Trends in Green Wireless Access

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Reducing CO_2 emissions is an important global environmental issue. Over the recent years, wireless and mobile communications have increasingly become popular with consumers. Today's typical wireless access network consumes more than 50% of the total power consumption of mobile communications networks. Growth of mobile Internet service usage is expected to drive the growth in wireless access data rates and usage. The current rate of power consumption per unit of data cannot be sustained as we move towards broadband wireless access networks and anticipated increases in wireless data traffic. This paper, first, examines typical energy consumption in mobile communications networks and traffic trends, and it subsequently discusses target power consumption reduction for the evolving broadband wireless networks to be environmentally acceptable and sustainable. It describes several technologies that can contribute towards reaching this target.

1. Introduction

Global climate change and the need to reduce energy consumption are acknowledged these days. The volume of transmitted data continues to increase by a factor of approximately 10 every five years. Currently, 3% of the world-wide energy is consumed by the information and communications technology (ICT) infrastructure, which causes about 2% of the world-wide CO_2 emissions (comparable to the world-wide CO_2 emissions from airplanes or one quarter of the world-wide CO_2 emissions from cars).[1),2)] In the case of a well-known global cellular operator, energy use associated with network operation accounts for around 80% of the company's CO_2 emissions.

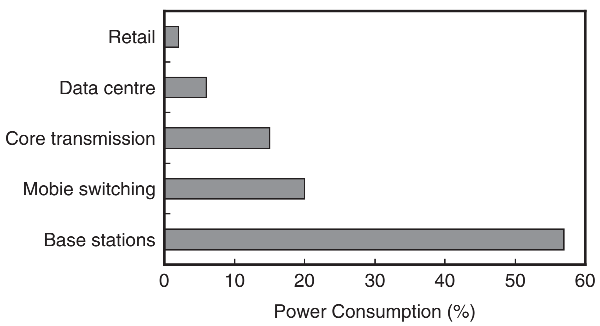
Wireless networks have firmly established themselves as a key and convenient means of communications that enables efficient and effective business operations. Today more than four billion people in the world have access to a mobile phone. Mobile phones have become indispensable in modern social and domestic life. Thus like modern transportation systems, wireless networks are here to stay for the foreseeable future. Consequently reducing the energy consumption of wireless networks is considered vital for the future.

The typical power consumption in a European mobile network of a well-known global cellular operator is shown in **Figure 1**. This excludes the power consumed by user terminals. More than 50% of the energy consumption is directly attributed to base station (BS) equipment and more than 30% to mobile switching and core transmission equipment. Thus these are the prime targets for energy savings.

Fujitsu's BSs for the evolving third-generation (3G) systems are some of the most advanced designs in the world, providing full-featured compact low-power-consuming base stations. **Figure 2** shows how Fujitsu's BS power consumption has dramatically decreased over the years from early 3G wideband code division multiple access (W-CDMA) BSs to modern 3G high-speed packet access (HSPA) and 3G Long Term Evolution (LTE) BSs.

As we enter the wireless broadband era, finding ways to improve energy efficiency and reduce CO_2 emissions is rapidly emerging as one of the key challenges besides the usual ones of achieving cost-efficient provision of coverage, greater capacity, and innovative applications. As demanded data rates in wireless access systems continue to increase (doubling every two years),[3] the energy per delivered bit needs to fall at the same rate if not at a faster rate. Some operators are advocating challenging targets of reducing the overall energy consumption of mobile networks to less than 1% of today's power consumption over the next decade. Such an ambitious target has already been adopted for the Core 5 research programme of the Mobile Virtual Centre of Excellence in the UK.[4]

The following sections examine and describe some of the promising technologies and approaches that could enable more energy efficient wireless networks.



Source: Vodafone Group Plc

Figure 1
Typical breakdown of power consumption in a single European cellular network.

