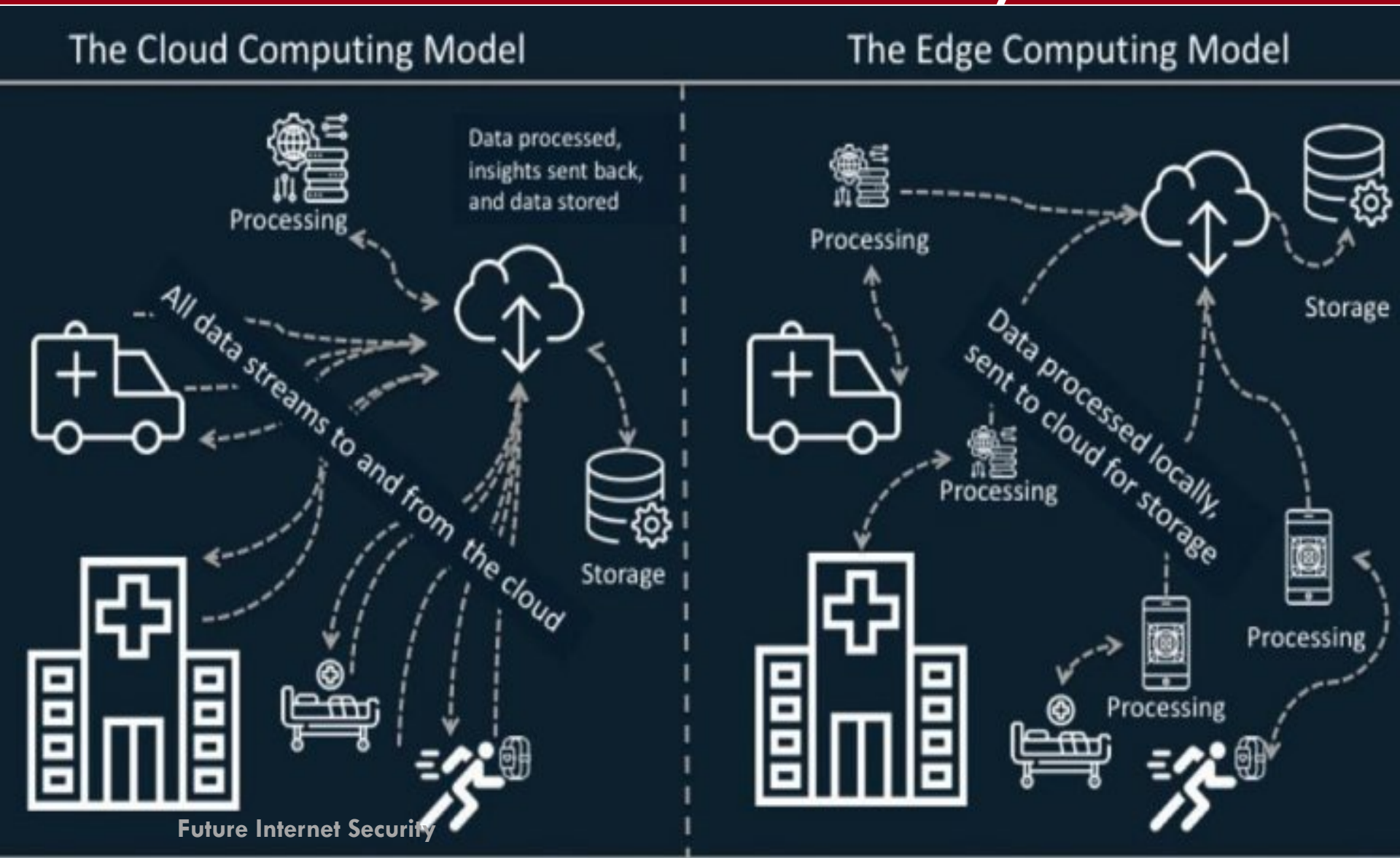
"***Latency***" is based on 3 major component:

transmission delay + routing and switching + IT response time

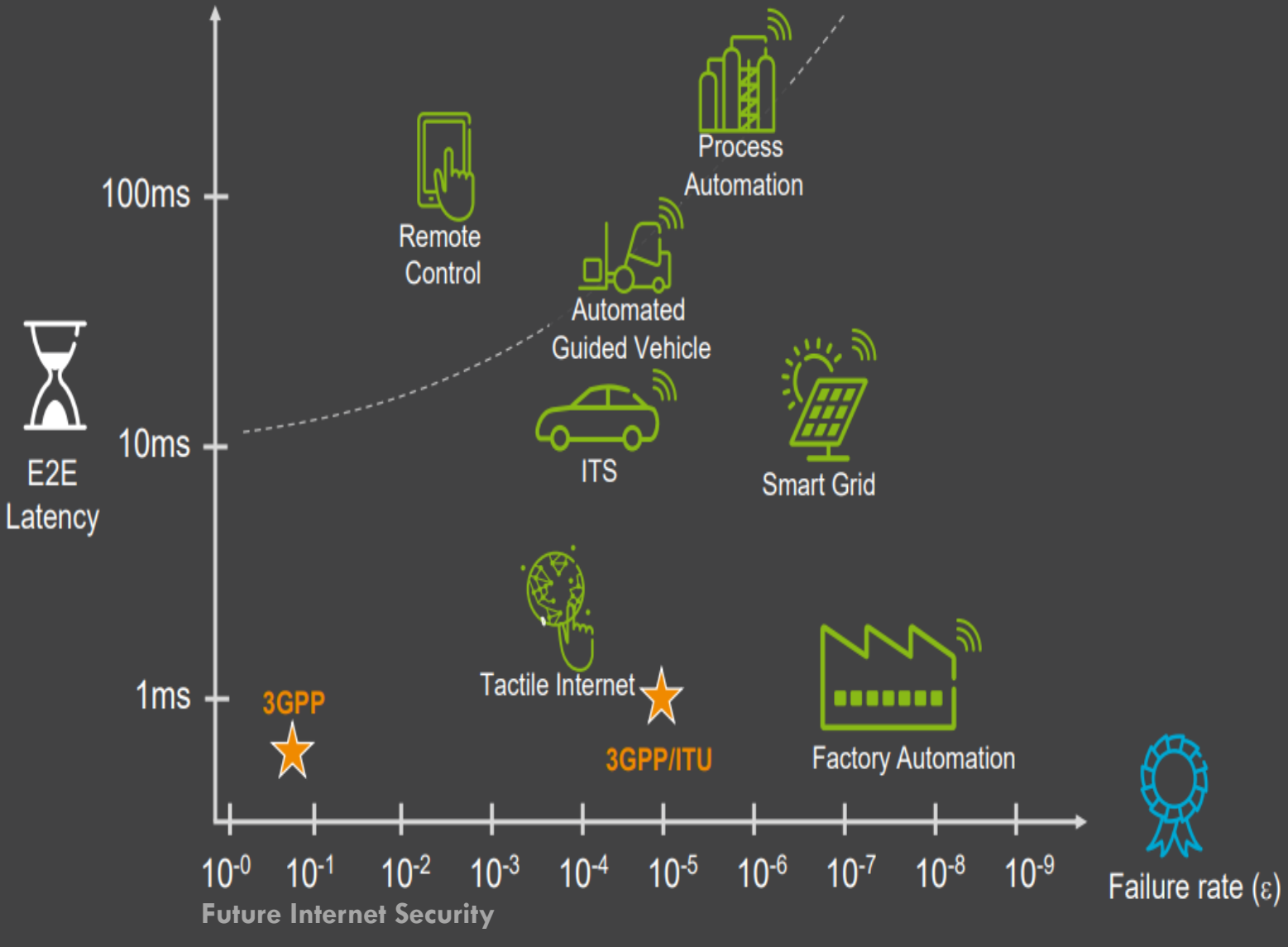
Wireless / Wired

