Introduction to 5G –
with Applications
Part 1

Tommy Svensson
Professor (full), PhD, Leader Wireless Systems
Department of Electrical Engineering, Communication Systems Group
Chalmers University of Technology
tommy.svensson@chalmers.se

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Outline

- Part 1 5G - New era of Mobile Communications
  - Towards a Smarter Society
  - Basics of 5G
- Part 2 – Cellular V2X
  - Designing the 5G V2X Radio Interface
  - Integrated Moving Networks
  - Conclusions

A New Era Begins

Internet -> Mobile Internet -> …

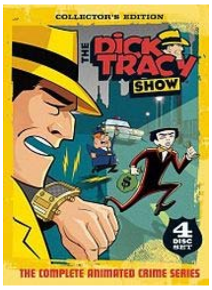
-> Wireless => Internet of Things

Source: https://www.aeteurope.com/news/technologies-secure-internet-things/

-> Robustness, Low latency => Internet of Skills!

Source: https://www.ericsson.com/thinkingahead/the-networked-society-blog/2017/02/14/virtual-reality-comes-age-internet-skills/

Dick Tracy Comic Strip



Dick Tracy (originally Plainclothes Tracy), a square-jawed, hard-hitting, fast-shooting, and intelligent police detective.
Created by Chester Gould, the strip made its debut on October 4, 1931, in the Detroit Mirror. [Wikipedia]

James Bond - Tomorrow Never Dies – BMW Car Chase

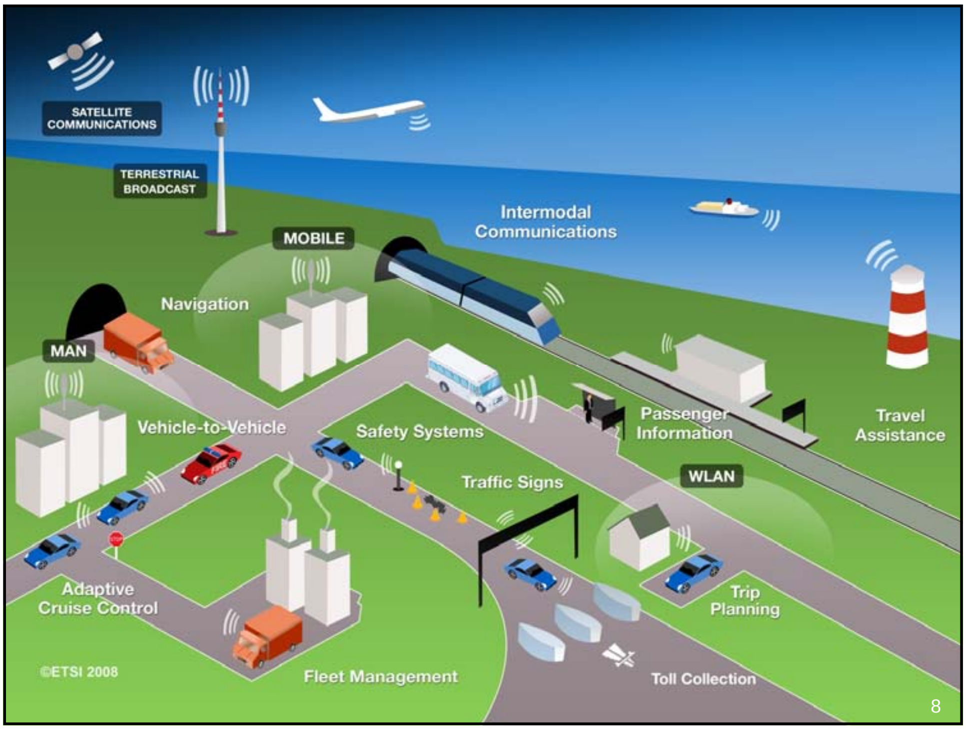
http://www.youtube.com/watch?v=qKAME9fAA-4&feature=youtu.be&t=4s

Eureka - SARAH

The house SARAH (Self Actuated Residential Automated Habitat) implements "ambient intelligence”.

Eureka is an American science fiction television series that premiered on Syfy on July 18, 2006. The fifth and final season ended on July 16, 2012. [Wikipedia]

http://www.youtube.com/watch?v=O8Jm-AIRqwQ&feature=youtu.be&t=2m11s



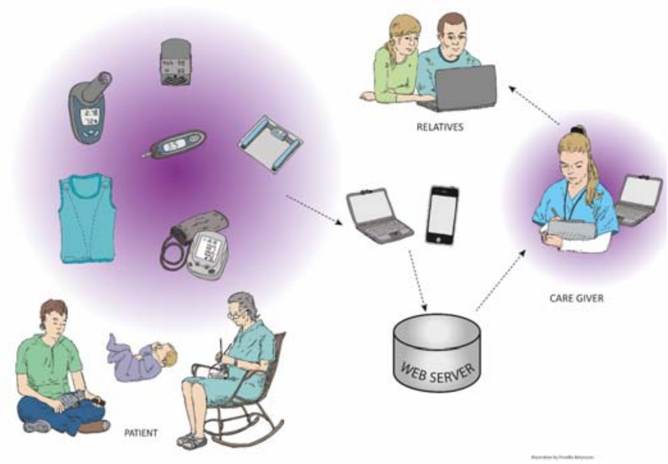
Smart Grids for Sustainability

Consumer -> Prosumer

Source: https://www.energy.gov/eere/articles/consumer-vs-prosumer-whats-difference

