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A Survey on Energy Efficient Base Station Sleeping Techniques in Green Communications

A.Gopal
Department of Electronics and Communication Engineering
NNRG, Hyderabad, Telangana, India

Dr. Dhiraj Sunehra
Department of Electronics and Communication Engineering
JNTU, Jagtial, Telangana ,India

Abstract- **Energy efficiency is an important factor in cellular networks which is facing a major concern mainly because of environmental, economic and quality of service considerations, in addition making these networks “greener”. The main energy consumer in the cellular networks is Base Station; efforts have been made to reduce the energy consumption by dynamically switching off base stations and find ways to improve the energy efficient model for next generation cellular networks. In this survey we present the techniques related to energy efficient hardware components, cell switch on/off components, multiple input and multiple output management, deployment of heterogeneous networks and adoption of renewable energy sources. In addition, this paper discusses about each technique with various facts and figure which highlights the necessity of green communication with particular focus on techniques related to sleep mode in base stations and thereby offer clear insights to researchers about how to choose the best ways to reduce energy consumption in green cellular networks.**

Key words– Base Station, Energy Consumption, Cellular Network, Green Networking, Energy Efficiency, On-Off schemes.

I. Introduction

In present scenario, energy consumption has increased tremendously in wireless networks. Thus, improving energy efficiency has become a major concern for future. In general, a wireless access network have mobile user with their core network interfaced with the radio base stations. Hence we can say wireless networks mainly consist of BS, network operator and mobile terminals. Until recently, the primary objectives for cellular networks have been improving the Quality of service (QoS) and increasing the throughput, rather than focusing on making efficient utilization of the available resources from various wireless networks for energy conservation. There has been a tremendous increase in the power consumption due to which energy price and emission of C02 which leads to Green house effect have increased. Thus, ICT is raising questions about energy conserving, and thus it is focusing on the solutions which are more energy efficient. Figure1 reports the energy consumption in cellular networks.

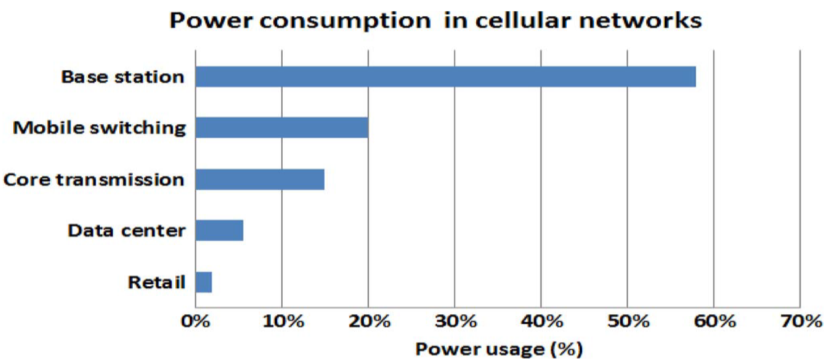

Fig (1) Breakdown of energy consumption of cellular networks

BS’s consumes most of the energy resources in wireless networks. Approximately 57% of the total energy provided by the operator is consumed by base station. In total, 0.2-0.4 GW of power is consumed by approximately 3 billion MS’s worldwide and nearly 4.5 GW of power is consumed by 3 million BS’s, thus due to this high consumption of power there is emission of CO_2.

Thus due to above reason environmental and financial concerns for network operators have increased. From an environmental point of view, the telecommunication industry will responsible for increase in co2 emission from

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2% to 4% by the year 2020. In addition, nowadays most of the cellular devices operate on the rechargeable batteries and their battery life is approximately 2-3 years and after which they are disposed, which triggers environmental concerns. Moreover, Energy dissipation from transmitter circuits and receiver circuits causes the dissipation of heat and also causes electronic pollution. From a financial perspective, reducing electrical energy consumption is economically important issue for the cellular network operators. The operational expenditure (OPEX) is crossing $10 billion dollars for electricity consumption globally for cellular networks. Of the total operational expenditure (OPEX) European markets energy bills costs about 18% while in India it's nearly 32%. Energy expenses are about 50% of the OPEX for those networks which are off grid. Finally, from the quality of experience perspective of user, it has been shown that more than 50% of users have complaint against the battery life time. Thus, for this requirement of energy there have been exponential increases in battery capacity with time. Therefore, the mobile terminal's time of operation during battery charging is one of the most vital factors with respect to quality-of-service (QoS) for the users.

