

Green Communications for a Low-Carbon World

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Since the development of wireless technology in the last century, mobile radio services have penetrated into all sectors of the society. Today, a variety of wireless systems are in use and there has been an increasing demand for high throughput data services in indoor environments as well as outdoor environments. Moreover, encouraged by the popularity of smartphones, ebook readers, Internet-of-Things (IoT) and the widespread use of social networking applications, upcoming 5G wireless systems are expected to connect billions of users and hundreds of thousands of devices across the world. However, operation of these wireless systems comes at the price of high energy consumption. As a result, today's Information and Communication Technology (ICT) has put a heavy strain on the planet's rapidly dwindling energy resources. Therefore, to reduce the carbon foot print of wireless operation, there is a need to develop energy-efficient green techniques. On a parallel development, smart grids marketed as the next generation of power

delivery network aims to automate and control energy distribution in different parts of the electric grid. By doing so, smart grid operations can reduce energy losses and promote efficient energy usage among the end-users. To this end, telecommunication services provide an efficient mechanism to enable smart grid operation and optimization. In the next sections of the article, our aim is to introduce energy-efficient green communication

techniques as related to modern wireless system implementation as well as to explain the usefulness of ICT for implementing the smart grid.

Solutions that can Meet Throughput Requirements in Mobile Communication Systems

Today's data-hungry applications require high throughput communications. To provide such requirements, cellular system

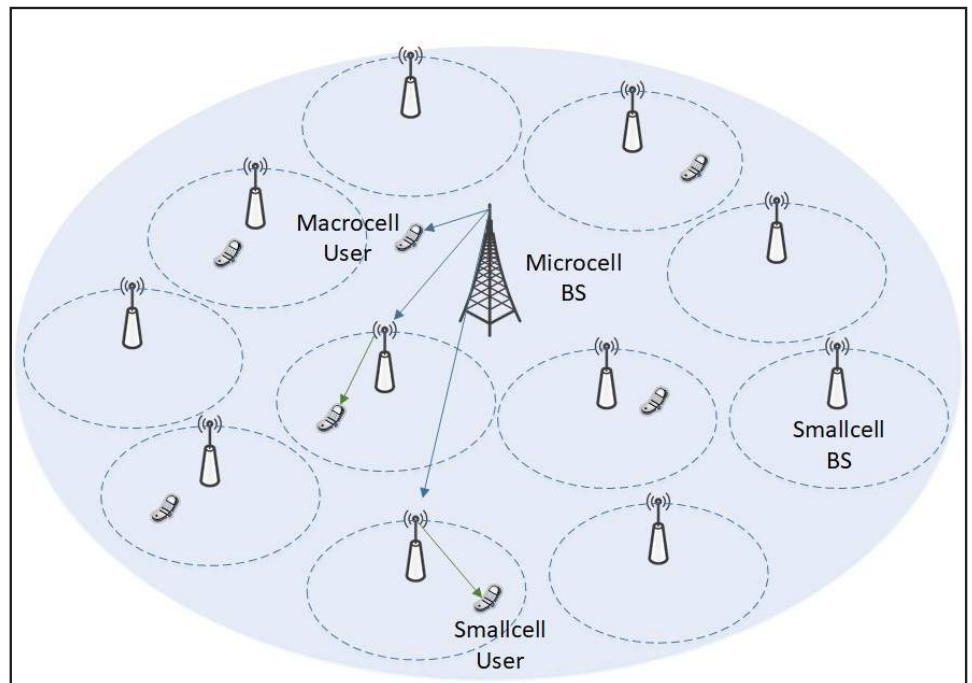


Figure 01 : A small cell network with reduced transmitter-receiver distance

designers have considered several solutions such as [1]

- Reduction of transmitter-receiver distance so that signal attenuation becomes low
- Exploitation of unused large swaths of new frequencies primarily in the millimeter wave bands and
- Deployment of massive multiple-input multiple-output (MM-MIMO) antenna array terminals.

