Paper

Assessment of Area Energy Efficiency of LTE Macro Base Stations in Different Environments

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Abstract—Energy efficiency (EE) of wireless telecommunications has become a new challenge for the research community, governments and industries in order to reduce CO_2 emission and operational costs. EE of base stations (BSs) in cellular networks is a growing concern for cellular operators to not only maintain profitability, but also to reduce the overall negative impact to the environment and economic issues for wireless network operators. In this paper, a framework focuses on the Area Energy Efficiency (AEE) evaluation of LTE BSs is presented. The parameters affect on the AEE and the coverage area of LTE BS in different scenarios are investigated. AEE analysis has been done using a few key performance indicators including transmit power, bandwidth, load factor with the assumption of different scenarios (urban, suburban and rural). The simulation results show that the LTE BSs have better AEE in an urban environment for cell radius less than 750 m compare with the suburban and rural environments. Furthermore, it is obvious that there is a strong influence of traffic load, BW and transmission power on AEE of LTE network. On the other hand, AEE increases significantly as the BW size increases. Finally, it has been shown that the AEE of LTE macro BS decreases with increasing the percentage of traffic load for all scenarios.

Keywords—Area Energy Efficiency, LTE, Macro Base Station.

1. Introduction

Addressing the issue of green communications has benefits to many stakeholders including the industry, academic researchers and government agencies. The cellular industry can realize cost savings and lower their impact to the environment, government agencies realize a fulfillment of administrative goals for energy savings as well as development of standards and metrics, while researchers can push the boundaries of current technologies and theories in material science, distributed computing and system engineering. Telecommunication section and especially cellular networks are parts of Information and Communication Technology (ICT) that is rapidly expanding throughout the globe. With new technologies like Third Generation (3G) and Long Term Evolution (LTE) coming to the market, this section will grow more in a future.

Currently, telecommunication sectors are responsible for about 12% of total energy consumption of the world and generates approximately 1% of CO_2 emissions [1] with percentages expected to rise further. In [2] the authors proposed the deployment of LTE macro base station (BS) to study the impact of modulation and coding schemes (MCS), bandwidth (BW) size and transmitted power on the energy efficiency for urban environment. They showed that the higher transmission power results in lower EE. The difference actually diminishes when cell size increases. At its diameter around 1200 m, it was found that the EE is almost equal for all transmission power considered. On the other hand, EE increases significantly as the BW increases. Similar effect on EE is observed when MCS changes from lower order to the higher-order scheme. In cellular networks, the prime energy users are base stations (BSs), backhaul servers and routers. Around 80% energy is consumed by the BSs [3]. Because of this statistic, most of the energy saving research had been focused on the BS.

This paper investigates the area energy efficiency (AEE) issue on LTE networks and more specifically it is based on simulation for the outdoor environments. The environment's scenarios for the simulation were done with three different environments: urban, suburban and rural. Results have conducted and discussed to show the performance of LTE network from the AEE perspective. A comparison analysis is done in terms of energy saving for a specific macro BS deployment between the three different scenarios.

2. Methodology

2.1. Propagation Model

In general, there are many factors that cause the deterioration of signal quality such as distance dependent path losses, shadowing, outdoor/indoor penetration loss and radiation pattern. The received power P_{rx}, from a BS at a distance of d and angle θ from the main lobe of the antenna can be calculated as [4]:

$$P_{rx}(d,\theta,\psi) = P_{tx} - \left[PL(d) + \kappa + A_h(\theta)\right] + \psi_{dB}, \qquad (1)$$

where P_{rx}, P_{tx}, PL, κ, A_h, ψ and θ denote to receive power and transmit, path loss, penetration loss, antenna radiation pattern, shadow fading and theta, respectively.

Equation (1) assumes that all the signal gains and losses are expressed in decibels. The random variable ψ is used to model slow fading effects and commonly follows a log normal distribution. The antenna pattern $A_h(\theta)$ depends on the mobile's location relative to the BS which has been adopted from [4]. In addition to path loss and shadowing, another factor which affects the channel quality is penetration loss for users indoors.

