Contents

1 5G R&D: HOW TO ACTIVELY PARTICIPATE .................................................................................. 3
2 5G – A PRIMER .......................................................................................................................... 4
3 5G RESEARCH DIRECTIONS ........................................................................................................ 5
   3.1 NEW 5G RAN REQUIRES NEW NETWORK ........................................................................ 5
   3.2 WIRELESS SYSTEM CONVERGENCE: LTE-A AND WiFi .................................................... 6
   3.3 TOTAL CONVERGENCE: FIXED AND SATELLITE ............................................................... 6
   3.4 CUSTOMIZATION AND FLEXIBILITY ................................................................................. 7
   3.5 SOFTWARE-IZATION ............................................................................................................. 7
   3.6 COMPLEXITY MANAGEMENT ............................................................................................. 7
   3.7 SECURITY AND ROBUSTNESS ............................................................................................ 8
   3.8 THE 5G DEVICES AND APPLICATION ............................................................................... 8
4 A BEST PRACTICE FOR MEANINGFUL RESEARCH ................................................................. 10
5 OPEN5GCORE – STATUS QUO .................................................................................................. 12
   5.1 OPEN5GCORE REL. 1 FEATURES .................................................................................... 12
   5.2 DESIGNED FOR R&D .......................................................................................................... 15
6 PROFITING FROM 5G-READY RESEARCH AND TESTBEDS IS POSSIBLE TODAY ..................... 16
7 ACRONYMS AND DEFINITIONS ................................................................................................ 17
8 REFERENCES .............................................................................................................................. 18

Authors

Thomas Magedanz, Marius Corici, Mikhail Smirnov, Andreas Weber, Ancuta Corici, Florian Schreiner, Bernd Bochow, Dragos Vingarzan Fraunhofer-Institut für Offene Kommunikationssysteme, FOKUS in Berlin

Stefan Covaci, Jakub Kocur, Valentin Vlad, Giuseppe Carella, Julius Mueller Technische Universität Berlin

Contact
Website: www.Open5GCore.net
Contact the experts at: info@Open5GCore.net
1

5G R&D: How to Actively Participate

Having the goal to provide a revolution of the telco environment, the 5G system includes the design and development of a new radio network, of a comprehensive convergence core and backhaul infrastructure, of customization and parallelization mechanisms and of novel management and automation technology [1].

As 5G will develop technologies virtually in all the areas of the network infrastructure including the convergence of currently separated domains, it becomes harder to provide high-visibility research contributions, which is harmonized and integrated with the other network domains.

For creating trust into research and for improving the R&D results, we propose an improved process in which all stages of research are accompanied by a realistic implementation enabling the speed-up and the immediate reflection of the innovation towards original design, detailed specification, demonstrations and practical experimentation in comprehensive enough environments to be meaningful.

For this, Fraunhofer FOKUS provides its extensive know-how into developing novel concepts, and their practical implementation and industry oriented evaluation, building up on top of more than 20 years of applied research experience.

Acting as a technology path finder, Fraunhofer FOKUS is able to provide clear and measurable innovation, design and specification into an integrated comprehensive network environment in the areas of radio access network support, convergent core networks, intelligent network management and simple administration, connectivity and application management, virtualisation and monitoring, with the aim of increasing trust and accelerating adoption of novel technologies.

Additionally, through the new Open5Gcore toolkit, FOKUS provides a fast means for practical implementation, customization, evaluation and demonstration of new ideas into a comprehensive and realistic running 5G environment, as much as it is understood at this moment. Through this, Open5Gcore acts as a technology accelerator towards the technical development as well as an efficient tool for presenting and creating trust into the research results towards business, market and standardization decision factors.

Figure 1 - 5G Ecosystem: new Radio, more Devices, new Industry Branches, eHealth, Smart Cities
2
5G – A primer

What is 5G?

5G represents the wireless telco ecosystem beyond LTE/EPC. It aims to provide a new radio access network ([6], [7] [11]) with ultra-high capacity, low delay and energy efficiency for an extremely high number of diversiﬁed devices and applications.

