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A survey on 5G: The next generation of mobile communication

Nisha Panwar [a], Shantanu Sharma [a,*], Awadhesh Kumar Singh [b]

[a] Department of Computer Science, Ben-Gurion University of the Negev, Israel

[b] Department of Computer Engineering, National Institute of Technology, Kurukshetra, India

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ABSTRACT

The rapidly increasing number of mobile devices, voluminous data, and higher data rate are pushing to rethink the current generation of the cellular mobile communication. The next or fifth generation (5G) cellular networks are expected to meet high-end requirements. The 5G networks are broadly characterized by three unique features: ubiquitous connectivity, extremely low latency, and very high-speed data transfer. The 5G networks would provide novel architectures and technologies beyond state-of-the-art architectures and technologies. In this paper, our intent is to find an answer to the question: "*what will be done by 5G and how*?" We investigate and discuss serious limitations of the fourth generation (4G) cellular networks and corresponding new features of 5G networks. We identify challenges in 5G networks, new technologies for 5G networks, and present a comparative study of the proposed architectures that can be categorized on the basis of energy-efficiency, network hierarchy, and network types. Interestingly, the implementation issues, *e.g.*, interference, QoS, handoff, security–privacy, channel access, and load balancing, hugely effect the realization of 5G networks. Furthermore, our illustrations highlight the feasibility of these models through an evaluation of existing real-experiments and testbeds.

1. Introduction

The evolution of the cellular network generations is influenced primarily by continuous growth in wireless user devices, data usage, and the need for a better quality of experience (QoE). More than 50 billion connected devices are expected to utilize the cellular network services by the end of the year 2020 [1], which would result in a tremendous increase in data traffic, as compared to the year 2014 [2]. However, state-of-the-art solutions are not sufficient for the challenges mentioned above. In short, the increase of 3D ('D'evice, 'D'ata, and 'D'ata transfer rate) encourages the development of 5G networks.

Specifically, the fifth generation (5G) of the cellular networks will highlight and address three broad views, as: (i) user-centric (by providing 24 × 7 device connectivity, uninterrupted communication services, and a smooth consumer experience), (ii) service-provider-centric (by providing a connected intelligent transportation systems, road-side service units, sensors, and mission critical monitoring/tracking services), and (iii) network-operator-centric (by providing an energy-efficient, scalable, low-cost, uniformly-monitored, programmable, and secure communication infrastructure). Therefore, 5G networks are perceived to realize the three main features as below:

- *Ubiquitous connectivity*: In future, many types of devices will connect ubiquitously and provide an uninterrupted user experience. In fact, the user-centric view will be realized by ubiquitous connectivity.

* Corresponding author.
E-mail addresses: panwar@cs.bgu.ac.il (N. Panwar), sharmas@cs.bgu.ac.il (S. Sharma), aksingh@nitkkr.ac.in (A.K. Singh).

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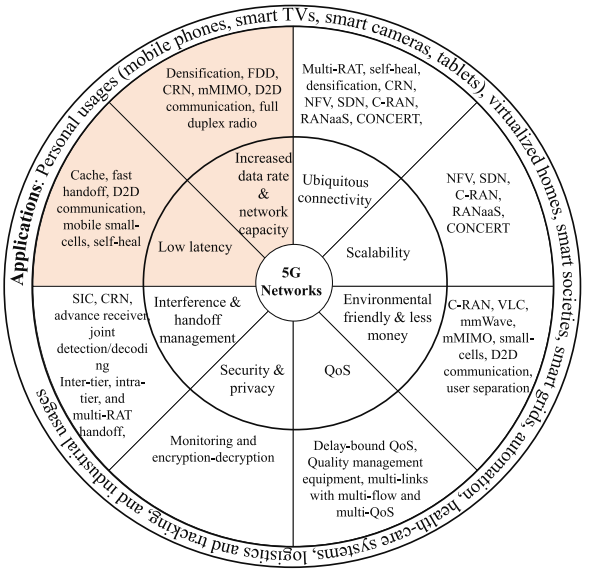

Fig. 1. Requirements and proposed solutions for the development of 5G networks. The inner, middle, and outermost layers present requirements, solutions, and applications of 5G networks, respectively. Two colored wedges highlight primary features of 5G networks.

