Study the Challenges of Using and Development of 5G Networks

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Abstract: The main goal of this paper is study of the challenges of using and development of 5G networks. 5G is a wireless connection built specifically to keep up with the proliferation of devices that need a mobile internet connection. It's going to allow people send texts, make calls, and browse the web as always—and it will dramatically increase the speed at which data is transferred across the network. 5G will make it easier for people to download and upload Ultra HD and 3D video. 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. 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.
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1. Introduction

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

5G networks are perceived to materialize the three main features as below:

• Ubiquitous connectivity: In the 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.

• Zero latency: 5G networks will support life-critical systems and real-time applications and services with zero delay tolerance. Hence, it is envisioned that 5G networks will realize zero latency, i.e, very low latency of the order of 1 millisecond. 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.

Therefore, the revolutionary scope and the consequent advantages of the envisioned 5G networks demand new architectures, methodologies, and technologies (see Figure 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.

In this paper, we will review the vision of the 5G networks, advantages, applications, proposed architectures, implementation issues, real demonstrations, and testbeds. We would like to emphasize that there are some review works on 5G networks by Andrews et al., Chávez-Santiago et al., and Gavrilovska et al., 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.

Heterogeneous wireless networks (HetNets) are composed of wireless networks of diverse access technologies, e.g., the third generation (3G), 4G, wireless local area networks (WLAN), WiFi, and Bluetooth. HetNets are already standardized in 4G; however, the basic architecture was not intended to support them. Furthermore, the current cellular networks allow a UE to have a DL channel and a UL channel must be associated with a single BS that prevents the maximum utilization of HetNets. In HetNets, a UE can select a UL channel and a DL channel from two different BSs belonging to two different wireless networks for performance improvement.

The current cellular networks have a single BS installed near the center of the cell and interacts with all the UEs irrespective of the indoor or outdoor location of the UEs; while UEs stay indoors and outdoors for about 80% and 20% of the time, respectively. Furthermore, the communication between an indoor UE and an outside BS is not efficient in terms of data transfer rate, spectral efficiency, and energy-efficiency, due to the attenuation of signals passing through walls. Dimensions and quantification of projected capacity growth in 5G was shown in Figure 1.

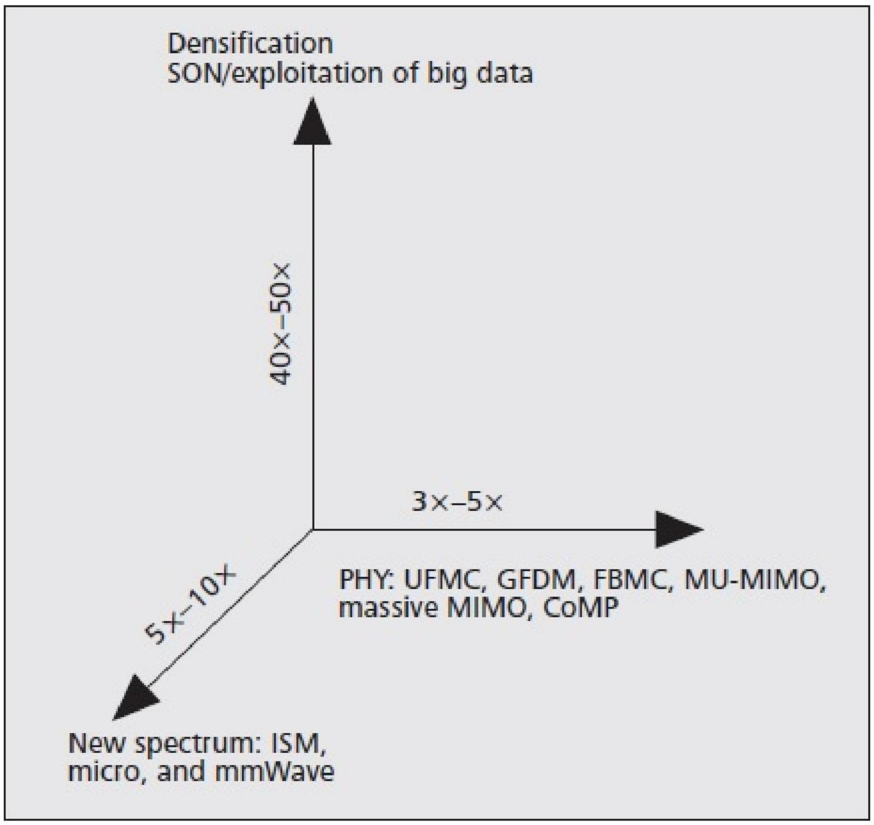

Fig. 1. Dimensions and quantification of projected capacity growth in 5G.