In this paper, a 20 dB of attenuation has been assumed to account for outdoor/indoor penetration loss, denoted by κ, which can be found in [5] and [6]. The path loss PL in decibels (dB) for a distance d can be expressed into three different categories, namely urban, suburban and rural areas, which take into account distance, line of sight existence, antenna height, and the average building height with the applicability ranges from 5 to 50 m as proposed in [5] for all environments.

However, the urban scenario usually has a great concentration of BSs due to the demand for capacity. The path loss in urban scenario before the break point d_{BP} can be written in the following form:

$$PL = 22.0\log_{10}(d) + 28.0 + 20\log_{10}(f_c)\,, \tag{2}$$

where d is the distance in meters, and f_c is the carrier frequency in GHz. After d_{BP}, the path loss is founded via:

$$\begin{aligned} PL = 40.0\log_{10}(d) + 7.8 - 18\log_{10}(h'_{BS}) - \\ - 18\log_{10}(h'_{UT}) = 2\log_{10}(f_c)\,, \end{aligned} \tag{3}$$

where h'_{BS} and h'_{UE} are the effective antenna heights at the BS and the User Equipment (UE). The effective antenna heights h'_{BS} and h'_{UE} are computed as follows: $h'_{BS} = h_{BS} - 1.0$ m, $h'_{UE} = h_{UE} - 1.0$ m, where $h_{BS} = 25$ m and $h_{UE} = 1.5$ m are the actual antenna heights proposed in [5] for urban area.

The suburban scenario is modeled to correspond to typical city's periphery with major habitation blocks with several floors. While the remaining territory corresponds to rural low dense populated scenarios that can be crossed by important highways. The path loss in suburban and rural scenarios before the d_{BP} can be written as:

$$\begin{aligned} PL = 20\log_{10}\left(\frac{40\pi d f_c}{3}\right) + \\ + \min(0.03h^{1.72}, 10)\log_{10}(d)\min(0.044^{1.72}, 14.77) + \\ + 0.002\log_{10}(h)d\,. \end{aligned} \tag{4}$$

While after d_{BP}, the path loss for these two scenarios is founded via:

$$\begin{aligned} PL = 20\log_{10}\left(\frac{40\pi d f_c}{3}\right) + \\ + \min(0.03h^{1.72}, 10)\log_{10}(d)\min(0.044^{1.72}, 14.77) + \\ + 0.002\log_{10}(h)d + 40\log_{10}\left(\frac{d}{d_{BP}}\right). \end{aligned} \tag{5}$$

Here h is building height in meters.

2.2. Cell Coverage Area

The cellular system coverage is generally designed for a given minimum received power $P_{\min}$ at the cell boundary. The $P_{\min}$, which is also known as the receiver sensitivity can be written in closed-form for cell coverage area C as [7]:

$$C = Q(a) + \exp\left(\frac{2-2ab}{b^2}\right)Q\left(\frac{2-ab}{b}\right), \tag{6}$$

where:

$$a = \frac{P_{\min} - P_{rx}(R)}{\sigma_{\psi dB}}, \quad b = \frac{1-\alpha\log_{10}(e)}{\sigma_{\psi dB}}, \tag{7}$$

where α denote to path loss exponents and σ_{dB} is the standard deviation of shadow fading [7].

The reference sensitivity $P_{\min}$ level is the minimum mean received signal strength applied to both antenna ports at which there is sufficient SINR for the specified modulation scheme to meet a minimum throughput requirement of the maximum possible. It is measured with the transmitter operating at full power. $P_{\min}$ is a range of values that can be calculated using the Eq. (8) [8]:

$$P_{\min} = \mathrm{kTBW} + \mathrm{NF} + \mathrm{SINR}_{req} + \mathrm{IM} - \mathrm{G_d}\,, \tag{8}$$

