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RESEARCH ARTICLE

NEW DEVELOPMENTS AND RESEARCH CHALLENGES FOR 5G WIRELESS SYSTEMS AND NETWORKS

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ABSTRACT

Over the past few decades, mobile and wireless communications as well as Internet have been the most profound and important technologies in information technology that are rapidly growing and continuously changing human life. Despite the tremendous potentials of wireless networks, several significant research challenges remain to be addressed before widespread deployment of wireless networks, including isolation, control signaling, resource discovery and allocation, mobility management, network management and operation, and security as well as non-technical issues such as governance regulations, etc. In recent years, the demands of mobile data keep thriving, meanwhile, the smart phone and mobile applications become increasingly powerful and varied. These lead to a sporadic opportunity to combine both mobile communications and Internet, i.e. mobile Internet. In this paper, we present a critical review of New Developments and Research Challenges for 5G Wireless Systems and Networks. The paper includes discussions on technology development approach toward 5G, some supporting technologies, technology components and then research challenges in 5G wireless systems.

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INTRODUCTION

The communication needs of ubiquitous machine-type devices ranges from low complexity devices such as sensors and actuators to more advanced devices such as medical devices. The resulting requirements vary widely in terms of payload size, frequency of transmission, complexity, cost, energy consumption, transmission power, latency, etc., and cannot be met to a full extent by today's cellular networks (Afif Osseiran *et al.,* 2014). "Massive deployment of sensors and actuators" is a typical application where small sensors and actuators are mounted to stationary or movable objects and enable a wide range of applications connected to monitoring, alerting or actuating. The requirements will be to provide connectivity for hundreds of thousands of devices within one cell, enable long battery life (on the order of a decade) and low cost device implementations, so as to support the billions of connected devices expected by 2020 (ICT-317669 METIS project, 2013). The technical challenge is to integrate the communication of ubiquitous things in mobile networks and to manage the overhead created by the high number of devices. nFor instance, the test-case "dense urban information society" does not require the extreme data rates as in the "virtual reality office" case or the latency connected to "traffic efficiency and safety", but foresees that both humans and machines enjoy reasonably high data rates at reasonably low latencies, both indoors and outdoors, and also when devices are moving jointly in crowds as e.g. on a pedestrian sidewalk. The key difficulty here is hence to address the product of multiple requirements under constrained network deployment costs. In particular, the requirement will be to enable in 95% of locations and time an experienced data rate of 300 Mbps and 60 Mbps in downlink and uplink, respectively, and a data rate of 10 Mbps between sensors and devices for instance. Ultimately, the network is required to provide the above date rate while sustaining an average traffic volume of 500 Gbyte per device and per month. This corresponds to about 1000 times today's average monthly traffic volume per subscriber (ICT-317669 METIS project, 2013).

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Technology development approach toward 5G

The performance of the proposed technologies, according to the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS), will be evaluated according to the research objectives and Key Performance Indicators (KPIs) (Afif Osseiran *et al.,* 2014). The research work will be directed by the concept development to ensure a consistent integration of the developed technology components. Additional features can be added to capture emerging market, societal, technical, and economic trends. The following technologies will be developed and integrated:

Direct Device-to-Device (D2D) Communication

This refers to direct communication between devices, without user-plane traffic going through any network infrastructure as depicted in Fig. 1. Under normal conditions the network is controlling the radio resource usage of the direct links to minimize the resulting interference. The goals are to increase coverage, to offload backhaul, to provide fallback connectivity, and to increase spectrum utilization and capacity per area.

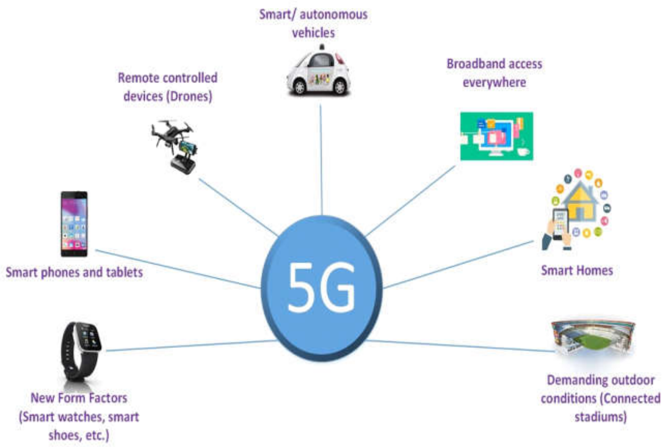

Fig. 1. Device-to-device communication through 5G

Massive Machine Communication (MMC)