Processing and Storage

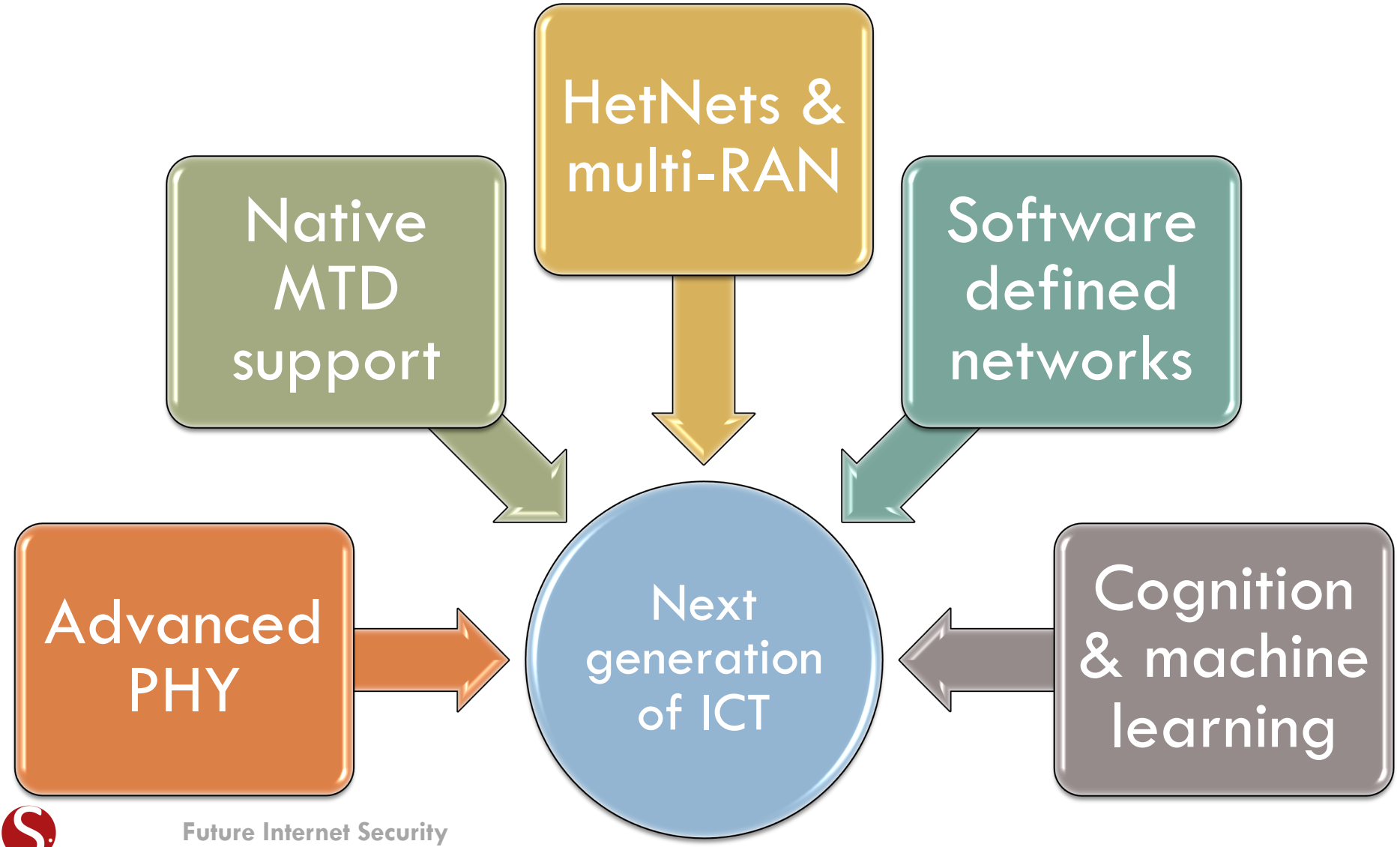
Local processing to reduce the latency: the ECM