where $kTBW$ is the thermal noise level in units of dBm, in the specified bandwidth (BW), NF is the prescribed maximum noise figure for the receiver where LTE defines an NF requirement of 9 dB for the User Equipment (UE), SINR_{req} is Signal to Interference plus Noise Ratio that required for choosing modulation and coding scheme, IM is the implementation margin and $\mathrm{G_d}$ represents the diversity gain which is equal to 3 dB [8]. $P_{\min}$ is a target minimum received power level below which performance becomes unacceptable [7]. Note that $a = 0$, when the target minimum received power equals the average power at the cell boundary, $P_{\min} = P_{rx}(R)$ and $P_{rx}(R)$ is the received power at the cell boundary due to path loss alone. An extra implementation margin is added to reflect the difference in SINR requirement between theory and practicable implementation [8].

2.3. LTE Data Rate Model

Theoretical peak data rates are difficult to achieve in practical situations only in extremely good channel conditions because of limited by the amount of channel impairments noise and interference from own and other cells. The maximum theoretical data rate for single antenna transmission in static channel can be derived through conventional Shannon's formula which is given in Eq. (9). The data rate R_T in unit of bits per second can be expressed in terms of two parameters which are the bandwidth and the signal to noise ratio SNR.

$$R_T = \mathrm{BW} \times \log_2(1 + \mathrm{SNR})\,. \tag{9}$$

In LTE system, a modified Shannon formula is used to accurately estimate the achieved data rate after taking channel impairments into account.

$$R_T = F \times \mathrm{BW} \times \log_2\left(1 + \frac{\mathrm{SINR}_{req}}{\eta_{\mathrm{SNR}}}\right). \tag{10}$$

where $F = \eta_{BW} \cdot \eta$ in which the η_{BW} accounts for the system bandwidth efficiency of LTE and η_{SNR} accounts for the SNR implementation efficiency of LTE. It should be noted that LTE is performing less than $1.6 \sim 2$ dB from the Shannon capacity bound because it's not constant and changes with the geometry factor (G-factor), the G-factor distribution is defined as the average own cell power to the other cell power plus noise ratio with OFDMA in a wide system bandwidth this corresponds to the average SINR [8]. It was shown that this impact can be accounted for using the fudge factor (η) multiplying by the parameter (i.e. $\eta = 0.9$ and $\eta_{BW} \cdot \eta = 0.75$). η_{SNR} is a parameter for adjusting SNR efficiency which is almost equal to one [9].

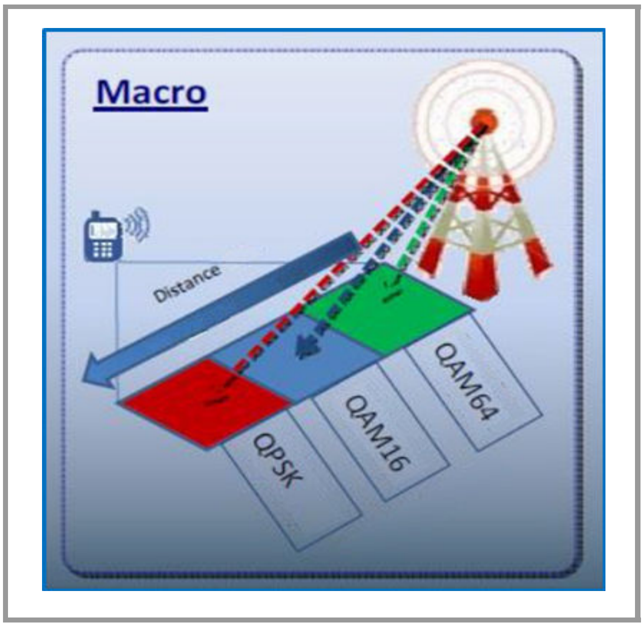

Fig. 1. MCS selected based on user distance.

The MCS selection is depend on the distance between the eNodeB and the UE. The low MCS can be suitable for large distances as the experienced SINR is low while the higher MCS is preferred at short ranges with high data rate demands. Figure 1 shows how the different MCS are selected according to the distance between eNodeB and UE based on the received SINR.

