Future Radio Interface: Outcome and Outlook from the 5G-PPP Project 'ONE5G'

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Outline

- ONE5G project summary
- ONE5G key scenarios and technology development
- ONE5G key outcomes and contributions to 3GPP NR and 5G advanced
- ONE5G critical use cases and the 3GPP NR support
- Future radio interface and the strategic research and innovation agenda (SRIA) 2021-27
- Discussion & Outlook

ONE5G: E2E-aware Optimizations and advancements for the Network Edge of 5G New Radio

- The European-funded 5GPPP project **ONE5G** tackles the design of advanced air-interface technologies and optimizations from an end-to-end (E2E) perspective for 5G, **beyond the first standard release** (3GPP Rel. 15)
  - 14 partners, Budget: 8 M€
  - Duration: 25 months (01.06.2017 – 30.06 2019)
  - 5G-PPP Phase 2 project
  - Coordinator: Nokia Bell Labs

ONE5G has developed E2E performance optimization enablers to further boost the performance of the first version of 5G, to be more comprehensive:
- Address all services (eMBB[1], URLLC[2], mMTC[3]), including verticals
- In various environments, from dense urban (Megacity) to large underserved areas

[1] : Enhanced Mobile BoradBand
[2] : Ultra-Reliable and Low-latency Communications
[3] : massive Machine-Type Communications

ONE5G key scenarios

- Megacities
  - A dense urban scenario.
  - Challenge: address simultaneously the wide variety of services and devices.
  - Throughput, capacity and connection density will be crucial.
- Underserved areas
  - Low to very low density areas, with no or limited access to Internet.
  - Challenge: provide solutions for cost-efficient roll-out of 5G.
  - Coverage, power consumption and cost will be the key.

Technology development for the two selected scenarios

Megacities	
Throughput	- Massive MIMO enablers (CSI acquisition, beam management, array formats, …)
Connection density	- Non-Orthogonal Multiple Access (NOMA) - Centralized Radio Access Networks (CRAN) - Social network info gathering for network optimization
Simultaneous support of multiple and differing services	- Pre-emptive scheduling - Grant-free access - Dynamic multi-connectivity management - Prediction algorithms - QoE balancing - Mobility Enhancements

Underserved Areas	
Coverage	- Beamforming / precoding - Array formats - D2D relaying
Cost	- Precoding and signal shaping for wireless backhaul - Standalone unlicensed frequency bands - Network slicing to adjust price levels
Power Consumption	- RRC state handling and DRX - Efficient front-end implementation

NOMA: Non-Orthogonal Multiple Access
CRAN: Centralized Radio Access Network
MIMO: Multiple-Input Multiple-Output

RRC: Radio Resource Control
DRX: Discontinuous Reception
D2D: Device to Device

Key link technologies and enhancements beyond Rel. 15 for multi-service operation and practical implementation

- ONE5G developed different technical components, leading to 11 clusters addressing multi-service operation and practical implementation.

Multi-service operation

Towards practical implementation

Multi-service access solutions

Enhanced NOMA schemes for improved capacity, reduced latency, and service coexistence

Grant free solutions for URLLC

Extreme reliability enabled by multi-link connectivity

Massive MIMO enablers

Pilot contamination mitigation

Massive MIMO beamforming for backhaul and multicast

Low-complexity CSI acquisition and robust beamforming

Massive MIMO array designs and efficient implementation

High-quality CSI for massive MIMO and CRAN

Interference Management

Advanced link coordination

Flexible functional split in CRAN

Cell-free operation

CSI: Channel State Information

Key networking technologies for improved system performances

- ONE5G developed techniques impacting the RAN to optimize the E2E user-experienced performance, characterized through Key Quality Indicators (KQIs).
  - For all technical components, we provide the benefits and gains with respect to KQIs and E2E user-experienced performance (examples below)

Network Availability
CRAN split options

Network Accessibility
D2D relaying
RRC state handling

Service Integrity
Scheduling (delay optimal user and channel scheduling, CRAN multi-cell scheduling,…)
Social network info gathering for network optimization QoE proactive management
Dynamic spectrum aggregation

Service Accessibility
RRC state-handling
Configured grants for periodic non-synchronous UL URLLC traffic

Service Retainability
5G NR mobility solutions
Power consumption reduction for mMTC

MEC: Multi-access Edge Computing
D2D: Device-to-Device

ONE5G key outcomes (1/2)

- ONE5G has characterized E2E performance through KQIs and used them to develop enablers:
  - addressing the constraints of multiple services, through new scheduling schemes (between 20 and 50% gains w.r.t. the KQIs, and even more for central/multi-cell schedulers).
  - ONE5G also improved E2E performance through innovative traffic-steering mechanism, performing load balancing based on QoE parameters and context awareness.