Smart Cities for Sustainability

e-Health



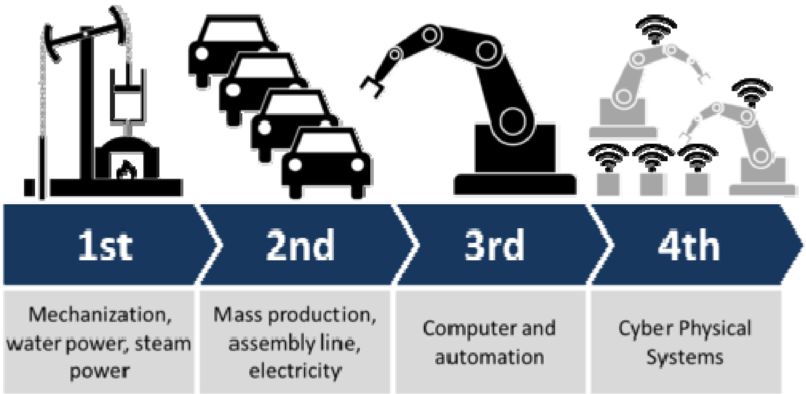
Agriculture 2.0

Vertical Farming

Source: cesens http://www.cesens.com/en/

Source: http://climateandcapitalism.com/2012/12/13/vertical-farming/

Industry 4.0

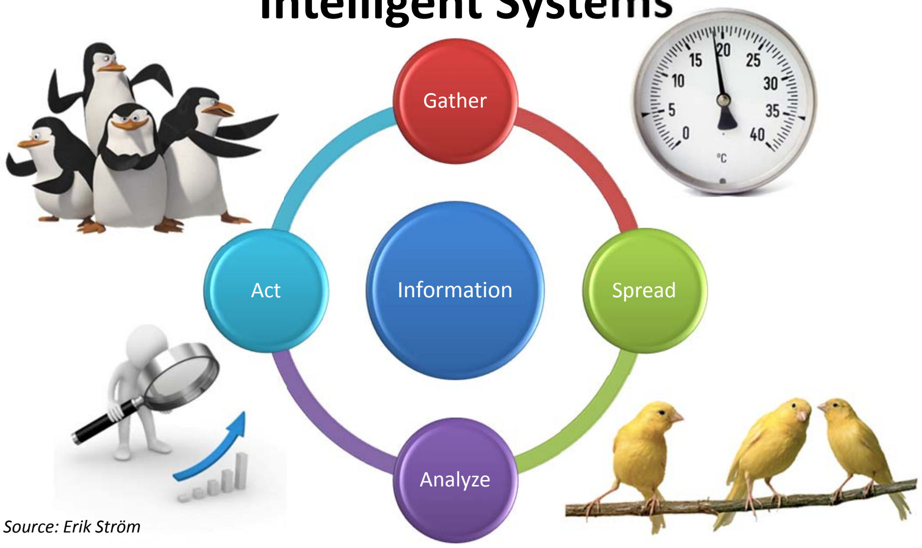


Source: Wikipedia https://en.wikipedia.org/wiki/Industry_4.0

From Products to Services

- Proactive/Predictive Maintenance

Communications – the Enabler for Intelligent Systems

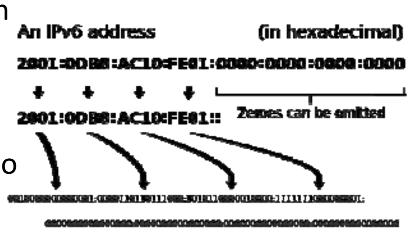


Source: Erik Ström

Internet of Things

Source: https://blogs.cisco.com/security/iot-securing-the-next-chapter-of-the-digitization-book

- "Internet of Things" (IoT) was first coined by Kevin Ashton, cofounder of the Auto-ID Center at the Massachusetts Institute of Technology (MIT), which created a global standard system for RFID back in 1999.
- IoT was used to describe the revolution once computers start generating and collecting data by themselves over the Internet without any human input.
- With IPv6, there are now more than 3.4×10^{38} i.e. trillion, trillion, trillion unique IP addresses (IPv6: 128 bits, IPv4: 32 bits) - space for ANYTHING and EVERYTHING to be connected to the Internet (number of atoms on the surface of Earth ~1.26×10^{34}).