The above-mentioned statistics have motivated researchers in both academia and industry to develop techniques to reduce the energy consumption of cellular networks, thereby maintaining profitability and making cellular networks "greener." In general the goals associated with green cellular networks:

(i) improvement of energy efficiency,
(ii) improvement of the intelligence of the network through tradeoffs between energy consumption and external conditions, that is, traffic loads,
(iii) integration of the network infrastructure and network services to enable the network to be more responsive and to require less power to operate,
(iv) Reduced carbon emissions.

There are various distinctive approaches to reduce energy consumptions in a mobile cellular network. Approaches in previous research can be broadly classified into the following five categories.

1) Improving energy efficiency of hardware components.
2) Turning off components selectively.
3) Optimizing energy efficiency of the radio transmission process.
4) Planning and deploying heterogeneous cells.
5) Adopting renewable energy resources.

In this paper, we provide a brief overview of the techniques that have been considered in previous studies for use in saving energy, including a discussion of the principles of operation.

The remainder of the paper is organized as follows. Section 2 discusses facts and figures that motivate the green cellular networking. Then, in Section III energy efficiency metrics of interest with respect to BS sleep mode techniques in cellular networks are discussed. Next, Section-IV discusses the various approaches to energy consumption. After that, specific research and applications of sleep mode in various network standards are discussed in Section V. Finally, the survey is concluded in Section VI.

II. Facts and Figures

A. Traditional Mobile Network Design Strategies

Previously, mobile networks, or wireless communication networks in general, have been designed with the objective of optimizing coverage, capacity, spectral efficiency or throughput. Clearly, it does not necessarily maximize energy efficiency. Also, traditional facilities were mostly designed to endure peak load and extreme conditions. Many of them are even dimensioned with redundancy, providing extra capacity to possible peak load, in order to allow for unexpected events. As a result, the system is significantly under-utilized during non-peak hours, creating an opportunity for possible energy saving. It is worth noting that traditional design objectives are potentially contradictory to green ones, which makes green networking an interesting and technically challenging research field. Therefore, a new networking paradigm is urgently needed so that existing networks will maintain the same level of QoS while reducing the amount of energy consumed in the future.

B. Mobile Network Energy Consumption

It was estimated that ICT roughly accounted for about 10% of global electricity consumption and up to 4% of global carbon dioxide emissions (around 1 billion tons, approximately equal to that of aviation industry and one fourth of emission by cars worldwide) as of early 2013. ICT's share in global carbon emissions were expected to grow every year, and double to 4% by the year 2020. Smart phones were introduced to market during 2000 and later tablets were also introduces in markets. These devices access the cellular networks thus remarkably contribute in the power consumption. However the traditional mobile features were replaced by the energy efficient OS like iOS, android, windows. In the recent years, the usage of 3G and 4G have increased to a great extent which allows users to do much more work compared to traditional (2G,1G) networks. Thus the downloading or reading of e-book has increased to great extent. Thus all the activities are responsible for the power consumption. Generally an LTE networks consume about 60 times more than that of the 2G network for providing the same level of coverage. With the increase in the mobile devices the numbers of BS, data centre's and other network equipment's will also thus resulting in the increase in power consumption. In the remote places generally off grid BS are establishes which cost 10 times more than the On-grid BS as they are by fuel which is costly power source. Generally deployment of the small cells that is pico, micro cells instead of macro cells could conserve some energy. Thus these cell are deployed in large numbers in the area having dense number of BS's and also at the edges of cell to improve the spectral efficiency. Thus all of the above facts predict there could be great potential for further traffic growth and thus resulting more energy consumption.

