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A Review on 5G Technology Research Activities

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ABSTRACT

This paper summarizes the main initiatives toward 5G wireless communication networks. Emphasis is paid on the program and project activities as well as on the recent literature. A closer look to a wide range of 5G related projects is conducted. Literature review is restricted to recent thematic IEEE Communications Magazine 5G issues and relevant white papers from different sources. The aim is to shed some light on what 5G is about: what are the building blocks of core5G system concept, what the main challenges are and how to tackle them. The studied references indicate that in addition to capacity boosting technologies 5G needs to offer, e.g., low latency, ultra-reliable communications, and massive connectivity. Thus, the most demanding part in 5G development will be the design of flexible enough system concept platform that allows successful integration and management of various distinct technologies optimized for diverse use cases.

Keywords: - Include at least 5 keywords or phrases

1. Introduction

Increasing Internet data traffic has driven the capacity demands for currently deployed 3G and 4G wireless technologies. Now, intensive research toward 5th generation wireless communication networks is progressing in many fronts. 5G technology is expected to be in use around 2020. This paper scratches the surface on various 5G activities by reviewing a wide range of various research projects, recent literature and 5G white papers from key players in the wireless technology. The intention is to help understanding what 5G is about and how different 5G initiatives aim at getting there.

There is no unique definition (yet) for 5G [1], [2]. However, a general consensus is building around the idea that 5G is merely integration of several techniques, scenarios and use cases rather than the invention of a new single radio access technology. As technical requirements over currently existing technologies (4G) [3] lists the following:

- 1000 times higher mobile data volume per area,
- 10 to 100 times higher typical user data rate,
- 10 to 100 times higher number of connected devices,
- 10 times longer battery life for low power devices,
- 5 times reduced end-to-end latency.