Challenges and Opportunities




https://www.youtube.com/watch?v=PIyhdEHCBCw&feature=youtu.be
https://www.youtube.com/watch?v=t6OzlgXY1BY

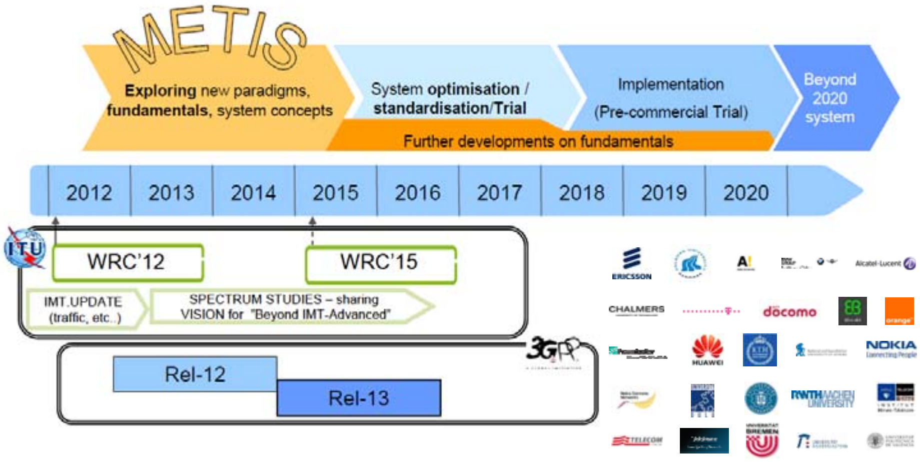
Challenges and Opportunities

In need for Privacy regulations
Source: http://communicationandmediastudies.wordpress.com

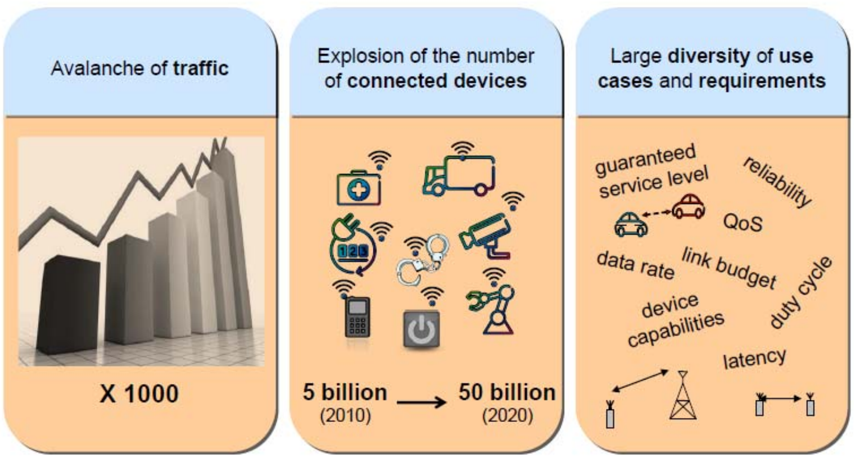
- Authentication
- Authorization
- Integrity
- Privacy
- …

The METIS Project

Lay the foundation & **Ensure** a global forum & **Build** an early global consensus for beyond 2020 “5G”mobile & wireless communications



https://www.metis2020.com/



METIS Overall Technical Goal

A system concept that, relative to today, supports:

- 1000 times higher mobile data volume per area,
- 10 to 100 times higher number of connected devices,
- 10 times to 100 times higher typical user data rate,
- 10 times longer battery life for low power Massive Machine Communication (MMC) devices,
- 5 times reduced End-to-End (E2E) latency.

Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

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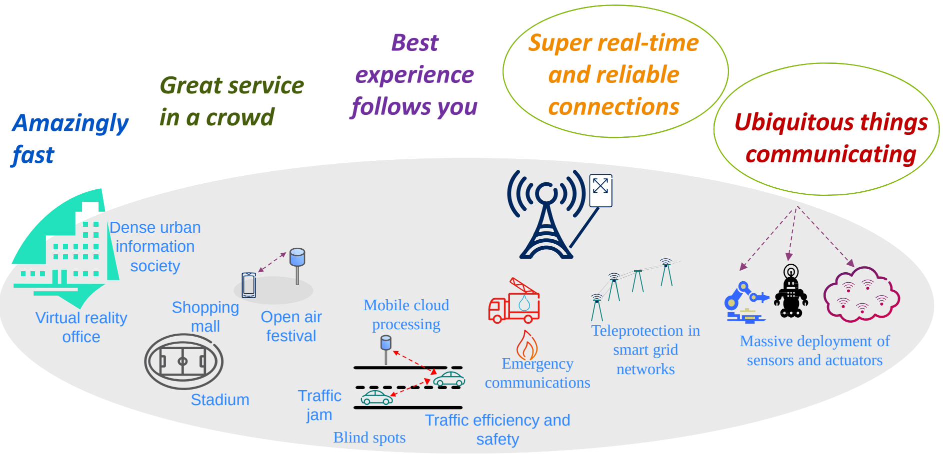
METIS Scenarios and Test Cases