III. Energy Efficiency Metrics

Energy efficiency metrics provide information that can be used to assess and compare the energy consumption of various components of a cellular network and of the network as a whole. These metrics also help us to set long-term research goals for reducing energy consumption. With the increase in research activities pertaining to green communication and due to the intrinsic differences and relevance of various communication systems and performance measures, it is difficult for one single metric to suffice. Hence, several standardization bodies and forums have considered energy efficiency in their network implementation strategies. However, energy efficiency metrics have been classified in three main categories in, that is, (i) facility-level, (ii) equipment-level, and (iii) network-level metrics. On the other hand, highlighted another type of metric, called the access-node level. The facility-level metric refers to high-level systems (such as data centers). The Green Grid (TGG) association of IT professionals proposed the metrics of power usage efficiency (PUE) and data centre efficiency (DCE) to evaluate energy efficiency in data centers Despite being a good metric for quickly assessing the performance of data centers at a macro level, PUE, which is defined as the ratio of total facility power consumption to total equipment power consumption, fails to account for the energy efficiency of individual pieces of equipment. Therefore, to quantify efficiency at the equipment level, a measure of the ratio of the energy consumption to the performance of a communication system would be more appropriate. Facility-level metrics assess initial power usage but do not reflect the energy efficiency of individual pieces of equipment. Thus, equipment-level metric, such as power amplifier efficiency metric, which quantify the performance of individual pieces of equipment, are required. The ATIS has introduced the telecommunications energy efficiency ratio (TEER), which is the ratio of useful work to power consumption and is measured in units of Gbps/Watt. Another equipment-level metric, the telecommunications equipment energy efficiency rating (TEEER), introduced by Verizon Networks and Building Systems, quantifies the total energy consumption as the weighted sum of the amounts of energy consumed by the equipment under different load conditions. Another equipment-level metric is the energy consumption rating (ECR), which is the ratio of the energy consumption to the effective system capacity, measured in units of Watt/Gbps.

However, even the busiest networks do not always operate under full load conditions. Therefore, it would be useful to complement metrics such as the ECR to incorporate dynamic network conditions such as energy consumption under full load, half load, and idle conditions. Other metrics suitable for these purposes include the ECRW (weighted ECR), ECR-VL (energy efficiency over a variable-load cycle), and ECR-EX (energy efficiency over an extended-idle load cycle). Hence, ECR provides manufacturers insight into the performance of hardware components. However, these metrics (ECR, TEER, and TEEER) are unable to capture all the properties of a system. While the definitions of energy efficiency metrics at the component and equipment levels are fairly straightforward, it is more challenging to define energy efficiency metrics at the system or network level. Network-level metrics assess energy efficiency at the network level by considering the features and properties of the capacity and coverage of the network. The ETSI has defined two network-level energy efficiency metrics. The first metric is the ratio of the total coverage area to the power consumed at the site and is measured in units of km^2/Watt. The second metric is the ratio of the number of subscribers to the power consumed at the site and is measured in units of users/Watt.

IV. Approaches to Reduce Energy Consumption

A. *Efficient Design of Hardware Components*

Approaches of the first category aim to improve hardware components (such as power amplifier) with more energy-efficient design. The performance of most components used in current cellular network architecture is unsatisfactory from the energy efficiency perspective. Considering, for example, the power amplifier, the component consuming the largest amount of energy in a typical cellular base station (BS), more than 80% of the input energy is dissipated as heat. Generally, the useful output power is only around 5% to 20% of the input

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power. Studies showed that the potentially optimized ratio of output power to input power for power amplifiers (*power efficiency*) could be as high as 70%. Accordingly, substantial amount of energy savings can be achieved if more energy efficient components are adopted in the network. However, the implementation cost for these approaches is high. For example, a power amplifier module with 35% power efficiency for small cell WCDMA or LTE BSs (cover at most an area of a radius of 2 km) costs around $75. The cost will be even higher for larger coverage or higher power efficiency. Therefore, careful consideration in both operational and economical aspects by network operators is required before decisions on hardware replacement are made.

