5G communications: development and prospects

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Helsinki, Finland
26th May, 2016
Vision

“The advanced 5G infrastructure is expected to become the nervous system of the Digital Society and Digital Economy”
Günther Oettinger, European Commission, MWC 2016

“Client Server”

“Multi-Tenant”

Convergence of:
1. Cloud computing
2. UE Computing power
3. Connectivity at high speed

DL: 1Gb/s
UL: 500Mb/s
LTE-A target

Convergence of:
1. Cloud computing
2. UE Computing power
3. Connectivity at high speed

2010

“Client Server”

Bit pipe and Free Communication Services

2020

“Multi-Tenant”

Nervous system of the Digital Society and Economy

“The smart phone is the extension of what we do and what we are, the mobile is the answer to pretty much everything”
Eric Smith, Google, MWC 2010

“DL: 1Gb/s
UL: 500Mb/s
LTE”
Main 5G initiatives ongoing globally

- Stanford CIS
- UC SWARM
- NYU Wireless
- WINLAB
- 5GIC UK
- 5GIC at University of Surrey
- 5GIC at University of Surrey
- EU 5G PPP in Horizon 2020 (€700mn)
- White Paper
- UK
- 5GIC at University of Surrey
- http://www.surrey.ac.uk/5gic
- US
- 4G (5G) Americas: White Paper
- China
- IMT-2020 (5G) Promotion Group
- 863 Research Program
- Future Forum: White Paper
- Japan
- 5G Promotion Forum (ARIB)
- White Paper
- Korea
- 5G Forum as PPP
- White Paper
- NGMN
- White paper

http://www.3gpp.org/technologies/presentations-white-papers
European Commission main investments and targets

- **€12.5bn / €80bn EU funds**: Horizon 2020 investment in ICT Research in 2014–2020

- **From the lab to the market**: from electric cars, to robots → help care for elderly generation

- **€5.5bn PPPs**: 5G, Robotics, Photonics, Factory of the Future, HPC, Big Data and Security

- **Open access for true innovation**: sharing knowledge and reaping the benefits of big data
**5G Public Private Partnership (PPP): €700 mn → €1.4+ bn**

**EU 5G socio-economic analysis:** €56.6 bn 5G investment (EU28 Member States) → Value: €425.5 bn (7.5x), Jobs: 7.184 mn

- **5G-PPP Phase III** (2018-20 EU Public funds €425mn): Large scale trials in Europe with Verticals
- **5G-PPP Phase II** (2017-18, EU Public funds €148mn): Verticals, Satellites, Optical, SW networks
- **5G-PPP Phase I** (2015-16, EU public funds €125mn): 19 retained Actions

**Notes:**
1. SRIA: Inputs to Work Programme
2. WP: 5G Vision and for Verticals
3. PP: Pre-structuring Models
4. Policies: Positioning papers
5. PR: Communication/Cooperation

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**Governing Structure:**
- **Association:** M30+
  - General Assembly
  - Association Statutes and Modus Operandi of Association
  - Working Groups launched
- **5G Infrastructure Association Board**
- **Secretory General**
- **Head of Office**
- **European Commission**
  - Partnership Board
  - Steering Board (Project Coordinators plus Association representative)
  - Technology Board (Project Technical Managers plus Association representative)

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**Activities:**
- 5G-PPP Phase I (2015-16, EU public funds €125mn): 19 retained Actions
- 5G-PPP Phase II (2017-18, EU Public funds €148mn): Verticals, Satellites, Optical, SW networks
- 5G-PPP Phase III (2018-20 EU Public funds €425mn): Large scale trials in Europe with Verticals

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**EU 5G socio-economic analysis:**
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**5G PPP Projects:**
- **5G Architecture**
  - Working Group 1
  - Working Group 2
  - Working Group n

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**Source:** 5G Infrastructure Association

- **CogNet**: Building an Intelligent System of Insights and Action for 5G Network Management
- **SELFNET**: Framework for SELF-organized network management in virtualized and software defined networks
- **CHARISMA**: Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for Intelligent and Secure Media Access
- **SUPERFLUIDITY**: Superfluidity; a super-fluid, cloud-native, converged edge system
- **5GEx**: 5G Exchange
- **VirtuWind**: Virtual and programmable industrial network prototype deployed in operational Wind parks
- **SONATA**: Service Programming and Orchestration for Virtualized Software Networks
- **METIS-II**: Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society-II
- **COHERENT**: Coordinated control and spectrum management for 5G heterogeneous radio access networks
- **SPEED-5G**: Quality of Service Provision and capacity Expansion through Extended-DSA for 5G
- **5G-Norma**: 5G NOvel Radio MultiService adaptive network Architecture
- **SESAME**: Small cells coordination for Multi-tenancy and edge services
- **5G Xhaul**: Dynamically Reconfigurable Optical-Wireless Backhaul/Fronthaul with Cognitive Control Plane for Small Cells and Cloud-RANs
- **FANTASTIC-5G**: Flexible Air INTERface for Scalable service delivery within wireless Communication networks of the 5th Generation
- **mmMAGIC**: Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications
- **Flex5Gware**: Flexible and efficient hardware/software platforms for 5G network elements and devices
- **Xhaul**: The 5G Integrated fronthaul/backhaul