Source: METIS Deliverable D1.1 "Scenarios, requirements and KPIs for 5G mobile and wireless system", https://www.metis2020.com/

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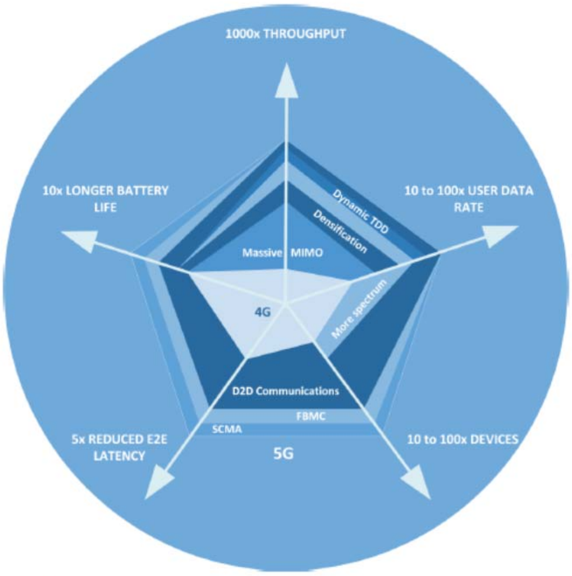
METIS goal evaluation



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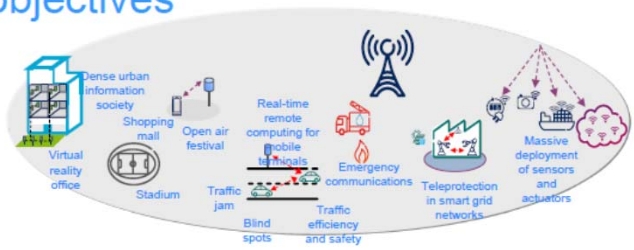
Simulation results and METIS technical objectives



- Larger bandwidths (at higher frequencies) necessary to meet 5G demands
- Massive MIMO can increase the spectral efficiency by a factor of 20
- Indoor UDN capacity scales $\propto N_{AP}$ when interference coordination is used
- D2D can increase system capacity and reduces latency to $\approx$TTI length
- New waveforms and multiple-access technologies can reduce access time
- Traffic concentration reduces battery consumption, and improves coverage and throughput.

1000x mobile data volumes ✓

10x – 100x end-user data rates ✓

10x – 100x number of devices ✓

10x longer battery life ✓

5x lower latency ✓

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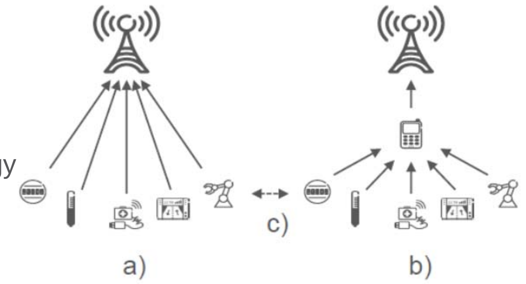
METIS System Concept: Massive Machine Type Communications (M-MTC)

User features

- Scalable connectivity
- Wide area coverage
- Deep penetration
- Low cost, complexity & energy consumption

Technical features

- Very low signaling overhead
- Licensed ITU-IMT spectrum access
- Time synchronous access
- One common air interface for all radio access types
- Both connectionless and always-connected
- Both contention-based and access reservation



MMC radio access types
a) Direct access
b) Accumulation/aggregation point type of access
c) M2M access

METIS System Concept: Ultra-reliable MTC (U-MTC)