This provides up- and down-scalable connectivity solutions for tens of billions of network-enabled devices, which is vital to the future mobile and wireless communication systems. Machine-related communications also known as Machine-to-machine communication (M2M), have a wide range of characteristics and requirements such as data rate, latency, and cost, that often differ substantially from those of human-centric communication. M2M technology, as shown in Fig. 2, has a wide range of applications warehouse management, remote control, robotics, traffic control, logistic services, supply chain management, fleet management and telemedicine. Some applications of M2M that you may or may not be familiar with are a vending machine that can message the distributor when a particular item is running low, or a smart meter that wirelessly gathers information from a water or electric meter and transmits the data to a central power station, or an RFID could be attached to an animal in its natural habitat to monitor its movements and behavior. M2M is based upon machine-generated data; this is the kind of data that often exists behind the scenes of a company infrastructure in the form of message queues, sensor data, GPS data, and a wide range IT log data namely application logs, point of sale logs, server logs, virtual machine logs, web proxy logs, etc.. In fact, the machine-generated data will increase to 42% of all data by 2020, up from 11% in 2005 (Jeffrey Walker, 2015).

Moving Networks (MN)

It is used to enhance and extend coverage for potentially large populations that are part of jointly moving communication devices. Fig. 3 shows a moving network node or a group of such nodes that can form a “moving network” and that communicates with its environment, i.e. other nodes, fixed or mobile, that are inside or even outside the moving entity.

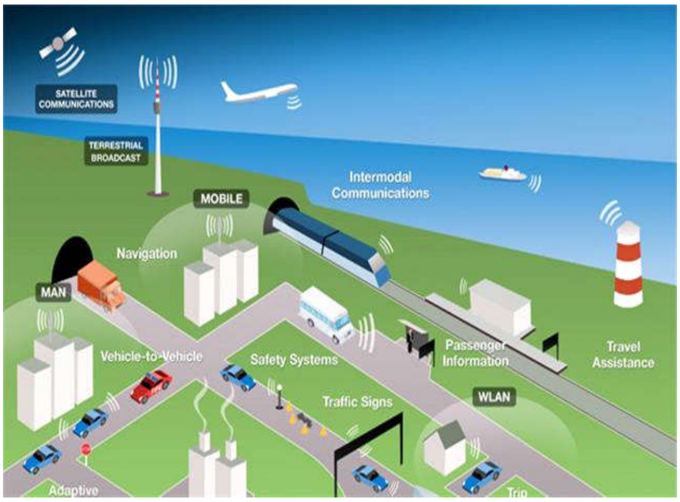

Fig. 2. Machine-to-machine communication infrastructure

Enabling mobility has always been one of the major driving forces since the development of cellular communications. The ability to support mobility has also evolved from nomadic to vehicular speed. For instance, the design of LTE-Advanced can support mobility up to 350 km/hr. However, it is becoming more and more evident that communications under such high speed is very challenging (Hsien-Wen Chang *et al.,* 2015).

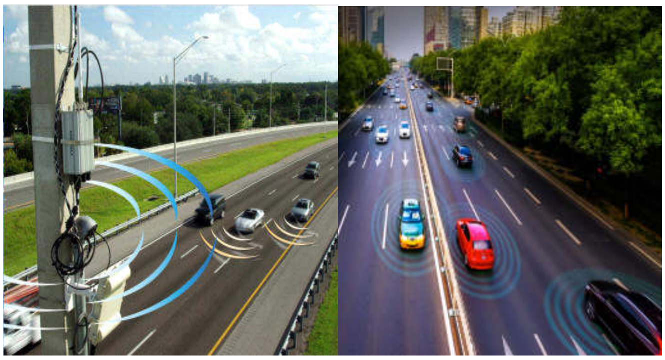

Fig. 3. Moving Networks Infrastructure

Ultra-Dense Networks (UDN)

