in which the spatial inconsistency of current drop-based channel models requires novel modeling approach.

Some research groups also conducted research and measurements on the time-varying dual-mobility channel. The method of ray tracing is widely used to characterize the ray propagation in a dynamic environment [165–168]. However, the granularity of ray tracing results will be affected greatly by the database of the specific environment and computation capability of workstations. Additionally, the variation of propagation paths and the transition between LOS and NLOS propagation are often neglected. A 3-D time-varying channel model is proposed for the 5G dual-mobility channel which can address the problem of spatial inconsistency [169].

11. Green communications

The number of devices that would be connected to the network is expected to increase 100 times and the data volume is expected to increase over 1000 times in the next decade. While achieving these benchmarks is in itself a challenge, we should also meet these requirements in an affordable and sustainable way. Although the contribution of mobile communications to the CO_2 footprint is less than a percent now, we should try to reduce it further. Operators are already facing that the power bills have become a significant part of the operating expenditure. So, lowering the energy consumption and moving towards green communication alternatives are not only important from an environmental perspective, they are also significant from an economic perspective.

11.1. Network planning and deployment

Energy efficiency of the cellular network can be improved by adopting several network deployment strategies [170]. These strategies can be base station cooperation, different topologies of cells, and distributed antenna systems. Significant improvements in the energy efficiency can also be achieved in heterogeneous cellular networks by using small cells. Currently, small cell base stations are placed at locations to enhance the network capacity as well as keeping the cost of infrastructure and deployment low. Therefore, by choosing the location of the microcells and relays optimally within the range of a macro cell, they can significantly offload the macrocell and produce energy savings while providing a better coverage [171]. These optimizations are especially efficient in areas where extremely high capacity and data rates are needed like offices, shopping malls, subway stations, etc., where the user density is large. Since most of these places are indoor, indoor access points should be deployed so that energy wastage due to wall penetration can be avoided.

Another complication in cellular networks is the high variability of network traffic with time due to the patterns in which everyone tends to access the network at the same time. This causes huge difference between the average and peak hour cellular traffic. Reports indicate that this difference between peak and average traffic is increasing and the peak rate of traffic is expected to grow much faster than the rate of growth of average traffic [13]. This makes network operators deploy more base stations to support the peak hour traffic. This causes unnecessary power consumption and waste when it is not needed. This could be reduced by systematically switching off some of the base stations that are not required to be operating. Based on the traffic pattern, analytical models can be developed to identify optimal BS switch off times [172]. It was also observed that the variation of traffic demands among different network operators serving the same geographical area is significantly different [173]. Hence, the network infrastructure of several network operators could be shared among them to dramatically reduce energy consumption while providing better coverage and capacity. A study of European cellular network operators concluded that a reduction in energy consumption by 35–60% could be achieved by such sharing of infrastructure between network operators [174].

11.2. Harvesting renewable energy resources

Another approach to achieve green communication networks is to harvest the renewable energy resources like solar, wind, vibrations at the BS and use them for its operation, reducing or even eliminating the use of conventional power consumption. A cognitive radio network that not just utilizes the spectral holes for transmission, but also minimizes the energy consumption by opportunistically harvesting energy from ambient sources is presented in [175]. In addition to harvesting natural sources of energy like solar, wind, and vibrations, they also propose to harvest synthetic sources of energy like microwave power transfer. They provide a comprehensive study of the solar energy that can be harvested and whether a BS operating on solar power can be made sustainable. They conclude that by storing the surplus energy received in afternoon and used in evenings, continuous self-sustainability can be achieved during periods of abundant sunlight and even in winter, drawing power from the grid can be avoided for three to six hours a day. Another work [176] incorporated both solar and wind power to power the base station. They also propose to use fuel cell based energy sources for deployment in urban areas where deploying solar and/or wind powered base stations will not be feasible. Besides providing a reduction in energy consumption, use of renewable energy resources will also enable setting up self-sustainable BS in remote locations where power is not available, thereby improving the coverage.