Adding to the new radio and its management, 5G represents the complete ecosystem: core network, convergence with 3rd party wireless, fixed and satellite, backhaul, management, supporting the convergence of 4G legacy wireless networks and the efficient end-to-end application delivery.

5G: Market Perspective

From market perspective, 5G ecosystem aims at a twofold direction evolution of the telco environment. First, a vertical development aims at better communication for end customers through existing commodity devices such as phones, computers, TV-sets, sensors and actuators, etc. by providing a low delay/high capacity end-to-end communication system, considering the integration of storage in the network (ICN/CDN).

Targeting to support the user expectations towards more efficient controlling and sharing of their environment, 5G sets a new level of requirements for providing highly automated, reliable and with negligible latency communication. It responds naturally to human interaction, thus immersing the human being into an environment of connected devices under her or his control [3].

Following the trend of computerization in traditional industries, 5G promotes a second horizontal development of the telco communication systems towards other businesses with different requirements in terms of remote management, reliability and security such as factory automation (the Industrie 4.0 German initiative [4]), eHealth, energy, transportation, critical infrastructures and delay tolerant networks. Through remote control and technology specific automation, 5G aims to cover the remaining socio-economic spectrum into a comprehensive convergence system.

Additionally, the high ﬂexibility, parallelization and customization make the 5G environment efﬁcient and affordable for any network, spanning from very small to very large, local or global, professional and enterprise networks as well as smart cities. Through this, 5G addresses any business association or individual enabling a separate, virtualised, highly customized network control infrastructure to each of these customers.

5G Key Technological Challenges as from 5GPPP [2]:

- x1000 data volume / geographical area
- x10 lower energy consumption
- Average service creation time cycle 90 hours to 90 minutes.
- Facilitating very dense deployments of wireless communication links
- Advanced user controlled privacy
- Scalable management framework for fast deployment
- OPEX reduction with more than 20% of today
- Multi domain virtualised networks and services
3
5G Research Directions

For providing an incentive towards research, this section presents a list of research directions within the 5G environment which come under the competence of Fraunhofer FOKUS. The list does not assume any priority or comprehensiveness.

While concentrating on a single research direction provides most effective results, the understanding or the practical integration into a comprehensive system for feasibility purposes increases the trust into the innovation and ultimately receives better visibility and acceptance by the R&D community.

3.1 New 5G RAN requires new Network

The new 5G Radio Access Network (RAN) wants to use more efficiently the radio resources by enlarging its spectrum in very dense areas >6GHz [7], and with better spectral efficiency <6GHz.

Apart from the development of the new physical transmission layers [8] and of the radio resource scheduling, which by themselves constitute a very large research topic, the 5G RAN will require additional technology.

First, the radio signaling protocols have to be further evolved according to the new characteristics including a network latency down to just a few milliseconds end-to-end for the data path [7], security and authentication mechanisms, mobility, etc.

Additionally, with the foreseen increase in density (Gbps/km²) of the radio networks, we expect an average decrease in the cell size. Because the macro network will be maintained for high speed devices, the decrease in cell size will result in a deployment of a large number of small cells [7]. Concepts such as opportunistic small cells in licensed and unlicensed spectrum and authorized shared access provide the means for sharing the wireless environment [9].

A large number of cells of different coverage sizes, serving a massive number of subscribers require a new level of parallelization to be achieved in the network architecture. Additionally, the core network has to support cell dynamic capacity and activity changes in a smooth and scalable way. A possible solution is to create a
dynamic management plane handling cell configuration apart from the subscribed control plane, in tandem with the correspondent macro-cells and/or spectrum allocation mechanisms.

In regard to the dynamic attachment to the network of single or groups of cells, novel mechanisms explicitly integrating with the backhaul are required in order to provide subscriber connectivity control on top of opportunistic, unreliable or self-backhauling solutions by leveraging technologies such as Software Defined Networks (SDN) [10], carrier aggregation and local breakout with minimal service disruption [23][21].

Finally, with the further support of edge network functions, through dynamic software deployments, the functionality split between RAN and Core Network becomes fuzzier. It is foreseen that specific, locally customized deployments will require a different functionality split for authentication, authorization, resources management, QoS and mobility support.