A growing number of UEs and the corresponding surge in the bandwidth requirement for the huge amount of data transmission certainly necessitate the novel enhancement to the current technology. In this section, we highlight requirements of the future 5G networks. Dramatic upsurge in device scalability. A rapid growth of smart phones, gaming consoles, high-resolution TVs, cameras, home appliances, laptops, connected transportation systems, video surveillance systems, robots, sensors, and wearable devices (watches and glasses) is expected to continue exponentially in the near future. Therefore, 5G networks are perceived to support massively connected devices. Massive data streaming and high data rate. A vast growth in a number of wireless devices will of course result in a higher amount of data trading (e.g., videos, audio, Web browsing, social-media data, gaming, real-time signals, photos, bursty data, and multimedia) that will be 100-times more as compared to the year 2014 and would overburden the current network. Thus, it is mandatory to have matching data transfer capabilities in terms of new architectures, methods, technologies, and data distribution of indoor and outdoor users. Spectrum utilization. The two different channels (one for a UL and another for a DL) seem redundant from the point of view of the spectrum utilization. In addition, the currently allocated spectrums have their significant portions under-utilized. Hence, it is necessary to develop an access control method that can enhance the spectrum utilization. Furthermore, the spectrum utilization and efficiency have already been stretched to the maximum. It definitely requires spectrum broadening (above 3 GHz) along with novel spectrum utilization techniques. Ubiquitous connectivity. Ubiquitous connectivity requires UEs to support a variety of radios, RATs, and bands due to the global non-identical operating bands. In addition, the major market split between time division duplex (e.g., India and China) versus frequency division duplex (e.g., US and Europe) so that UEs are required to support different duplex options. Hence, 5G networks are envisioned for seamless connectivity of UEs over HetNets. Zero latency. The future mobile cellular networks are expected to assist numerous real-time applications, the tactile Internet, and services with varying levels of quality of service (QoS) (in terms of bandwidth, latency, jitter, packet loss, and packet delay) and QoE (in terms of users' and network-providers' service satisfaction versus feedback). Hence, 5G networks are envisioned to realize real-time and delay-bound services with the optimal QoS and QoE experiences.

Challenges in the Development of 5G Networks

The vision of 5G networks is not trivial to achieve. There are several challenges (some of the following challenges are shown in Figure 1 with their proposed solutions) to be handled in that context, as mentioned below:

The deployment of more BSs in a geographical area, use of the higher frequency bands, and link improvement might support the network capacity expansion, billions of UEs, high data rate, high volume of data, and efficient backhaul data transfer to the core network. However, the implementation of these solutions is a cumbersome task in terms of economy and energy intake. Hence, the network capacity is required to be significantly increased, keeping the energy consumption and cost under strict control.

Scalability and flexibility. These are the most prominent features of the future mobile communication. The future cellular infrastructures and methodologies must be designed to work in HetNets. Moreover, a vast number of potential users might request simultaneously for a set of services. Therefore, 5G networks must be powerful enough to support a scalable user demand across the coverage area.

A full duplex wireless radio uses only a single channel for transmitting and receiving signals at identical time and frequency. Thus, a full duplex system achieves an identical performance as having different UL and DL channels, and hence, increases link capacity, saves the spectrum, and cost. However, the implementation of full duplex systems is not trivial, because now a radio has to use sophisticated protocols for the physical and the data link layers, and mechanisms to remove the effects of interference. The advantages of a full duplex radio in 5G networks.

In 5G networks, a UE may receive interference from multiple macrocell base-stations (MBSs), various UEs, and small-cell base-stations (SBSs). Hence, it is required to develop an efficient (in terms of avoiding network overload) and reliable (in terms of perfect interference detection and decoding) interference management technique for channel allocation, power control, cell association, and load balancing.

The current radio access network (RAN) consumes 70%-80% of the total power. The wireless technologies consume lots of energy that lead to huge CO2 emission and inflate the cost. It is a serious threat to the environment. Thus, it is required to develop energy-efficient communication systems, hardware, and technologies, thereby the ratio between the network throughput and energy consumption is equitable.

Economic impacts: A revolutionary change in the future mobile communication techniques would have drastic economic impacts in terms of deployment and motivation for user participation. It is critical to provide an entirely new infrastructure due to economical stretch. Therefore, the cost of deployment, maintenance, management, and operation of an infrastructure must be affordable from the perspective of governments, regulating authorities, and network operators. Also, the cost of using D2D communication should be feasible, so that devices involved in D2D communication should not charge more than using the services of a BS [15, 46]. Further, the projected revenue growth is much lower than the traffic growth; hence, it is required to develop 5G networks in a manner that both network operators and users get honey in their hands.

