Energy Efficiency in Cellular Networks

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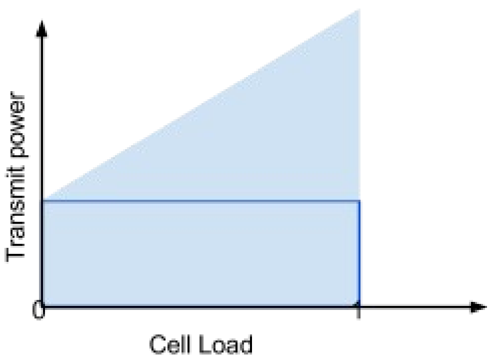
Cellular systems are the largest and the most pervasive data networks in the world. As of 2014, the are about 7 billion cellphones in the world, almost equal to the human population. Till recently, cellular networks were designed with capacity and coverage as the metrics, with very little emphasis on their energy efficiency. However, due to the scale of the current cellular networks, their energy consumption can no longer be neglected. Cellular networks currently utilize about three percent of the global energy and growing.

Cellular base stations consume about ninety percent of the total energy in a cellular network. In particular, the air-interface (radio and power amplifier) utilizes about fifty percent, while the digital processing requires about fifteen percent of the total energy. Hence, a reduction of transmit power or improvement in base band processing efficiency would lead to a significant energy savings.

Current cellular standards like LTE are multi-carrier systems and exhibit significant improvement in spectral efficiency compared to older standards like GSM. The increased spectral efficiency is mainly from using higher order modulation like 16-QAM (64-QAM), and multiple antennas for transmission. RF power amplifiers have a typical efficiency of about 15-20 percent at saturation. However, multi-carrier signals have a high peak-to-average power ratio and a high linearity constraint. Because of the linearity requirements, the operating point of the RF amplifier has to be backed-off which increases with the modulation being used. This reduces the efficiency of the amplifier significantly. Hence, while there is an increase in spectral efficiency with higher modulation, it is not very clear as to the improvements in terms of energy efficiency. Multiple antennae enhance this efficiency loss, because of additional RF chains.



Every BS has to transmit pilots for call setup and synchronization, even when there are almost no users. See Figure. The pilot transmissions utilize about 25-30 percent of the total transmit power. Hence, advances in physical layer processing such as better modulation formats, MIMO would just help reduce the remaining 75 percent. So, better control channel planning is necessary to reduce the fixed transmission cost and is an active research area. Also, there has been significant research on utilizing sleep modes for the BS based on the user load, with minimal hit on QoS.

Since transmission power is a significant component of a BS energy profile, huge saving can be achieved if the transmission power can be reduced, while maintaining coverage. Small cells introduced in LTE are a step in this direction and the main idea is to decrease the cell size by adding more number of micro BSs. Since, the required transmit power decreases non-linearly with the cell size (for example as $1/r^4$), the transmit power in a small scales scales down much faster than the additional number of BSs required to maintain coverage. In addition to saving transmit power, small cells also reduce the load per BS, thus resulting in more fixed power savings. However, it turns out that the cell size cannot be made very small and there exists an optimal size in terms of energy consumption.

In this talk, we will look at the energy efficiency (defined appropriately) of cellular networks. In particular, LTE standard will be contrasted with other existing standards in terms of energy and spectral efficiency. Existing techniques and challenges for improving energy efficiency, like BS sleep modes, small cells will be discussed.

Bio: Radha Krishna Ganti (S'01–M'10) is an Assistant Professor at the Indian Institute of Technology Madras, Chennai, India. He was a Postdoctoral researcher in the Wireless Networking and Communications Group at UT Austin from 2009–11. He received his B. Tech. and M. Tech. in EE from the Indian Institute of Technology, Madras, and a Masters in Applied Mathematics and a Ph.D. in EE from the University of Notre Dame in 2009. His doctoral work focused on the spatial analysis of interference networks using tools from stochastic geometry. He is a co-author of the monograph Interference in Large Wireless Networks (NOW Publishers, 2008)