This addresses the high traffic demands via infrastructure densification as shown in Fig. 4. The goals are to increase capacity, increase energy efficiency of radio links, and enable a better exploitation of spectrum. UDN are orders of magnitude more dense than today, assuming for instance several access nodes per room indoors and an access node on each lamp post outdoors, which of course raises severe interference and mobility challenges and an increased pressure on cost per access node. Increasing the traffic density in areas like airports and large shopping malls requires both outdoor and indoor deployment to provide seamless coverage and capacity. Such an example requires indoor LTE small cells, unlicensed LTE and WLAN/ 802.11n/ac solutions to complement outdoor macro and small cells. By 2025 or 2030, Nokia expects UDNs will be covering most urban indoor and outdoor areas with small cells providing cell edge data rates of 100 Mbps to everyone. These data rates are expected to be common in 2030 UDN deployments (Nokia white paper). Densifying the network aims principally to keep customers happy by providing them with better than expected services. Too many users on the same cell will affect accessibility and usability. Operators need to provide users with optimum quality while keeping the Total Cost of Ownership (TCO) to a minimum.

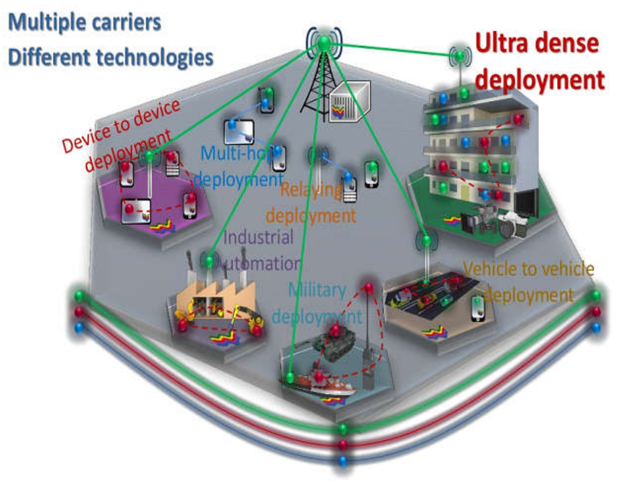

Fig.4. Ultra-Dense Networks Infrastructure

Ultra-Reliable Communication (URC) and Architecture (Arch)

It will enable high degrees of availability. METIS aims at providing scalable and cost-efficient solutions for networks supporting services with extreme requirements on availability and reliability. The architecture provides a consistent architectural framework integrating different centralized and decentralized approaches. METIS will research and introduce a novel, architectural concept that can take advantage of the developed technology components in a scalable way.

Other Technologies

Apart from the above technologies and applications, the following technologies can also potentially impact 5G.

Millimeter Wave

An obvious way of increasing the throughput will be through bandwidth expansion. However, the available bandwidth below 6 GHz is limited, and re-farming analogue TV spectrum will not sufficiently meet the growing demand. Already, there are efforts to look beyond 6 GHz and also at the millimeter wave frequencies to evaluate their feasibility for use in future networks. However, the characteristics of higher frequencies are not well studied, and measurement campaigns and channel modeling for different scenarios and environments will be required before transmission technologies can be designed for them. It is believed that millimeter wave frequencies holds the most promise, and there are already on-going efforts to make this a possibility. Millimeter wave frequencies of 28 GHz and 38 GHz are extensively studied to understand their propagation characteristics in different environments, paving the way for their use in future wireless systems (Radio Spectrum Policy Group, 2011).

Shared Spectrum

Although cognitive radio was often touted as a solution to the problem of frequency spectrum shortage, it is seldom adopted as there are always concerns about the impact on the primary user or license holder of the spectrum. An alternative solution proposed which can potentially solve this dilemma is Authorized Spectrum Access (ASA) also known as Licensed Spectrum Access (LSA) (Radio Spectrum Policy Group, 2011). The concept of LSA is to allow authorized users to access licensed spectrum based on certain conditions set by the licensee of the spectrum. This would allow under-utilized spectrum to be more effectively used and also solve the problem of quality of service for the primary user.

Big data

Like in many other market sectors and industries, big data will also bring about lots of challenges and opportunities in 5G wireless. First of all, cellular networks have to provide efficient infrastructure support for this data deluge. For example, the future M2M or Internet of Things (IoT) applications will generate a vast amount of data. This proves to be a major technical challenge for RANs. Secondly, new network architectures may emerge from the necessity of running big data applications. There is close synergy between cloud computing, software defined networking, and Network Function Virtualization (NFV). A convergence of these technologies can be envisaged to form highly robust and reliable 5G platforms for big data as shown in Fig. 5. Thirdly, making informed decisions and extracting intelligence from big data is an extremely important and yet non-trivial task [3]. For example, cellular operators can make use of various customer network access data to reduce churn rate and seek new revenue opportunities. The smart grid, as another example, can be seen as a huge sensor network, with immense amounts of grid sensor data from various sensors, meters, appliances and electrical vehicles. Data mining and machine learning techniques are essential for efficient and optimized operation of the grid.