A. Selectively Switching of Components

The second category covers approaches that selectively turn off some resources in the existing network architecture during non-peak traffic hours .Approaches in this category generally try to save energy by monitoring the traffic load in the network and then decide whether to turn off (or switch to sleep mode, also referred as low-power mode or deep idle mode in some literature), or turn on (or switch to active mode, ready mode or awake mode) certain elements of the network. Unnecessary energy consumptions, for example, air conditioning under-loaded BSs, can be avoided by adopting such sleep mode mechanisms. These approaches generally involve switching certain elements including but not limited to power amplifiers, signal processing unit, cooling equipment, the entire BS, or the whole network back and forth between the sleep mode and the active mode. Most often sleep mode techniques aim to save energy by selectively turning off BSs during “off-peak” hours. BSs consume the highest proportion of energy in cellular networks. On the other hand, dense BSs deployments today lead to small coverage area and more random traffic patterns for individual BS, which make sleep mode operations more desirable. Given the constraint that some components (e.g., a minimum number of BSs) must always stay on to support the basic operation of the network, as well as the execution of the switch operation depends on the fluctuations in traffic profile, the reported energy saving is not as high as that of component-based approaches. Also, while it is good to save energy, BS sleeping might negatively impact Quality of Service (QoS) in the network because of decreasing capacity, unless specific remedial solutions are adopted concurrently. Nonetheless, because sleep mode techniques are based on current architecture, they have the advantage of being easier to test and implement as no replacement of hardware is required and the performance can be evaluated by computer simulation.

B. Energy Efficiency of Radio Transmission Process

The third category works on the radio transmission process. Approaches belong to this category work on the physical or MAC layer. Advanced techniques including MIMO technique, cognitive radio transmission, cooperative relaying, and channel coding and resource allocation for signaling have been studied to improve energy efficiency of telecommunication networks. A variety of approaches have been proposed to efficiently utilize resources in time, frequency and spatial domains to achieve energy saving. Similar to approaches based on sleep mode, this family of approaches generally does not require upgrade of hardware components in the system. However, trade-offs between energy efficiency and other performance metrics of the network are probably inevitable. Also, measuring errors due to complicated uncertainty issues such as noise and interference have yet been well corrected. Based on information theory, four fundamental trade-offs related to energy efficiency on wireless networks have been acknowledged, namely deployment efficiency—energy efficiency, spectrum efficiency—energy efficiency, bandwidth—power and delay—power.

C. Planning and Deployment of Heterogeneous Cells

The fourth category tackles the problem by deploying small cells, including micro, pico and femto cells, in the cellular network [36]. These smaller cells serve small areas with dense traffic with low power-consuming cellular BSs which are affordable for user-deployment and usu-ally support plug-and-play feature. In contrast to conventional homogeneous macro cell deployment, such *heterogeneous deployment* reduces energy consumption in the network by short-ening the propagation distance between nodes in the network and utilizing higher frequency bands to support higher data rates. The major constraint of these approaches is the extra small cells bring additional radio interferences as compared to conventional homogeneous macro cell networks, which might negatively affect user experience. Meanwhile, if too many micro, pico or femto cells are deployed, the trend of saving may even be reversed because of extra embodied energy consumed by newly deployed cells as well as overhead introduced in transmission. Therefore, the number of extra smaller cells, as well as their locations, needs to be carefully planned in order to reduce total energy consumption. It has also been noticed that integrating heterogeneous network deployment with sleep mode schemes can potentially achieve significant gains in terms of energy saving.