- ONE5G has developed multiple solutions to minimize power consumption through
  - efficient use of the Discontinuous Reception (DRX) framework and configuration of BWP (Bandwidth Part) timers.
  - RRC state handling (about 70% longer battery life in no data scenario, or 40% for infrequent data),
  - use of D2D relaying,
  - specific array design or use of digital beamforming (50% gain compared to hybrid beamforming).

ONE5G key outcomes (2/2)

- ONE5G has developed multiple solutions to facilitate the implementation of 5G key technologies (Massive MIMO) and architectures (CRAN), with for example
  - techniques to improve the acquisition and quality of CSI, reducing the training overhead (up to 50%).
  - Implementation of Massive MIMO has also been addressed with proposition of new arrays.

- ONE5G has proposed enablers to improve the coexistence of multiple services, such as preemptive scheduling or MU-MIMO null-space based preemption scheduling , NOMA and Grant-Free Access, improving the reliability for URLLC (decreasing the number of collisions by 30%, increasing the number of served devices for mMTC by 25% or improving the resource efficiency by 20-25% for coexistence of eMBB and URLLC services).

- ONE5G has considered the needs and specificities from verticals throughout the project's lifetime, up to the PoCs and techno-economic assessment, with solutions either generic or dedicated to a vertical (such as RRC state selection for V2X, grant-free access for factories,…).

ONE5G key contributions to 3GPP NR and 5G advanced

- ONE5G worked on enhancements of first version of Rel. 15 and preparing the next releases.

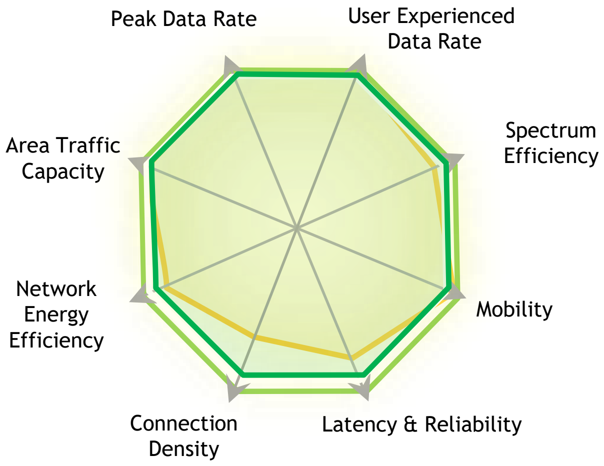
- Consensus developed through the technical discussions within WPs
  - Identifications of synergies between partners, joint work leading to joint publications.
  - 3GPP guidelines accounted for in the simulations wherever applicable and reasonable.

- Contributions of partners to standardization
  - Submission of 51 Tdocs.
  - Rel. 15: 8 features in Rel. 15 specifications.
  - Rel. 16: 11 topics contributed to relevant Work Items and Study Items.
  - Rel. 17 and 18: 24 topics as candidate features for Rel. 17 and 18.

- Positive EC review results
  - *“Project has delivered exceptional results with significant immediate or potential impact …”*

5G is now. Can it fully support vertical applications such as I4.0?

