5G RESEARCH AREAS AT CEA-LETI
FROM 5G RESEARCH TO 5G PRE-INDUSTRIALIZATION

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SERVING A VARIETY OF 5G WIRELESS APPLICATIONS

Mobile communications
Challenges: increasing data rate, future cellular systems, 4A any rate anytime anywhere affordable, reduction of communication energy footprint (GreenCom), monitoring interference and service coverage, heterogeneous networks - HetNets, small cells

⇒ Spectrum efficiency, cooperative communications, HetNets, Femto / Macro RRM, Cognitive radio, Flexible radio systems...

Intelligent Transportation Systems (ITS)
Challenges: traffic management, car centric services (maintenance, routing), Electric Car services, infotainment / entertainment

⇒ QoS system, mobility management, privacy and security, entertainment communication systems, propagation and adaptable antenna systems...

Advanced manufacturing - e-agriculture
Challenges: factory of the future, increasing competitiveness, new production and management communication systems, robust communication systems (coexistence, interference management), supply chain management

⇒ Wireless sensor networks, robust communication, M2M, RFID/NFC, indoor localization...

Health wellness
Challenges: hospital equipment, management and supply chain support, no-emission wireless communication systems (clean wireless), smart implants, telemedicine, health monitoring, ambient assisted living...

⇒ Body Area Network, Visible Light Communication, in vivo integration, contactless autonomous systems, indoor localisation, very high data rate communication systems, privacy, security...

Smart cities, Smart grid
Challenges: infrastructure monitoring, city infotainment services, utility supply chain management, waste collection and management systems, citizen mobility assistance, urban smart transportation systems

⇒ Long range sensor network, robust communication, M2M, security and privacy...

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KEY 5G TECHNICAL CHALLENGES

- Targets 1 Gbps in wide area (Peak data rate ~ 10 Gbps)
- Ad hoc deployment, dynamic spectrum access, white spaces, shared spectrum, fragmented spectrum
- High data rate, coverage HetNets, cooperative Nwks
- M2M, scalability, security, privacy, WSN

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5G TECHNOLOGIES AT CEA-LETI

**Antennas optimization**
- Miniature
- Smart
- Integration

**Chanel propagation modeling**
- Characterization
- Modeling
- Emulation

**Contactless**
- Arduous application
- VHBR (Very High Bit Rate)
- Power harvesting

**Cellular IoT**
- Physical layers
- Protocols

**Wireless sensors networks (WSN)**
- Central network
- Mesh network
- Specific Scenario

**Localization**
- Radio link
- Localization algorithms
- Multi-modality

**COMMUNICATION**

**RADIO LINK DESIGN, OPTIMIZATION & CHARACTERIZATION**

**ANTENNAS MINIATURIZATION & INTEGRATION**

**RFID SOLUTION DESIGN FOR HARD ENVIRONMENT**

**LOCALIZATION & NAVIGATION**

**5G below 6GHz**
- Disruptive air interface
- Advanced protocols
- Network architecture

**5G above 6GHz (mmW)**
- New physical layers
- Evolved protocols

**LiFi**
- Physical layer
- Protocol stack
- Platforms

**Flexible & Cognitive radio**
- Air interface
- MAC layer
- Demonstrator
ACTIVITIES

- **Fields of expertise**
  - Wireless digital communication systems
  - Study, specification and link/system level simulations (PHY/MAC)
    - Information theory and signal processing
    - Wireless communication protocols
  - Algorithm / Architecture analysis and matching
  - Hardware and embedded software architectures for real time digital communication systems
  - Prototype specification and design for advanced proof of concepts

- **Main applications**
  - Broadband wireless systems
  - Cellular: 5G (below 6GHz and mmW)
  - TVWS and cognitive radio
  - Optical wireless communications

- **Specific equipments**
  - Computer grid for intensive simulations
  - Lab equipments for prototyping and real time measurement and analysis

Challenges

- Spectral efficiency for communication systems
- New spectral resources
- Waveforms, modulation and coding
- Radio resource management
- HW/SW architectures
**ACTIVITIES**