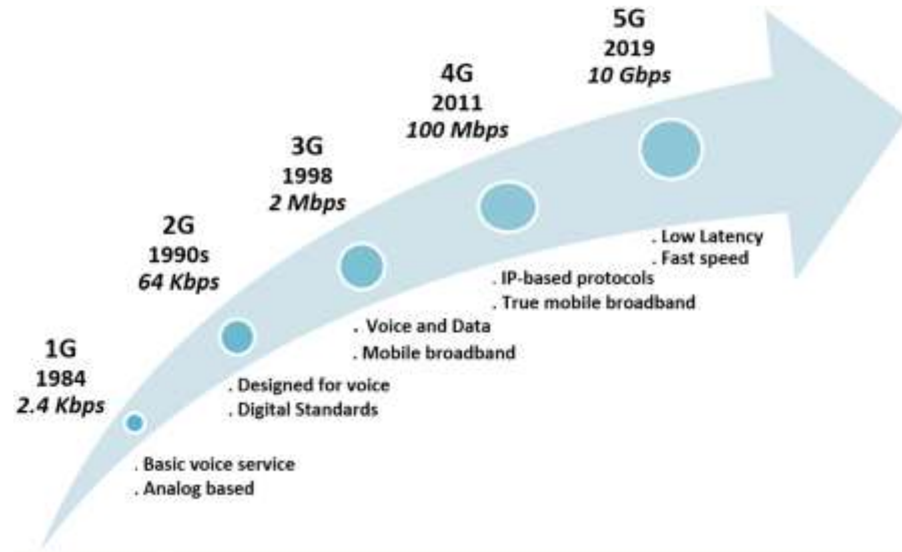

Fig. 1 The evolution of mobile communications

2. Literature Serve

A. 5G Section

Paper [4] challenges us to rethink relationship between energy and spectral efficiency (EE vs. SE). Co-design of these should be important part of 5G research. The ideal future system should have EE improvement for each SE point, larger win-win and smaller EE-SE trade-off region and smaller slope in EE-SE trade-off region. No more cells is another statement that suggests 5G to shift from cell-centric thinking towards soft user and C-RAN centric designs. The third point is to rethink signaling and control mechanisms for diverse traffic types. As the fourth aspect [4] introduces the concept of invisible base stations. It covers the deployment of massive MIMO in the form of irregular antenna arrays where antenna elements can be embedded into the environment (thus making base stations virtually invisible). Finally, full duplex radio is proposed as one useful technology component for 5G.
Similarly to the previous article, Boccardi *et al.* in [5], list five disruptive viewpoints toward 5G. Conventional base station based cellular structures (up/downlink, control/data channels) are expected to give way to more agile device-centric architectures where diverse nature of traffic and network nodes can be handled better. Additional broad bandwidths are available in millimeter waves and should be taken into use. Massive MIMO has potential for 5G as it is scalable technology at node level and enables new deployments and architectures. Devices are getting more intelligent and that should be reflected both at node and higher architectural level. As an example, D2D connectivity and mobile device caching have implications on 5G system design. An integral part of 5G should also be natural support for machine-to-machine (M2M) communication where the number of connected devices can be extremely large and high reliability and low latency are required.
Network densification is the main focus area of [6]. The two dimensions in this trend are over space and over frequency. Spatial domain is mostly covered by dense deployment of small cells whereas frequency domain densification comprises of aggregating larger chunks of radio spectrum from diverse bands into effective use. In parallel, high-capacity low-latency backhaul need to be developed to guarantee enhanced user experience.
Reference [7] makes the following key observations: 1) microcellular capacity increase is likely to reach its limits, 2) measures for mobile performance require updating, and 3) the variety of both the radio access technologies and the devices is increasing. 5G era needs co-optimization of networks, devices, and applications to achieve required improvements in service performance and efficiency. 5GNOW project's vision on 5G waveform design is reflected in [8]. The idea is to loosen the synchronism and orthogonally requirement by design and allow a controllable amount of waveform crosstalk. The resulting multi-carrier waveforms have some competitive edge over well-established OFDM technology. Lower end of the frequency spectrum has already been reserved to a large extent for various legacy systems. Therefore, broad contiguous bandwidths are only available at high center frequencies, e.g., millimeter waves. Reference [9] delves into millimeter-wave beam forming and its feasibility as a candidate technology for 5G. In addition to the theoretical prospects, prototyping status is reviewed so that practical aspects of millimeter-wave communications become addressed as well Full duplex (FD) technology is one potential building

block to be considered for 5G. Paper [10] concentrates on this technology and especially in self-interference mitigation that must be effective in FD systems to make them practical. Reference [11] differentiates outdoor and indoor scenarios in 5G cellular architecture design to avoid high wall penetration losses. Distributed antenna system (DAS) and massive MIMO technologies help in this. Indoor coverage can be provided via such short-range wireless technologies as WiFi, femtocells, visible light communication (VLC), and mm-waves whereas outdoor users are served by heterogeneous architecture including large MIMO networks, mobile femtocells and cognitive radio networks. Caching popular content in intermediate servers decreases redundant traffic in core network and thus alleviates network congestion problems. Current and foreseeable caching techniques for 5G are discussed in [12]. Fettweis and Alamouti [13] acknowledge that cellular telephony first had huge impact on voice services and later on data delivery. However, regarding Internet there is still much to be exploited by 5G technologies. As a result a user-centric future tactile Internet will utilize technological advancements in content delivery, control (response times) and monitoring (endurance).

B. 5G White Papers

4G Americas has very recently published a 44 page summary of global 5G initiatives [23] that overviews regional 5G activities in Europe, Asia and America. In addition to research projects, 5G related actions in standardization bodies (e.g., 3GPP, ITU, IEEE), associations (e.g., TIA), alliances (e.g., NGMN and WWRF) and industry are listed.

Nokia Solutions and Networks white paper [24] shares the view that 5G is unlikely to be just a single new radio access technology (RAT) but more like a combination of existing air interface technologies both in licensed and unlicensed bands with some novel technologies optimized for specific use cases and scenarios (e.g., ultra-dense deployments). Furthermore, more spectrum and small cell base stations are needed (network densification) and network performance needs enhancements (e.g., virtual zero latency) to make 5G reality.

Huawei has defined so-called “5G Hyper Service Cube” [25] to show 3D-illustration of how different types of services fit inside it. Dimensions in the cube are 1) throughput (kbps/km^2), 2) delay (ms), and 3) number of links (per km^2). As an example multi-user ultrahigh definition telepresence and smart sensors lie in the opposite corners of the cube as the former requires extremely high throughput and low number of connections and low latency whereas the latter service can tolerate large delay with low throughput but requires a large amount of links. Main design objectives for 5G are: 1) realization of massive capacity and connectivity, 2) support to very diverse set of services, applications, users and requirements, and 3) efficient and flexible utilization of all available non-contiguous spectrum resources.