Similarly to the 2G and 3G radio evolutions, it is expected that when significant technology advancements are settled for the 5G radio, they will be beneficial also to newer generations of LTE.

3.2 Wireless System Convergence: LTE-A and WiFi

Learning from more than 20 years of carrier grade RAN deployments, the 5G environment does not expect itself to become a single radio network. Instead due to different coverage and capacity requirements it is expected that the co-existence with newer generations of LTE will be welcomed [11].

Especially for indoor communication with no exact resource guarantees, WiFi and LTE in unlicensed spectrum will provide high capacity low delay communication, affordable, customer managed networks which will co-exist with the macro- deployments [11].

For a coherent architecture, the 5G environment should consider, from the beginning, such a heterogeneous wireless ecosystem and afterwards develop the specific core network functionality in a harmonized manner including access control and security, mobility, session, resource management, RAN sharing [21] and network controlled multi-homing [26].

3.3 Total convergence: fixed and satellite

As the 5G wireless environment is expected to have a large amount of the functionality located at the edge of the network and as multiple points of presence to the application platforms and to the Internet have to be considered, a more deep integration with fixed and satellite networks has to be considered [1].

This includes the support for fixed devices connected wirelessly, such as part of M2M networks, and mobile devices connected to wireless terminations of fixed networks through home WiFi or dense areas hotspots.

Similarly, satellites will continue to address market niches such as connecting vessels, airplanes and remote areas and to provide public safety and emergency-response, health and home-based services, by leveraging terrestrial technologies.

Although at different levels, the fixed and the satellite networks may be used as shared environment for backhaul and as extensions of the wireless network towards dense environments or rural and potential sub-urban areas. For this, several items should be further researched: the most appropriate convergence architecture, coherent identity management, access control, resource- and network- management.
3.4 Customization and Flexibility

With the common acceptance of cloud technology/network functions virtualisation (NFV) as a means to provide computing and storing resources on demand and to flexibly scale these resources whenever required [12], a two direction evolution is possible: towards optimizing the existing service and towards addressing new markets.

First, network virtualisation comes with very short deployment duration and on-demand dimensioning, enabling very short life cycles and runtime updates, thus providing immediate feedback in case any specific customization or operation policy has to be modified.

Additionally for a multi-cloud environment, virtualised network functions may be dynamically placed in specific locations, optimizing services depending on the momentary situation and operator policies.

Secondly, multiple parallel infrastructures may be deployed for the same service with specific customization for each customer. Thus, the large all-purpose communication network of the operator may be split into multiple smaller cost-effective networks, addressing the requirements for more secure enterprise, factory or critical infrastructures [25] as well as providing cost efficient service for the long tail market.

In this context, the capabilities for easy customization and adjustment of the robustness level (such as massive parallelization, load balancing, high availability, and runtime migration path between versions) become the main differentiator when the same type of services offered.

From a networking perspective, there is a need for providing the same flexibility through programmability to match the cloudification of the infrastructure. SDN technology provides the means to adapt the network flexibly to the dynamic needs and to mirror the network functionality towards a virtualised environment [13], [14].

Although the basic mechanisms for both NFV [12] and SDN are already available, they have to be further leveraged through customization towards the specific robustness, heterogeneous infrastructure, policies and network functions, delay and capacity characteristics of the 5G environments.

3.5 Software-ization

Software-ization is one of the most powerful concepts proposing the complete implementation of the core network, and partially of the radio, functions as software which runs on top of common hardware platforms for development and maintenance efficiency reasons.

The common acceptance of network implementation as software brings new levels of development efficiency, including the use of common libraries and APIs, alternative inter-process communication for co-located programs as well as parallelization and synchronisation techniques apart from protocol based interfaces.

Specific to software developments, the rather complex standardization process, which is currently in place, is partially replaced by best practice open source implementations acting as de-facto standards such as OpenStack. However, these de-facto standards usually lack in functionality especially in the area of security and reliability, thus providing also a means for market differentiation of the different products.