3GPP NR support



eMBB + FWA + uRLLC + mMTC

NR Framework
- Waveform & channel coding
- Frame structure, flexible numerology
- Flexible duplex
- Massive MIMO

Spectrum
- 600MHz to 52.6GHz

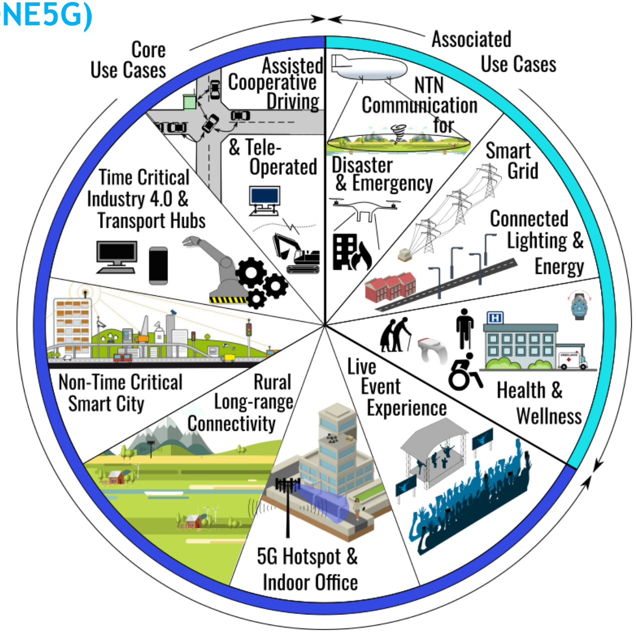
Architecture
- UL&DL decoupling
- CU (central unit) - DU (distributed unit) split

NR Improvement
- New multiple access
- eMBB enhancement
- Self-backhaul

Spectrum
- Up to 100GHz

Vertical Digitalization
- URLLC
- mMTC
- D2D/V2X
- Unlicensed

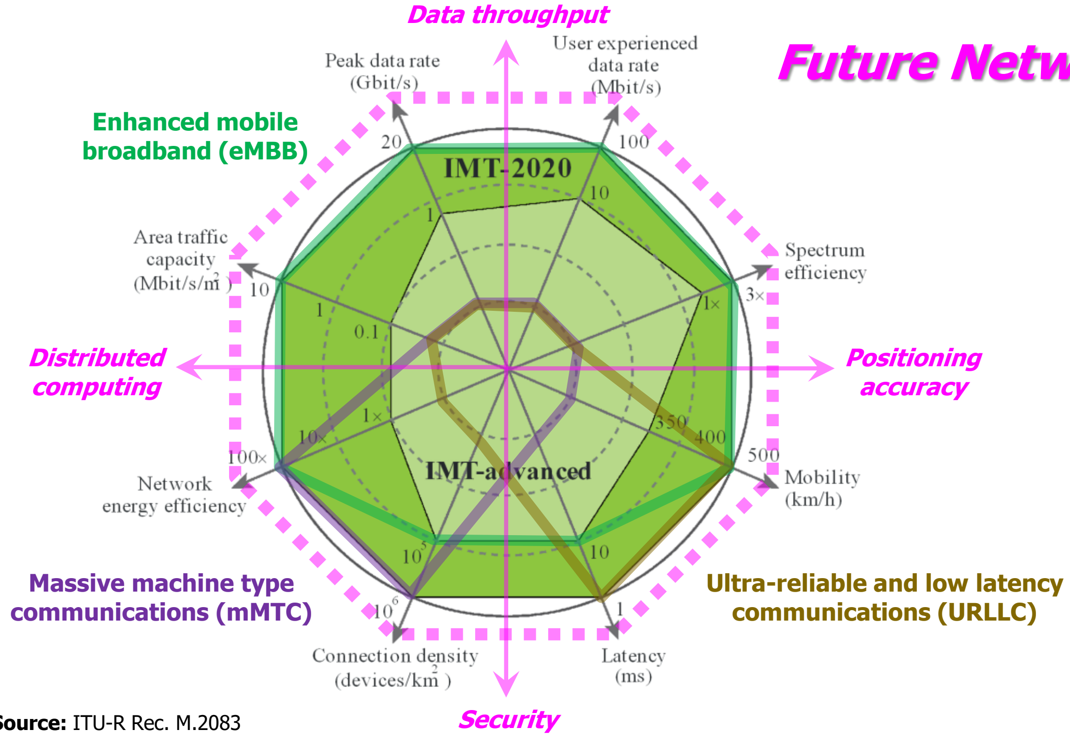
9 use cases (ONE5G)



3GPP NR supports many use cases, but not all (e.g. I4.0)!