In principle, reducing the transmitter-receiver distances (Figure 1) allows the transmit power to be reduced to support a given quality-of-service. However, such networks should be carefully planned so that interference does not become a major source of performance degradation. Millimeter waves do not travel long distances and thus only creates limited interference. Still power hungry transceiver chains are required to implement millimeter wave networks. Further, due to the use of a large number of antennas, high circuit power consumption

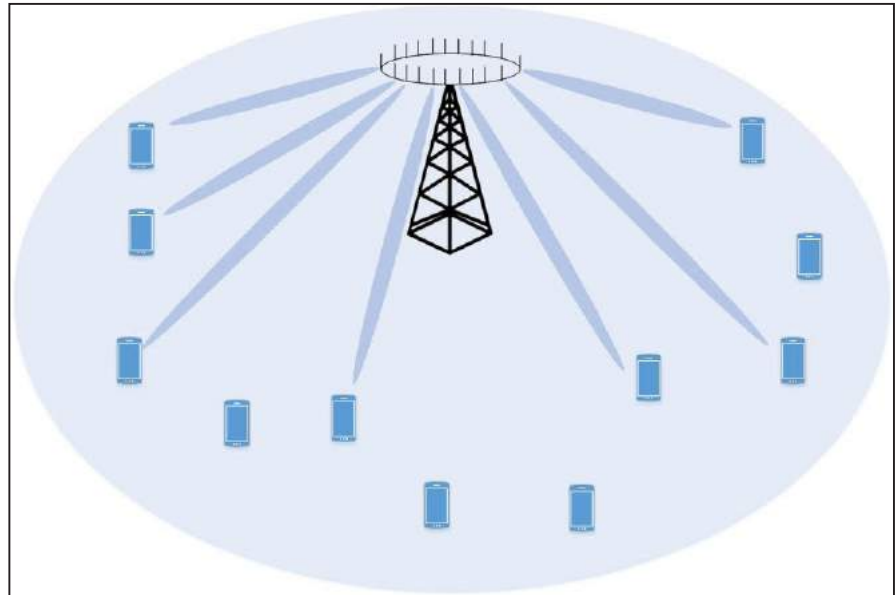


Figure 02 : A massive MIMO network with hundreds of antennas at the base station

in MM-MIMO systems (Figure 2) can result in low energy-efficiency. Hence, it is clear that while these solutions can increase the system throughput, network energy consumption should be minimized and made sustainable. Some of the green technologies that can improve the energy efficiency of

modern communication systems are described as follows:

Green Solutions for High Energy-Efficiency

a) Energy-Aware Cell Design

With the introduction of every generation of cellular systems, we have witnessed shrunken cell sizes. Due to the small cell sizes, users often cross several cells over the period of their service. As a result, handover requirements in the network become common and thus increase the signaling demand and energy consumption. To take care of handovers, umbrella cells are deployed. Specifically, a large macro-cell having an extended coverage

