5G communications: development and prospects

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Sydney
13th April, 2016
Vision

“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

“Client Server”

Bit pipe and Free Communication Services

2010

“Multi-Tenant”

Nervous system of the Digital Society and Economy

2020

“The advanced 5G infrastructure is expected to become the nervous system of the Digital Society and Digital Economy”

Günter Oettinger, European Commission, MWC 2016

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

Convergence of:
1. Big data
2. Artificial intelligence
3. Connected networks

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

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UL: 500Mb/s
LTE-A target

Convergence of:
1. Cloud computing
2. UE Computing power
3. Connectivity at high speed
Main 5G initiatives ongoing globally

- Stanford CIS
- UC SWARM
- NYU Wireless
- WINLAB
- 5GIC UK
- 5GIC in Horizon 2020 (€700mn)
- White Paper
- 5GIC at University of Surrey
- http://www.surrey.ac.uk/5gic

- 4G (5G) Americas: White Paper
- IMT-2020 (5G) Promotion Group
- 863 Research Program
- Future Forum: White Paper

- 5G Promotion Forum (ARIB): White Paper

- 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 (€700 mn → €1.4+ bn)

EU 5G socio-economic analysis: €56.6 bn 5G investment → EU28 Member States: value €425.5 bn, 7.184 mn jobs

- 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 Actions

Decuping - ongoing

Communications-networks-oriented ETP

M1000+ (I, SME, R)

HUAWEI TECHNOLOGIES CO., LTD.
D. Soldani

Source: 5G Infrastructure Association
5G-PPP: Exploitation of results

5G research in FP7 and in the private sector

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

3GPP Work Items and 3GPP Releases

3GPP Study Items

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

ITU-R Vision and Recommendation

WRC preparatory process

Trials

Prototype and product development

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


Release 12 Release 13 Release 14 Release 15

Winter Olympics, Korea FIFA World Cup, Russia 2018 Summer Olympics, Japan FIFA World Cup, Qatar 2022

Source: 5G Infrastructure Association
Usage scenarios of IMT for 2020 and beyond (5G)

- **Future IMT**
  - Enhanced Mobile Broadband
  - Smart Home / Building
  - Voice
  - Smart City
  - Massive Machine Type Communications
  - Gigabytes in a Second
  - 3D video, UHD Screens
  - Work and Play in Cloud
  - Augmented Reality
  - Industry Automation
  - Mission Critical Application
  - Self Driving Car
  - Ultra-Reliable and Low-Latency Communications

- **New Air Interface**
  - Flexibility & Spectrum Efficiency

- **New Architecture**
  - One Physical Network
  - Multiple Industries

- **Key Metrics**
  - 100 Billion Connections
  - 1 Millisecond Latency
  - 10 Gbit/s Peak Speed
Enhancement of key capabilities from IMT-Advanced (3GPP LTE) to 5G

- User Experienced Data Rate (0.1~1Gbit/s)
- Area Traffic Capacity (Tens of Tbit/s/km²)
- Peak Data Rate (Tens of Gbit/s)
- Mobility (500+ km/h)
- Latency (ms level)
- Connection Density (10⁶ devices/km²)
- Energy Efficiency
- Cost Efficiency

Enhanced Mobile Broadband
Massive Machine Type Communications
Ultra-Reliable and Low Latency Communications

ITU-R

[5G Promotion Group]
Summary of the key resolutions at WRC15 as 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)

**Sub6GHz**

**Primary** (Coverage & Mobility)

**Complementary** (Capacity)

**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
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
   iCub
   4K stereo video binaural audio

3) Reasoning

4) Acting

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

4G
- EPC
- LTE
- 6GHz
- Existing Spectrum

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

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

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

Flow 1 | Action 1
---|---
Flow 2 | Action 2

Switch 1
Flow 1 | Action 1
---|---
Flow 2 | Action 2

Switch 2 (Access point)
Switch 3 (Access point)
Switch 4

Controller
Mobility Management Application (MMA)

Web Server

Graph showing performance metrics:
- Overall Time
- Inside Controller
- Inside MMA

160%
High band non-standalone assisted by low band

Marco Site @ Sub6GHz
- Connectivity & coverage & mobility

Small Cell @ Above 6GHz
- High traffic offloading

5G Small Cell

HF Coverage

UP: User Plane
CP: Control Plane

UP: User Plane
CP+UP

Self-Backhaul

5G Macro Cell
Multiple access techniques

Non-orthogonal multiple access (NOMA): time and frequency resources sharing in the same spatial layer via **power domain** 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

**SIC** = Successive Interference Cancellation

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

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

**Per-subcarrier pulse shaping**: using prototype filter with steep power roll-off for shaping subcarrier signals in both frequency and time domain

**Sub-band filtering**: applying filters to a group of subcarriers after OFDM modulation

<table>
<thead>
<tr>
<th>Pulse shape design parameters</th>
<th>Waveform Name</th>
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<tr>
<td><strong>Pulse length</strong></td>
<td><strong>Pulse shapes</strong></td>
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<tr>
<td>$K=1$</td>
<td>Rectangular</td>
</tr>
<tr>
<td>$K=1$ (NFFT long)</td>
<td>Rectangular</td>
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<tr>
<td>$1 \leq K &lt; 1.5$</td>
<td>Various</td>
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<tr>
<td>$K=4$</td>
<td>Long pulse</td>
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<tr>
<td>Arbitrary $K$</td>
<td>Various</td>
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</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**
- Flexible frequency multiplexing
- Simple channel equalization
- Multi-antenna transmission
- Efficient spectrum utilization
- Low out-of-band emission (OOBE)
- Affordable computational complexity
- Possibility to incorporate other waveforms
- Backward and forward compatibility
- Multi-service with different time and frequency numerology (e.g. CP, sub-carrier spacing (symbol duration), TTI at different carrier frequencies)

**Cons**
- Non-orthogonal in time and quasi-orthogonal in frequency
- More prone to delay-spread channels
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) applications
- 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

10, 32 Gbps

51.6 bps/Hz

200MHz BW | 18 Layers

Technology Innovations

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

9.6GHz BW
115 Gbps
5G timeline

<table>
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<th>2018</th>
<th>2019</th>
<th>2020</th>
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<td>Si: 5G enhancements</td>
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5G Deployment (Announcements)

### 3GPP timeline

**Phase 1** by H2 2018 to address a more urgent subset of the **commercial needs** (to be agreed)

**Phase 2** by Dec 2019 for the IMT 2020 submission and to address all identified use cases & requirements

➔ New radio design forward compatible to optimally support the use cases of Phase II
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