D. Adoption of Renewable Energy Sources

The last category includes approaches that adopt renewable energy resources. Compared to current widely used energy resources such as hydrocarbon which produces greenhouse gases, renewable resources such as hydro, wind and solar power stand out for their sustainability and environmental friendliness. Telecom manufacturers have planned the supply of solar power operated cellular BSs in underdeveloped areas such as Bangladesh and Nigeria, where roads are in poor condition and unsafe, so delivering traditional energy resources for off-grid BSs (e.g., diesel) cannot be guaranteed]. Energy harvesting techniques, namely exploiting available energy from such renewable resources to complement existing electric-operated infrastructure, would probably be the long-term environmental solution for the mobile cellular network industry. Especially for those areas without mature network infrastructure, deploying energy harvesting networks would be ideal. For developed countries with completed infrastructure, however, the same question of embodied and replacement cost arises as the component-based approaches. While service migrates from the obsolete electric-operated BSs to the new energy harvesting BSs, it is technically challenging to preserve fault-tolerance and data security without any service interruption.

In the next section, we focus on the sleep mode techniques in BSs, and provide more details beyond the coverage of previous surveys. As discussed above, sleep mode techniques do not require upgrade of equipment; therefore they have the benefit of low implementation cost since replacement of hardware is avoided. In surveying the literature, we have observed that studies on the topic of applications of sleep mode techniques to mobile networks made different assumptions on system and power models, e.g., the effect of traffic load on energy consumptions. We discuss these inconsistencies in the paper and demonstrate that the benefit of sleep mode techniques is significantly affected by the assumptions.

V. Base Station Switching Applications

A. Design Principles

Certain principles of design should be followed during the implementation of the base stations. The main elements during the design and evaluation of base station design are - location of the design and evaluation of base station design are - location of BS, traffic load of BS in the geographical region, coverage of BS and its propagation environment along with the energy consumption of BS. Information theory or tele-traffic are most discussed research methodologies. Tele traffic or queuing is used to evaluate traffic characteristics and fast moving calls. Information theory is basically about evolution of QoS based on path loss between the transmitter and receiver also on fading effects. For instance SNR falls bellows some certain amount of threshold then the call of the user should be dropped. Thus these two theories give a complementary explanation of calls being blocked or dropped in a network for improving QOS.

B. BS sleep mode in 4G network

4G is the newest commercially available cellular network standard today. Some novel features enable possibilities for dedicated energy-efficient research exclusively applicable to 4G networks. For example, in WCDMA, HSPA and earlier (e.g., GSM) network standards, both UE and BSs need to comply with certain minimum amount of transmissions (e.g., pilot and control signals) even when no user data is transmitted. Consequently, the entire BS needs to be switched off in order to achieve energy saving, which is a fairly complex and costly operation. On the contrary, in 4G network standards including LTE, LTE-advanced and WiMAX, by the introduction of the discontinuous transmission (DTX) and discontinuous reception (DRX) and the multiplexing scheme deployed orthogonal frequency division multiple access (OFDMA), individual transceivers could be switched off whenever there is no data to transmit or receive. Seeing this, some provisions for power saving protocols based on sleep mode of transceivers have been proposed for 4G standards. There have been proposals to lower power consumption of LTE networks by exploiting DTX and DRX schemes to switch certain energy consuming components in UE or BSs into sleep mode in idle periods. Basically, both DTX and DRX reduce transceiver duty cycle while it is in active operation, but no packet is being transmitted. DRX focuses on the uplink transmission and power of UE while DTX works on the downlink and thus it is relevant to energy consumption of BSs. Here we focus on DTX.

