A Technology Vision of the Fifth Generation (5G) Wireless Mobile Networks

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Abstract. 5G is now the next generation of wireless communication systems. The general demonstration of one technology vision for fifth generation mobile networks is presented in this work. The vision of 5G technology provides guidance for the definition of requirements, architecture, and other aspects. By expanding the performances limits of mobile networks, it is necessary for the 5G to include a flexible designing which can optimize network utilization with large range of examples for partnership and business models. The 5G should include flexibility to optimize the network usage by design. Modular network functions with the ability of on demand deployment and scaling capabilities need to be included in the architecture. The purpose of this inclusion would be to handle the accommodation of various demands in a cost-effective and agile manner. Direct communication in D2D services is one of the new 5G networks characteristics. Advanced technologies such as massive MIMO and millimeter-wave radio systems have significant impact on design of cellular architecture. It is crucial for 5G technology to maintain a massive traffic volume owing to increase efficiency of radio link and density of cells. Also, it is necessary for the network to be transformed in a cloud architecture, which coordinates radio resources of multi-radio access, and inter-cell interference during network deployment. Research trends in 5G tell us that using an aggregation of technologies, it is possible to realize numerous goals. Our use case study for the perspective period post-2020 shows extremely broad variety of applications and their attributes performance.

Keywords: Wireless technology · Research activities · Standardization process · Network densification · Cloud architecture · Use case study · 5G requirements

1 Introduction

The fifth generation (5G) is the next step in the evolution of mobile communication. 5G represents a key component in the vision of unlimited access to information and data sharing. The next generation is positioned to fulfill the requirements (large increment in traffic volume/density and connectivity, including multi-layer densification) in abroad range of use cases. Industry demands 10x higher data rate for users and 1000x more capacity. Additionally, devices directly communicate (D2D) to each other, including vehicle-to-vehicle (V2V), machine-to-machine (M2M), etc. All impose different

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requirements to be optimized in mobile broadband data access [1, 2]. The long battery lifetime, high reliability, massive number of devices, very low response time, require further improvements. Reducing the power consumption in cellular network is particularly a challenge because a simultaneous increase in peak data rates and capacity is needed. There is a requirement for 5G to achieve a spatio-temporal consistent user experience in a highly heterogeneous environment consisting of multiple access technologies, multilayer networks, several types of different devices with different types of user interactions, etc. The requirements can be grouped along with identification of system devices, user, business demands, network management and service enhancement. Mobile network operators are under the stress of continuously incremental demand for higher data rates, larger network capacity, high spectral, and energy efficiency [3]. Technology trends provide an insight about the approach to be taken in order to limit the gap which is present between the expected and existing capabilities.

Many research trends in 5G have demonstrated that a lot of goals can be achieved with the aggregation of technologies. Since initial support of the European Commission to the research projects in early 2013, the pursue of innovative solutions for 5G has begun worldwide. Standardization bodies share the vision that target year for the initial commercialization of 5G networks is 2020. The final goal is to achieve seamless communications between machine-to-machine (M2M), human-to-human (H2H), and human-to-machine (H2M). However, it is expected that 5G will be a collision of different radio access technologies (RATs), differently sized network tiers, backhaul connections, transmit powers, and number of heterogeneous and smart devices [4].

The structure of this overview paper is as follows. We start with an outlook of wireless technology evolution, continue with 5G research activities and standardization processes. The emphasis is on key advantages of 5G technology, such as massive MIMO, mm-wave radio-technology, device-to-device (D2D) communication as well as heterogeneous cloud radio-access networks. Next, network densification impact on spectral efficiency gain and transmit power reduction are analyzed. The presentation concludes use case study of selected applications.

2 Wireless Technology Evolution and Research Activities

The technology of wireless phones is dated back to the middle of the 20th century and they were not considered to be portable handset. The usage and most probably the manufacturing of the first ever wireless phones as well was in Japan in 1979. About the same time, Nordic Mobile telephone (NMT) was also working towards the development of similar wireless phone technologies [5]. A few years later, Motorola mobiles in USA made the wireless phone technology.

The first generation (1G) mobile networks was introduced in 1970. The systems were referred to as cellular due to the method by which the signals were handed off between stations. Cell phone signals were based on analog system transmission. The global mobile phone market grew by 30–50 percent annually. The number of subscribers worldwide reached approximately 20 million by 1990 [6]. Some of the most popular standards for 1G systems were NMT, AMPS (Advanced Mobile Phone System), TACS (Total Access Communication Systems).

2G phones were introduced in the early 1990s. The GSM (Global Systems for Mobile Communications) network offered digital modulation to improve voice quality and coverage, together with additional data services, such as paging, faxes, text messages and voice mail. GSM networks deployed time division multiple access (TDMA) and code division multiple access (CDMA) technologies [7]. An 2.5G intermediary phase uses the GPRS (General Packet Radio Service) which delivers packet-switched data capabilities to existing GSM networks. The Internet becomes popular and the importance of Internet Protocol (IP) in packet-switching increased. Phones start supporting Web browsing, multimedia services and streaming. EDGE network increases data rate from to 20–40 Kbps, with 171,2 Kbps as a peak value.