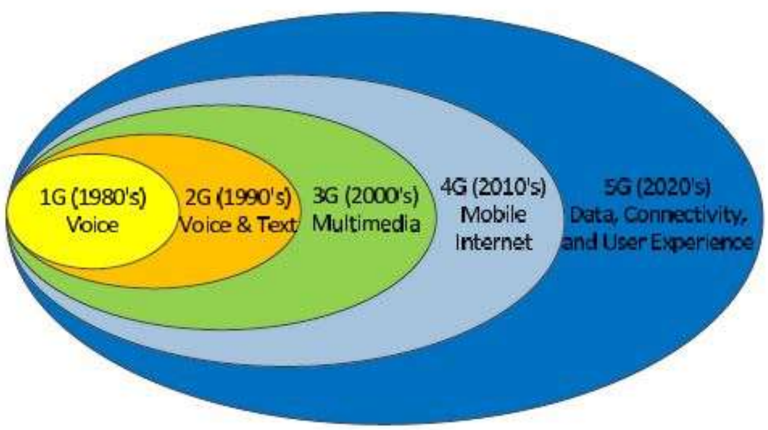

Fig. 2. Development of service types over wireless mobile generations.

Ericsson [26] reckons the following properties to be integral part of 5G: very high mobile broadband service level everywhere, ultra-high traffic capacity and data rates, huge number of low-power machine-type communication devices, proximal communication, ultra-reliable communication, energy efficiency and sustainability, and new spectrum assignments. Datang white paper [27] sees evolution, convergence and innovation to form the technology routes toward 5G. Fig. 2 shows how supported services evolve from 1G speech delivery via 3G multimedia up to versatility of 5G networks. ZTE [28] sees user experience being in focus of 5G research instead of only increasing network capacity. From the technical point of view the main challenges are: 1) massive traffic volumes, 2) gradual transfer to intelligent cloud architecture, 3) thorough convergence of networks and services, and 4) convert networks to have much more configurable capabilities. NTT DOCOMO [29] highlights the importance of lower and higher frequency bands' effective integration in order to achieve the intended 5G system capacity (1000-fold) and typical data rate (100-fold). This can be supported by phantom cell concept (where control and user planes are separated) and by flexible duplexing. In high frequencies new numerology and waveform design is needed and in lower frequencies nonorthogonal multiple access (NOMA) can be utilized.

3. Intelligent automation and economic contributions of 5G networks

Manufacturing industries are moving towards digitalization for several reasons, including increasing revenue by better serving their customers, increasing demand, beating the competition, decreasing costs by increasing productivity and efficiency, and decreasing risk by increasing safety and security. A recent study identified the key challenges and requirements in digitization industries digitization (Ericsson 2017). These requirements range from:

• Ultra-reliable, resilient, instantaneous connectivity for millions of devices.
• Low-cost devices with extended battery life.
• Asset tracking throughout the ever-changing supply chains.
• Performing remote medical procedures.
• Using AR/VR to enhance the shopping experiences.
• Using AI to enhance operations in multiple areas or enterprise-wide.

5G delivers a high-speed, reliable, and secure broadband experience, and will be a major technology for growing industry digitization. It will provide the networks and platforms to drive the digitization and automation of Industry 4.0. It will support the massive rollout of intelligent IoT and the widespread adoption of critical communications services (GSMA 2017).
In summary, 5G networks enable service providers to build virtual networks tailored to applications requirements such as:

• Mobile broadband communication, media and entertainment, and the Internet
• Machine-to-Machine (Massive IoT) Retail, shopping, manufacturing
• Reliable low latency Automobile, medical, smart cities
• Critical communications
• Others Industry-specific services, energy, etc.

4. 5G for the Internet of Things (IoT)

A. Internet of Things Defined The "Internet of things" (IoT) is an extension of the Internet and other network connections to different sensors and devices—or "things". The concept is based on a general rule that 'Anything that can be connected will be connected (Attaran 2017b). This includes everything from industrial equipment such as car engines, jet engines, the drill of an oil rig, washing machines, coffee makers, cellphones, wearable devices, and much more. IoT provides a higher degree of computing and analytical capabilities to even single objects. IoT is a rapidly evolving technology that more and moreindustries are willing to adapt to improve their efficiency. Smart terminals, mobile broadband, and cloud computing enable widespread connectivity, transforming the way we perceive the world around us people (Attaran 2017b)