- **Know how**
  - Signal processing: modulation, channel coding, equalization, synchronisation, MIMO techniques, multicarrier systems, …
  - Information theory, cooperative communications, network coding
  - MAC protocols, Radio Resource management and interference mitigation
  - Link Level Simulations (PHY), System level simulations (MAC/RRM)
  - Digital wireless solution specification and design (HW/SW design)
  - Hardware / software partitioning for real-time wireless systems
  - Optimized design with various figure of merit (power consumption, data rate, …)
  - Integration with third party HW/SW/Analog
  - HW demo with design of custom platforms (HW&SW) & field tests

**Challenges**

- Spectral efficiency for communication systems
- New spectral resources
- Waveforms, modulation and coding
- Radio resource management
- HW/SW architectures
### 5G BELOW 6GHz

#### Disruptive air interface

- Waveforms: FBMC, filtered OFDM, single carrier, narrowband
- (M)MIMO, Beam forming
- Full duplex
- Channel coding: LDPC & polar code
- HW and SW flexible platforms

#### Advanced protocols

- Interference management: ICIC, Network controlled Discontinuous transmission
- Flexibility and multi services: Scheduling for heterogeneous QoS Scheduled/contention based access (RRM)
- Load balancing
- Joint Network channel coding

#### Network architecture

- Mobile edge cloud computing
- Resources sharing, caching, and clusterization
- Heterogeneous deployments (HETNETS), including access and backhaul

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### Capacity increase: x100

- x10 in spectral efficiency: (M)MIMO, Full duplex, out of band radiation
- x10 in densification (access points, connected objects)

### Latency reduction: /5

- Content caching,
- Protocols (QoS aware, HARQ)
- Flexible TTI

### Consumption reduction: /10

- Network, protocols, components
- PAPR (Peak average power ratio): 7dB

### Reduction of jitter protocol

- Mission critical applications
- Robust PHY layer and quasi deterministic MAC layer
### New physical layer

- Waveforms: FBMC, BF-OFDM, single carrier
- RF impairments compensation
- Beam forming and tracking: hybrid architecture
- FEC: LDPC
- HW architecture for parallel processing

### Evolved protocols

- Mobility: users and access points
- Scheduling for heterogeneous QoS: time / frequency / beam
- Macro-cell off loading and heterogeneous networks
- Interference management: ICIC, Network controlled, Discontinuous transmission, Self-organized network (SON)

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**Density increase: x100**
- Ultra dense networks (UDN) and Self Organized networks (SON)
- Advanced interference management schemes
- C-RAN vs D-RAN

**New frequency bands:**
- x10 in spectrum
- 100Ghz-300GHz
- Adaptation of PHY and RF layers

**Throughput increase: x100**
- Towards Tbpps
- Joint optimization of backhaul/fronthaul/RAN

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**5G ABOVE 6GHz (mmW)**

**5G Champion**

**5G MiEdge**

**mmMAGIC**
**FLEXIBLE & COGNITIVE RADIO**

**Air interface**
- New modulation (FBMC)
- Advanced receivers:
  - Oversampled FFT
  - Channel estimation for fragmented spectrum
- Spectrum quality indicator:
  - Sensing mechanisms
  - Interference measurement
  - Primary user detection

**MAC layer**
- Flexibility and multiservices
- Cross layer mechanisms (FBMC)
  - Loose synchronization
  - Fragmented spectrum
- Shared spectrum access
- Offload/aggregation of shared bands
  - multi-RAT management, DSA, LAA

**Demonstrator**
- Compatibility with IEEE DYSPAN P1900.7 (TV White Spaces)
- Flexible radio
  - Frequency, band, fragmentation
- Field trials (ARCEP UHF licence)

**Identification of new bands**
- Survey of regulatory actions (2.3, 3.5 GHz)
- Primary user detection
- Definition of a suitable access to shared spectrum

**Exploitation of shared bands**
- Aggregation (DL and UL) of these bands
- Management of generated interferences
- Control and user plane split

**Extension of the standard to new profiles**
- QoS support for unlicensed bands
- Contention/scheduled access equilibrium to be integrated in the standard