Frenger *et al.* introduced and discussed the feasibility of the so-called cell DTX (where certain number of cells in a site are set to operate in DTX mode) in LTE by only transmitting mandatory synchronization signals in a downlink radio frame, leaving six out of ten sub-frames empty. In this way, the radio transmitter can be turned off. They also compared the performance of the traditional cell micro DTX scheme and an enhanced cell DTX scheme. The enhanced scheme was claimed to achieve 89% savings in a realistic traffic scenario compared to the scenario without cell DTX while the micro cell DTX provided an energy reduction of 61%. In a similar study, Wang *et al.* proposed a novel time-domain sleep mode design in BSs. By optimally selecting the number of active sub frames in each frame according to the traffic load, the energy efficiency in LTE networks can be improved. The authors presented that an energy reduction of up to 90% can be obtained at low traffic load.

CoMP (coordinated multi-point transmission) is another feature of LTE standard which can also be utilized for sleep mode applications. It eliminates the need for increasing transmission power of active BSs to maintain the coverage of sleeping BSs. An optimized approach based on CoMP is presented in such that the amount of power saving less extra power consumed in backhaul and signal processing is maximized, by selecting an optimized set of points for coordination.

C. BS Sleep Mode and Cooperative Relays

Migration of traffic by the nodes which are moving in mobile networks is considered to be more economically better instead of increase in the radiation power from near-by base stations which are active, as energy consumed by relays is very less when compared to base stations. Relays are can be helpful for making message forwarding more effective in future time instances. In order to minimize overall consumption, relay triggering solution for the mobile cellular network industry. Especially for those areas without mature network infrastructure, deploying energy harvesting networks would be ideal. For developed countries with completed infrastructure, however, the same question of embodied and replacement cost arises as the component-based approaches. While service migrates from the obsolete electric-operated BSs to the new energy harvesting BSs, it is technically challenging to preserve fault-tolerance and data security without any service interruption.

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D. Base station sleep mode implementation with renewable sources

Renewable energy sources such as solar and wind are not available at all times, constrained by natural condition. There-fore, it is essential to distinguish them from traditional energy sources when applying BS sleep mode techniques on a network powered by both sources. When there is a lack of power supply, BSs operated by renewable energy resources could possibly not be able to support its associated traffic and might be forced to switch off. To overcome this possible shortage, energy harvesting technique is proposed to exploit renewable energy sources. Spare energy from renewable resources is stored and used when input power from the source does not suffice. Furthermore, stored energy could be even used to maintain the coverage of sleeping conventional BSs, thus reduce (more expensive and unsustainable) energy consumption from traditional sources.

The design principle for energy harvesting is to save energy in conventional BSs, and minimize possible energy outage in renewable energy operated BSs. In this work a greedy way of utilizing stored energy has been proved to be inefficient and could lead to frequent outages. Instead, dynamic programming algorithms based on the number of battery states in each BS have been discussed to optimize network performance, evaluated by a weighted combination of blocking probability and energy consumption.

VI. Conclusion

In this survey firstly we have discussed about the importance of green communication and facts and figures that motivate to adopt green communication techniques. Later we have discussed recent advancement in the research of BS sleep mode techniques in cellular networks, which is one of the major methods to reduce total energy consumption. For BS sleep mode techniques, the main saving comes from the fixed part of energy consumption in under-utilized BSs. The potential for energy saving is large in areas where the traffic is highly variant and relative low as compared with full capacity of BS, and where BSs are densely deployed. Also, the larger the fixed proportion of energy consumption in BSs is (the case in macro BSs), the larger amount of saving can be possibly attained.

REFERENCES

[1] GreenTouch. [Online]. Available: http://www.greentouch.org/

[2] Int. Telecommun. Union, “ITU Green Standards Week,” Geneva, Switzerland, Sep. 2011. [Online]. Available: http://www.itu.int/ITU-T/ climatechange/gsw/201102/index.html

[3] G. Fettweis and E. Zimmermann, “ICT energy consumption—Trends and challenges,” in *Proc. 11th Int. Symp. Wireless Pers. Multimedia Commun.*, Lapland, Finland, Sep. 2008, pp. 1–4.