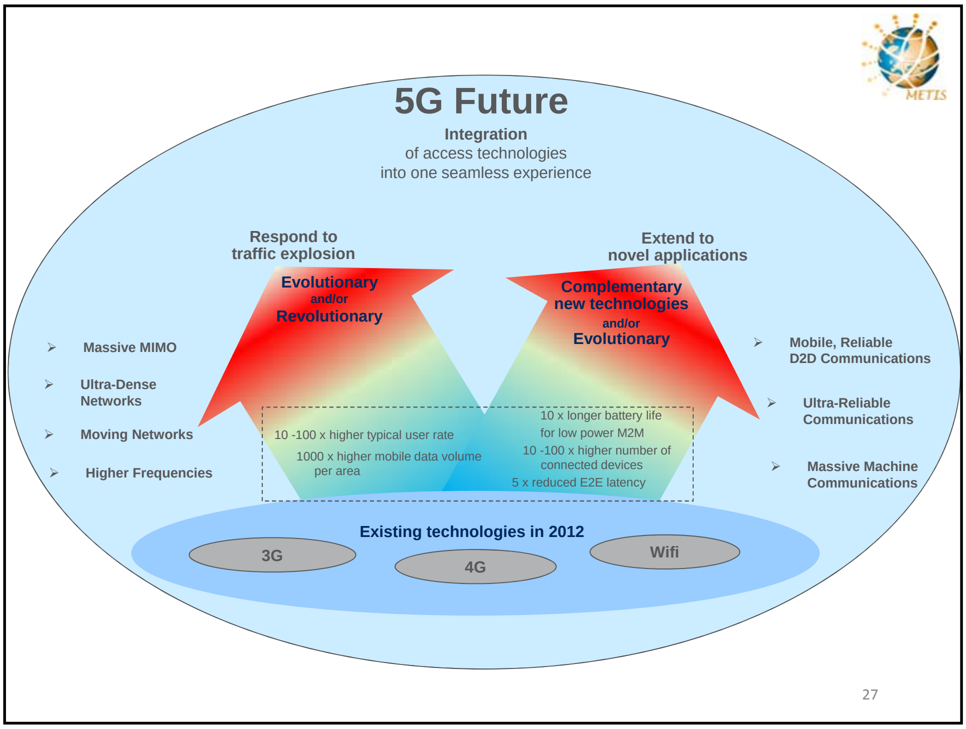
User features

- Ultra-reliable
- Low-latency
- Low rates

3GPP: "Ultra Reliable Low Latency Communication (URLLC)"

Technical features

- Network-controlled D2D: efficient arbitration of devices that compete for resources
- Ad hoc D2D as a fallback
- Fast discovery and link establishment
- Multi-operator operation
- Highly robust links
- Dedicated spectrum desirable


5G Future
Integration
of access technologies
into one seamless experience
Respond to
traffic explosion
Evolutionary
and/or
Revolutionary
Extend to
novel applications
Complementary
new technologies
and/or
Evolutionary
Massive MIMO
Ultra-Dense
Networks
Moving Networks
Higher Frequencies
Mobile, Reliable
D2D Communications
Ultra-Reliable
Communications
Massive Machine
Communications
10 -100 x higher typical user rate
1000 x higher mobile data volume
per area
10 x longer battery life
for low power M2M
10 -100 x higher number of
connected devices
5 x reduced E2E latency
Existing technologies in 2012
3G
4G
Wifi
METIS
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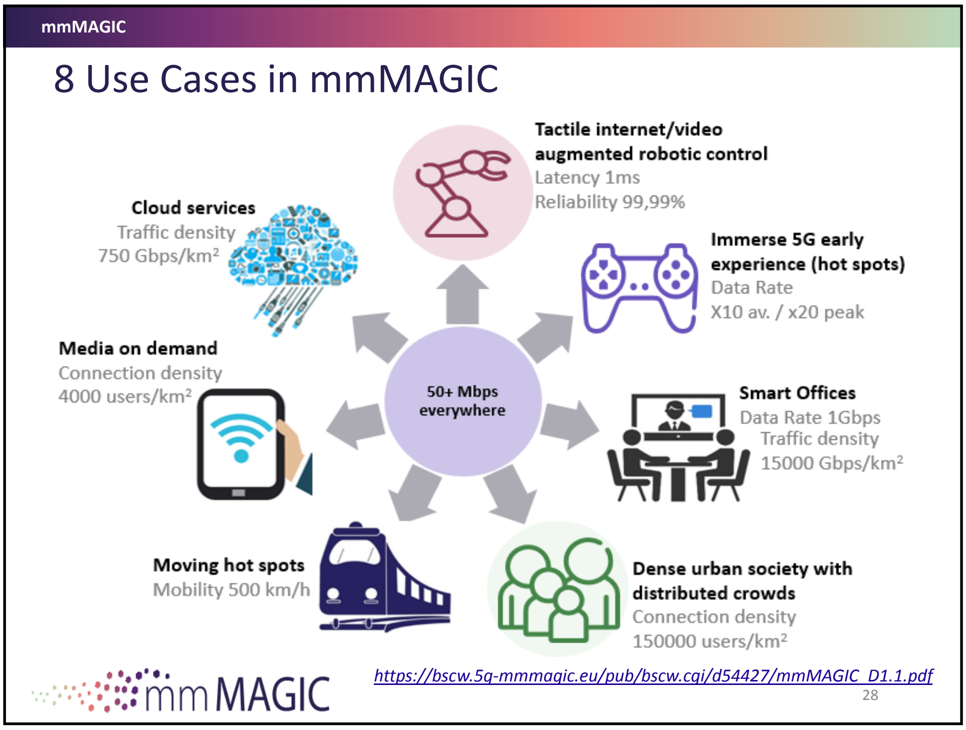
mmMAGIC
8 Use Cases in mmMAGIC
Tactile internet/video
augmented robotic control
Latency 1ms
Reliability 99,99%
Cloud services
Traffic density
750 Gbps/km²
Immerse 5G early
experience (hot spots)
Data Rate
X10 av. / x20 peak
Media on demand
Connection density
4000 users/km²
50+ Mbps
everywhere
Smart Offices
Data Rate 1Gbps
Traffic density
15000 Gbps/km²
Moving hot spots
Mobility 500 km/h
Dense urban society with
distributed crowds
Connection density
150000 users/km²
mmMAGIC
https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d54427/mmMAGIC_D1.1.pdf
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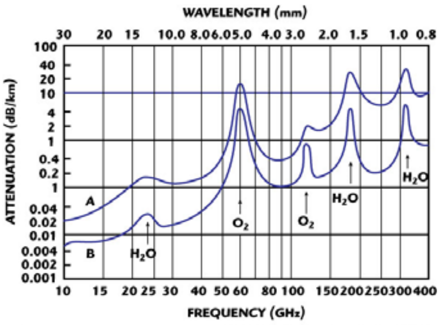
mmMAGIC