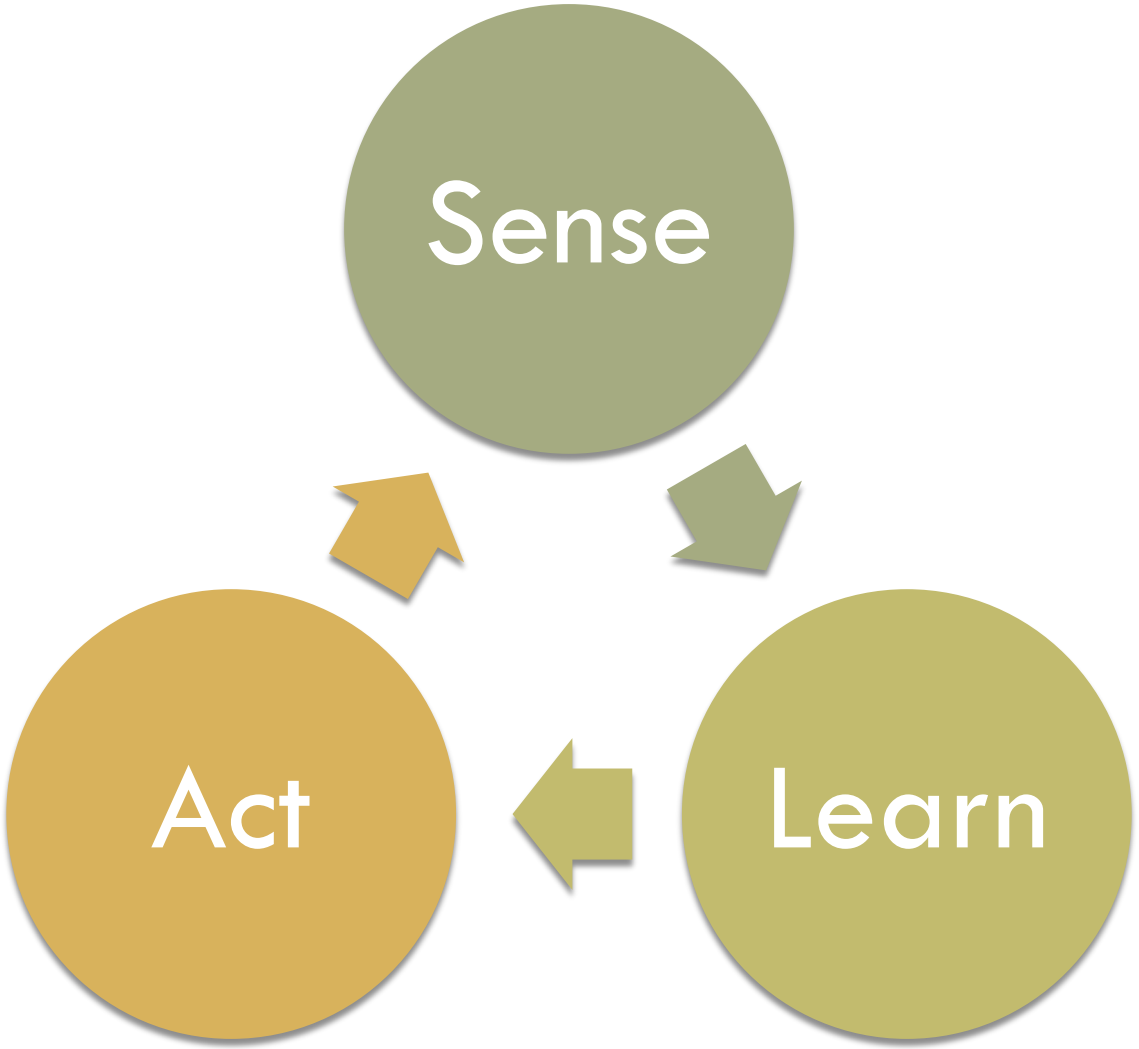
Latency reduction versus reliability



Machine Learning



The cognition cycle



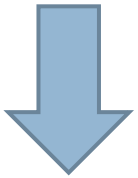
True for human, true for networks