[4] O. Blume, H. Eckhardt, S. Klein, E. Kuehn, and W. M. Wajda, “Energy savings in mobile networks based on adaptation to traffic statistics,” *Bell Labs Tech. J.*, vol. 15, no. 2, pp. 77–94, Sep. 2010.

[5] Z. Hasan, H. Boostanimehr, and V. K. Bhargava, “Green cellular net-works: A survey, some research issues and challenges,” *IEEE Commun. Surveys Tuts.*, vol. 13, no. 4, pp. 524–540, 2011.

[6] Y. Zhang, P. Chowdhury, M. Tornatore, and B. Mukherjee, “Energy efficiency in telecom optical networks,” *IEEE Commun. Surveys Tuts.*, vol. 12, no. 4, pp. 441–458, 2010.

pp. A. P. Bianzino, C. Chaudet, D. Rossi, and J. Rougier, “A survey of green networking research,” *IEEE Commun. Surveys Tuts.*, vol. 14, no. 1, 3–20, 2012.

[7] D. Kimball *et al.*, “High-efficiency WCDMA envelope tracking base-station amplifier implemented with GaAs HVHBTs,” *IEEE J. Solid-State Circuits*, vol. 44, no. 10, pp. 2629–2639, Oct. 2009.

[8] K. J. Cho, J. H. Kim, and S. P. Stapleton, “A highly efficient Doherty feedfor-ward linear power amplifier for W-CDMA base station applications,” *IEEE Trans. Microw. Theory Techn.*, vol. 53, no. 1, pp. 292–300, Jan. 2005.

[9] O. Arnold, F. Richter, G. Fettweis, and O. Blume, “Power consump-tion modelling of different base station types in heterogeneous cellular networks,” in *Proc. Future Netw. Mobile Summit*, Dresden, Germany, Jun. 2010, pp. 1–8.

[10] Y. Wei, J. Staudinger, and M. Miller, “High efficiency linear GaAs MMIC amplifier for wireless base station and femto cell applica-tions,” in *Proc. IEEE Topical Conf. PAWR*, Tempe, AZ, USA, Jan. 2012, pp.49–52.

[11] C. Han *et al.*, “Green radio: Radio techniques to enable energy-efficient wireless networks,” *IEEE Commun. Mag.*, vol. 49, no. 6, pp. 46–54, Jun. 2011.

[12] H. Claussen, L. Ho, and F. Pivit, “Effects of joint macrocell and resi-dential picocell deployment on the network energy efficiency,” in *Proc. IEEE 19th Int. Symp. PIMRC*, Sep. 2008, pp. 1–6.

[13] TriQuint, “RF Power Amplifier Module: TGA2450-SM.” [Online]. Available: http://store.triquint.com/ProductDetail/TGA2450-SM-TriQuint-Semiconductor-Inc/472292/

[14] J. Wu, S. Zhou, and Z. Niu, “Traffic-aware base station sleeping control and power matching for energy–delay tradeoffs in green cellular net-works,” *IEEE Trans. Wireless Commun.*, vol. 12, no. 8, pp. 4196–