3.6 Complexity Management
The 5G environment is foreseen to become even more complex, beyond human administration capabilities due to the integration of a new 5G access network, a high diversification of the radio-access within the same technology, convergence with other wireless access technologies and backhaul, massive parallelization, separate administration on top of a single shared physical infrastructure and the localization and distribution of applications.

New automation mechanisms and big data learning algorithms are required, aiming to minimize human intervention and to respond rapidly to exceptional cases, including self-configuration, self-optimization, self-healing and self-protection. Nodes with learning and cognitive capabilities will need to discover their network vicinity and to negotiate parameter settings with their neighbors and other nodes [15] as well as to understand and to appropriately respond to the subscriber situational context.

In order to maintain the cost-benefit ratio effective and scalable, the intelligent algorithms have to be adapted to the flexible features of the network, such as the network functions placement, backhauling selection, self-connection to the core network, autonomic network islands, etc. Also, as much as possible, the flexibility features should be adapted to the most efficient algorithms.

Solutions for the network management of the virtualized networks need to consider the reuse and if needed the extension of the existing 3GPP Management reference model. To ensure a smooth migration to virtualised network functions, the management of virtualized networks has to be compatible as much as possible with the existing network management defined in 3GPP.

It is important to mention that a certain human interaction will still be needed to influence the network and by setting the governance policies and taking care of the major exception cases [15], especially without requiring very specialized, highly educated experts.

### 3.7 Security and Robustness

One of the main features required for trusting a new technology is related to providing insurance against external or fortuitous exception cases due to attacks, failures or defects [16]. These items become even more important when the same infrastructure is shared between multiple tenants having different administrators. Every flexibility feature, such as self-scaling brings a new set of requirements in terms of robustness of the overall system.

The 5G dynamic access control, connectivity of network islands through different backhauls, isolated network areas and local connectivity provide novel mechanisms for ensuring a more efficient service, however posing new security threats to the overall system.

Multiple parallel virtual network infrastructures pertaining to different tenants and sharing the same physical infrastructure pose other threats in relationship to privacy and denial of service which are unacceptable for specific classes of professional services such as e-Health, transportation or enterprise networks.

Additionally, when passing the control of the network from installing physical components to an abstract, service-enabling, software broker, a specific level of trust in seamless auto-recovery and fault management is required. It should include evolved mechanisms for load balancing, subscriber balancing, high availability, fault reporting, fault management, remote administration, prediction algorithms, etc.

### 3.8 The 5G Devices and Application
For understanding and developing in an integrated manner a comprehensive 5G environment a large level of attention has to be given to the connected devices, services and application communication characteristics.

Devices are foreseen to span from small sensors, with challenged power consumption, and stringent delay concerns, up to high capacity real-time communicating devices. Based on these characteristics different connectivity models can be adopted and identified by the network, depending on the momentary conditions, such as device multi-access capabilities, radio access networks available in the vicinity, availability of the services in the proximity [24], neighboring devices for direct or infrastructure based communication [27], etc.

Currently, in order to obtain better services, on top of a best-effort end-to-end network, application developers are concentrating on distributing and localizing their critical services and on looking for alternatives to single TCP socket end-to-end data path realization. An efficient 5G environment has to be able to support such features by providing appropriate connectivity, break-out and caching mechanisms and support for backhauling of application specific information from the break-out points towards the centralization nodes [23].

Additionally better mechanisms for traffic classification and service chain selection based on the operator policies need to be analyzed in order to support a more efficient and flexible service steering between devices and application providers.
Since the 5G environment is still in its early development phase, the specific technology to be further developed is not yet settled. For this reason, we do not aim to provide a definitive destination point expressing comprehensively what 5G is. Instead, we propose a best practice alternative for making research results meaningful, based on the experience we have accumulated in more than 10 years of developing testbed infrastructures addressing telco R&D industry and academia needs.

From our perspective, the critical points of meaningful research activities, resulting in valuable IPR, are to provide appropriate innovation to the business needs and to convince the decision factors, the marketing and in general the scientific community on its value. This can be achieved only, through applying the appropriate process at every step of research.

