Internet of Things and 5G

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Outline

• Introduction to Internet of Things
• The European road to 5G:
• Some research highlights at Chalmers
Wireless Communications in Dense Heterogeneous Networks
Active Research Topics in Research Area

Wireless Systems at Chalmers

• Cooperative communications
  – CoMP with HARQ
  – Massive MIMO
  – HetNets, Relaying
  – D2D, Finite block length

• Moving networks

• Waveforms for
  – Machine Type Communications (IoT)
  – Coverage at high carrier frequencies

• Satellite return link scheduling

• Ultra-dense wireless networks
  – mm-wave based access, backhaul and fronthaul
  – Hybrid links

• Energy efficient/harvesting networks

• Cloud-RANs
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
Communications is Everywhere!
Smart Grids for Sustainability
Smart Cities for Sustainability
e-Health
Communications – the Enabler for Intelligent Systems

Gather

Information

Act

Spread

Analyze
Internet of Things

• “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 a trillion, trillion, trillion unique IP addresses (IPv6: 128 bits, IPv4: 32 bits) - space for ANYTHING and EVERYTHING to be connected the internet.
Challenges and Opportunities
Challenges and Opportunities

In need for privacy regulations
Source: http://communicationandmediastudies.wordpress.com
Challenges and Opportunities

Avalanche of traffic

Explosion of the number of connected devices

Large diversity of use cases and requirements

Most things will use wireless connections!
Can we do it with 5G?
Research is ongoing towards a 5G standard supporting Machine Type Communications (MTC)!
Mobile and wireless communications Enablers for the 2020 Information Society

EU FP7 ICT-317669-METIS

www.metis2020.com
Communications Systems group at Chalmers
Impacts Wireless Standards: 3G, 4G, 5G, and counting...

https://www.metis2020.eu
https://ict-artist4g.eu
http://projects.celtic-initiative.org/winner+
METIS Overall Objectives

Lay the foundation & Ensure a global forum & Build an early global consensus for beyond 2020 “5G” mobile & wireless communications
Why Competitive Organisations are Collaborating

- Increasing investment in solutions
- Increasing IPR portfolios

Chance for consensus building decreasing

Pre-competitive early collaborative research

Standardisation in early competitive environment

Chance for consensus building

Grade of concept maturity

IPRs

Increased maturity makes consensus building difficult

Increasing IPRs portfolios make consensus building difficult

- Thus, important to build international consensus building at an early stage!
METIS Overall Technical Goal

A system concept that, relative to today, supports:

› 1000 times higher mobile data volume per area,
› 10 times 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.mesis2020.com/
METIS Scenarios and Test Cases

- **Great service in a crowd**
- **Amazingly fast**
- **Best experience follows you**
- **Super real-time and reliable connections**
- **Ubiquitous things communicating**

**Source:** METIS Deliverable D1.1 “Scenarios, requirements and KPIs for 5G mobile and wireless system”, [https://www.metis2020.com/](https://www.metis2020.com/)

Additional use cases has been proposed by NGMN Alliance, ‘NGMN White Paper,’ Feb. 2015 (available online [https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf](https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf))
METIS 12 Test Cases

› TC1: Virtual reality office
  - 3D tele-presence and virtual reality

› TC2: Dense urban information society
  - Consistent quality of experience in urban environments

› TC3: Shopping mall
  - Generalized and/or personalized location-based services for guiding, advertisement or product information

› TC4: Stadium
  - Peaks of traffic due to the big amount of people gathered at the same place for the period of time of the event

› TC5: Teleprotection in smart grid network
  - Messages must be sent between substations to prevent the power system from cascading failures and damage, timely information is critical.

› TC6: Traffic jam
  - Support public cloud services in vehicle traffic jam situations.

Source: METIS Deliverable D1.1 “Scenarios, requirements and KPIs for 5G mobile and wireless system”, https://www.metis2020.com/
METIS 12 Test Cases

› TC7: Blind spots
  - The ubiquitous capacity demands of future users will be challenging to satisfy in blind spots, such as rural areas with sparse network infrastructure or in deeply shadowed urban areas.

› TC8: Real-time remote computing for mobile terminals
  - Support public cloud services on the move, also at high speeds.

› TC9: Open air festival
  - Sudden need for high capacity in rural areas.

› TC10: Emergency communications
  - Basic communications must be maintained in natural disaster situations.

› TC11: Massive deployment of sensors and actuators
  - Small sensors and actuators that are mounted to stationary or movable objects typically need only transmit data occasionally, e.g. in the order of every minute, hour, week.

› TC12: Traffic efficiency and safety
  - Warn drivers of dangerous situations, intervene through automatic braking or steering to avoid an accident. Enable highly automated driving to reduce travel time, fuel consumption, and CO2 emissions and also to increase safety and traffic efficiency.