**Industrial valorisation**
- Technological transfer of FBMC
**LIFI – OPTICAL WIRELESS COMMUNICATION**

**Physical layer**
- Waveforms
  - Multicarrier, PAM
  - Frequency domain equalization
  - Compensation of optical and analogue impairments
- MIMO
- Adaptive processing (Tx/Rx)

**Protocol stack**
- Multi user access
- Heterogeneous QoS
- Full duplex
- Transparent IP link

**Platforms**
- Characterization testbed
  - Spectrum analysis
  - Propagation channel analysis
  - Algorithm optimization (HIL)
- HW/SW partitioning
- Electronic Architecture
  - Consumption optimization
  - Reduction of form factor

**Throughput:** x5-x20
- Automatic link adaptation
- Spectral efficiency increase (bit loading, MIMO)
- Bandwidth increase (RGB LED, micro-LED, Laser sources)

**Range:** x5
- Optical front-end: lens, collimation
- MIMO processing

**Density increase:**
- Multi-cell access
- Interference management
EM field covered from 100 MHz to 90 GHz

VHF-EHF band (100 MHz – 18 GHz)
Shielded anechoic chamber

On-vehicle antennas
Antenna arrays (e.g. base station, massive MIMO)

MM-Wave high-gain antennas (e.g. backhaul)
EM field covered from 100 MHz to 90 GHz

UHF-SHF band (900 MHz – 40 GHz)
Shielded anechoic chamber

Beam-steering antenna arrays

Miniature antennas (e.g. user terminal)
EM field covered from 100 MHz to 90 GHz

**MM-Waves (30-90 GHz)**
Anechoic chamber with on-chip probing capability 2.3x2.3x3.4 m$^3$.

**AuT**

**On-chip/in-package antennas**

**In-package antenna arrays**

**Relative Power (dB)**

**Angle (deg.)**
OTA EMULATED CHANNEL REPLAY (BELOW 6 GHZ)

*Full chain tested under realistic and controlled channel models*

Evaluation of the impact of antennas, housing (smartphone, tablets, laptops, set-top-box,...), environment
- **5 labs**: 200+ people dedicated to telecommunications & RF SoC CMOS integration
- Address manufacturability issues to accelerate the transfer from research to production
FBMC: New 5G modulation for efficient spectrum usage

VLC: Visible Light Communications
- Use off-the-shelf LED
- Radio for User terminal and Backhaul
60-GHz Transceiver module on HR silicon (CEA-LETI)

- Compact size: 6.5×6.5×0.6 mm³,
- HR silicon integration with integrated antennas
- CMOS transceiver (CMOS 65 nm)


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60-GHz Transceiver module on HR silicon (CEA-LETI)

- Wireless HD std: 7 Gbps (OFDM 16QAM)
- Operates over the 4 IEEE channels between 57 and 66 GHz.
Localization & Tracking (Indoor and Outdoor):
- Complete SoC (Tx/Rx radio IC + Embedded SW)

Antennas Design
PACKAGING, INTEGRATION, MEMS: A NEED FOR MMW PRE-INDUSTRIALIZATION

8000 m² clean rooms with state-of-the-art pre-industrial 200-mm micro-fabrication facilities

3D packaging & integration
- Silicon interposer technology
- Passive components and antenna integration

Higher miniaturization
RF MEMS switches and capacitors
(Ex. for mmW reconfigurable antennas)

- Low-loss switches
- Low-loss phase-shifters
5G SMART ANTENNA SYSTEMS – INNOVATIONS

- Low-complexity system architectures for beam steering
  - Beam steering transmit array, hybrid beamforming, dynamic tracking algorithm, multi-user beam control
  - High-gain wideband compact antenna
- Proof-of-concept for mm-wave 5G/radar system
  - mm-wave channel measurements and 3D modeling
  - Mapping and navigation algorithms
  - Tracking algorithm for moving hotspot
  - Long frames and high order modulations

Benchmark of mm-wave personal radar architectures
Requirements on system design

Beam tracking transmit array system
Switchable radiating source on silicon interposer

V-band backhauling antenna
Requirements on PA output power
(photo courtesy of Radiall)