Challenges and Opportunities at mmWaves

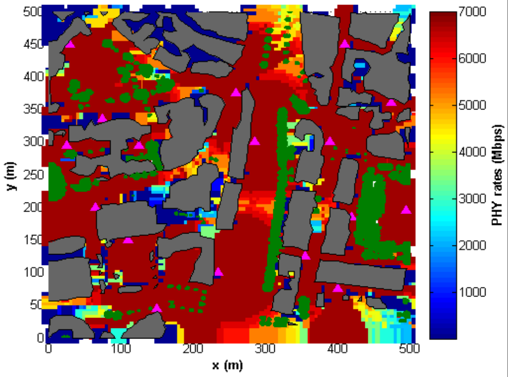
Worse attenuation, but wide system bandwidths available



Average atmospheric absorption of MMWs: (A) Sea Level: T = 20°C, P = 760mm, H_2O = 7.5 g/m³ (B) 4 km altitude: T = 0°C H_2O = 1 g/m³

Source: Microwave Journal: http://www.microwavejournal.com/legacy_assets/FigureImg/AR_4772_Fig02_L.jpg

Worse multipath and large shadowing/blocking effects, but possibility for dense reuse



- *D5.1 "Initial multi-node and antenna transmitter and receiver architectures and schemes" March 2016, https://5g-mmmagic.eu*
- *[ABA+15]: Abdullah, N.F.; Berraki, D.; Ameen, A.; Armour, S.; Doufexi, A.; Nix, A.; Beach, M., "Channel Parameters and Throughput Predictions for mmWave and LTE-A Networks in Urban Environments," inVehicular Technology Conference (VTC Spring), 2015 IEEE 81st , vol., no., pp.1-5, 11-14 May 2015*

mmMAGIC

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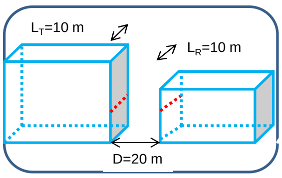
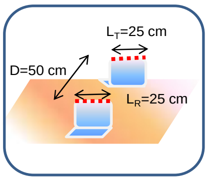
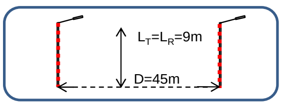
Massive MIMO at Both Tx, Rx (MMIMMO)



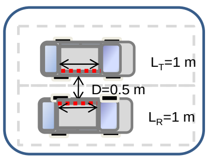
scenario 1: communicating buildings, **N=512, f=30.72GHz**



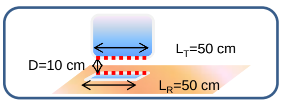
scenario 3: communicating laptops, **N=32, f=76.8GHz**



scenario 2: communicating lamp posts (these are heights and separations in France), **N=256, f=42.7GHz**



scenario 4: side-to-side communicating cars (non moving), **N=256, f=38.4GHz**



scenario 5: communicating laptop-screen, **N=512, f=61.4GHz**

Legend:

Uniform linear antenna array

Friis transmission equation

$$P_{RX} = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi r} \right)^2$$

transmit power

wavelength

received power

gain of transmit and receive antennas

separation distance

"Free space path loss"

Hundreds of bits/s/Hz possible using "Block Discrete Fourier TransForm based Spatial Multiplexing with Maximum Ratio Transmission" (B-DFT-SM-MRT)

D.-T. Phan-Huy, P. Ratajczak, R. D'Errico, A. Clemente, J. Järveläinen, D. Kong, K. Haneda, B. Bulut, A. Karttunen, M. Beach, E. Mellios, M. Castaneda, M. Hunukumbure, T. Svensson, "Massive Multiple Input Massive Multiple Output for 5G Wireless Backhauling", IEEE Globecom'2017 ET5GB workshop.