Source: METIS Deliverable D1.1 “Scenarios, requirements and KPIs for 5G mobile and wireless system”, https://www.metis2020.com/
Technical Enablers: Underlay Networks

- Good potential for capacity, cost and energy efficiency gains
- Challenging interference and mobility problems

Small cells: also at home

Moving small cells: in vehicles

Device-to-Device (D2D)
Enabling Massive Machine Communications (MMC)

- Using D2D to support MMC
  - Exploit cellular devices as relays/aggregators to the Machine-Type Devices (MTDs) attempting access to the base station.
  - Reuse cellular resources by underlaying MMC-Type D2D links on cellular downlink and uplink, while give outage guarantees.

- Incorporate unreliable energy supply and energy harvesting in solutions
Medium Access Control (MAC) for MMC

Access Reservation

Connection oriented
- user context stored in the network
- current choice in cellular networks
- inefficient for packets with very short length (high control overhead)

Direct Random Access

Connectionless
- well suited to serve access of packets with very short length
- low signaling overhead
- no user context stored in the network
Flexible Multiple Access

Orthogonal multi-user multiplexing

Non-orthogonal multi-user multiplexing

Overloaded multi-user multiplexing

• Less collision even with overloaded concurrent users
• Low multi-user detection complexity
• Low latency (ms) due to grant free access

Non-active tone

Frequency adaptive (TDMA/OFDMA)

Non-frequency adaptive (B-IFDMA or B-EFDMA)

Device transmits once and sleeps

2.7x
Combining the Best of Constrained Envelope and OFDMA – CPM-SC-FDMA - A Precoded SC-FDMA Scheme

CPM-SC-FDMA can provide at least 4 dB better RF end-to-end performance than convolutional coded QPSK modulated SC-FDMA (CC-QPSK-SC-FDMA)
METIS System Concept
Massive MTC (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

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
- Massive MIMO
- Ultra-Dense Networks
- Moving Networks
- Higher Frequencies

Extend to novel applications
Complementary new technologies and/or Evolutionary
- Mobile, Reliable D2D Communications
- Ultra-Reliable Communications
- Massive Machine Communications

Existing technologies in 2012
- 3G
- 4G
- WiFi

- 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
Technology roadmap

### Timeline

- **2015**
  - Q1: Vision
  - Q2: ITU IMT-2020
  - Q3: WRC-15

- **2016**
  - Q1: RAN "5G" WSA
  - Q2: RAN "5G" WSA
  - Q3: SA "5G"
  - Q4: SAI SMARTER SI

- **2017**
  - Q1: Tech. Requirements
  - Q2: Channel modeling
  - Q3: SI: Evaluation of solutions
  - Q4: SA system work

- **2018**
  - Q1: WRC-15
  - Q2: Proposals
  - Q3: Evaluation
  - Q4: SAI SMARTER WI

- **2019**
  - Q1: Vision
  - Q2: Tech. Requirements
  - Q3: Proposal
  - Q4: Specification

- **2020**
  - Q1: Vision
  - Q2: Tech. Requirements
  - Q3: Proposal
  - Q4: Specification

### Milestones

- White Paper Rel. 1 published
- Detailed requirements available, Technology feasibility explored
- Initial R&D & system design done, 1st prototypes ready, Start standardization
- Standards (1st Rel.) ready
- Start IOT & customer trials
- Ready for deployment

### SDN/NFV

- ETSI NFV/MEC, ONF, Open Daylight, OPNFV, Open Stack, IEEE SDN, IETF VNFpool/NFV, ...

### 5G PPP

- Phase 1 (Exploration, R&D, ...)
- Phase 2 (Optimization, demos, ...)
- Phase 3 (Large scale trials)

### Technology solutions

- Mature features enhanced to fit 5G requirements
- Emerging features expected to mature with the 5G architecture
- Novel 5G-specific features
4G Evolution

Source: Elektroniktidningen 2/16

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

Alternatives: GPRS, ZigBee, Bluetooth, WiFi, Sigfox, LoRa, …
mm-wave Based Mobile Radio Access Network for Fifth Generation (5G) Integrated Communications

Horizon 2020 Public Private Partnership Consortium

Coordinator: Samsung Electronics, Europe Ltd.
Technical Management: Ericsson AB

Duration: 24 months
Budget: EURO 8.26M
Coordinator: Maziar Nekovee, Samsung
Technical Manager: Peter von Wrycza, Ericsson

https://5g-mmmagic.eu
### Selected use Cases and Critical KPIs (mmMAGIC, METIS, NGMN)