- *Zero latency*: The 5G networks will support life-critical systems, real-time applications, and services with zero delay tolerance. Hence, it is envisioned that 5G networks will realize zero latency, i.*e*., extremely low latency of the order of 1 millisecond [3,4]. In fact, the service-provider-centric view will be realized by the zero latency.
- *High-speed Gigabit connection*: The zero latency property could be achieved using a high-speed connection for fast data transmission and reception, which will be of the order of Gigabits per second to users and machines [3].

A few more *key features of 5G networks* are enlisted and compared to the fourth generation (4G) of the cellular networks, as below [5–7]: (i) 10–100*x* number of connected devices, (ii) 1000*x* higher mobile data volume per area, (iii) 10–100*x* higher data rate, (iv) 1 ms latency, (v) 99.99% availability, (vi) 100% coverage, (vii) $\frac{x}{10}$ energy consumption as compared to the year 2010, (viii) real-time information processing and transmission, (ix) $\frac{x}{5}$ network management operation expenses, and (x) seamless integration of the current wireless technologies.

The revolutionary scope and the consequent advantages of the envisioned 5G networks, therefore, demand new architectures, methodologies, and technologies (see Fig. 1), *e.g.*, energy-efficient heterogeneous frameworks, cloud-based communication (software-defined networks (SDN) and network function virtualization (NFV)), full duplex radio, self-interference cancellation (SIC), device-to-device (D2D) communications, machine-to-machine (M2M) communications, access protocols, cheap devices, cognitive networks (for accessing licensed, unlicensed, and shared frequency bands), dense-deployment, security–privacy protocols for communication and data transfer, backhaul connections, massive multiple-input and multiple-output (mMIMO), multi-radio access technology (RAT) architectures, and technologies for working on millimeter wave (mmWave) 30–300 GHz. Interestingly, 5G networks will not be a mere enhancement of 4G networks in terms of additional capacity; they will encompass a system architecture visualization, conceptualization, and redesigning at every communication layer [8].

Several industries, *e.g.*, Alcatel-Lucent [9], DOCOMO [10], GSMA Intelligence [6], Huawei [11], Nokia Siemens Networks [3], Qualcomm [12], Samsung [13], Vodafone,[1] the European Commission supported 5G Infrastructure Public Private Partnership (5GPPP) [5], and Mobile and Wireless Communications Enablers for the Twenty–Twenty Information Society (METIS) [7], are brainstorming with the development of 5G networks. Currently, the industry standards are yet to be evolved about the expected designs and architectures for 5G networks.

Scope of the paper. In this paper, we will review the vision of the 5G networks, advantages, applications, proposed architectures, implementation issues, real demonstrations, and testbeds. The outline of the paper is provided in Fig. 2. In Section 2, we will elaborate the vision of 5G networks. Section 3 presents challenges in the development of 5G networks. Section 4 addresses the currently proposed architectures for 5G networks, *e.g.*, multi-tier, cognitive radio based, cloud-based, device proximity based, and energy-efficient architectures. Section 5 presents issues regarding interference, handoff, quality of services, load balancing, channel access, and security–privacy of the network. Sections 6–8 present several methodologies and technologies involved in 5G networks, applications of 5G networks, and real demonstrations and testbeds of 5G networks, respectively.

We would like to emphasize that there do exist some review works on 5G networks by Andrews et al. [14], Chávez-Santiago et al. [15], and Gavrilovska et al. [16], to the best of our knowledge. However, our perspective about 5G networks is different, as we deal with a variety of architectures and discuss several implementation affairs, technologies in 5G networks along with applications and real-testbed demonstrations. In addition, we intentionally avoid an mmWave oriented discussion in this paper, unlike the current work [14–16].

We encourage our readers to see an overview about the generations of the cellular networks (see Table 1) and the crucial limitations of current cellular networks in the next section.

1.1. Limitations of the conventional cellular systems

The 4G networks are not substantial enough to support massively connected devices with low latency and significant spectral efficiency, which will be crucial in the future communication and computing. In this section, we discuss a few crucial aspects in which conventional cellular networks lag far behind, thereby motivating the evolution of 5G networks.

[1] http://www.surrey.ac.uk/5gic/research.