2.4. LTE Power Consumption Model

The main goal of the power consumption model in this paper is to make realistic input parameters available for the simulation. This model also allows fair comparing between different environments and different macrocell BS deployments. The power models have been selected from [10], [11] for different environments cases for LTE deployment.

The power model of macro BS described in [10] has a linear relationship between average radiated power per site and average power consumption. The power consumption calculation is modified to be changed according to the traffic load level and the BS components features. The consumed power P_c by the BS i can be expressed as:

$$P_c = L \cdot N_{sec} N_{ant} (\mathrm{A} P_{tx} + \mathrm{B}), \tag{11}$$

where $L \in [0, 1]$ is the load factor and N_{sec} and N_{ant} denote the BS's number of sectors and the number of antennas per sector, respectively. P_c and P_{tx} denote the total power per BS and the power fed to the antenna, respectively. The coefficient A accounts for the part of the power consumption that is proportional to the transmitted power (e.g., radio frequency amplifier power including losses caused by feeders and cooling of sites), while B denotes the power that is consumed independent of the average transmit power and models the power consumed (e.g., signal processing, site cooling, backhaul, and as well as a battery backup) [10], [12]. Both these coefficients are constant for macro BS. The power model is calculating power consumption with respect to transmit power P_{tx} this assumption is valid because currently deployed macro sites power consumption depends upon the traffic load [10]. The parameter L models the activity level of the BS which describes the portion of resources which are allocated for transmission, where zero and full load correspond to no active user in the cell and providing one or more users with all resources available, respectively.

However, it may be unsuitable to observe only power consumption for comparing the networks with different site densities. This is because they may have different coverage's. In order to assess the power consumption of the network relative to its size, the notion of area power consumption APC measured in [W/km^2] is introduced as the total power consumption in a reference cell divided by the corresponding reference area [10], [13]:

$$APC = \frac{P_c}{A_{macro}}, \tag{12}$$

here A_{macro} is the macro reference area which can be expressed as [10] and [13]:

$$A_{macro} = \frac{3\sqrt{3}}{2} d^2. \tag{13}$$

It was shown that for a hexagonal deployment the area power consumption metric yields an optimal coverage cell size [10].

2.5. Energy Efficiency

The extrapolation of current trends undertaken by many literatures reveals that for a sustainable growth of wireless communications, an improvement of LTE energy efficiency is required. In this study, energy efficiency assessing a framework is studied via network level simulations.

The total network energy efficiency EE_T which is defined as the ratio of total amount data delivered and the total power consumed measured in bits per Joule [14], is represented by:

$$EE_T = \frac{\sum_{i=1}^{N_{BS}} R_i}{\sum_{i=1}^{N_{BS}} P_{c_i}} . \tag{14}$$

where P_c is the power consumption and R_i is the total data rate with a BS i. N_{BS} is the total number of BSs. As know, cell coverage is a primary concern in the design of wireless data communications systems. Increased inter-site distances (ISDs) generate larger coverage areas. With the same transmission power, different cell size can lead to different individual date rate and accordingly various energy efficiency. Therefore, observing the mere energy efficiency per site is not enough for comparing networks with different cell size. Moreover, another important metric is used through this research to evaluate the energy efficiency of the network relative to its size. The Area Energy Efficiency (AEE) metric which is defined as a bit/Joule/unit area is used as a performance indicator metric. The AEE for LTE network can be expressed as [15]:

$$\text{AEE} = \frac{EE_T}{A_T} , \tag{15}$$

where the aforementioned EE_T and A_T are the total energy efficiency and total area of LTE network respectively.

3. Simulation Procedure and Results

The EE performance of the network corresponding to its size and deployment can be more accurately assessed by comparing the AEE performance under different sector radius and scenarios. In the following subsections, the LTE performance in terms of AEE is presented. Furthermore, the effect of environment type on AEE is demonstrated. Later, by considering different traffic load scenarios, the impact of traffic load on AEE has been explained and discussed. The parameters that are affecting the AEE of LTE macro BS are investigated. The impacts of parameters like different traffic load, BW and P_{tx} on AEE.