5. 5G and manufacturing industry

Manufacturing companies around the world are under extreme competitive pressure due to shorter business and product lifecycles. Margins are being squeezed more than ever, and workforces are aging and becoming costlier to maintain. To compete globally, manufacturing companies have to improve efficiency and reduce costs through new process innovations—technologies like robotics, warehouse automation, smart factories, and flexible manufacturing help. 5G networks and IoT will play crucial roles in enhancing and enabling these manufacturing advances. 5G networking technologies provide the network characteristics essential for manufacturing. 5G will give manufacturing companies a chance to build smart factories and truly take advantage of technologies such as automation, artificial intelligence, and augmented reality for troubleshooting. 5G is a significant technology for industry digitalization that directly enhances connectivity, quality, speed, latency, and bandwidth. 5G could help overcome manufacturing problems and pain points, including connectivity issues such as insufficient bandwidth, speed, and latency issues. 5G will also improve connectivity for a large network of sensors for predictive maintenance of factory floor machines and robots. 5G networks will allow for higher flexibility, lower cost, and shorter lead times for factory floor layout changes and alterations. 5G networks, services, and connectivity capabilities have the potential to transform production, business models, and sales in ways that will benefit manufacturing. Advanced 5G networks and information processing technology can streamline smart factories, improve internal and external communications, and unify full product life cycle management on a single network. Other important pain points and crucial manufacturing use cases 5G can overcome are summarized in Table 1 (Ericsson 2019).

6. 5G advantages for healthcare

5G networks and services provide mobile health platform advantages such as integrated mobility and advanced connectivity so doctors and nurses can achieve patient monitoring anywhere, anytime. 5G technology enables patients to use wearable devices to transmit their health symptoms and status. 5G enhanced mobile broadband with faster speed and more bandwidth can help doctors have access to patient's information for remote monitoring and diagnosis.

5G networks enable factory robots to communicate their task and position, allowing them to do more tasks efficiently and wirelessly. Drones could fly over a field of crops, using sensors on the ground, to sort, pick, feed, and water individual plants. In April 2019, a Chinese neurosurgeon successfully operated on a patient suffering from Parkinson's disease. The doctor used a pacemaker-like implant on a patient that was about 1864 miles away during the surgery.

This surgery was only possible because of the lightning-fast connection of 5G networks that allows surgeons such as the one in China to control an off-site surgical robot and operate in real-time (China Daily 2019). A recent study by Ericsson identified different ways the healthcare industry can derive value out of 5G networking technology (Ericsson 2018). They are summarized below:

7. 5G for smart cities

In addition, 5G is a critical element in providing better networking in our technological world. For example, a smart city integrates information and communication technology and 5G networking solutions in a secure fashion to manage a city's different functions. Those functions include, but are not limited to, schools, libraries, transportation systems, hospitals, power plants, water supply networks, waste management, law enforcement, and other community services. There is a need for finding a way of aggregating multiple layers of data, spanning traffic flows, individual transactions, human movement, shifts in energy usage, security activity, and almost any major component of contemporary economies. 5G technology can facilitate this aggregation. 5G technology can facilitate this aggregation. The savings gained from Smart Cities is incredible. For example, smart water technology can save $12 billion annually. Sensors installed in individual vehicles can be linked to broader systems that help to manage traffic congestion across the city.

• Effective capture of the vast amount of patient data.
• Real-time mobile delivery of rich medical data.
• Improved availability of suitable infrastructure.
• Improved security of patient data and superior data storage.
• Ability to accurately control remote medical equipment without delay.
• Ability to incorporate augmented and virtual reality for enhanced training of interns.
• Facilitate the connectivity and operations of smart medical objects and instruments such as syringes, beds, and cabinets.

Conclusion

This paper gives an overview of different 5G activities around the world and particularly in Europe. The special attention is paid on key literature, projects and programs focusing on 5G technology. Although the 5G concept is still evolving the review reveals emerging common features. Performance enhancements are mainly expected from a combination of network densification (e.g., small cells, D2D), increased spectrum (enhanced carrier aggregation, spectrum sharing, beyond 6 GHz frequencies), and enhanced wireless communication technologies (e.g., massive MIMO, new waveforms, virtual zero latency RATs). Machine-type of communications will have increasing proportion of the network connections and traffic. Combination of moving networks and ultra reliable communications truly calls for novel solutions due to strict technical requirements in challenging propagation conditions. Network virtualization, especially in the form of Cloud RAN development will also have a significant role in 5G. Use cases, scenarios and spectrum allocations altogether have so high variability that utmost agility, scalability and reconfigurability is necessary in the integration of the overall 5G system concept.

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