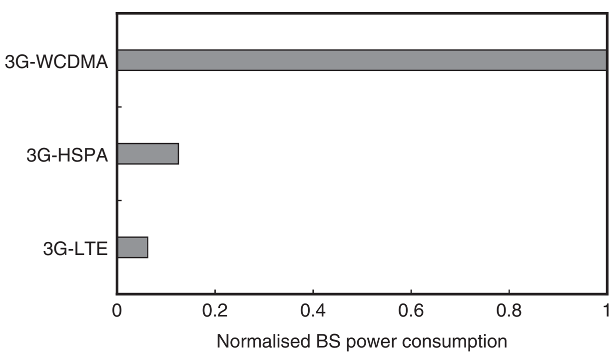


Figure 2
Normalised power consumption of Fujitsu base stations.

2. Energy efficiency in BSs

In modern BSs, radiated useful signal energy accounts for typically 5–10% of the total electrical energy consumption. This suggests there is a big potential for significantly reducing BS energy consumption. State-of-the-art radio-frequency (RF) amplifiers today have power efficiencies that approach 45%. Traditionally the typical macrocell BS housings have been large and have required air-conditioned cooling units, which themselves consume a significant proportion of the energy. Even the non-air-conditioning-based designs utilising cooling fans consume a significant portion (e.g., 10–15%)[5] of the total BS energy consumption.

By contrast, modern BS equipment[6] is naturally air cooled and in many cases does not use cooling fans, thus completely eliminating the "forced" cooling function and the associated energy consumption. This has dramatically reduced the energy consumption of state-of-the-art BSs for broadband wireless access such as 3G LTE and the Worldwide Interoperability for Microwave Access (WiMAX) standards. Such modern BSs already have energy consumption around 50% lower than those of the traditional designs.

One of the most advanced power amplification technologies in the mobile cellular industry is currently the Doherty RF power amplifier with digital pre-distortion technology. Fujitsu's advanced RF amplifier design combining the GaN-transistor-based Doherty

RF amplifier and digital pre-distortion achieves overall power amplifier efficiency of 45%. This, together with low-power digital baseband processing, means that Fujitsu BSs do not need cooling fans or air-conditioned enclosures. There is still considerable room for improvement in the power amplifier efficiency.

The power consumption of digital integrated circuits is expected to decrease as the geometry of transistors shrinks, which will increase the power efficiency of baseband processing circuits in the base stations. For easy upgrading and feature enhancement, modern BSs utilise reconfigurable logic and flexible BS architectures. Whilst such an approach has clear benefits for the operators in terms of maintenance and upgrade costs, it does introduce a power consumption penalty.

The increase in power efficiency of RF power amplifiers and baseband processing circuits means reduced power consumption, which also proportionally reduces energy wastage in the power supply unit.

3. Core network

The core network consumes a significant portion (more than 30%) of the total operational energy consumed in today's mobile networks. Overall, the shift to Internet-protocol-based (IP-based) routing and switching systems has improved the efficiency of the core network substantially over recent years. Modern mobile switching centres and other network nodes (such as the serving general packet radio service support node [SGSN], mobile multimedia gateways, and Authentication, Authorization and Accounting [AAA] servers) have already made significant advances in terms of reduced energy consumption: they consume around one third to one half less energy than their early predecessors.

The 3G LTE core network, in contrast to 3G and 3G-HSPA networks, is a flat all-IP-based architecture, so it can enjoy the rapid advances in low-power, low-cost routers and server equipment. Consequently the power consumption of core network nodes and gateway servers on a per-user basis as well as on a per-delivered-bit basis is expected to fall considerably over the next decade. In addition, concepts such as adaptive Ethernet transmission rate switching depending on traffic load could help reduce the power required to transport each bit. For example a fully loaded 100-Mb/s Ethernet link can consume 1/4 of the power consumption of an unloaded 1-Gb/s Ethernet link.[7)]

Sleep-mode technologies imported from energy-efficient data centre designs can also help reduce network node power consumption. For example, the use of proxy server techniques to put many of the network nodes into sleep mode during low-traffic periods not only reduces the idle-mode power consumption of the processor units but also reduces the number of active communication links.