Source: D5.1 "Initial multi-node and antenna transmitter and receiver architectures and schemes" March 2016, https://5g-mmmagic.eu

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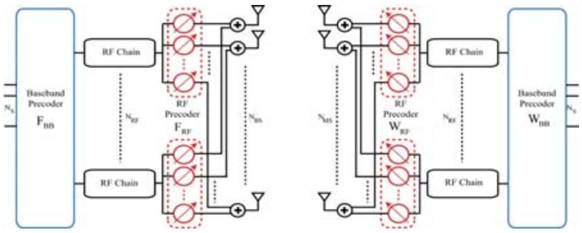
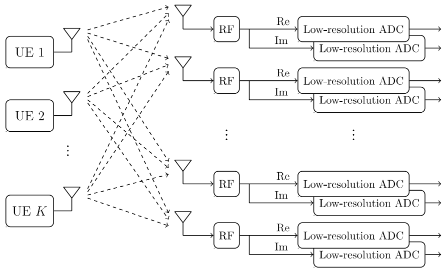
Hybrid and Low-precision Beamforming for Massive MIMO



© O. El Ayach, S. Rajagopal, S. Abu-Surra, Z. Pi, and R. Heath, "Spatially sparse precoding in millimeter wave MIMO systems," IEEE Transactions on Wireless Communications, vol. 13, no. 3, pp. 1499–1513, March 2014

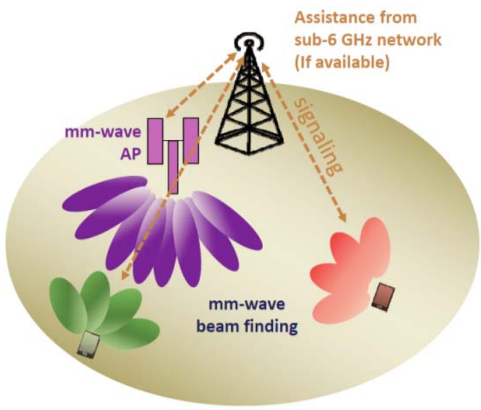


Low resolution DACs also at transmitter?
Might increase uncontrolled interference!

© C. Studer and G. Durisi, "Quantized massive MU-MIMO-OFDM uplink," Sep. 2015. [Online]. Available: http://arxiv.org/abs/1509.07928

Initial Access: Beam Finding/Tracking at mmWave

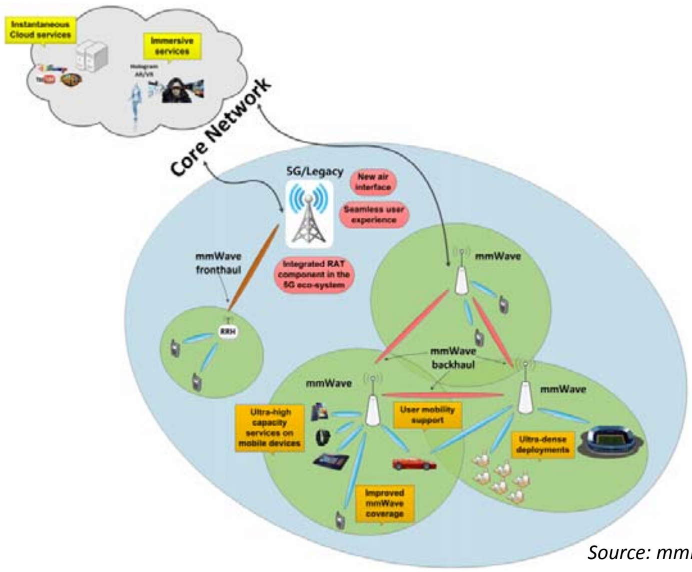
- **Design KPI's**
  - Access delay
  - Access ratio
  - Overhead
  - Complexity
  - Availability and accuracy of context information
  - Standalone/non-standalone operations support
  - Antenna configurations support



- Exploit sub-6 GHz coverage
- Exploit contexual information
- Coupling beamforming and initial access
- Support different transceiver/antenna configurations

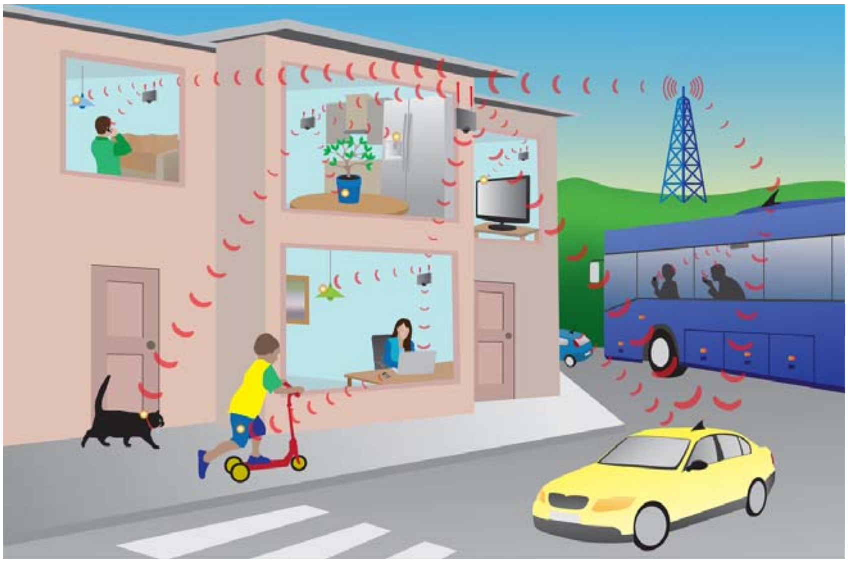
Beam finding/tracking – the key for enabling low latency mm-wave access.