3G phones were introduced in 1998. Globally standardized 3G service UMTS (Universal Mobile Telecommunication System) sustain higher data rates up to 2 Mbps and open the way to Internet applications. Various mobile devices compatible with a set of standards could be used throughout the world. One possibility could be the use of UMTS which allows for internet access from any location together with global roaming. An 3.5G intermediary phase towards the road of 4G generation supports higher throughput HSPA (High Speed Packet Access) technology with the peak speed of 14,4 Mbps.

4G technology is commercially available since 2006. It provides rates of transmission up to 20 Mbps and simultaneously Quality of Service (QoS) which allows prioritizing traffic according to the type of application. In order to keep pace with the demand for data access by several services, the speeds for 4G are being further increased. Also, worldwide roaming becomes reality. A wider bandwidth is provided to vehicles and devices moving at high speeds within the access area by 4G networks. Long Term Evaluation (LTE) is the latest wireless cellular system since 2009, which comes with a new OFDMA (Orthogonal Frequency Division Multiplexing) air interface and an All-IP network. LTE-Advanced is deeply optimized for wireless data throughout all the layers of its protocol stack, unlike HSPA (High Speed Packet Access) technology which is constrained to operate within 3G networks. It promises several improvements in performance in addition to the increased data rate. This achievement is due to the support provided by technologies such as coordinated multi-point enhanced multi-antenna capabilities, carrier aggregation, relaying and improved inter-cell interference coordination for LTE cells as well as heterogeneous networks (HetNets) and small cells supporting aggressive spectrum spatial reuse.

Designing, dimensioning and optimization of telecommunications and ICT infrastructure have changed substation only over the recent years in line with changes towards 4G/5G wireless multiservice networks, networks convergence, and mobile communications as well as. A substantial increase in the amount and complexity of issues which were previously tackled by engineers and theoreticians follows each generation of technology. However, the essential tasks in developing engineering tools and algorithms for the design, analysis dimensioning and optimization of 5G wireless networks, remain the same:

(a) develop new technologies for increasing radio network capacity,
(b) evaluation and determination of the relationship between the QoS/QoE parameters and the parameters characterizing traffic sources (services),

(c) control and optimize the usage of radio network resources, and
(d) enhance the capabilities of data transport, transmission, and reception between end users and the core network.

The move to 5G has a greater focus on applications as well as a novel approach to operator and vendor business models. This will derive a further set of dimensions to simulation, measurement, and validation with a unique emphasis on software and applications relating to network performance. Today, 5G wireless technology holds a place amongst the biggest research areas within both industry and academia. A number of technology components which aim to achieve ambitions goals are being revealed through research. Some examples of the most important 5G research initiatives and activities include:

- Research projects funded by EU as part of the 7th Framework Program (FP7) started in September 2012,
  - *METIS* research project as part of the FP7 started in November 2012,
  - *Horizon2020* is seven years EU FP8 research and innovative program (2014–2020),
  - *5GPP* infrastructure public-private partnership project is a joint initiative between the ICT industry and the European Commission.
- *5G Innovative Centre*: 5G research center in the UK started in November 2013,
- China: IMT-2020 and Future Forum (February 2013)
- Taiwan: Office Science and technology working with the National Science Council on a print for 5G development in 2014.
- *5G Forum*: Korean industry-academy-R&D cooperation system, established in May 2013,
- Japan: ARIB established as a new working group (2020 and beyond) in September 2013.
- USA: Several universities - led research projects sponsored by key industry players.

Some of the most important 5G standardization processes include:

- 3rd Generation Partnership Project (3GPP) started its work on 5G in March 2015 and defined a timeline for the standardization.
- ITU Radiocommunication Sector (ITU-R) setting the stage for 5G research activities in early 2012, started a program to develop next-generation IMT-2020 cellular systems.

3GPP joined together seven global telecommunications SDOs (ETSI, ARIB, TTC, CCSA, TTA, TSDSI, ATIS), and has made provision for their members to have access to a stable environment producing Specifications and Reports which define the technologies. The creation and organization of the standards for a number of mobile communication systems including 2G, 3G, HSPA, LTE and 5G has emerged from this collaboration. In 2015, 3GPP began working on four technical reports outlining the new services and markets technology enablers, based on potential 5G requirements (Fig. 1). The completion of these reports were attained in June 2016 and used as input for R15 release, set for the standardization of the first phase of 5G requirements by June 2017.