11.3. User-centric design

The traditional cell based coverage of a geographical area does not provide the required elasticity to accommodate the diverse requirements of 5G cellular networks. To overcome this, it is proposed to get rid of BS centric design of cells and move to a user-centric concept of “no more cells” [145]. They propose to retire the cell based design to a user-centric design with amorphous cells, decoupled signaling and data and decoupled downlink and uplink. This enables the small cells within the macrocell to be turned off when they have no traffic. This cannot be done in the traditional cell based network. The decoupling of uplink and downlink will enable more efficient resource allocation. This enables a user to send uplink data through one cell and get downlink data from another cell when the cells are heavily loaded in downlink and uplink respectively.

With the use of SDN that provides separation of control and data plane, this kind of architecture becomes easier to implement. This could be exploited to provide each user with a single radio resource control connection with macro BS and dual data connection with both macro BS and micro BS [177]. The collaboration between macro and micro BS is utilized to minimize control channel overhead and cell-specific reference signals in order to achieve a pure data carrier for small cells. This architecture was shown to provide 90% energy efficiency gain while still achieving a throughput improvement of more than 17%.

11.4. Smaller frame overhead

It is also noted in [145] that the traditional cellular networks are designed for conventional streaming applications. The diverse traffic requirements have exposed the inefficiencies of conventional cellular networks and brought in new challenges. There are several applications that use small sized persistent bursty traffic like instant messaging services. Other types of applications like MTC and D2D communications also send small bursts of data [10]. These applications generate smaller packets that are sent at regular intervals. They cause the mobile device to switch between idle and connected states and it may consume much power. The size of these packets is also small so that this cycle happens very frequently. Another problem with this type of traffic is that these packets are very small and hence the signaling overhead in header data might be significant compared to the actual data size. To combat this scenario, a lightweight radio resource connection state without maintenance overhead for handover and channel status feedback has been introduced in 3GPP Release 11. There are also many modifications proposed to the random access procedures to handle this type of traffic like implementing predetermined dedicated preambles or sending the data in the uplink resource allocated for radio resource control requests. Some contention based methods have also been proposed [178] where the devices directly send packets in a contention-based manner.

11.5. Green metrics

In order to evaluate the energy efficiency of wireless communication systems, a group of green metrics is necessary to be established for the 5G networks. The green metrics are useful in research and development in energy efficient components, standardization of energy efficient equipment manufacturing, and quantified assessment on system performance. Therefore, based on the structure of a wireless communication network, the green metrics can be measured on three levels, namely, component, equipment, and system levels [179].

According to current signal processing architecture in wireless communication networks, the electronic components normally are filters, power amplifiers, A/D converters, and antennas at the RF side. So on the component level, the green metrics can be characterized as the gain of the RF component, radiated efficiency of antennas, or power efficiency in power amplifiers. The measurements for the green metrics in the above components are straightforward, and are normally showed in the component's specification lists.

As to the level of equipment, the performance of green metrics cannot be easily measured and should be evaluated in different environments. Although the equipment consists of numerous electronic components, the green metrics of the equipment are not simple linear additions of those parameters in each component. In the standard operation mode, the equipment should consume less amount of energy than in busy operation mode, while in idle operation mode the energy consumption should be the least. In Europe, the standardized metric in this case is the Energy Consumption Rating (ECR) which can be expressed as the actual energy consumption divided by the effective system throughput, as defined by the ETSI [180].

In current wireless networks, green metrics are evaluated in cellular networks, wireless local area networks, satellite systems, and ad hoc networks [179]. However, since in the 5G visions, ultra-dense networks will be deployed to provide more layers of networks with wider coverage, and new frequency bands will be licensed for cellular networks, there should be another novel set of green metrics for 5G wireless networks. The 5G green metrics should be defined by network layers. Two examples are the signal processing energy efficiency in the physical layer and the modulation and user association energy consumption in the medium access control layers. More research efforts should be encouraged to expedite the standardization of 5G green metrics [181].