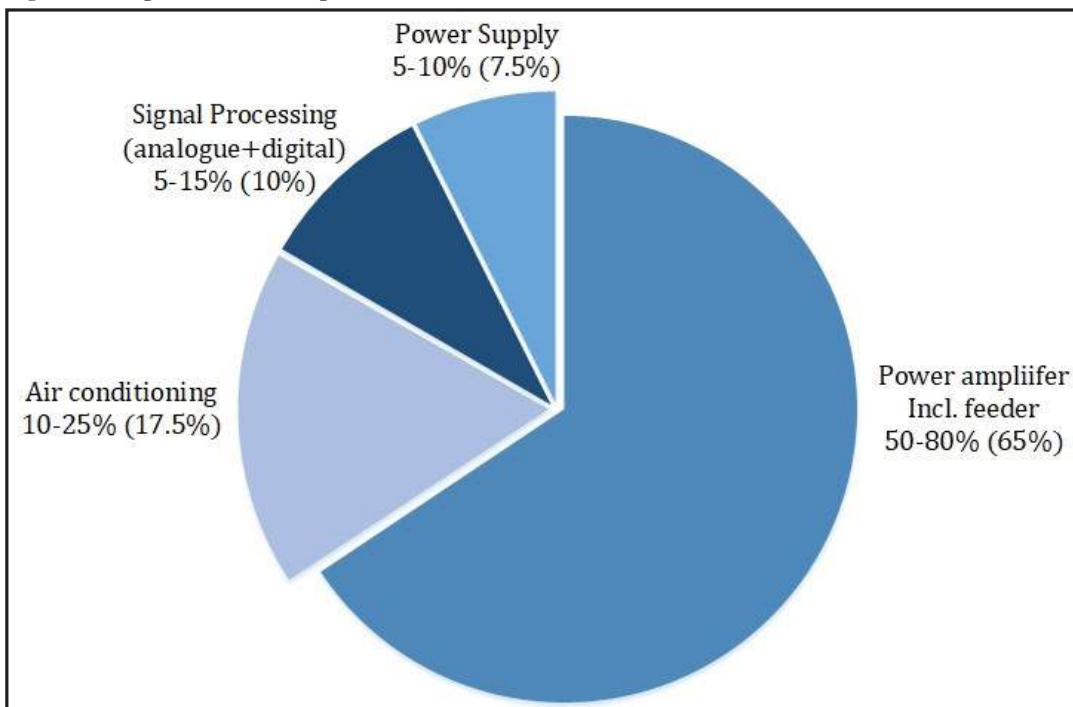


Figure 03 : Power consumption in base stations [2]

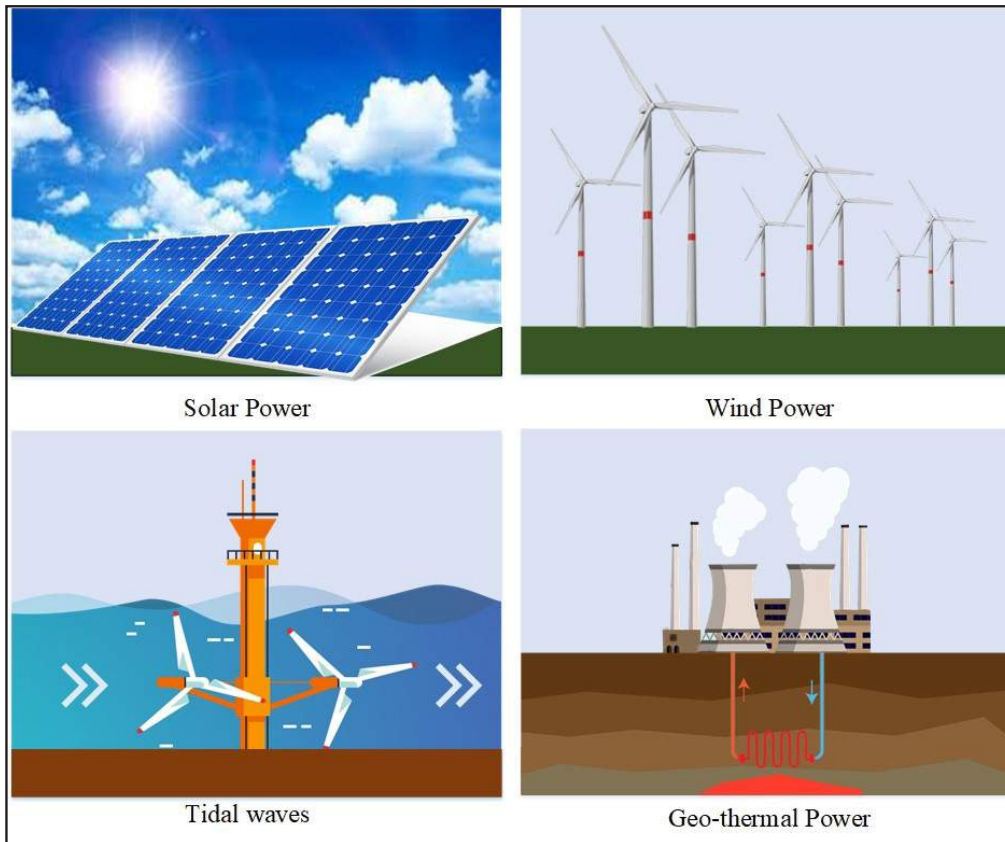


Figure 04 : Renewable energy sources

area and extra radio resources together with micro-cells, which operate on millimeter wave small base stations to reduce signaling overhead are deployed.

b) Base Station on/off Switching

Statistics show that operational load on most of today’s base stations are not heavy [2]. However, they are kept switched on regularly and hence, rather unnecessarily consume large amounts of energy. In addition, day traffic shows dips at certain times of the day, for example at night and early morning hours. Therefore, switching off transmitters at optimized time intervals is an effective policy to promote energy savings.