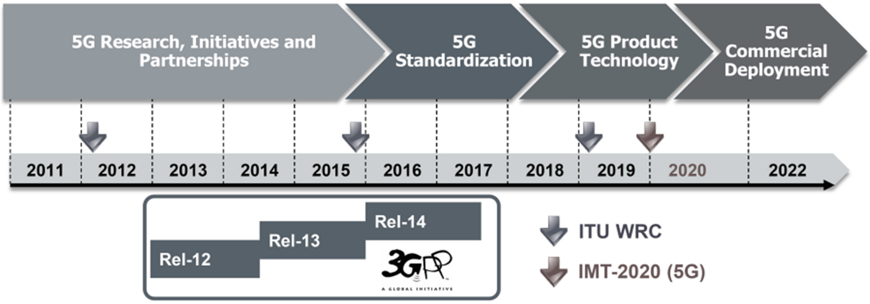

Fig. 1. 3GPP and ITU timeline for 5G: research, standardization, and technology.

ITU-R Working Party 5D has finalized its timeline towards IMT-2020. The finalization of ITU-R's version of 5G mobile broadband and connected society (Table 1) was done in September 2015.

Table 1. ITU standardization process for defining 5G technology.

Vision		Defining the technology	
2012–2015	2016–2017	2018–2019	2019–2020
Development plan	Spectrum arrangements	Proposals	Spectrum arrangements
Market/services view	Technical performance requirements	Evaluation	Decision & radio framework
Technology/research kickoff	Evaluation criteria	Consensus building	Detailed IMT-2020 radio interface specifications
Vision & framework	Invitations for proposals	CPM report	Future enhancement/update plan & process
Name IMT-2020	Sharing study parameters	Sharing study reports	
<6 GHz spectrum view	Sharing studie		
>6 GHz technical view			
Process optimization			

3 Technology Components

In what follows key advantage of 5G technologies has to be pointed out such as:

- A large bi-directional bandwidth with high resolution is offered by the technology.
- Containment of billing interfaces with advanced features.

- Provision of supervision tools for high-end subscribers.
- Massive data (in Giga bit) broadcasting.
- Highly performing transporter class gateway.
- Statistics about traffic with high accuracy.
- Option for the management of bandwidth from remote sites.
- Very high speeds for both download and upload.
- Improved and enhanced connectivity across the globe.

Block scheme for designing of All-IP mobile network is presented in Fig. 2.

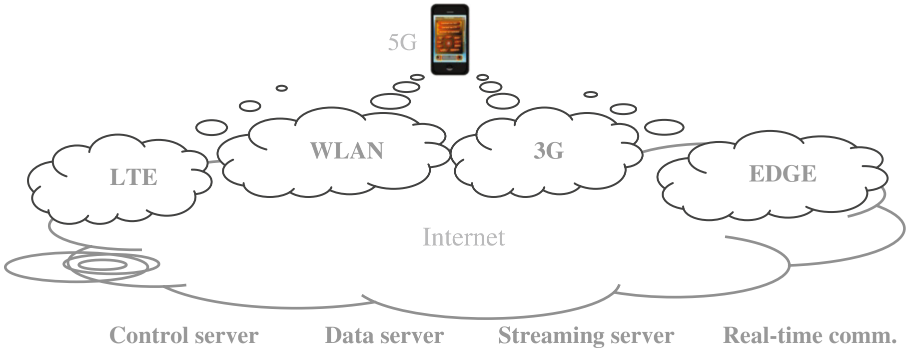

Fig. 2. 5G network model of All-IP system for wireless and mobile networks interoperability.

The achievement of the following ambitious goals is aimed by a number of technology components:

- massive (large-scale) multiple input- multiple output (MIMO),
- millimeter wave (mmWave),
- network densification,
- heterogeneous dense networks,
- heterogeneous cloud radio access networks,
- direct device to device (D2D) communications in the inband and outband form.

5G has diverse requirements, however, not all of these will need to be satisfied at once because different applications make different demands on system performance. The question often arises when discussing candidate technology components is what about the increase of the data rate. As a conclusion, the required increase in data rate could be achieved through:

- densification of the network to an extreme level with the aim to improve the area spectral efficiency, which means more nodes per unit area and frequency
- making better usage of the 5 GHz unlicensed spectrum by moving towards millimeter-wave (mmWave) spectrum with the aim for increased bandwidth
- making use of the advances in Multiple-Input Multiple-Output (MIMO) techniques to obtain an increased spectral efficiency.

When planning the future cellular system capacity, we based on the well-known *Shannon* theory of mathematical communication model, as an example of a cellular system, where following relation can be applied [8]:

$$R \leq C = m(B/n)\log_2(I + S/(S+N)) \tag{1}$$

This means that the throughput per user R is upper bounded by capacity C of an additive white *Gaussian* noise channel. The parameter m, integer spatial multiplexing factor, denotes the number of spatial streams between a base station (BS) and user equipment (UE), B denotes the BS signal bandwidth, while the load factor – integer parameter n, denotes the number of users sharing the given BS. Finally, S denotes the desired signal power, while I is the interference power and N represents the noise power at the receiver end.