4. Energy efficient deployment architectures

In the next generation of mobile communication systems, the net transmit power required per transmitted bit is expected to be considerably lower. Both the 3G LTE and IEEE 802.16m standards incorporate a variety of features and techniques that enhance spectral efficiency and energy efficiency and extend the communication range, for example, multiple-input multiple-output (MIMO) transmission and reception techniques. In contrast to conventional systems without multiple transmit antennas, a MIMO diversity transmission does not need as much energy per bit to reach a given distance. Similarly the use of advanced multiple antenna systems utilising closed loop feedback enabling beamforming MIMO schemes would further reduce the required transmission energy per transmitted bit. In addition, the use of hybrid automatic repeat request (HARQ) and advanced resource allocation and packet scheduling can minimise the transmission energy per bit required to serve a given set of users.

The use of sleep mode in BSs during periods of low traffic loads could reduce the idle-mode power consumption. For example, in a multicarrier BS, one can simply power down some of the carriers, reducing the power consumed by broadcast signals such as pilot tones and that consumed by idling transceiver circuits. In the case of a micro/pico cell network overlaid with a macrocell network to provide much needed capacity in peak traffic periods, the sleep mode can be applied to micro/pico cells during the low-traffic periods. In this way we can reduce total idle-mode power consumption of BSs across the entire mobile network during low-traffic periods.

Strategic use of repeaters and relays can enable power efficient and cost efficient coverage. The achievable path loss savings depend on various parameters such as the path loss model, cell sizes, and shadowing conditions. For example, path loss reduction ranges from 21 dB for a cellular multihop system[8] to 3–7 dB for a two-hop system.[9] Depending on the system and network design approach taken, these path loss savings could potentially reduce overall power consumption in the network.

Similarly the concept of a home-BS or femto-BSs could significantly enhance in-building coverage without requiring excessive transmit power from conventional BSs. An Ofcom case study[2] suggests that femto-BSs can potentially reduce overall network power consumption by as much as a factor of 7 compared with macro-BS-only deployment. However, as with relays and repeaters, care must be taken with idle-mode power consumption of femto-BSs so as not to negate any power savings that would be achieved through transmission power savings.

Feeder loss can be significant (e.g., 3 dB or more) in macrocell sites where the BS equipment would normally be located at the base of the tower for easier maintenance access. Masthead RF amplifiers have the potential to significantly reduce power loss due to feeder cables.

A carefully designed, optimised, and engineered radio network could significantly reduce overall power consumption and significantly minimise the site count.

5. Role of renewable energy sources

Renewable energy sources will undoubtedly play an increasingly significant role towards reducing CO_2 emissions. Solar power and wind energy can usefully complement and reduce the net electrical power intake from the grid. In addition, such sources can also help power remote BS sites where the electricity grid is not readily available; i.e., they can complement fossil-fuel-powered generators. This will help to reduce CO_2 emissions.

6. Conclusion

Reducing CO_2 emissions is an important global environmental issue. As demanded data rates continue to rise, environmentally sustainable communications networks must reduce the energy per delivered bit at the same rate if not at a faster rate. This paper briefly examined some of the promising technologies and approaches that could lead to the next generation of energy efficient wireless communication networks without degrading network performance.

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Mr. Vadgama graduated from the University of Surrey in 1984. He subsequently joined Philips Research Laboratories (UK), where his work included the development of an advanced mobile communication system (UMTS) and linearization of RF power amplifiers. In 1991, he joined Fujitsu (UK), where he was initially engaged in the development of GSM terminals and subsequently in R&D of advanced technologies for IMT2000 base stations. He chaired the Industrial Steering Committee of the Personal Distributed Environments (PDE) research group in the Core 3 research programme of the Mobile Virtual Centre of Excellence in the UK from 2003 to 2005. Currently, he is Manager of the Wireless Broadband research group and Assistant Division Manager for the Network Systems Research Division at Fujitsu Laboratories of Europe Ltd. His current research interests include 3G-LTE Advanced and IEEE 802.16m wireless broadband access networks and wireless body area network technologies.