4209, Aug. 2013.
[15] J. Louhi, “Energy efficiency of modern cellular base stations,” in *Proc. 29th INTELEC*, Sep./Oct. 2007, pp. 475–476.
[16] P. Frenger, P. Moberg, J. Malmodin, Y. Jading, and I. Godor, “Reducing energy consumption in LTE with cell DTX,” in *Proc. IEEE 73rd VTC Spring*, Linkoping, Sweden, May 2011, pp. 1–5.
[17] I. Ashraf, F. Boccardi, and L. Ho, “Sleep mode techniques for small cell deployments,” *IEEE Commun. Mag.*, vol. 49, no. 8, pp. 72–79, Aug. 2011.
[18] G. Micallef, P. Mogensen, and H. Sch, “Cell size breathing and possi-bilities to introduce cell sleep mode,” in *Proc. EW Conf.*, Lucca, Italy, Apr. 2010, pp. 111–115.
[20] M. A. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, “On the ef-fectiveness of single and multiple base station sleep modes in cellular networks,” *Comput. Netw.*, vol. 57, no. 17, pp. 3276–3290, Dec. 2013.
[21] Y. S. Soh, T. Quek, M. Kountouris, and H. Shin, “Energy efficient heterogeneous cellular networks,” *IEEE J. Sel. Areas Commun.*, vol. 31, no. 5, pp. 840–850, May 2013.
[22] H. Tabassum, U. Siddique, E. Hossain, and M. Hossain, “Downlink per-formance of cellular systems with base station sleeping, user association, scheduling,” *IEEE Trans. Wireless Commun.*, vol. 13, no. 10, pp. 5752– 5767, Oct. 2014.
[23] S. Cui, A. Goldsmith, and A. Bahai, “Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks,” *IEEE J. Sel. Areas Commun.*, vol. 22, no. 6, pp. 1089–1098, Aug. 2004.
[24] G. Li *et al.*, “Energy-efficient wireless communications: Tutorial, survey and open issues,” *IEEE Wireless Commun.*, vol. 18, no. 6, pp. 28–35, Dec. 2011.
[25] M. Butt *et al.*, “On the energy–bandwidth trade-off in green wireless networks: System level results,” in *Proc. 1st IEEE ICCC*, Beijing, China, Aug. 2012, pp. 91–95.
[26] Y. Zou, J. Zhu, and R. Zhang, “Exploiting network cooperation in green wireless communication,” *IEEE Trans. Commun.*, vol. 61, no. 3, pp.999–1010, Mar. 2013.
[27] C. Xiong, G. Li, S. Zhang, Y. Chen, and S. Xu, “Energy- and spectral-efficiency tradeoff in downlink OFDMA networks,” *IEEE Trans. Wireless Commun.*, vol. 10, no. 11, pp. 3874–3886, Nov. 2011.
[28] C. Xiong, G. Y. Li, S. Zhang, Y. Chen, and S. Xu, “Energy-efficient re-source allocation in OFDMA networks,” *IEEE Trans. Commun.*, vol. 60, no. 12, pp. 3767–3778, Dec. 2012.
[29] D. Feng *et al.*, “A survey of energy-efficient wireless communications,” *IEEE Commun. Surveys Tuts.*, vol. 15, no. 1, pp. 167–178, 2013.
[30] A. Attar, H. Li, and V. C. M. Leung, “Green last mile: How fiber-connected massively distributed antenna systems can save energy,” *IEEE Wireless Commun.*, vol. 18, no. 5, pp. 66–74, Oct. 2011.
[31] Y. Zou, Y.-D. Yao, and B. Zheng, “Opportunistic distributed space–time coding for decode-and-forward cooperation systems,” *IEEE Trans. Signal Process.*, vol. 60, no. 4, pp. 1766–1781, Apr. 2012.
[32] H. ElSawy, E. Hossain, and M. Haenggi, “Stochastic geometry for mod-eling, analysis, design of multi-tier and cognitive cellular wireless net-works: A survey,” *IEEE Commun. Surveys Tuts.*, vol. 15, no. 3, pp. 996–1019, 2013.
[33] M. Li, P. Li, X. Huang, Y. Fang, and S. Glisic, “Energy consumption optimization for multihop cognitive cellular networks,” *IEEE Trans. Mobile Comput.*, vol. 14, no. 2, pp. 358–372, Feb. 2015.
[34] Y. Chen, S. Zhang, S. Xu, and G. Y. Li, “Fundamental trade-offs on green wireless networks,” *IEEE Commun. Mag.*, vol. 49, no. 6, pp. 30–37, Jun. 2011.
[35] G. He, S. Zhang, Y. Chen, and S. Xu, “Fundamental tradeoffs and evaluation methodology for future green wireless networks,” in *Proc. 1st IEEE ICCC*, 2012, pp. 74–78.