Requirements of 5G:

The number of devices is increasing day by day this is causing a huge bandwidth requirement for the huge amount of data transmission certainly necessitate the novel enhancement to the current technology. we highlight necessary parts of the future 5G networks.

**Dramatic upsurge in device scalability.** The number 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 grow exponentially in the near future. Therefore, 5G networks are perceived to support massively connected devices [1, 15].

**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 transfer (e.g., videos, audio, Web browsing, social-media data, gaming, real-time signals, photos, busty data, and multimedia) that will be 150-times more as compared to the year 2016 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 [15, 60].

**Spectrum utilization.** The use of two different channels (one for a Up Link and another for a Down Link) seem redundant from the point of view of the spectrum utilization [9]. In addition, the currently allocated spectrums have their significant portions under-utilized [12]. Hence, it is necessary to develop an access control method that can enhance the spectrum utilization. Again, 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 [34].

**Uninterrupted connectivity.** Uninterrupted 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 [13].

**3 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:

**Data rate and network capacity expansion with energy optimization.** 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.

Proposed solutions: Network densification or small-cell deployment [15, 28, 107] (Section 4.1), cognitive radio networks (CRNs) [16] (Section 4.2), mMIMO [71, 81, 87] (Section 6), network offload using D2D communication [33, 104, 113] (Section 4.3), efficient backhaul networks [51, 88] (Section 4.1.1), energy-efficient architectures [62, 83] (Section 4.5), full duplex radios [27] (Section 6), NFV, and SDN based architectures [14, 78, 97, 119] (Section 6).

**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 [78, 94]. Proposed solutions: NFV- and SDN-based architectures [14, 78, 97, 119] (Section 6).

**Single channel for both UL and DL.** A full duplex wireless radio [27] 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 [122], and mechanisms to remove the effects of interference [59]. The advantages of a full duplex radio in 5G networks are given in [56, 59, 64].

**Handling interference.** Handling interference among communicating devices is a well-known challenge in the wireless communication. Due to a growing number of UEs, technologies (e.g., HetNets, CRNs, full duplex, and D2D communication) and applications, the interference will also increase in 5G networks, and the state-of-the-art technique may not perform well in the future cellular networks [61]. 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.

Proposed solutions: Self-interference cancellation [64, 59], an advance receiver with interference joint detection/decoding, and network-side interference management [86]. We will discuss these solutions in Section 5.1.

**Environmentally friendly.** The current radio access network (RAN) consumes 70%-80% of the total power [64,193 114]. The wireless technologies consume lots of energy that lead to huge CO2 emission and inflate the cost. It is serious threat to the environment [107]. 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.

Proposed solutions: Cloud-RAN (C-RAN) [114, 62], visual light communication (VLC) [114], mmWave [114], separation of indoor and outdoor users [114], joint investigation of spectral efficiency and energy-efficacy [64, 62], multi-tier architectures [62], D2D communication [33, 104, 113], mMIMO architectures [62], and full duplex radios [64]. Except the above-mentioned solutions, we will discuss some special techniques/architectures in the context of energy-efficiency in 5G networks in Section 4.5.

**Low latency and high reliability.** Low latency and high reliability are critical in several real-time applications, e.g., message transmission by robots monitoring patients, life safety systems, cloud-based gaming, nuclear reactors, sensors, drones, and connected transportation systems. However, it is very challenging to have very low latency and reliable delivery of data over a large-scale network without increasing the network infrastructure cost, as it requires the development of techniques providing fast connections, quick handovers, and high data transfer rate.

Proposed solutions: Caching methods [29, 112], VLC, mmWave, mMIMO (Section 6), fast handover techniques [40, 93, 102] (Section 5.2), and D2D communication (Section 4.3). Network performance optimization. The performance parameters, e.g., peak data rate, geographical area coverage, spectral efficiency, QoS, QoE, ease of connectivity, energy-efficiency, latency, reliability, fairness of users, and implementation complexity, are crucial for a cellular network [107]. Hence, a general framework for 5G networks should substantially optimize these parameters. However, there are some tradeoffs among all parameters, which further emphasize the need of a joint optimization algorithm.

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 [14]; hence, it is required to develop 5G networks in a manner that both network operators and users get honey in their hands.

**High mobility and handoff.** 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.

Proposed solutions: Inter-tier, intra-tier, and multi-RATs handoff mechanisms, and a mechanism for secure handoff [40, 93, 102, 52], which we will discuss in Section 5.2.

**Self-healing infrastructures.** A self-healing infrastructure finds a failed macrocell or small-cell (i.e., a cell that is unable to work because of hardware failures, software failures, or misconfigurations) with the help of neighboring cells and provides a way for communication to the affected users by adjusting the transmission power and operating channels in the neighboring cells [41, 111]. The design of a self-healing network insists on the frequent communication among cells; hence, it brings in the following challenges, as: (i) develop an efficient algorithm that can detect and reconfigure a failed cell with insignificant communication and computational overheads in the minimal detection time, and (ii) reconfiguration of a failed cell should not lead to degradation of nearby cells’ services.

Proposed solutions: A small-cell network with self-healing property is suggested in [111], which we will discuss in Section 4.1.2.

**QoS.** 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 burst 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 [123, 120].

Proposed solutions: Delay-bound QoS [62, 120], intelligent equipment [123], and multi-link with multi-flow and multi-QoS [69] have been suggested, which we will discuss in Section 5.3.

**Security and privacy of the network and UEs.** 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 and UEs in Section 5.6.

Proposed solutions: Physical layer security [118], monitoring [105, 48, 76], secret adaptive frequency hopping [76], encrypted- [79], and policy-based communications [67], which we will discuss in Section 5.6. All the above mentioned methodologies and technologies are comparatively studied in Table 2.