The 5G wireless UEs are meant for retaining an active service connection while frequently moving from one cell to another or from one RAT (e.g., 3G, 4G, 5G, WiFi, Bluetooth, and WLAN) to another. The mobility adaptation for the wireless services should not back-off even at a very high speed as a UE inside a moving vehicle. Moreover, during a particular interval, many UEs move from one place to another; for example, moving to offices from residential areas in the morning. As a result, 5G networks are envisioned to use the spectrum in the best manner and to cope up with pace of the device movement.

QoS guarantee in 5G networks has inherent difficulties, e.g., node mobility, multi-hop communication, resource allocation, and lack of central coordination. In addition, in 5G networks, a huge amount of bursty and multimedia data, multi-RATs, and low latency bound for different applications and services are major hurdles in achieving the desired QoS. Hence, it is challenging to design fast and efficient algorithms to maintain real-time QoS without overloading a BS.

Security and privacy of 5G network: The promising features of 5G networks bring in hard challenges in the design of security and privacy oriented 5G networks. For example, a huge number of new types of social (all-time connected) devices may originate several types of attacks like impersonation, denial-of-services (DoS), replay, eavesdropping, man-in-the-middle, and repudiation attacks. Also, the transfer of a huge volume of data in secure and high speed manners is critical while preventing malicious files to penetrate. In addition, the network densification needs to be secure and requires fast-secure handoff of UEs. We further highlight challenges in security and privacy of the network.

Wang et al. suggested a way for separating indoor and outdoor users and using a mobile small-cell on a train or a bus. For separating indoor and outdoor users, a MBS holds large antenna arrays with some antenna elements distributed around the macrocell and connected to the MBS using optical fibers.

Advantage of the deployment of 5G network.

• High data rate and efficient spectrum use: The small physical separation between a SBS and UEs (served by the same SBS) leads to a higher data rate and a better indoor coverage. Also, the spectrum efficiency increases due to fewer UEs in direct communication with a MBS.

• Energy saving: The use of small-cells reduces the energy consumption of the network (by not involving MBSs) and of UEs (by allowing UEs to communicate at a shorter range with low signaling overhead).

• Money saving: It is more economical to install a SBS without any cumbersome planning as compared to aMBS, and also the operational-management cost is much lower than the cost associated with a MBS.

• The plug-and-play utility of small-cells boosts the on-demand network capacity.

• Less congestion to a MBS: SBSs offload UEs from a MBS so that the MBS is lightly loaded and less congested, and hence, improve the system capacity.

• Easy handoff: Mobile small-cells also follow the advantages of small-cells. Moreover, they provide an attractive solution to highly mobile UEs by reducing handoff time overheads, since a mobile small-cell is capable to do the handoff on behalf of all related UEs.

Advantages of CRNs in 5G networks

• Minimizing interference: By implementing a CRN at small-cells, cognitive small-cells can avoid interference very efficiently by not selecting identical channels as the channels of neighboring small-cells.

• Increase network capacity: The spectrum holes can be exploited for supporting a higher data transfer rate and enhancing bandwidth utilization.

Resource allocation methods: Now, we will review an architecture and some methods for resource allocation in D2D communication. Social-Aware D2D Architecture: As D2D communication is very efficient for close proximity UEs, keeping this fact in view, Li et al. suggested a social-aware D2D communication architecture based on the social networking. The architecture, see Figure 4, has four major components as:

• Ties: They are similar to friend relations in a social media, and hence, may be used as a trust measurement between two UEs. Allocating more spectrum and energy resources to UEs with strong ties can increase the peer discovery ratio, avoid congestion, and improve spectral efficiency.

• Community: It is similar to a group on Facebook and helps in allocating more resources to all the UEs in a community to decrease content duplication and increase the network throughput.

• Centrality: It is similar to a node that has more communication links/friends in a social network. The concept of centrality in D2D communication reduces congestion and increases the network throughput by allocating more resources to a central node.

• Bridges: They are similar to a connection between two communities. Hence, two devices forming a bridge can be allocated more resources as compared to other devices.

Hoang et al. provided an iterative algorithm for subcarrier4 and power allocation such that the minimal individual link data rates and proportionate fairness among D2D links are obtained. A 2-phase service-aware resource allocation scheme, called SARA, is proposed. In the first phase of SARA, resources are allocated on-demand to meet different service requirements of D-UEs, and in the second phase of SARA, the remaining resources are allocated to D-UEs such that the system throughput increases.