3.1. Simulation Procedure

In this section, the simulation procedure and system parameters are discussed. There are three different environments are chosen for study campaigns one is an urban type environment. The second is a suburban site like a small city while the third is with a rural environment. Single LTE macro BS covers a hexagonal shaped area as shown in Fig. 2 in which R is the cell radius and A_{macro} is the coverage area.

The cell size is determined according to the minimum received power level constraints. The receiver sensitivity is calculated based on sufficient SINR for the specified

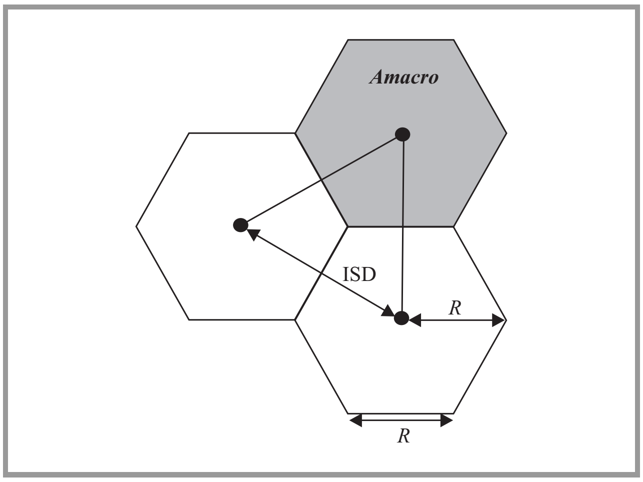

Fig. 2. Corresponding cell geometry.

modulation scheme to achieve a minimum requirement of 95% coverage degree. The received SNR is calculated based on the received power level and white noise which are estimated according to the path loss model described in 3GPP TR 36.814 [5]. Then, the achievable data rate within each BS's coverage area is determined based on the SNR distribution in the cell. The power consumption models consist of dynamic power consumption which is fully depended on the traffic load as expressed in Eq. (11). The simulation parameters are based on 3GPP macrocell model with a system bandwidth of 10 MHz with UE height of 1.5 m. The 2.6 GHz spectrum band is used since this is the band allocated to LTE operators in Malaysia [16]. Effective environment height which is subtracted from the actual antenna height for BS and UE to find their effective antenna heights is assumed to be equal to 1 m. IM of 2.5 dB is assumed for all QPSK modes, while 3 dB and 4 dB are generally expected for 16QAM and 64QAM respectively [17]. However, the typical assumptions for the SINR values for different MCS that are used in the simulation assumptions equal the ones in [8]. The proposed simulation model for evaluating the EE in LTE macro BS in different environments is an extension of the work in [18] as shown in Fig. 3.

Table 1
Simulation parameters

Notation	Description	Default
f_c	Carrier Frequency [GHz]	2.6
BW	Bandwidth [MHz]	10
N_{sec}	Number of sectors	3
N_{ant}	Number of antennas	2
MCS	Modulation Coding Scheme	1/3 QPSK [8]
P_{tx}	Transmit Power [dBm]	46
G_d	Diversity gain [dB]	3 [8]
C	Coverage degree	95%
NF	Noise Figure [dB]	9 [8]
A_i B_i	Power consumption parameters [W]	21.45 354.44 [11]

Various parameters have been used in all simulation scenarios to analyze the EE behavior under specific circumstances. Simulation parameters are listed in Table 1 and simulation procedure flow chart shown in Fig. 3.