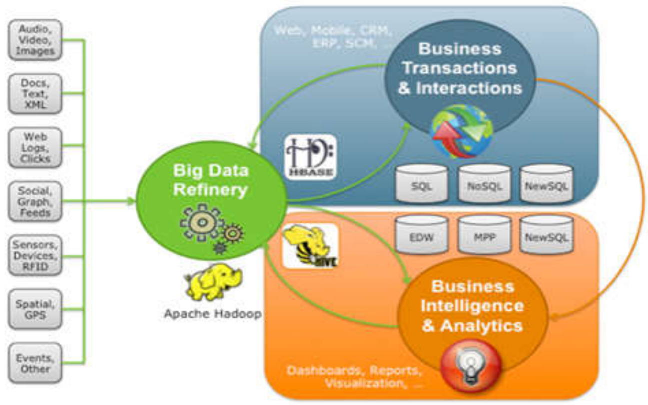

Fig. 5. Next-Generation Data Architecture

Indoor Positioning

While indoor positioning itself does not improve throughput or coverage, it has large implications on various applications and the quality of communications. Accurate positioning of user terminals can provide the network with additional information that can help in resource allocation and quality of service improvement. It can also enable a plethora of applications, including position based handover, resource allocation, and location based services (Woon Hau Chin *et al.,* 2015).

Technology components

In order to develop the connectivity solutions and mobile communication system for the beyond 2020 society with its broad range of service and application requirements, METIS develops the following technology components where significant progress beyond state-of-the-art is required: radio-links, multi-node/multi-antenna technologies, multi-layer and multi-RAT networks and spectrum usage (Afif Osseiran *et al.,* 2014). These technology components are briefly described hereafter.

Radio-Links

To efficiently support the vast range of identified use cases and scenarios, an air interface providing a "one-fits-all" solution does no longer seem to be the favorable choice. Instead, the air interface for the future mobile radio system should become more flexible, providing different solutions for particular use cases and applications under a common umbrella framework (ICT-317669 METIS project, 2013). For UDN, where the system is expected to support a large range of carrier frequencies, flexibility is brought to the system by an air interface with a scalable frame structure, providing a low-cost solution for adapting the system to the signal conditions specific for the utilized bands. The efficient support of machine type communication in parallel to human-centric communication is enabled by an optimized signaling structure, reducing the signaling overhead for MMC. Requirements of car-to-car applications are addressed by solutions aiming to improve the reliability and the quality of transmission at high vehicular speeds, embracing also novel approaches for channel estimation and prediction. For the physical layer, a particular challenge is the efficient support of a broad range of data rates going from low-rate sensor applications up to ultra-high rate multi-media services. For this purpose, waveforms, coding & modulation schemes and suitable transceiver structures are investigated. Faster-than-Nyquist (FTN) transmission is studied as a technique for increasing the data rate at the cost of a higher complexity of the receiver design. Filtered and filter bank based multi-carrier schemes are considered potential new waveform candidates for the future mobile radio system, since they allow for the efficient use of fragmented spectrum and facilitate spectrum sharing with other services and applications. In the context of advanced transceiver design, full duplex transmission seems to be a promising technology, allowing a node to simultaneously transmit and receive a signal and thus increasing the spectral efficiency of the link (ICT-317669 METIS project, 2013).

Multi-node/Multi-antenna Transmission

Multi-node/multi-antenna technologies are addressed to achieve the performance and capability targets of 5G wireless systems (ICT-317669 METIS project, 2013), by looking at both evolutions of 4G technologies and at disruptive changes at both node and architectural level as shown in Fig.6. Massive-multiple input multiple output i.e. Massive-MIMO is studied in order to deliver very high data rates and spectral efficiency, or enhanced link reliability, coverage and/or energy efficiency. Part of the work is dedicated towards assessing the impact of real-world challenges, like channel estimation and pilot design, antenna calibration, link adaptation, and propagation effects. Another part of the work is dedicated towards studying the effect of new types of array deployments. Another part of the work is further exploring the theoretical limits of Massive-MIMO (ICT-317669 METIS project, 2013). Advanced inter-node coordination is expected to achieve significant increases in spectrum efficiency and user throughput and improvements for users with unfavorable radio conditions. METIS is currently exploring three different broad research directions related to inter-node coordination. The first one is a further improvement of classical coordination techniques. Network densification, reliability and support of moving networks may make relaying and multi-hop communications one of the central elements in the wireless architecture (in contrast to existing wireless networks where multi-hop communications have been considered as an additional feature). Intensive research will address network densification through the use of infrastructure deployed relays and techniques for wireless backhauling. Specifically, wireless network coding, buffer-aided relaying, and joint processing of interfering flows are considered by METIS promising research directions to make wireless relaying a viable option for efficient in-band backhauling.