3.1 Benefits and Shortcomings of Massive MIMO

A cellular base station (BS) serves a multiple number of single-antenna terminals over identical time-frequency intervals. Efficient time division duplexing (TDD) based on reverse-link pilots enables the BS to estimate the reciprocal channels. A 5G system uses massive MIMO technology with even hundreds of BS antennas. Massive MIMO relies on phase-coherent but computationally very simple processing of the signal from all antennas. The more BS antennas is equipped with, the more possible signal paths and the better the performance, on the other hand, more antennas increases complexity of signal processing and energy consumption. Nevertheless, the advantages of massive MIMO is so immense that the effect of thermal noise becomes negligible, while the system performance can only be limited by the pilot pollution [9]. High-order multiuser transmission and improved SNR provide increase in spectral efficiency of the system. This can support high-order multiuser communication. The same time and frequency resources are shared by a large number of users without any significant interference with each other [10]. Some specific benefits of a massive MIMO system are [11]:

- A 10 times or more increase in capacity is obtained by Massive MIMO with a simultaneous100 times improvement in the efficiency of radiated energy.
- The aggressive spatial multiplexing causes an increase in capacity.
- The fundamental principle that makes the significant increase in energy efficiency possible is that with a large number of antennas, energy can be focused with extreme sharpness into small regions.
- It can be implemented using low-power and inexpensive components.
- Using the flow of large numbers and beamforming in order to avoid fading tips, a significant reduction of latency on the radio interface is enabled on the system.
- Multiple access layer is simplified because each subcarrier will have substantially the same channel gain.
- The whole bandwidth can be allocated to each terminal, thereby making redundant most of the physical layer control signaling.
- These systems offer a lot of possibilities to eliminate harmful signal.

Before incorporating massive MIMO in the 5G cellular architecture [12], recent research trends have to be pointed out. For example, beamforming requires a large amount of channel state information which is not convenient for the downlink. Massive MIMO shortcoming is as follows:

- It may not be practical for FDD but due to the channel reciprocity, it can be used in TDD systems [13].
- Massive MIMO lack pilot contamination from other cells with high transmit power, and suffers from thermal noise otherwise [11].

3.2 Millimeter-Wave Technology

Bandwidth expansion is an obvious way to increase the throughput. Mobile communication systems use sub-3 GHz spectrum which is becoming increasingly crowded as the mobile traffic demands grow. On the other hand, a vast amount of spectrum in the 3–300 GHz range remains underutilized. mmWave frequencies of 28 GHz and 38 GHz are studied to obtain a proper understand of their propagation characteristics in 5G systems [14].

Two main features of the mmWave technology are identified as large amounts of bandwidth, which enable a very high throughput coverage, and very small wavelength which enables the deployment of several large antennas in a specific area. The main challenges for mmWave communications include large path loss (especially with non-line-of-site propagation), signal blocking/absorption by various objects in the environment, and low transmission power capability of current amplifiers.

Signal attention can be combated using large antenna arrays driven by smart beam selection tracking algorithms [15]. With the high density of mmWave BSs, the cost to connect every BS via a wired infrastructure can be very high. One solution is to allow some mmWave BSs to connect to the backhaul via other mmWave BSs. Due to large beamforming gains, the mmWave inter-BS backhaul link can be deployed in the same frequency as the mmWave access link. Cost-effective and low-latency solutions for wireless backhaul will be essential for supporting the envisaged densification in high capacity 5G networks.

3.3 Network Densification

Reduction of the cell size is one of the solutions available to operators for growing data rates demands. The question often arises is how to increase the spatial efficiency through higher frequency range. The answer is to reduce directly the cell size. As for reducing the transmit power, it can be done if the propagation power loss is lower. On the other hand, coverage is improved by deploying indoor cells under the assumption of serving overflow traffic from macro cells when required.

Cell site density needs to be drastically increased to accommodate large volume of traffic within a small geographical area. In the first three generation of cellular networks, cell layouts had rather homogeneous topology, i.e., system base stations had the same configurations for transmitting power and antenna gain. Base stations were more or less equally distanced. Cell splitting can be viewed as offloading traffic from macro base stations to low-power nodes, which help fill the coverage holes in a homogeneous layout [16]. In order to provide a convenient coverage as well as improved spectral and energy efficiency, heterogeneous networks (HetNets) can be considered as a perspective solution. HetNets represent the concurrent operation of different technologies, as well as various BSs classes (i.e., macro, pico, and femto). It introduces centralized or distributed processing, coverage and capacity, inter-cell coordination, and improved performance at cell edge.

Base stations become smaller and more numerous and more users locate within the same spectrum. As for base station classification, widely spread backhaul network is required to support it. Hence, the number of backhaul links will increase along with the number of base stations. Network and backhaul densification are shown in Fig. 3.