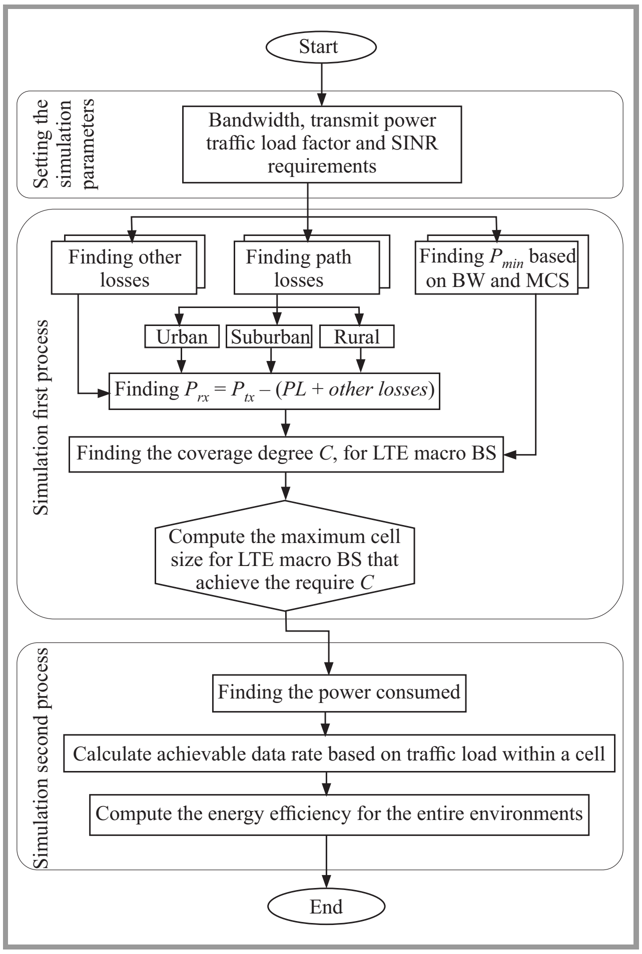

Fig. 3. Simulation model flow chart.

3.2. Simulation Results

AEE for three scenarios at full load. There are different coverage area sizes of LTE BSs due to the deployment environments, there are different data rates for each BS in each environment according to its size and therefore different EE's. Thus, the AEE is used to evaluate the EE of LTE network relative to its size. The AEE has been calculated based on a Eq. (15). In Fig. 4, the AEE versus cell radius for three environments with full load (100%) is plotted. It is obvious that AEE decreases as the macrocell BS's radius increases. Moreover, it can be shown that the LTE BSs have better AEE in urban environment with cell size less than 750 m. For cell radius more than 750 and 1500 m, the LTE performance becomes better in suburban and rural environments respectively. More specifically, at the first 700 m the better AEE is can achieve in urban area but at 710 m the suburban area becomes better than urban and rural, also at 1055 m the rural area became better than urban areas as shown in Fig. 4. This is because the impact of shadowing, path losses as well as the penetration

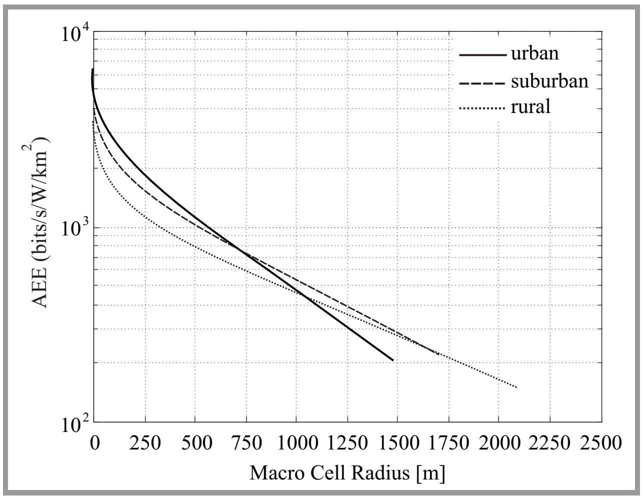

Fig. 4. AEE versus cell radius for three environments.

losses has become more significant in the urban area at long distances as compared with the rest environments.