Network slicing in self-backhauled mm-wave Networks - Where should we do the computing?

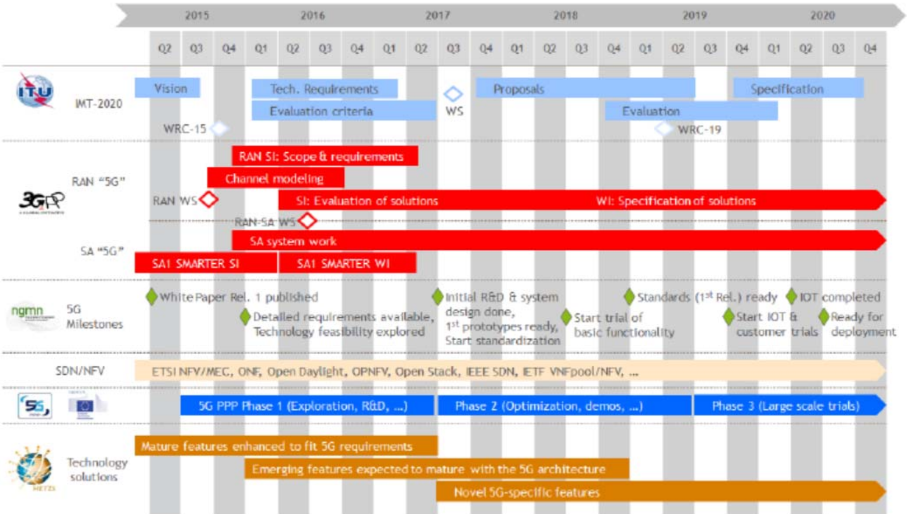


Source: mmMAGIC

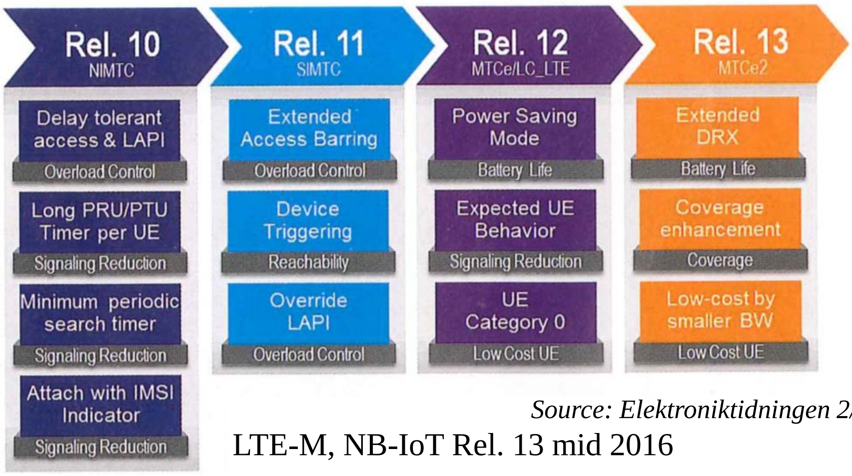
How Deployment Could Look Like



Technology Ecosystem and Roadmap



4G Evolution Related to IoT



Source: Elektroniktidningen 2/16

LTE-M, NB-IoT Rel. 13 mid 2016

Alternatives: GPRS, ZigBee, Bluetooth, WiFi, Sigfox, LoRa, …

Take Home Messages

A new era begins –
- Wireless Internet of Things
- Wireless Internet of Skills

Communications enablers:
- 4G and various Low Power Wide Area Network (LPWAN) technologies are already here
- 5G will support Extreme Mobile Broadband (xMBB) massive IoT (mMTC) and Ultra Reliable Low Latency Communication (URLLC)

Digitalization
- Combined with Information Technologies (Big Data, Machine/Deep learning, Artificial Intelligence) we can address our Grand Challenges – Climate, Aging population, Scarce resources, …
- Internet of Things will disrupt most areas of the society
  - Products -> **Services** with products as enablers (functional view)
  - Enables a shift of perspective from Typical/Average -> **Individual** needs of consumer/customer/client
- Grand challenges related to Security and Privacy – Need for debates how we want our future society!