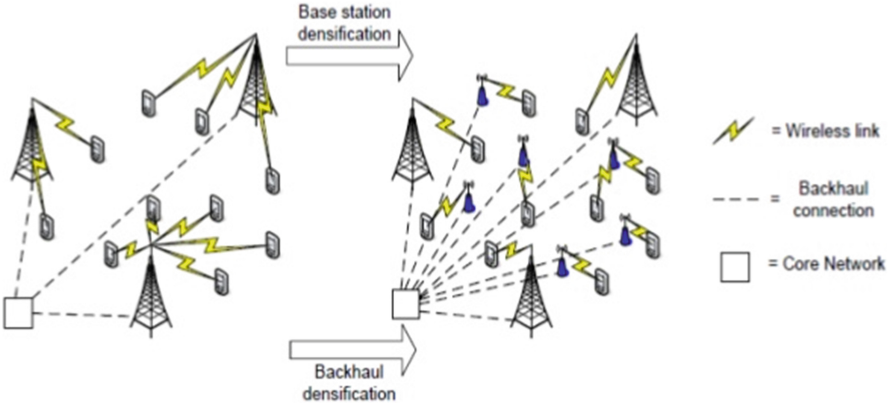

Fig. 3. Network and backhaul densification (backhaul connections can be either wired or wireless) [16].

Two advantages of increasing the BS density are shown in Fig. 4. The decrease of total transmission power of the network while maintaining linear area spectral efficiency (ASE) gain is shown in Fig. 4a. And the reduction in total transmission power as base station density increases is shown in Fig. 4b. Therefore, a higher throughput and reduced overall radiated power by the base station antennas is enabled by the increase of the base station density. The reduction in the overall transmit power may have positive effects for reducing the aggregate interference in primary network which share spectrum with a secondary system of small cells [18]. It is useful in future scenarios based on shared access schemes LSA/ASA in which small-cell networks exploit new spectrum-sharing opportunities.

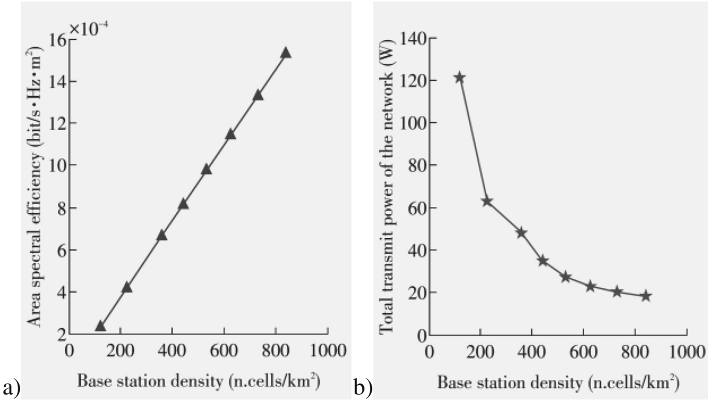

Fig. 4. Reduction in total transmit power of the network: (a) area spectral efficiency gain vs. base station density, (b) transmit power reduction vs. base station density [17].

3.4 Heterogeneous Cloud Radio Access Network

5G networks are expected to support multiple radio access technologies (RATs) with overlapping coverage creating rich opportunities for combining and aggregating capacity. In order to realize this, 5G systems need to support an integrated virtual access network. Single end-to-end network architecture enables joint management and simultaneous use of radio resources to significantly improve network capacity and reliability of wireless link.

Cloud architecture is a solution for coordinating different categories of network and radio resources in a seamless and transparent method. 5G networks are a mix of new network components and existing systems as well as RATs of a non-cellular kind. Within each generation of networks, the allocated spectra may be different, depending on country, operator, or year of deployment. Highly licensed and unlicensed spectrum may be included in radio resources. A cloud architecture for unified coordination of network access in converged multi-RAT network is shown in the Fig. 5.

H-CRAN (Heterogeneous Cloud Radio Access Network) based 5G systems are traffic-driven and user-centric. The H-CRAN centralized server platform receives and processes the baseband signals from several hundred BSs when small cells are connected to macrocells with low-latency high-rate backhaul [19, 20]. The evolution of H-CRAN includes even more advanced techniques such as joint resource allocation across multiple RATs and simultaneous processing of multiple users signals to further increase capacity of 5G systems. Network is characterized by attributes of both cloud computing and software defined functionality. In order to improve spectral and energy efficiency [21], four key H-CRAN functionalities need to be implemented:

- The self-organizing functionality of H-CRAN automatically configures and optimizes the traffic, front-haul, and radio resources, regulating operations of the management plane without human interaction.