- **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:

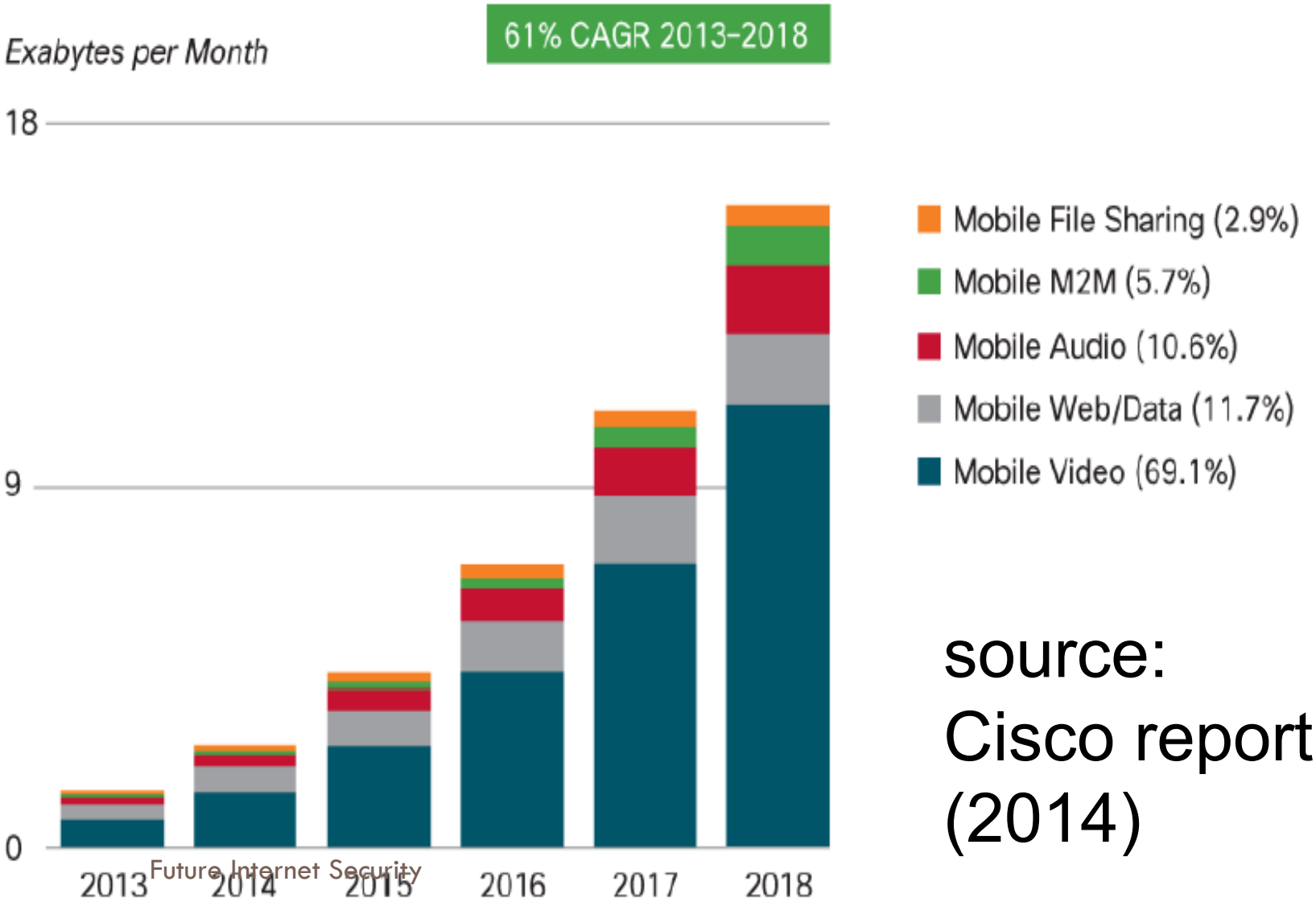
- exploits local information to achieve its goal
- shares it with its neighbors