Source: EURO-5G, 5G Infrastructure Association

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HUAWEI TECHNOLOGIES CO., LTD.
Phase II: Pre-structuring model

www.5g-ppp.eu

ICT-07-2017 – 5G PPP Research and Validation of critical technologies and systems - €100mn RIA (+ €3mn CSA)
Strand 1: Wireless access and radio network architecture/technologies
Strand 2: High capacity elastic - optical networks
Strand 3: “Software Network”

ICT-08-2017: 5G PPP Convergent Technologies - €40mn IA + €5mn RIA
Strand 1: Ubiquitous 5G access leveraging optical technologies
Strand 2: Flexible network applications
Cooperation in access convergence

Source: 5G Infrastructure Association
International cooperation: status of MoU and JD

- **China**
  - MoU signed with IMT-2020 (5G) Promotion Group on September 29, 2015 in Beijing

- **Japan**
  - MoU signed with The 5G Mobile Communications Promotion Forum on March 25, 2015 at NGMN Industry Conference in Frankfurt, Germany

- **Korea**

- **USA**
  - MoU signed with 4G Americas on March 2, 2015 at Mobile World Congress 2015 in Barcelona, Spain

- **Multilateral MoU on a series of Global 5G Event**
  - Two events per year with rotation between continents: Beijing and Rome in 2016
  - MoU signed between IMT-2020 (5G) Promotion Group, 5GMF, 5G Forum, 5G Americas and 5G Infrastructure Association on October 20, 2015 in Lisbon

Source: 5G Infrastructure Association
5G-PPP: Exploitation of research and innovation results

5G research in FP7 and in the private sector

Results from FP7 Projects contributed to ITU-R on 5G vision and requirements

ONF, Open Daylight, OPNFV, Open Stack, ...

ITU-R Vision and Recommendation

WRC preparatory process

3GPP Work Items and 3GPP Releases

3GPP Study Items

Contributions to standardisation and regulatory process via member organisations in respective bodies

5G PPP Phase I → 5G PPP Phase II → 5G PPP Phase III

3GPP Study Items

Prototype and product development

Trial


Release 12 Release 13 Release 14 Release 15 Release 16

Winter Olympics, Korea
FIFA World Cup, Russia 2018
Summer Olympics, Japan

Source: 5G Infrastructure Association
Beyond 5G-PPP: European Commission “Action Plan”

- **Actionable recommendations** endorsed by Industry to: Industry itself, the Commission, MS, and possibly financial actors (e.g. El Bank)
- Cooperation with Telco's and vertical industries to **identify opportunities and barriers** for investment in 5G deployment in Europe and to make (actionable) recommendations
- Release the "5G Action Plan for Europe" at the same time as the review of the **Telecom Regulatory Framework** (Sept-Oct 2016)

- **Working groups**
  - **WG1**: 5G-enabled ecosystems, use cases and common calendar
  - **WG2**: Large scale / pre-commercial trial(s) in Europe
  - **WG3**: Regulatory environment and boosting infrastructure investment
Usage scenarios of IMT for 2020 and beyond (5G)

- Enhanced Mobile Broadband
  - Gigabytes in a Second
  - 3D video, UHD Screens
- Smart Home / Building
  - Work and Play in Cloud
  - Augmented Reality
- Smart City
  - Industry Automation
  - Mission Critical Application
  - Self Driving Car
- Future IMT
  - Massive Machine Type Communications
  - 100 Billion Connections
  - 1 Millisecond Latency
  - 10 Gbit/s Peak Speed

New Air Interface
- Flexibility & Spectrum Efficiency

New Architecture
- One Physical Network Multiple Industries
Enhancement of key capabilities from 3GPP LTE to 5G