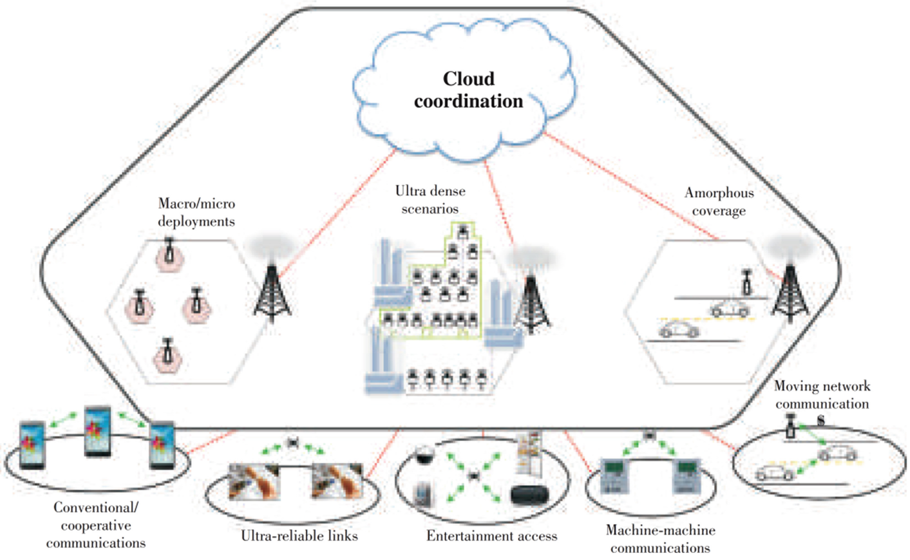

Fig. 5. 5G unified cloud architecture: network access using cloud-coordination [16].

- The radio resource cloudization technology decreases the inter-tier interference and improve reuse of the radio resources.
- The cognitive processing technique is used in the overlaid scenario to avoid inter-tier interference and make small cells work cooperatively when the overall system load is not high.
- The big data mining functionality bring in machine learning (ML) technology into large-scale cooperative signal processing and intelligent networking. Adaptive ML techniques prepare 5G system for the future Internet/IoT traffic properties and user demands.

3.5 Direct Device-to-Device (D2D) Communication

The main goal for direct device-to-device communications (D2D) is to improve the overall spectral efficiency for wireless systems. User terminals are in a position to form a direct link without the influence of BSs and core networks. Also, a special case of the densification of network is D2D communication. D2D communication helps increase the density of low-power nodes (LPN) with wireless backhaul. A device acts as a LPN for unicasting, multicasting or broadcasting traffic directly to the user without being routed through the network [10]. In 5G networks, the system capacity is expected to be increased by D2D, especially for big outdoor events in dense urban environments. This is especially useful for proximity services where sharing and exchanging local information by users in the vicinity is of concern.

D2D communications are divided into two classes: inband and outband, as shown in Fig. 6 [22]. Inband D2D communications occur in licensed spectrum. It means that cellular spectrum is used for both D2D and cellular links. The motivation for choosing inband communications is high reliable control over licensed spectrum. Inband communications are further divided into underlay and overlay categories. In the case of underlay approach, cellular and D2D communication share the same radio resources. On the other hand, in overlay communication, cellular resources are dedicated to D2D links. Inband D2D communication is advantageous in the sense that underlay concept increases the cellular spectral efficiency by exploiting the spatial diversity. Cellular spectrum is controlled by BS. Thus, the QoS provisioning is not a challenging issue. On the other hand, cellular resources might be wasted in overlay D2D concept, while the interference management among D2D and cellular transmission in underlay is challenging [23]. Inband power control and interference management solutions usually explore complex resource allocation methods. The main criteria of choice is higher spectral efficiency.

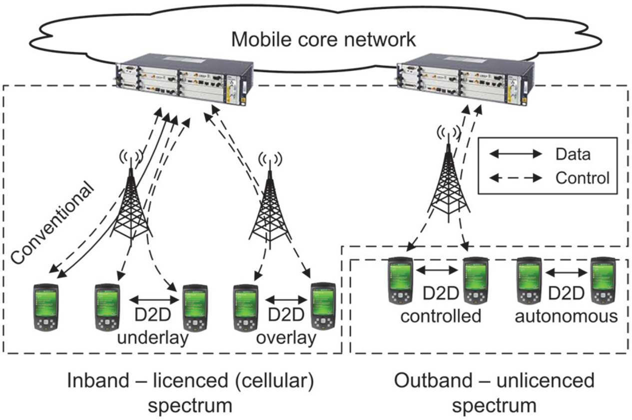

Fig. 6. Two classes of direct device-to-device communications: inband and outband.

The major motivation in using outband D2D communication is the elimination of the interface between direct and cellular lines. An extra interface is required by unlicensed spectrum and is usually adopted in two environments: WLAN and WPAN wireless networks. Outband D2D communications are further divided into autonomous and controlled communication. In autonomous outband communications, the cellular network controls all the communication but leaves the D2D communication to the users, while in controlled outband communication, the management of a second interface is under the cellular network. It means that the secondary interface is not under cellular control. Since outband communication does not occur in the cellular spectrum, there is no interference issue as in inband. However, only mobile devices with two different interfaces (WiFi and LTE) can use outband D2D. In that way users can have simultaneous maintaining D2D and cellular communication. The significant benefit of outband communications are absence of interference between cellular and

D2D users. It should be added that there is no need to dedicate cellular resources to D2D spectrum like in overlay inband approach [15]. Outband D2D communications have some disadvantages. The BS does not control the interference in unlicensed spectrum. Also, the efficient power management between two wireless interfaces is crucial because the power consumption of the device can be increased.