c) Power Control and Mode Selection

Utilized since the inception of wireless days, power control is an effective mechanism to prevent interference among receivers. Without power control, interference can severely degrade both the uplink and downlink performance of wireless networks. In the literature, depending on the availability of channel state information, various optimal and sub-optimal power control schemes that minimize transmit power while guaranteeing performance above pre-defined values have been proposed. Mode selection is another energy saving strategy that can be implemented in cooperative/machine-type networks. In machine-type communication, devices have the

choice of communicating through a regular base station (cellular mode) or directly with each other and enable energy-efficient design.

d) Green Transceiver Architectures

Conventional microwave and millimeter wave systems use all-digital architecture that need a reserved radio-frequency chain at each antenna [1].

However, power consumption in such all-digital architecture is excessive due to the need for very high speed sampling. To lower the power consumption, designers can deploy an analog beamforming

architecture where rudimentary analog phase shifters are used instead. However, analog beamforming has the drawback of only supporting single user transmission. As such, a compromise between digital and analog beamforming, namely, a hybrid beamforming approach to improve the energy efficiency becomes an attractive solution.

e) Power Amplifier Improvements

As one of the essential parts of a base station, radio consumes more than 80% of base station’s energy requirement [2]. Further, half of the power of radio is consumed in the power amplifier (Figure 3). Most of the power is wasted as heat in the power amplifier due to low efficiency design. Surprisingly, total

efficiency of currently deployed power amplifiers in systems such as GSM, UMTS and CDMA only range from 5% to 20%. Therefore, there is much scope to improve the efficiency of power amplifiers through innovative electronic design. Moreover, reducing the high peak-to-average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) signals will allow power amplifiers to operate at a high efficient point and thus to save energy.

To this end, use of renewable energy sources such as solar, wind, geo-thermal and tidal waves (Figure 4) are alternative solutions that can reduce operation costs and greenhouse gas emissions. Recent advances made in the areas of solar panel technology, wind turbine technology and electronics continues to fuel significant interest on renewables as alternative sources of energy for telecommunication systems. Energy harvesting from renewables for system operation comes at the price of several

A fundamental characteristic of energy harvesting communication systems is that energy cannot be used prior to harvesting. Hence, they should be equipped with a battery of sufficient capacity for storage. Also, there is a need to optimize system operation depending on the statistics of energy arrivals. In particular, resource allocation algorithms that work either on offline or online policies should be invented to match communication performance requirements with available energy