Figure 3 - R&D Best Practice

1. Motivating research – to be able to perform research activities, these have to be fully motivated, in terms of the novel technical capabilities to be provided and of the market advantage to be targeted. For this, along the state of the art and future assessment of technology and market experts, a large role is played by practical demonstrations of the existing capabilities enabling decision factors to easily identify the requirements as well as the path to be followed in order to reach easily relevant results.

2. Novel Ideas – a direction and a plan for research are usually not enough for innovating. Besides searching the literature, adapting concepts, providing new protocols and state machines according to project requirements, testbed customization and practical code snippets developments on a functional trial-and-test basis, are required. Testbeds and real-world devices give the opportunity to trigger new ideas and ensure their own scientific development, thorough design and specification, which otherwise would be more difficult.

3. Simulation environments – simulations (and their less complex counterpart as back-of-the-envelope computations) provide a means to initially evaluate a new idea within a model, which in some cases may be very complex, concentrating only on a specific area of expertise i.e. radio or core. From our perspective simulations are providing the best tools for parameter optimizations when the end-to-end architecture is settled.

4. Prototyping in Real Environments – Developing a novel idea as part of a realistic, and as much as needed, comprehensive environment enables to create the highest degree of trust into a novel concept. A realistic testbed
environment provides functional proof-of-concept and a means to evaluate the impact and the side effects of the proposed solution within an almost real network. Through additional benchmarking, optimizations at all network levels can be measured and compared to the state of the art, bringing a high degree of confidence towards standardization and community acceptance.

5. Product prototyping – developing a novel product usually requires that all the developers have access to own, or third party, products which due to their carrier-grade characteristics are hard to procure or to customize. A realistic testbed provides a shortcut counterpart for the developed functionality, providing, in a condensed form, the external functionality.

6. Integration, interoperability and trials – for early understanding of the available technologies, for vendor selection and for motivating later investments, integration and inter-op are essential. However, in some situations parts of the complete system are missing, are delayed or less customizable. In order to be able to perform trials from early phases or with missing functionality, a pragmatic approach is to start from a comprehensive testbed and then, to gradually replace the components with the final prototypes.

7. Product implementation and marketing – one of the major challenges in product implementation is the standard compatibility. Testbeds implementing the standard protocol stacks and the standard functionality provide an initial best-practice.

   Similarly, for marketing a product, a realistic mobile testbed, which provides the rest of the functionality in the system around the product, allows to make practical demonstrations virtually anywhere, thus motivating sales, not only research activities.

A very important factor, essential to any R&D activity, is the design of the appropriate model enabling further relevant analysis and decision taking. A model provides the generic context and requirements for innovation and represents the basis for the implementation and the assessment. An appropriate model should be as simple as it can be to provide meaningful results, but not simpler. In case of complex environment such as 5G, a model should include all the different development areas, however, in a meaningful simple form. Such a model can be provided only through a large experience in understanding the dynamics of the environment and in the realization of relevant practical results.
Open5Gcore [17] represents a two-folded concept: it covers all the carrier-grade telco oriented research within the 5G field and it represents the practical implementation of the resulting concepts in a comprehensive environment. From both, the Fraunhofer partners can benefit for fast accumulation of know-how and for hands-on developments.

In realizing our research activities, we have a strong focus on direct applicability of the proposed solutions in the real-world environment, focusing on scalability and integration into graceful architectures, sacrificing ultra-optimizations. Specifically, due to the large number of industry partners, Fraunhofer FOKUS shaped its research activities to pragmatically respond to long, medium and short time requests concentrating on the essentials.

Building on top of the know-how accumulated in the last years, Fraunhofer FOKUS is able to tackle and to provide research results aiming at standardization and later productization of the 5G environment based on various directions including the ones presented in the previous sections. With the development of 5G, we see a large opportunity to leverage and to further continue our activities in developing novel concepts, algorithms, design and specify comprehensive architectures with a thorough care for assessing the state of the art and the results against realistic metrics.

Additionally, the research results are prototyped into the Open5Gcore toolkit, representing a mirror of momentary pre-standard development stage for the 5G ecosystem, including NGMN Alliance recommendations [33], 3GPP Rel. 12 [29] and forward, IETF [32], ETSI NFV [30], ONF [31].