Self-adaptation to the environment to achieve network wide goals

Cognition applied to the **entire network**

Multimedia growth

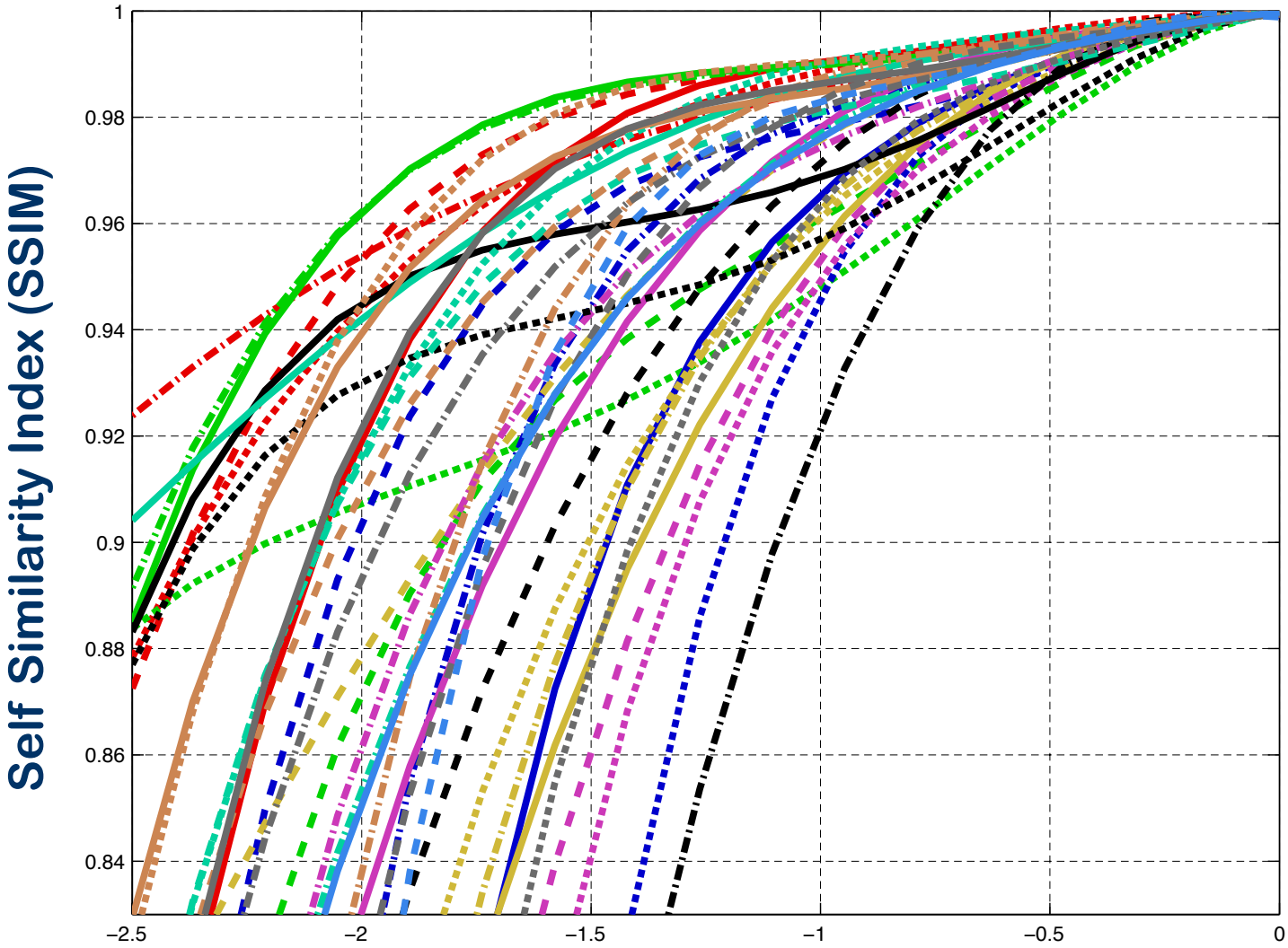


source:
Cisco report
(2014)