4 Use Case Study

5G supports evolution of established mobile broadband use cases encompassing various applications with variable performance attributes. Video applications which are delay-sensitive evolve to ultra-low latency. Best effort applications evolve to reliable and ultra-reliable. Vehicular high speed entertainment applications evolve to mobility on demand for connected objects. Furthermore, use cases will be delivered across a wide range of devices and across a fully heterogeneous environment. The use case study is an input to determine requirements and defining the technology base in the architecture for 5G. The use cases are a tool to ensure the comprehension of the level of flexibility required in 5G. NGMN (Next generation mobile network) alliance has come up with twenty-five use cases for 5G [24–26]. The eight groups with representative examples and imposed requirements are shown in Table 2.

Table 2. The 5G use case study and resulting requirements on technology.

Use cases	Representative examples	5G requirements
Broadband access in dense area	Pervasive video	Extremely high resolution video, end-to-end latency and data rate, concurrently active connections
	Smart office	Ultra-high bandwidth-intensive processing, instant communication by video
	Operator cloud services	Higher QoE as well as seamless interworking across clouds, networks, and devices
	Video/photo sharing	Ultra-high connection density, low latency, and high data rate
Broadband access everywhere	50+Mbps	Minimum user data rate and not a single user's theoretical peak rate
	Ultra-low cost networks	Low-cost deployment and operation of networks infrastructure and terminals
High user mobility	High speed train	Passengers satisfied with the service (e.g. up to 1000) at a speed of 500 km/h

(*continued*)

Table 2. (*continued*)

Use cases	Representative examples	5G requirements
	Remote computing	Robust communication links with low latencies together with high availability
	Moving hot spots	Real-time, Non-stationary, and dynamic provision of capacity
	3D connectivity and aircrafts	Typical routes have an altitude of up to 12 km, sporting event live services
Massive Internet of Things	Smart clothes	Overall management of the number of devices and sensors
	Sensor networks	High density of devices in a common communication and interworking framework
	Mobile video surveillance	Secured and highly reliable network with instant interaction and the right performance
Extreme real-time communications	Tactile internet	Audio and/or visual feedback and tactile control signal and in real-time within sub-millisecond
Lifeline communications	Natural disaster	Robust communications in efficient network and user terminal energy consumptions
Ultra-reliable communications	Automated traffic control	Ultra-low end-to-end latency communication with high reliability, and high scalability
	Collaborative robots	Low latency and high reliability of underlying control network
	eHealth	Reserve/prioritize capacity, security, authentication management, identity, and privacy
	Remote object manipulation	Very strict requirements in terms of security, latency, and reliability
	3D connectivity drones	Remote control system
Broadcast-like services	News and information	Real-time or non-real time services having a wide distribution focusing on either address-space focused (many end-users) or geo-location
	Local/regional/national/continental services	

4.1 Broadband Access in Dense Areas

This group focuses on service availability in densely-populated areas where for each square kilometer, there are thousands of people who live and work. An increasingly significant role will be played by three-dimensional (3D) services, and multi-user interaction. An essential aspect at the network close to the user is contest recognition in ensuring delivery of consistent and personalized services to the customers. The following use cases are included in this group.

- **Pervasive video** with extremely high resolution in person-to-group communication or person-to-person in everyday life will have much more advanced capabilities.
- **Smart office** scenario in where ultra-high bandwidth-intensive applications are required by hundreds of users, instant communication by video as well as vast amount of data processing in a cloud.
- **Operator cloud** support the future value-added services which need for higher QoE as well as seamless interworking across networks, and devices.
- **HD video/photo sharing** in open-air gathering/stadium requires ultra-high connection density, low latency, and high data rate combined altogether.

4.2 Broadband Access Everywhere

A minimum guaranteed data rate is needed everywhere for consistent user experience. Cost of infrastructure deployment is a key factor in further development of services. This group includes the two most important cases.

- **50+Mbps everywhere** broadband access is considered as the minimum user data rate in the coverage area, even at cell edges. The target value between 50–100 Mbps will be indicative depending upon the 5G technology evolution.
- **Ultra-low cost networks** deployment in scarcely populated areas to offer Internet access and provide the ability for new businesses to develop in underserved areas.

4.3 Higher User Mobility

The degree of mobility required depends upon the specific traffic devices. For example, vehicle demands accessing the Internet, enhanced connectivity for in-vehicle entertainment, autonomous driving, safety and vehicle diagnosis and, enhanced navigation through instant and real-time information. The following use cases are included in this group.

- **High speed train** reaches 500 km/h with passengers using high-quality mobile Internet for interaction, information, entertainment or office-like applications.
- **Remote computing** in transportation industry enables the ease of vehicle maintenance and offers novel services to customers in public transport.

- **Moving hot spots** is becoming a challenge in 5G which complements the stationary mode of planning in capacity and incorporates non-stationary, real-time, and dynamic provision of capacity.
- **3D connectivity** is implemented in civil aviation commercial services and 3D sporting event live services.