11.6. Open problems

In the above discussions of green communications, there are some tradeoffs and challenges also needed to be resolved. In this subsection, we present some open problems in green communications and give potential solutions to them.

Power control in green communications: Although there are several green communication solutions proposed for 5G cellular networks from the point of energy efficiency, it should be verified that achieving energy efficiency does not degrade the performance of networks in terms of data rate and other requirements. For example, in the case of multi-tiered network deployments, the user is not attached to the BS with maximum power. This causes the BS to experience higher interference from other BSs which would affect the received signal quality and hence the data rate that the user could achieve. The feasibility of implementation of some of solutions like harvesting solar and wind energy in dense localities and places where sunlight is not available throughout the year should be studied further.

Energy efficient hardware: Previous and current transceiver equipment and hardware in wireless communication networks are designed to achieve good performance in data throughput and reliability. However, such hardware is normally energy costly. In 5G systems, operators and equipment manufacturers should weigh heavier on the energy efficiency when designing and testing network equipment. The research in [182] examined the energy consumption in both office equipment and portable devices such as laptops and mobile phones. Based on the statistics of global energy consumption, the recommendations are made in perspectives of power management, battery life management, and utilization on energy harvesting to alleviate the issue. A globally adoptable energy saving recommendation can be an alternative to encourage energy saving activities around the world.

Energy efficient network architecture: The energy saving network architecture will be enabled by multiple technologies, which are also discussed in this paper, namely, massive MIMO, ultra-densification, SDN and NFV, D2D communications, and mobile cloud computing. The technology of massive MIMO can reach energy efficiency by the utilization of hundreds of antenna elements for high gains. By separating the control and data planes in BS, idle UEs will not waste energy on keeping connection with BS. The wireless software-defined network architecture will save configuration time and energy in traditional hardware. The approach of enabling direct device connection can further improve energy efficiency in the entire network. Furthermore, a series of reconfigurable and energy-scalable radio network solutions were surveyed in [181], which can also be of important reference to the 5G system design.

Battery technology enhancements: The novel battery technologies will also bring revolutionary changes on the next generation of energy efficient communication networks. Recent electrochemical research on novel energy sources has found that sugar can actually be an excellent energy provider, which offers an order of magnitude more energy than the same weight lithium-ion battery in smartphones [183]. The theory behind the sugar battery is based on using enzymes to extract the energy from sugar, which is similar to human digesting sugar to absorb energy. This prototype on sugar battery is promising in the utilization on sensors and other small devices which can expand their lifespan without adding extra weight. Additionally, unlike the lithium-ion battery which is a limited source and requires professional recycling procedures, the sugar battery is easy to refill and safe to use.

In addition, some plants have been discovered to be equipped with the capabilities of a solar panel. A group of researchers in the University of Cambridge found the Photo Microbial Fuel Cells (Photo-MFCs), which is a type of moss can transfer solar power into electric power [184]. Although the Photo-MFCs are still in the early stage of research and cannot harness energy with acceptable efficiency, the trend for the 5G green communications is clear ahead.

12. Radio access techniques

The different requirements explained in Section 2 urge us to rethink about the radio access technique design. The gigabit speed demand of 5G networks motivates that the underlying radio access technique should also be capable of supporting higher data rates. Since spectrum is a scarce and costly resource, spectral efficiency is a key factor of the radio access technique that would enable the gigabit speeds. Several applications that are envisioned in 5G network, like tactile Internet, require a very low latency of the order of 1 ms. This puts a constraint on the perspective of latency of the radio access technique, so that the lower latency required at higher layers can be attained. The other applications like IoT have scenarios where the devices are not connected to the BS at all times.

Ozgur Baris Akan, Chong Han, and Wolfgang Gerstacker for their valuable comments and suggestions to improve the quality of the paper.

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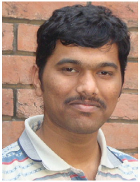

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