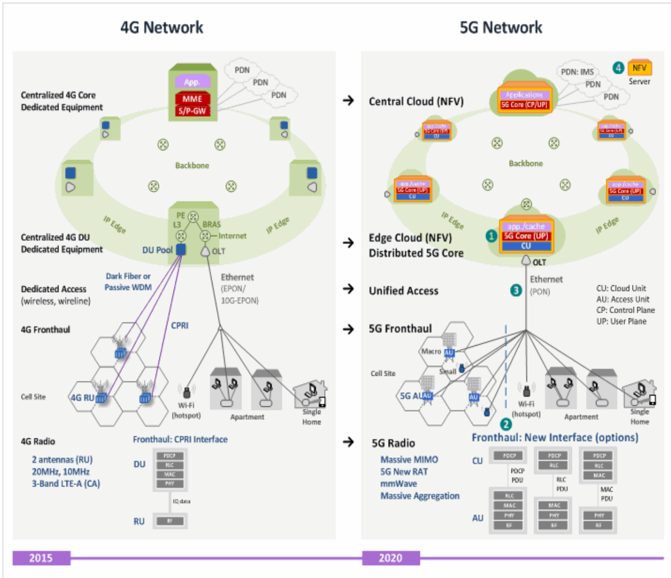

Fig. 6. Evolution from 4G Network to 5G Network

Heterogeneous Multi-RAT and Multi-Layer Networks

In 5G wireless systems, we will see a co-existence of legacy radio access technologies (RATs) and new access technologies, and also very dense multi-layer networks consisting of cells of very different sizes. Both aspects raise novel challenges in the field of interference and mobility management, which call for new approaches in how cellular systems are handled in general. For instance, the very dense deployments expected beyond 2020 will lead to less users per cell, and traffic will therefore be bustier, which suggests the usage of time division duplex (TDD) for a more efficient usage of radio resources. METIS is tackling these challenges by developing novel schemes tailored specifically towards moving cells, or towards low-power and low-cost machine-type devices. Here, a wide range of approaches is considered, including user autonomous, network assisted, or fully network driven service connectivity management. To address both interference and mobility management aspects in 5G in one holistic framework, METIS is also considering a complete redesign of control and user plane functionality, and novel cell concepts as for instance phantom or virtual cells which are fully or partially transparent to the device. One clear differentiator between a 5G system and earlier generations will be that one will move towards a proactive management of demand, mobility and interference instead of simply reacting to instantaneous channel, demand and network conditions.

This will be made possible by an extensive predication and exploitation of device and application context. Clearly, novel multi-RAT and multi-layer solutions require novel infrastructure enablers such as new network management interfaces, which are also investigated in METIS as the most promising technology components are becoming clear. Further, the partners are also investigating the integration of nomadic cells (e.g. access nodes mounted on vehicles) with the static infrastructure. Ultimately, the aim of the multi-RAT and multi-layer activities is to find answers to fundamental questions regarding interference and mobility management in 5G, for instance to which extent centralized approaches will be needed and which implications on the network infrastructure these bring. First investigation results, for instance assessing the gains of context awareness and enablers for cost and energy efficient network operations (ICT-31766 METIS project, 2013).