4.4 Massive Internet of Things (IoT)

IoT involve the interconnection of huge number of devices such as actuators, sensors, and cameras with a wide range of demands and characteristics. The use case includes/long-range/low-cost/low-power mobile type communication (MTC) and broadband with similar characteristics closer to human type of communication (HTC). The cases are as follows.

- **Smart clothes** involve a number of low-power, ultra-light, waterproof sensors integrated in people's clothing. These sensors measure various environmental and health attributes like body temperature, heart rate, blood pressure, breathing rate and volume, etc. The key challenge is the overall management of the number of devices, as well as the data and applications.
- **Sensor networks** require very high density and low-cost devices with high battery life. The aggregation of all smart services a common communications and inter-working framework is challenging task.
- **Mobile video surveillance** may evolve to be available on traffic devices, as well as safety and security personal for monitoring targeted area, specific events, etc. These applications require a high reliable and secure network with the right performance and instant interaction with back-end and remote systems.

4.5 Extremely Real-Time Communications

Use cases with strong demands for real-time interactions may require extremely high reliability, throughput, mobility, etc. Remote computing, with strict latency requirement, need highly available and robust communication links.

- **Tactile Internet** is a system where humans wirelessly control real and virtual objects in tactile interaction with audio/visual feedback. The main challenge is the expectation of real-time reaction to be within sub-milliseconds.

4.6 Lifeline Communications

These use cases include new applications for authority-to-authority communication, emerging disaster relief and prediction. Lifeline communications require the ability to support traffic surges and a very high level of availability.

- **Natural disaster** requires robust communications in case of earthquakes, tsunamis, floods, hurricanes, etc. Basic communications (voice, text messages) are needed in the disaster area in order to signal location/presence of survivors. Several days of user terminal operation should be supported.

4.7 Ultra-Reliable Communications

These use cases include applications requiring extremely low latencies and involving significant growth in remote control and operation. The following use cases are included.

- **Automated traffic control and driving** in advanced applications for safety which reduce the road accidents and improve traffic efficiency, require high reliability, low latency and high scalability 5G networks.
- **Collaborative robots and control network for robots** in applications with diverse tasks in different environment, require an underlying control network with very low latency and high reliability. For many robotics scenarios, a round-trip reaction time of less than 1 ms is anticipated.
- **E-Health** mobile applications of remote health monitoring include immediate and automatic surveillance of patients. The application is life critical and the system requires reserve/priorities capacity for the related communications, including out of coverage warnings. For each device, identity, privacy, security and authentication management must be ensured.
- **Remote object manipulation** in application like remote surgery has very strict requirements in terms of security, latency, and reliability.
- **3D connectivity drones** require terrestrial and up-in-the-air locations coverage in logistics application.
- **Public safety** requires enhanced and secure communications which include real-time video and sending high-quality pictures. Also, one of the main challenges is to ensure reliable communications over the entire footprint of the emergency services. Priority over the traffic is also required together with an ability for direct communications between devices and high security.

4.8 Broadcast-like Services

Real-time or non-real-time services are characterized by having wide distributions which can be either geo-location focused or address-space focused with many end-users. These services may distribute content as being currently done, but also provides a feedback channel for interactive services or acknowledgment information.

- **News and information** include receiving text/pictures, audio and video, everywhere and as soon as events happen.
- **Local broadcast-like services** is active at a cell level with a reach of 1 to 20 km (advertisements, festivals, fairs, congress/convention, stadium services as well as local emergency services).

- **Regional broadcast-like services** are required within 1 to 100 km (communication of traffic jam information, emergency warnings).
- **National broadcast-like services** are interesting as a substitute or complementary to broadcast services for radio or television. Industries will benefit from national broadcast like services to upgrade/distribution of firmware.

5 Conclusion

Fifth generation mobile systems aggregate best technologies and have an extraordinary capability to support software. The routing and switching provide high connectivity. Also, Internet access to nodes are distributed and can be deployed with wireless/wired network connections. The advanced systems such as massive antennas, millimeter-wave radio systems, and direct communication have significant impact on new heterogeneous network architecture. Cloud computing becomes a promising solution for high energy and spectral efficiency. However, cloud virtualization of communication hardware and software impose stress on architecture and protocols in software defined radio networks.

5G systems become adapted to big traffic load, which is fundamental for service ubiquity and to sustain a massive number of connections. The three requirements for 5G networks are always services presence and availability, a massive number of connections and energy efficiency. It is of importance to focus improvements in the following areas: network capacity, consistent user experience, flexibility, efficiency, innovation. 5G vision of these technologies provides guidance for the definition of architecture, requirements, and other aspects.

Consistent user experience is the driving force of 5G. Researcher in the field of wireless and mobile operators will come with innovative ways of converging networks, devices, and services. Versatile and intelligent 5G networks are able to support applications for great benefits of individuals and organizations. In that way, 5G systems will be comprehensive and able to penetrate in many aspects of people everyday life.

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