Energy-Efficient Architectures for 5G Networks

Energy-efficient infrastructures are a vital goal of 5G networks. Researchers have proposed a few ways of reducing energy in the infrastructure. Rowell et al. considered a joint optimization of energy-efficiency and spectral-efficiency. A user-centric 5G network is suggested in so that UEs are allowed to select UL and DL channels from different BSs depending on the load, channel conditions, services and application requirements. In a similar manner, decoupling of signaling and data is useful for energy saving; for example, a MBS may become a signaling BS while SBSs may serve all data requests. Thus, when there is no data traffic in a SBS, it can be turned off. A similar approach for decoupling of signaling and data is presented. However, a UE gets connected to a SBS according to instructions by a MBS, and hence, it results in less energy consumption at UEs' side due to less interference, faster small-cells' discovery, and MBS-assisted handover.

Hu and Qian provided an energy-efficient C-RAN architecture in a manner that RRHs serve almost a same number of UEs. They also present an interference management approach so that the power consumption of SBSs and MBSs can be decreased. Like Rowell et al., Hu and Qian also suggested that the association of a UE cannot be done based on entirely a DL channel or a UL channel, and a UE must consider both the channels at the time of association with a BS. Lin et al. suggested to include an energy harvesting device (to collect energy) and a spectrum harvesting controller (to collect spectrum) at SBSs.

Interference Management in 5G Networks

We have already seen challenges in interference management. In this section, we will review some techniques/methods for interference management in 5G networks. Nam et al. handled UE-side interference by using a new type of receiver equipment, called an advanced receiver, which detects, decodes, and removes interference from receiving signals. In addition, the network-side interference is managed by a joint scheduling, which selects each UE according to the resources needed (e.g., time, frequency, transmission rate, and schemes of multiple cells) for its association with a BS. Hence, the joint scheduling, which can be implemented in a centralized or distributed manner, requires a coordination mechanism among the neighboring cells. Hossain et al. proposed distributed cell access and power control (CAPC) schemes for handling interference in multi-tier architectures. CAPC involves: (i) prioritized power control (PPC), which assumes that UEs working under a SBS have a low-priority than UEs working under aMBS, and hence, low-priority UEs set their power so that the resulting interference must not exceed a predefined threshold; (ii) cell association (CA), which regards dynamic values of resources, traffic, distance to a MBS, and available channels at a MBS for selecting a MBS with the optimum values of the parameters; and (iii) resource-aware CA and PPC (RCA-PPC), which is a combination of the first two approaches and allows a UE to connect simultaneously with multiple BSs for a UL channel and a DL channel based on criteria of PPC and CA.

Conclusion:

In this survey, we discussed salient features, requirements, applications, and challenges behind the development of the next and the fifth generation (5G) of cellular mobile communication that is expected to provide very high speed data transfer and ubiquitous connectivity among different types of devices. We reviewed some architectures for 5G networks based on the inclusion of small-cells, cognitive radio networks, device-to-device communication, and cloud-based radio access networks. We find out that energy consumption by the infrastructure will be a major concern in 5G networks, and hence, reviewed energy-efficient architectures. We figured out several open issues, which may drive the future inventions and research, in all the architectures. The development of new architectures is not only a solution to 5G networks; there will be a need for handling other implementation issues in the context of users, e.g., interference removal, handoff management, QoS guarantee, channel accessing, and in the context of infrastructures, e.g., load balancing. During our illustration, we included several new techniques, e.g., full duplex radios, dense-deployment techniques, SIC, DUD, mmWave, mMIMO, and VLC. We also discussed the current trends in research industries and academia in the context of 5G networks based on real-testbed and experiments for 5G networks.

We conclude our discussion with a resonating notion that the designing of 5G infrastructure is still under progress. The most prominent issues are enlisted below, also providing elegant solutions to these issues would contribute in early deployment and long run growth of 5G networks.

• Security and privacy of devices, infrastructures, communication, and data transfer is yet to be explored. We believe that the current solutions based on encryption would not work in the future due to a huge number of devices. Intuitively, a solution that would use an authenticated certificate may be feasible.

• The development of network devices, infrastructures, and algorithms must be self-healing, self-configuring, and self-optimizing to preform dynamic operations as per the need, for example, dynamic load balancing, QoS guarantee, traffic management, and pooling of residual resources.

• The cloud computing is an attractive technique in the current trend for various applications. We have reviewed C-RANs; however, the current solutions do not consider an impact of virtualization for backhaul data transfer, the trust of the cloud, inter-cloud communication, ubiquitous service guarantee, and real-time performance guarantee with zero-latency. Thus, the development of C-RANs must address the major question that how much virtualization is good?

• Designs, developments, and usages of user devices, service-application models, and, especially, the network devices must be affordable to cater the needs of overwhelming users, service providers, and network providers.

• Zero latency is a primary concern in most of the real-time applications and services, especially, in the tactile Internet. However, all the existing architectures and implementations of 5G networks are far from achieving the zero latency. Therefore, the latest real-time and ultra-reliable network configurations must be improved to a latency free environment.

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