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Main Challenge (most critical KPIs)</th>
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<tbody>
<tr>
<td><strong>Media on demand</strong></td>
<td>Peak connection density (4000 users/km²)</td>
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<tr>
<td><strong>Cloud services</strong></td>
<td>DL traffic density (up to 750 Gbps/km²), mobility (up to 100 km/h)</td>
</tr>
<tr>
<td><strong>Dense urban society with distributed crowds</strong></td>
<td>Connection density (30000, up to 150000, users/km²), traffic density (7500 Gbps/km²), bandwidth</td>
</tr>
<tr>
<td><strong>Smart offices</strong></td>
<td>DL user data rate (1 Gbps), traffic density (15000 Gbps/km²)</td>
</tr>
<tr>
<td><strong>Immersive 5G early experience in targeting hot spots</strong></td>
<td>Data rate (x10 average, x20 peak) and cell densification (25 small cells/hotspot area)</td>
</tr>
<tr>
<td><strong>50+Mbps everywhere</strong></td>
<td>Coverage</td>
</tr>
<tr>
<td><strong>Moving hot spot</strong></td>
<td>Mobility (up to 500 km/h)</td>
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<tr>
<td><strong>Tactile internet / video augmented robotic control and remote-robot manipulation surgery</strong></td>
<td>Availability and reliability (99,999%), low latency (1 ms)</td>
</tr>
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[https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d54427/mmMAGIC_D1.1.pdf](https://bscw.5g-mmmagic.eu/pub/bscw.cgi/d54427/mmMAGIC_D1.1.pdf)
Granted 5GPPP-projects Follow up on FP7 METIS

• "P1": METIS II
  – Project Coordinator: Ericsson
  – Technical Coordinator: Nokia
• "P2": FANTASTIC 5G:
  – Coordinator: Alcatel-Lucent
  – Technical coordinator: Orange Labs
• "P4": mmMAGIC:
  – Coordinator: Samsung
  – Technical coordinator: Ericsson
• "P7": 5G-Xhaul, 5G-Crosshaul
• FP7: MiWEBA, MiWaveS, ...
Wireless System Projects cont.

Multi-Antenna Technologies for Wireless Access and Backhaul (MATWAB)

- **Heterogeneous networks**
  - Interference mitigation (reconfigurable multi-antenna systems, coordinated transmission/reception, …)
  - Wireless backhaul (e.g. mm-wave, interference mitigation in un-licensed bands, NLOS, multi-hop, repeaters, propagation measurements, propagation modeling, …)

- **Large scale MIMO**
  - Macro RBS with many antennas, array geometries, channel modeling, fundamental performance analysis, algorithms, 3-D beamforming, large scale MIMO vs reconfiguration of antenna parameters,…

- **LOS-MIMO**
  - channel modeling, measurements availability, sensitivity w.r.t. antenna separation, …
VINNOVA-MOST Eco Innovations project - Smart Wireless Networking for Green ICT

- High performing and energy efficient wireless networks
- Increase attractiveness of energy and environmentally efficient public transportation

The main objectives of the project are to

- Investigate the potential of advanced wireless connections for users on public transports.
- Integrate and optimize the support for moving small cells in wireless access systems and in heterogeneous radio access environments.
Efficient Load-Aware Dynamic Global Radio Resource Management in Multi-Spotbeam Broadband Satellite Networks

Improve the bandwidth efficiency of future broadband satellite systems with very high number of spotbeams.

- Dynamic global Radio Resource Management mechanisms that exploit feasible flexible satellite payload architectures
- Advanced return link burst scheduling algorithms
Vision for 5G Research - Integrated Moving Networks

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Integrated Moving Networks: Mutual Opportunities

- **Mutual benefits!**
- **More reliable V2X links:** Connect non-vehicular users to the Traffic Safety/Traffic Efficiency protocols (Pedestrians, cyclists, pets, …)
- **Better mobile systems efficiency:** Vehicles collect side information to improve the resource allocation and performance of the mobile network
- **New disruptive business opportunities:** exploiting vehicle sensed data
Fully Integrated Moving Cells in *Dense* Small Cells Heterogeneous Network
Conclusions

Internet of Things is coming – be prepared!
Master program Communication Engineering (MPCOM)

Year 1
- Introduction to communication engineering
- Digital communications
- Wireless communications
- Elective courses
- Random signals analysis
- Applied signal processing
- Elective courses

Year 2
- Elective courses
- Master's thesis

Communication hard-ware related:
- Fundamentals of photonics
- Laser engineering
- Radar syst. & applications
- Antenna engineering
- Electromag. waves and components
- Opto-electronics
- Microwave engineering

Communication algorithm related:
- Remote sensing
- eHealth
- Image analysis
- Wireless networks
- Matrix analysis w. applications
- Network security
- Multimedia and video communication
- Error control coding
- Image processing
- Satellite communication
- Computer networks
- Information theory adv. level
- Additional elective course
- Bayesian statistics
- Wireless link project
- Additional elective course

Compulsory courses.
Compulsory-elective courses.
Choose at least three
Elective courses.

* Biannual (2017, 2019, ...)
** Biannual (2016, 2018, ...)

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Further Specialization Course Packages

Combine your compulsory-elective and elective courses to tailor your education towards a certain specialization, or towards more fundamental topics.

To your help, we are currently developing suggested course packages in the areas of:

- Mobile Communication
- Internet Of Things
- Smart Society
- Industry 4.0
- e-Health
- Optical Communication
- Satellite and Sensing Systems
- Intelligent Transport Systems
- RF Hardware Design
- Information Processing