Our research stands for:

- Market adaptation – we follow the path of our partners
- Flexibility – easy adjustment of directions
- Future proof – going beyond the immediate next deployments
- Practical implementation – each concept has to be demonstrated
- Small steps – one step at a time, towards a large goal
- Openness – integrating and building on available know-how
- Pragmatism – accepting the technology as it is
- Trust – we believe in real results

5.1 Open5Gcore Rel. 1 Features

Fraunhofer FOKUS Open5GCore toolkit represents a pre-standard software implementation, of a comprehensive mobile environment beyond the 3GPP Evolved Packet Core architecture. The components of Open5GCore represent the R&D prototypes including the features with the highest industry relevance from the Fraunhofer FOKUS research activities.

Open5GCore follows the main research directions previously considered for the evolution of the 5G environment. The features are suitable for laboratory deployments and testing and not designed as products.
LTE/5G Signaling

For bridging with the physical wireless research activities, which represent a research area on their own, Open5GCore implements the subscriber oriented radio access network functionality. Through this means, new radio resource scheduling and integration with radio PHY can be easily achieved and demonstrated into a comprehensive environment as well as novel research into the area of flexible radio access network architectures such as C-RAN, integration of small cells, local coordination of access network selection, etc.

The LTE/5G signaling implements the complete protocol stack including NAS, RRC, PDCP, RLC and MAC emulation on top of Ethernet for both the eNB and the UEs. Additionally, a basic radio resource scheduler was implemented, through this, filling the gap between the radio and the core network research.

Functionality Co-location Features

The 5G core network is foreseen to bring a revolution on the design of the core network especially due to the introduction, on a large scale, of software engineering paradigms. For this, Open5GCore provides a set of modules which enables the co-location of control and data path functions, thus providing uniform functionalities, which can be distributed based on other principles.

Specifically, Open5GCore includes Diameter and a GTP internal exchange modules which provide the means to run, if needed, within the same software instance, multiple components such as MME, PGW, SGW and HSS. This way a lower delay into core network processing is achieved for a specific subscriber request.

Data Path Flexibility

Taking up the dynamics and flexibility of Cloud environments through SDN and NFV concepts, the Open5GCore introduces innovative approaches for a higher level of data path flexibility for load balancing; data path distribution and localization, for offloading; thus providing the basis for the on-demand customizable data exchange.

Open5GCore Rel. 1 supports the fundamental features for Distributed Mobility Management, data path management in full and partially virtualised network infrastructures, offloading and localization including flexible context aware support for shortest data path through the network, passing only through the base station,
support for single switch data paths and support for multiple parallel switches instantiated on demand.

Open5GCore enables the multiplication of User data path elements (Switches) and their dynamic selection, through Service Function Chaining (SFC) within the core network.

**Runtime Flexibility and Robustness**

Currently the network has a uniform set of policies, through this achieving a high level average efficiency. A next step is to customize as much as possible the connectivity of the different subscribers and not to allocate any later unused resources.

Open5GCore includes a large number of extensions for subscriber and management oriented dynamic network functions selection during runtime. It includes the support for the Diameter and GTP interfaces for selecting the next node being local (itself) or one of the many remote ones, through this supporting subscriber, capacity and localization based balancing of the network functionality and the initial steps towards a highly robust network infrastructure.

**Fundamental Core Network Functionality**

For providing a running operator environment from the initial stages of the research and thus, to enable the practical proof-of-concept, Open5GCore includes the fundamental core network functionality. It provides advanced LTE connectivity support by integrating with real eNBs and by using off-the-shelf Android and Linux OS devices.

This element represents a stripped down version of the 3GPP EPC as implemented in the former OpenEPC Rel. 5, including the eNB emulation with real protocols towards the core network, MME, HSS and the SGW and PGW adding post-Rel. 11 features which will be part of the 5G core.

Aiming at providing extensive flexibility, Open5GCore separates control and data plane using OpenFlow 1.4 protocol with added GTP support in the switches.

In order to reduce procedures delay the MME and the gateways control part were co-located within the same control machine (CTRL) preparing for a later distribution based on the software engineering paradigm.