New Radio requirements

<table>
<thead>
<tr>
<th>KPI</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak data rate</td>
<td>20Gbps DL 10Gbps UL</td>
</tr>
<tr>
<td>Peak Spectral efficiency</td>
<td>30bps/Hz - 15bps/Hz</td>
</tr>
<tr>
<td>Control plane latency</td>
<td>10ms</td>
</tr>
<tr>
<td>User plane latency</td>
<td>URLLC: 0.5ms UL&amp;DL</td>
</tr>
<tr>
<td>Mobility interruption time</td>
<td>0 ms</td>
</tr>
<tr>
<td>Inter-system mobility</td>
<td>With other IMT systems</td>
</tr>
<tr>
<td>Reliability</td>
<td>URLLC: P=10-5 in 1ms</td>
</tr>
<tr>
<td>Coverage</td>
<td>mMTC 164dB</td>
</tr>
<tr>
<td>Extreme Coverage</td>
<td>100-400 km voice/low data</td>
</tr>
<tr>
<td>UE battery life</td>
<td>mMTC 15 years</td>
</tr>
<tr>
<td>Connection density</td>
<td>mMTC 1M device/km2</td>
</tr>
<tr>
<td>Mobility</td>
<td>500 km/h</td>
</tr>
</tbody>
</table>
Summary of the key resolutions at WRC15 pertinent to 5G

**WRC15**

New or Harmonized bands for IMT Use
- 700MHz Band (694–790 MHz)
- L-Band (1427–1518 MHz)
- C-Band (3.4–3.8 GHz)

**WRC19**

New bands agreed for discussions in 2019
- 24.25–27.5 GHz
- 31.8–33.4 GHz
- 37–40.5 GHz
- 40.5–43.5 GHz
- 45.5–47 GHz
- 47–50.2 GHz
- 50.4–52.6 GHz
- 66–76 GHz
- 81–86 GHz

**Different channel characteristics to Sub6GHz**

## 3GPP

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Values or assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Frequency</td>
<td>around 30 GHz or around 70 GHz or Around 4 GHz</td>
</tr>
<tr>
<td>Aggregated system bandwidth</td>
<td>Around 30GHz or Around 70GHz: Up to 1GHz (DL+UL)</td>
</tr>
<tr>
<td></td>
<td>Around 4GHz: Up to 200MHz (DL+UL)</td>
</tr>
</tbody>
</table>
5G multi-tenant network and services vision

- FULL Immersive Experience
- ANYTHING as a Service

Outdoor (below 6GHz)

Indoor (above 6GHz)

1) Sensing
   - 4K/8K video
   - 24 beams audio
   - Camera array
   - Microphone array

2) Rendering and Interacting
   - Sound field
   - iCub

3) Reasoning
   - 100T OXC

4) Acting
   - 4K stereo video binaural audio
   - 360° video

5) Networking
   - 80Gb/s E-band link
   - 50Gb/s Macro
   - 100Gb/s Micro

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Network, air interface and spectrum usage evolution from 4G to 4.5G and 5G

**4G**
- **EPC**
- **LTE**
- **Existing Spectrum**: 6GHz, 100GHz

**4.5G**
- **vEPC**
- **LTE**
- **Massive-MIMO**
- **LTE-M NB-IoT**
- **eCA (32)**
- **256QAM**
- **LAA**
- **eD2D**
- **D2X**
- **Existing Spectrum**: 6GHz, 100GHz

**5G**
- **5G Network Functions**
  - Virtualization + Cloudformation (Plasticity)
- **Multiple Access**
  - **NEW AIR**
  - Full-Duplex Frame
  - Channel Coding
- **EPC**
- **vEPC**
- **5G Network Functions**
  - Virtualization + Cloudformation (Plasticity)
- **New Spectrum + Existing Refarming**: 6GHz, 100GHz
5G plastic architecture and example application to static machines type of traffic
Mobility Management Application (MMA) for SDN

- Topology: 10 Access Points, 200 active mobiles
- 10 Handovers/s with random mobility

- Configured flow for mobile device before handover
- Configured flow for mobile device after handover

**Diagram Description**

- **Flow 1**: Action 1
- **Flow 2**: Action 2
- **Switch 1**: M1
- **Switch 2**: (Access point)
- **Switch 3**: (Access point)
- **Switch 4**: Web Server
- **Controller**: Mobility Management Application (MMA)
- **SDN Control Links**: Green and red lines indicate configured flows before and after handover

**Graph**

- **Overall Time**: 160%
- **Inside Controller**: Green bar
- **Inside MMA**: Red bar
- **MMA Proactive**: Green bar
- **MMA Reactive**: Red bar

**Axes**

- X-axis: Delay (ns)
- Y-axis: Overall Time (ms)
High band non-standalone assisted by low band

Marco Site @ Sub6GHz
- Connectivity & coverage & mobility

Small Cell @ Above 6GHz
- High traffic offloading
Multiple access techniques

Non-orthogonal multiple access (NOMA): time and frequency resources sharing in the same spatial layer via power or code domain multiplexing, e.g. SCMA, MUSA, LDS-OFDM, etc.