FWA: Fixed Wireless Access

Future radio networks: Vision and potential targets



Source: ITU-R Rec. M.2083

Future Networks

Performance targets

- Tbps throughput
- sub-ms latency
- Gbps availability
- Extreme reliability
- mMTC everywhere
- Extreme energy efficiency
- Very high security
- Very high mobility
- High scalability
- cm-level localization
- …

Outline of strategic research and innovation agenda (SRIA) 2021-27

SRIA by Networld 2020 & 5G-IA (5G Infrastructure Association):

“Smart Networks in the context of NGI”

(Editor: Werner Mohr)

2. Network Architecture and Control
3. Radio Technology and Signal Processing (Editor: Wen Xu)
   - 3.1 Spectrum Refarming and Reutilization
   - 3.2 Millimeter Waves and Cellular Networks
   - 3.3 Optical Wireless Communication
   - 3.4 Terahertz Communications
   - 3.5 Ultra-massive MIMO
   - 3.6 Non-orthogonal Carriers, Full Duplex and Transceiver Design
   - 3.7 Enhanced Modulation and Coding
   - 3.8 Improved Positioning and Communication
   - 3.9 Random Access for Massive Connections
   - 3.10 Wireless Edge Caching
4. Optical Networks
5. Edge Computing and Meta-data
6. Network and Service Security
7. Communication Satellite Technologies
8. Human Centric and Vertical Services
9. Future and Emerging Technologies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5G IA
September 2018
Strategic Research and Innovation Agenda 2021-27
European Technology Platform NetWorld2020
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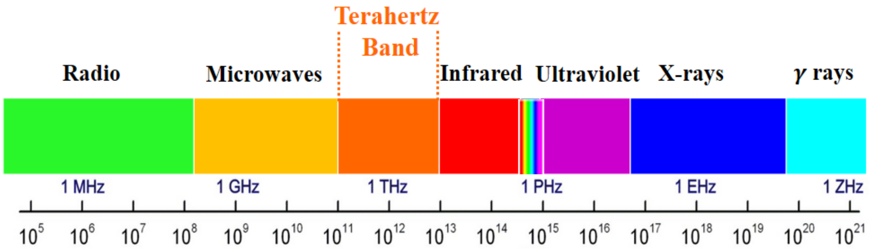
NGI: Next Generation Internet

Some radio and signal processing technologies



Source: https://bwn.ece.gatech.edu/projects/teranets/index.html

- How many radio interfaces?
- How many radio technologies (waveforms, modulation coding schemes, multiple access schemes, …)?
- For how many frequency bands?
- For how many groups/classes of scenarios/use cases/ requirements?
- How to harmonize?
- …

1. Spectrum Refarming and Reutilization

Motivation

- Spectrum reutilization among RATs offers an efficient utilization of resources and great flexibility, e.g., for load-balancing.

Target & Challenge

- Efficiently re-utilize the existing spectrum resources, improve spectral efficiency, reliability, availability, ...
- Joint utilization of licensed and unlicensed spectra.
- Spectrum usage supported by multi-RAT connectivity.
- E.g. using cognitive radio, AI based solutions. UE can choose the best RAT depending on link qualities.

2. Millimeter Waves and Cellular Networks

Motivation

- mmWave below 50 GHz has been considered for 5G NR by 3GPP.
- Diverse requirements on throughput, latency and reliability, pose new challenges, e.g. on backhaul links

Target & Challenge

- Efficient TX and RX beamforming (BF) in terms of high data rate, low power consumption, minimized size.
- Modulation coding scheme implementation with low power, low cost, high throughput.
- Develop overall system with target < 1pJ/bit.
- E.g. using multi-stream approach (e.g. OAM),1-bit ADC, constant envelope modulation, etc.

Some radio and signal processing technologies

3. Optical Wireless Communication (OWC)

Motivation

- OWC spectrum with infrared and visible light is ~2600X the size of the entire radio frequency spectrum.
- It can combine illumination and communication.
- Using 'solar cell' can achieve simultaneous energy harvesting and communication.

Target & Challenge

- Interference mitigation to ensure high UE SINR.
- The signals are positive and real-valued.
- LiFi-bespoke networking methods to be developed.
- Integration into the radio networks.

4. Terahertz Communication

Motivation

- THz (0.1-10 THz, between microwave and infrared) band largely unexploited.
- High-speed communication for a range of tens meters possible.