Spectrum Usage

According to METIS investigations, ways to enable and secure sufficient access to spectrum for beyond 2020 wireless communication systems by developing innovative spectrum-sharing concepts (Afif Osseiran *et al.,* 2014). This should lead to substantial improvements in the overall spectrum utilization and result in increased spectrum usage efficiency from a spectrum-oriented as well as an economic point of view. In the beginning, the focus has been on frequency-band analysis in order to identify new spectrum resources and to understand their characteristics and on a scenario analysis of future wireless communication systems in order to understand spectrum requirements for beyond 2020 systems. Frequency band analysis has been looking for opportunities even up to 275 GHz. In a second step, innovative concepts and enablers for shared spectrum usage and flexible spectrum management have been initially developed. Here, some examples of novelty include identification of required enablers for ultra-dense network deployments operating at high frequencies as well as spectrum management for autonomous and network-assisted D2D communication supporting high mobility. The frequency range 380 – 5925 MHz is currently used by many different services. It should be noted, that any radio access system aiming at providing coverage in an extended area must use this frequency range for technical and economic reasons. Therefore, most of the METIS scenarios and test-cases will need to use at least one RAT in this frequency range. Additionally, in order to fulfill the requirements of the described test-cases, the communicating devices must also be equipped with RATs that can access higher frequency ranges, with large bandwidths (ICT-317669 METIS project, 2013). Highest priority for next further work for frequencies above 6 GHz is on frequencies between 40 and 90 GHz. Initial analysis (Woon Hau Chin *et al.,* 2015) indicates that not only more spectrum and more efficient spectrum usage concepts are required but also spectrum engineering with respect to guaranteeing co-existence, compatibility, and coverage due to the broader range of application requirements.

Challenges in 5G wireless systems

Challenges in Device Discovery and Link Setup: In non-network assisted device discovery in D2D communications, there could be issues when there is a large number of devices around. Additionally, setting up and maintain links with more than one party can prove to be difficult, especially when operating in the same frequency.

Challenges of Massive Machine access: Compared to conventional human to human traffic in cellular networks, a huge number of M2M devices in a cell can pose serious system challenges in terms of radio access network (RAN) congestion and overload. Currently a number of proposals have been projected in the third generation partnership project (3GPP) to address the RAN overload issue. For instance back-off adjustment, access class barring, and M2M prioritization (Woon Hau Chin *et al.,* 2014). However, each of these methods has its strengths and weaknesses and none of them is widely acknowledged as the best solution. Security and privacy: Security has been widely discussed in various standardization bodies. For instance, in ETSI M2M (TSI TC M2M, 2009), M2M security focuses on several attributes of a user and their communications, including authenticity, authority, integrity, and confidentiality. To enable wide deployment of M2M services and especially enhance consumer acceptance, M2M privacy is of paramount importance. Different M2M applications and sectors such as e-health and smart metering may have different privacy requirements which have to be taken into account right from the beginning of system design.

Testing challenges of 5G systems: The use of wide channel bandwidths, high data rate requirements, fast response times, more complex antenna configurations, and support for multiple radio access technology (RAT)pose significant challenges to the development of next generation Bss and devices. Testing of 5G systems is not limited to the hardware only, but it will be also required to validate new communications algorithms and approaches. Some of the key design and measurement challenges for 5G systems include (Rumney *et al.,* 2013; Ekram Hossain and Monowar Hasan, 2015):

- The requirement to handle multiple channel bandwidths
- The operability in higher bands,
- The use of different transmission modes in LTE. For instance orthogonal frequency-division multiple access (OFDMA) for up-link, single-carrier frequency-division multiple access (SC-FDMA) for down-link and also provisioning for both transmission modes. time/frequency-division duplexing [TDD/FDD])
- The support for multi-RAT.
- The spectral, power, and time variations. This is due to, not only the heterogeneous network traffic and node density, but also the need to support multi-antenna techniques.

The issues related to measurement and testing of the receiver radios for the 5G systems may include (Rumney *et al.,* 2013): verifying the RF and baseband receiver; receiver performance under impaired conditions (phase noise and additive white Gaussian noise impairments); receiver performance testing; testing the MIMO- enabled systems.

Conclusion

The overall approach towards 5G wireless systems and networks is to build on the evolution of existing technologies complemented by the integration of complementary concepts and, when needed, new radio access technologies. The integration of the new radio concepts such as Massive MIMO, Ultra-Dense Networks, Moving Networks, Direct Device-to-Device Communication, Ultra-Reliable Communication, Massive Machine Communication, and others, and the exploitation of new spectrum bands will allow systems to support the expected dramatic increase in the mobile data volume while broadening the range of application domains that mobile communications can support beyond 2020. Although there is currently no clear consensus among academics and industrials on what will define 5G wireless systems and networks, it is believed that future 5G wireless networks will be a combination of different enabling technologies, and the biggest challenge will be to make them all work together.

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