**Basic NOMA:** SIC receiver

**Spatial Filtering NOMA:** Using 3D-BF, AAS, M-MIMO

**Network NOMA:** multi-user precoding

**SoDeMA = Software Defined Multiple Access**

**Example:** 6 Users, two bits mapped to a complex codeword, which are then multiplexed over four shared orthogonal resources (e.g. OFDM subcarriers)

**MPA = Message Passing Algorithm (MPA)**
Advanced waveforms

- **Per-subcarrier pulse shaping**: using prototype filter with steep power roll-off for shaping subcarrier signals in frequency and/or time domain
- **Sub-band filtering**: applying filters to a group of subcarriers after OFDM modulation

### Pulse shape design parameters

<table>
<thead>
<tr>
<th>Pulse length</th>
<th>Pulse shapes</th>
<th>Localization</th>
<th>Waveform Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K=1$</td>
<td>Rectangular</td>
<td>Time</td>
<td>CP-OFDM</td>
</tr>
<tr>
<td>$K=1$ (N_{FFT} long)</td>
<td>Rectangular</td>
<td>Time</td>
<td>ZP-OFDM</td>
</tr>
<tr>
<td>$1 \leq K &lt; 1.5$</td>
<td>Various</td>
<td>Time + Frequency</td>
<td>W-OFDM</td>
</tr>
<tr>
<td>$K=4$</td>
<td>Long pulse</td>
<td>Time + Frequency</td>
<td>FBMC/QAM</td>
</tr>
<tr>
<td>Arbitrary $K$</td>
<td>Various</td>
<td>Flexible</td>
<td>P-OFDM</td>
</tr>
</tbody>
</table>

(*) Additional band pass filter needed

The choice of either one of the two variants depends on the required degree of spectral and temporal confinement
Filtered-OFDM (F-OFDM)

**Pros**
- Multi-service with different time and frequency numerology (e.g. CP, sub-carrier spacing (symbol duration), TTI at different carrier frequencies)
- Low out-of-band emission (OOBE)
- Flexible frequency multiplexing
- Simple channel equalization
- Multi-antenna transmission
- Efficient spectrum utilization
- Affordable computational complexity
- Possibility to incorporate other waveforms
- Backward and forward compatibility

**Cons**
- Non-orthogonal in time and quasi-orthogonal in frequency
- Slightly more prone to delay-spread channels than P-OFDM
Pulse shaped OFDM (P-OFDM)

**Pros**
- Excellent OOB interference control and efficient utilization of narrow frequency bands
- Partitioning of spectrum into independent bands with excellent capabilities for coexistence of services in the same frequency band and spectrum sharing
- Any modulation order and MIMO capability
- Excellent robustness against synchronization errors
- Flexible frame structure with large subcarrier spacing for high Doppler in Vehicle to Anything (V2X) communications
- Short TTI length for low latency scenarios and one way ping delay < 0.5 ms

**Cons**
- Filter length may be limited by delay constrains
V2X P-OFDM Based Low Latency Real-Time (Demonstration)

Optimized baseband processing running on Intel platform x86_64 USRP SDR as RF frontend

Enabling D2D and cellular assisted D2D access

One way ping delay < 0.5 ms
New air interface

Service Oriented Radio (SOR): choosing different air interface components for different applications

Full Duplex  Massive MIMO

Mobile Internet  Internet of Things

Adaptive Air Interface

SCMA  Polar Code

P-OFDM/F-OFDM

One air interface fits many applications with high flexibility, at least a 3x spectral efficiency improvement.
Huawei 5G Low Band Test Bed
World’s Highest Throughput @ Sub6G

Technology Innovations

- 10Gbps
- 32 Gbps

Mbps

Layer

- 51.6 bps/Hz

- 200MHz BW
- 18 Layers

- F-OFDM
- SCMA
- Polar Code
- M-MIMO
Huawei 5G High Band Test Bed
World’s Highest Throughput @ E-Band

115 Gbps
9.6GHz BW
**3GPP timeline:**

- **Phase 1** by Sep 2018/Rel-15 for more urgent commercial needs (to be agreed) ➔ **Deployment 2H2020**

- **Phase 2** by Mar 2020/Rel-16 for all identified use cases/requirements: ➔ **Deployment 2H2021**

**NB:** New Radio (NR) design forward compatible so that features can be added in optimal way in later releases
Conclusions

5G tests and trials with Verticals essential step towards effective standardization

3GPP primary organization and others – such as, e.g., ONF and IETF – complementary

Public party crucial role in early consensus (e.g. 5GPPP), policies, regulatory processes

IP Rights shall not hinder 5G technologies adoption and market uptake
Thank you

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References