Target & Challenge

- New channel models: Spreading loss, molecular absorption loss, etc.
- New experimental platforms.
- Novel MAC protocols: The huge bandwidth may eliminate the need for contention-based schemes, etc.
- New congestion control to accommodate traffic in the order of Tbps.

5. Ultra-Massive MIMO

Motivation

- Ultra-Massive MIMO (UM-MIMO): Antenna arrays in the order of thousands of elements, e.g. for THz band.

Target & Challenge

- Construction of graphene-based antenna arrays.
- Channel modeling of UM-MIMO, incl. mutual coupling among antenna elements.
- Feeding/control of each antenna element.
- Real time estimation of 1000s of channel elements, feedback, ….
- Advanced space-time-frequency coding to exploit all diversities and achieve optimal performance, etc.

6. Non-orthogonal Carriers, Full Duplex and Transceiver Design

Motivation

- CP-OFDM commonly used. Relaxing the orthogonality constraint leads to a more efficient and flexible use of the wireless channel. NOMA can result in larger achievable rates.
- Self-interference cancellation techniques enable in-band full-duplex transceivers.

Target & Challenge

- Develop advanced waveform, non-orthogonal multiple access schemes, full-duplex schemes, etc, which can cope with THz channel, Tbps throughput, extreme URLLC, extreme asynchronous mMTC, extremely low power consumption, etc.

Some radio and signal processing technologies

7. Enhanced Modulation and Coding

Motivation

- Channel decoder is often considered as the most complex part of the TRX chain.
- Tbps throughput, extreme URLLC and low-energy consumption pose new requirements.

Target & Challenge

- Modulation coding schemes for Tbps and extreme URLLC, and with extreme low-power consumption.
- Modulation and coding schemes with performances close to Shannon limit, e.g. with signal shaping loss fully removed.

8. Improved Positioning and Communication

Motivation

- High accuracy positioning is a key enabler for many applications.
- For I4.0, V2X vulnerable road user discovery, etc, an accuracy of 10 cm may be required.

Target & Challenge

- Future wireless systems will have higher bandwidth, more antennas, densed network and D2D links, which enables a radio positioning with cm-level accuracy.
- With joint positioning and communication, improved spectral efficiency, energy efficiency, and reduced latency can be achieved.

9. Random Access for Massive Connections

Motivation

- Huge number of connected devices generating and transmitting very sporadic data (mMTC).

Target & Challenge

- Coordinate such a network without spending the whole network resource and node energy.
- Low complexity/energy protocols, low-cost devices.
- Ultra-massive number of devices with low overhead, and potentially with energy and latency constraints.

10. Wireless Edge Caching

Motivation

- On-demand video streaming and Internet browsing.
- The capacity of macro-cells is not sufficient.
- Wireless caching can increase spectral efficiency and reduce latency.

Target & Challenge

- Coding (e.g., combining edge caching with modern multiuser MIMO physical layer schemes).
- Protocol architectures (e.g., combining edge caching with schemes for video quality adaptation).
- Machine learning based content popularity prediction, to efficiently update the cached content.

Discussion & Outlook

- 5G is now. But it can still not fully support many challenging use cases, such as I4.0.
- Many 5G candidate technologies, such as those investigated in 5GPPP research projects (e.g. ONE5G), are not yet adopted. They may be further improved and utilized for Beyond-5G.
- Future radio interfaces (how many?) expected to address extremely diverse use cases/requirements, e.g.
  - Tbps throughput
  - sub-ms latency
  - Gbps availability
  - Extreme reliability
  - Extreme energy efficiency
  - Very high security
  - High scalability
  - cm-level radio positioning accuracy
  - IoT (large/small scale, mega/nano scale, …)
  - etc.
- To meet these requirements, the overall communication system, from lower layer (waveform, modulation coding, MIMO, …) to higher layers, from hardware to software, needs to be carefully studied.
- Networld2020/5G-IA identified radio technologies for NGI. Some have not been addressed for 5G, such as OWC and THz carriers. How to harmonize the system designs for possible carriers? …
- Machine learning as a tool will be increasingly tailored and integrated in wireless communications, esp. where no easy/feasible/optimal solution is available (e.g. channel prediction, network management, …).

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Thanks!

Questions?