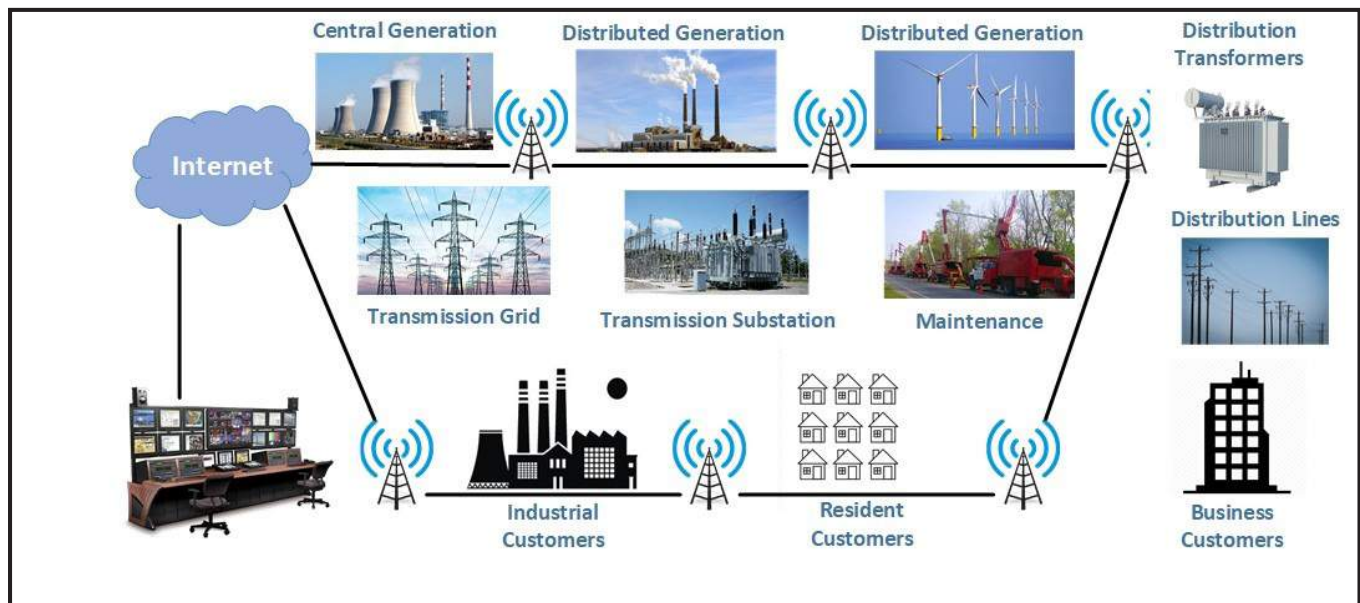


Figure 05 : Communications in the Smart Grid

Renewable Energy Resources for Sustainable Communications

There are many remote parts in the world where telecommunication system operators do not have sufficient access to grid electricity. A popular solution in such situations is to use diesel powered generators that release large quantities of CO₂ into the atmosphere. Also, diesel has to be transported to the cellular site and as a result, telecommunication operators have to tolerate extra costs with network operation.

challenges. In general, harvested energy from sources such as solar and wind power are intermittent, subjected to climatic conditions and may not be sufficient to operate large networks for prolong periods. Moreover, solar energy is not available at night time and also cloud cover significantly affects its generation. Wind power is available only at certain locations and transportation to the required telecommunication sites can result in heavy energy losses.

in the devices. Another pragmatic approach that can be adopted to overcome the intermittent nature of renewable sources is to harvest energy from a variety of sources. In this way, they could be used in a complementary manner to provide uninterrupted power to the communication devices. In emerging architectures such as distributed antenna systems, location diversity can also be exploited to implement an efficient network based on renewable energy sources. For example, transmitters located in favourable locations can

harvest more energy. Such base stations can assist the network by serving additional users or by transporting energy to other transmitters in need of energy. In this final part of the article, role and key aspects of communications in smart grid deployments that open up new ways of improving the energy efficiency of the present electric grid is described.

Communications for the Smart Grid

Smart grid technology promises to improve present day power grids with real-time control and energy efficient operations. As an example, within the smart grid architecture, household consumers can decide to store excess energy they generate and next support peak demand times of the network as required. Moreover, inclusion of renewable sources and storage devices in the electric grid allows the possibility of efficient demand to supply matching. It is worthwhile to note that data exchange in the grid creates new security problems and privacy issues that should be addressed.

It becomes clear that integration with communication systems opens the way to deploy flexible, scalable and secure smart grid solutions (Figure 5). Communication systems allow

- real-time load monitoring
- automated demand-response
- grid parameter visualization and
- asset tracking

tasks within the smart grid. Further, wireless-assisted smart metering enables measuring consumed power of devices; hence, the possibility of real-time pricing becomes

feasible. Communication systems are essential to the integration of renewable energy sources into the electric grid. They allow collection and transfer of relevant data within the smart grid so that resource allocation algorithms can be performed at the network operations center.

There are several communication requirements such as

- bandwidth
- reliability
- latency and
- security

to support different smart grid functions. Devices attached to the smart grid should have suitable bandwidths assigned to allow real-time two-way communication for data transfer. Communication reliability is another important factor to ponder, since smart grid environments are harsh, experience high temperatures and subjected to strong electromagnetic interference. Some smart grid applications may have stringent delay requirements. Therefore, in general, low latency communications are preferred. Finally, security is important to thwart intruders from hacking into the smart grid to trigger a system collapse. As a result, secure communication protocols supported by strong data encryption procedures should be used.

There are several communication technologies that can support smart grid applications. Among them, 4G LTE cellular systems allow long distance communication through backbone and internet connections. Technologies such as WiFi are suitable for advanced metering applications that records energy readings. In order to

connect power meters in a wide area, low-power wide-area network (LPWAN) technologies such as narrowband Internet-of-Things (NB-IoT) and Long Range (LoRa) can be used. Further, home appliances can be monitored using wireless sensor networks such as ZigBee and Bluetooth low energy. Powerline communications and Ethernet that support a range of data rates are also popular wired technologies useful for smart grid communications.

References

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