Using the fundamental functionality core network, testbeds can be customized and extended beyond the current standard in a simple environment containing a large number of representative features.

**Applications support**

On demand, Open5GCore integrates with the Fraunhofer OpenMTC [18] toolkit which provides a best practice service development support for distributed application deployments for both human multimedia communication and for medium scale customized M2M solutions.

**Benchmarking**

As we are in a very early stage of the development of 5G, one of the major requirements is to be able to provide also a quantitative measurement of the innovation value, in terms of communication characteristics and correspondent resources required in the network from a complete system perspective.

The Open5GCore Rel. 1 benchmarking supports the basic procedures for attachment, detachment and handover by providing the simulation of x1000s of subscribed devices connected to the 5G system, as well as the equivalent monitoring of the procedures from both the subscriber and the network perspective.

For a high configurability, similar to the Open5GCore network components, the Open5GCore benchmarking tool can be customized for various radio network
Virtualisation

For providing the fast setup of multiple customized testbeds, even in parallel, Open5GCore can be deployed on top of OpenStack based cloud infrastructures by using the Fraunhofer FOKUS OpenSDNCore [20] toolkit representing a practical implementation of ETSI NFV, Management and Orchestration (MANO) as well as of the state of the art SDN features.

OpenSDNCore Rel.2 goes beyond the current self-contained deployments, by being able to orchestrate the resources and the network for a multi-data center environment during runtime including network function placement, robust service chaining and integration with physical infrastructures.

5.2 Designed for R&D

Following the global success of OpenEPC [19], which sustained our R&D activities for the last 5 years, and with the purpose of enabling the expected network revolution to the 5G environment, we have decided to reboot the core network developments in an appropriate manner, by providing early pre-standard research and prototypes.

Similarly to OpenEPC, Open5GCore is a tool for assessing our 5G research, standing for openness, fast and effective prototyping and immediate demonstration of results in every step of research.

Open5GCore provides the means for proof-of-concept evaluations as well as for immediate qualitative assessment, being easy to deploy on top of cloud infrastructures (in the order of minutes) and with multiple customizable implementation architectures.

Finally, Open5GCore is not only a comprehensive testbed, but also an open cost-effective benchmarking environment for a complete 5th generation telco network.

Open5Gcore stands for:

- Customizable – deploying fast different architectures
- Openness/Education – full source code access, provides hands-on know-how
- Comprehensiveness – a full ecosystem
- Flexibility – modular design
- Standard oriented – mirroring pre-standard 5G advancements
- Agility – highly modular, easy to extend and interoperate with
- Fast demonstrations – comes pre-configured, ready to run
- Made for experimentation
  - Easy to deploy in cloud environments
  - Easy to replicate runtime conditions
  - Easy to benchmark and retrieve results
- Realistic – supports real/prototype radio and devices
- Resource efficient – low hardware costs
- Clonable – one testbed for each developer/testbed/demo
- Easy to integrate with 3rd party components, devices and applications
6
Profiting from 5G-ready research and testbeds is possible today

While evolving towards the 5G environment, there are several R&D steps which have to be taken for a large number of technologies, which were previously addressed as independent research domains on their own: mobile devices, radio and core networks, network management, application development and software engineering.

For 5G to be successful, a harmonized roadmap for all these technologies has to be prepared, starting with the current initial direction setting; first demonstrations, novel ideas and concepts; evaluations in comprehensive realistic network environments and standardization; simulations and optimizations up to pre-product and product developments, trials and pilots in order to have initial deployments around year 2020.

As an aggregator of R&D knowledge, Fraunhofer FOKUS is able to provide the appropriate support in all stages of this R&D, including development and extension of novel concepts, design and specification, implementation and assessment, enabling the research community to gain a fast know-how as well as to develop and to popularize their own meaningful results.