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

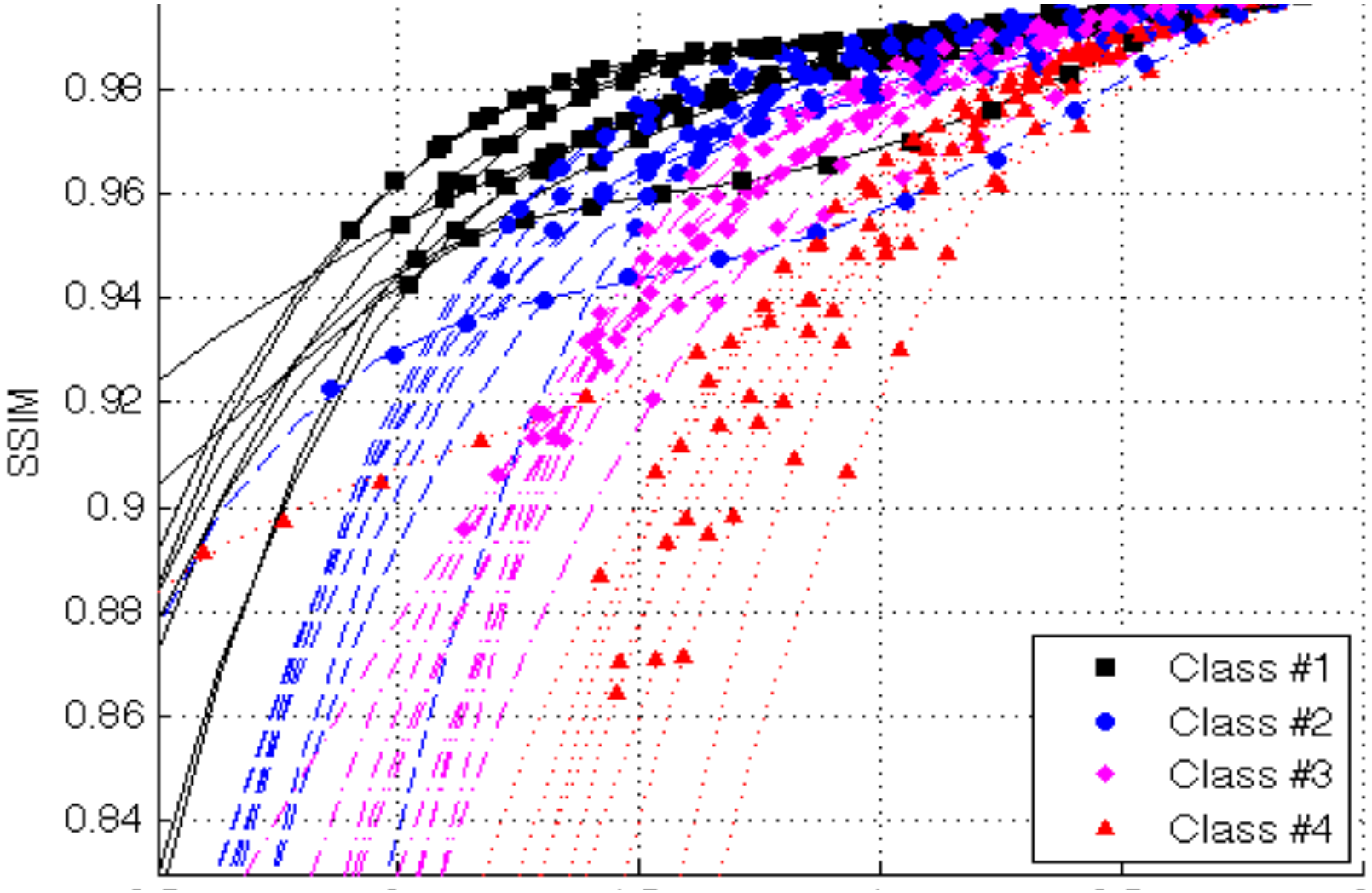
SSIM versus rate



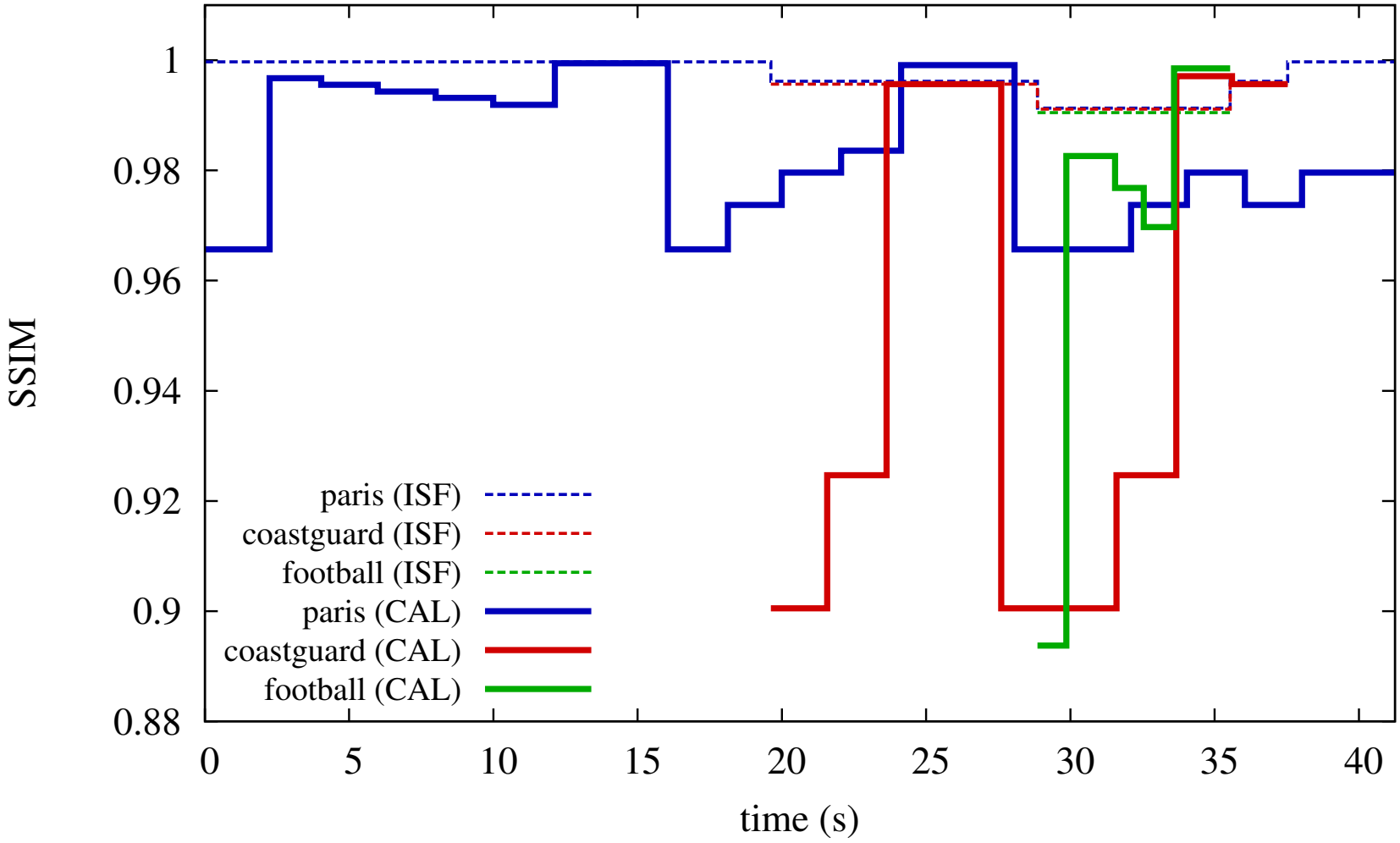
Requirements for video delivery

- 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



WHAT'S ABOUT 5G SECURITY?

Winter is coming…

Cloudification/Softwarization

- **Cloudification**
  - In legacy networks, security of function network elements relies largely on physical protection
  - In 5G, virtual network elements will run on cloud-based infrastructure → 5G infrastructure security must be taken into consideration!
- **Softwarization**
  - SDN improves flexibility, but introduces single point-of-failure issues
  - Network slicing isolates applications to provide better service differentiation. Source traffic policing becomes an issue

Heterogeneous access

- Multi-RAT but also multi-network
  - Issue: building security architecture suitable for different access technologies
- IoT devices represent a security threat
  - many ways to access networks (directly, via a gateway, or through a multi-hop mesh) → need to develop security trans-technology mechanisms
  - security management must be efficient and lightweight

Low-Delay Mobility Security

- Vehicles network, remote surgery,… require high reliability with a delay < 1 ms, also in mobility
- Need for fast security algos and mobility security may be redesigned & optimized for 5G

IEEE SPECTRUM

It's Surprisingly Easy to Hack the Precision Time Protocol

A simple attack can knock off a system's timing by 48 years

19 Jun

Pervasivity & privacy

- IoT is gonna spread basically everywhere, and it is already in most of our houses
  - Smartphones, google/amazon assistants, smart lighting, surveillance systems, roomba…
- a great amount of user privacy information will be carried over the 5G network → any information leak may lead to severe consequences

Technologies & privacy

- mmWaves, beamtracking, RF tomografy, … a lot of private information can be obtain from (or wormed out of) radio signals analysis

Household Radar Can See Through Walls and Knows How You're Feeling

Modern wireless tech isn't just for communications. It can also sense a person's breathing and heart rate, even gauge emotions

By **Fadel Adib**

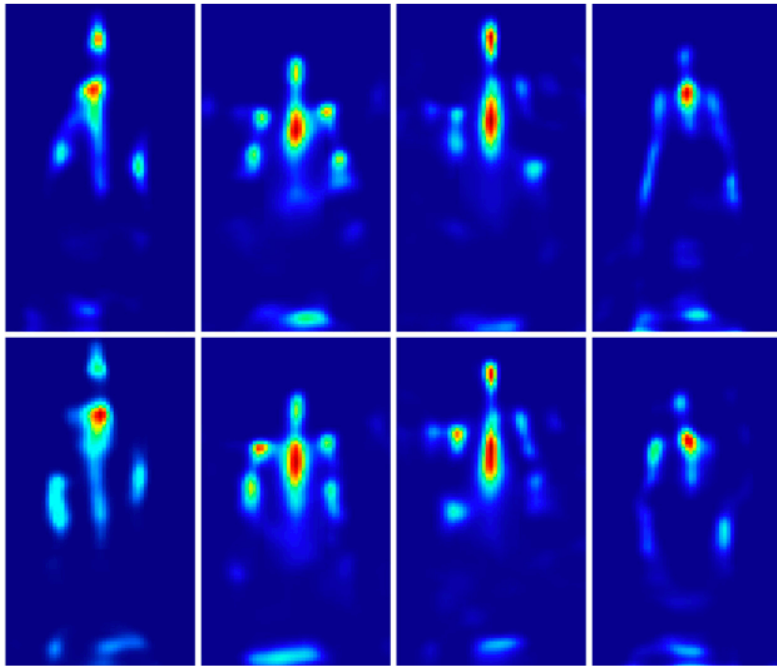


Image: Fadel Adib

Hidden Figures: These images of human figures were obtained using radio waves. Each column contains two images of the same person.

IEEE SPECTRUM

Technology frailties

- mmWave: can provide ultra-fast directional links, but it is easy to block
- Reflecting surfaces may help improve coverage or confuse tracking/beamforming algos
- ML can be used to solve very complex problems, but their black-box nature raises questions about their trustability

CVPR 2018

Robust Physical-World Attacks on Deep Learning Visual Classification

Conclusions

- Today IT and telco are **converging**
  - Telcos are requested to support a large and rapidly expanding set of applications/services
  - Telco need to define new models to valorize their infrastructure
- **The new trend**: telcos are becoming more cloud platforms than just a communication system
  - Trillions of devices are expected to be connected in the next years

Conclusions

- This revolution will bring along a wealth of **new applications** and **technologies** that will open new business cases, application scenarios, research opportunities…
- but… we all have to bear in mind

one

important

thing…

Game of Thrones Night King mural by Jonas Never at Brennan's | Photo: @never1959, Instagram

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DELL'INFORMAZIONE

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