As a companion to the research activities, the Open5GCore toolkit provides starting today the basis for immediate intuitive demonstration, practical implementation and trustworthy evaluation of the most preeminent concepts.
# Acronyms and Definitions

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>3GPP</td>
<td>3rd Generation Partnership Project</td>
</tr>
<tr>
<td>5G</td>
<td>5th Generation (of carrier-grade wireless communications)</td>
</tr>
<tr>
<td>5G PPP</td>
<td>The 5G Infrastructure Public Private Partnership</td>
</tr>
<tr>
<td>CTRL</td>
<td>Control</td>
</tr>
<tr>
<td>C-RAN</td>
<td>Centralised/Cloud RAN</td>
</tr>
<tr>
<td>DMM</td>
<td>Distributed Mobility Management</td>
</tr>
<tr>
<td>EPC</td>
<td>Evolved Packet Core</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunications Standard Institute</td>
</tr>
<tr>
<td>eNB</td>
<td>Evolved Node B; also: eNodeB</td>
</tr>
<tr>
<td>GTP</td>
<td>GPRS Tunnelling Protocol</td>
</tr>
<tr>
<td>HSS</td>
<td>Home Subscriber Server</td>
</tr>
<tr>
<td>IETF</td>
<td>Internet Engineering Task Force</td>
</tr>
<tr>
<td>IFOM</td>
<td>IP Flow Mobility</td>
</tr>
<tr>
<td>IPR</td>
<td>Intellectual Property Rights</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>M2M</td>
<td>Machine to Machine communication</td>
</tr>
<tr>
<td>MAC</td>
<td>Medium Access Control</td>
</tr>
<tr>
<td>MANO</td>
<td>(ETSI NFV) Management and Orchestration</td>
</tr>
<tr>
<td>MME</td>
<td>Mobility Management Entity</td>
</tr>
<tr>
<td>NAS</td>
<td>Non-Access Stratum</td>
</tr>
<tr>
<td>NFV</td>
<td>Network Functions Virtualization</td>
</tr>
<tr>
<td>NGMN</td>
<td>Next Generation Mobile Network (Alliance)</td>
</tr>
<tr>
<td>ONF</td>
<td>Open Networking Foundation</td>
</tr>
<tr>
<td>PDCP</td>
<td>Packet Data Convergence Protocol</td>
</tr>
<tr>
<td>PGW</td>
<td>Packet Data Network Gateway</td>
</tr>
<tr>
<td>RAN</td>
<td>Radio Access Network</td>
</tr>
<tr>
<td>RLC</td>
<td>Radio Link Control</td>
</tr>
<tr>
<td>RRC</td>
<td>Radio Resource Control</td>
</tr>
<tr>
<td>RTT</td>
<td>Round-Trip Time</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SDN</td>
<td>Software-Defined Networking</td>
</tr>
<tr>
<td>SFC</td>
<td>Service Function Chaining</td>
</tr>
<tr>
<td>SGW</td>
<td>Serving Gateway</td>
</tr>
<tr>
<td>UE</td>
<td>User Equipment</td>
</tr>
<tr>
<td>WiFi</td>
<td>Wireless Fidelity - IEEE 802.11 standards</td>
</tr>
</tbody>
</table>
References


References


[21] 3GPP TS 22.101, RAN Sharing Enhancements, Stage 1, March 2014;

[22] 3GPP TS 22.346, Isolated E-UTRAN Operation for Public Safety (IOPS), Stage 1, June 2014;

[23] 3GPP TR 22.828, Study on co-ordinated packet data network gateway (P-GW) change for SIPTO (CSIPTO), June 2014;

[24] 3GPP TR 23.713, Study on extended architecture support for proximity services, July 2014;


[26] 3GPP TR 23.861, Network based IP flow mobility, July 2014;

[27] 3GPP TR 22.807, Study on Enhancements for Infrastructure-based Data Communication between Devices, July 2014;

[28] 3GPP TR 32.842, Study on network management of Virtualized Networks, under preparation by 3GPP study group;


[33] NGMN Alliance 5G Initiative website, http://ngmn.org/workprogramme/5g-initiative.html
More information about Open5GCore can be found at:
www.open5Gcore.net

Contact the experts at:
info@open5Gcore.net

Fraunhofer Institute for Open Communications Systems (FOKUS)
Kaiserin Augusta Allee 31,
10589 Berlin, Germany
www.fokus.fraunhofer.de