AEE for three scenarios with different loads. The traffic load is another important factor that affects the network performance. It has a stronger impact on the data rate and the power consumption of LTE network and subsequently on its EE and AEE. The AEE versus cell radius for urban area under different loads shown in Fig. 5. It is clear that

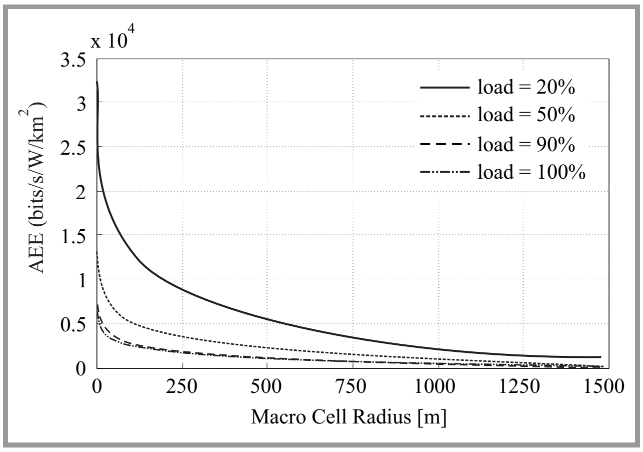

Fig. 5. AEE versus cell radius for urban environment with different loads.

the AEE decreases as the traffic load increases. In fact, the AEE's become almost equals as the traffic loads increased as shown in Fig. 5 the curve with traffic load 90% are very closed to the curve with a full traffic load scenarios. Moreover, it can be shown for all environments that the AEE decreases as the traffic load increases due to increasing in power consumption. The same AEE performance can be concluded for suburban and rural areas when varying the traffic load as shown in Figs. 6 and 7 respectively.

Table 2 summarizes the AEE performance for the three types of environments with different traffic load conditions at 100, 1000 and the cell edge for each environment. As

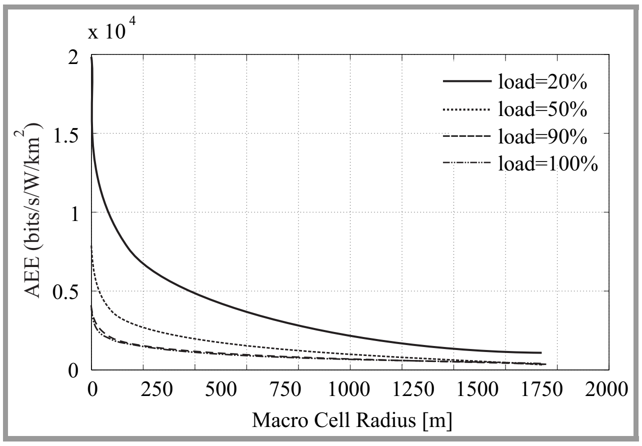

Fig. 6. AEE versus cell radius for suburban environment with different loads.

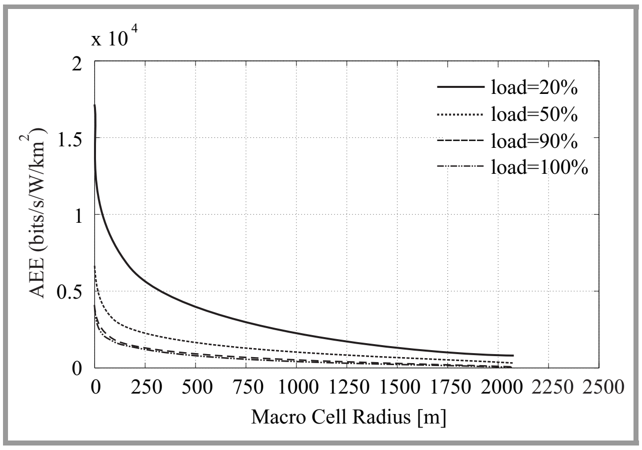

Fig. 7. AEE versus cell radius for rural environment with different loads.

mentioned before, the AEE of LTE macro BS at short distances is better for urban area than suburban and rural for all load conditions. As shown in Table 2 for cell radius more than 1000, the LTE performance becomes better in suburban and rural environments respectively.

Table 3 shows the LTE performance (BW = 10 MHz, 1/3QPSK, full load) in terms of AEE for different transmission powers. However, the AEE decreases as the transmission power increases for the same environment. In addition, it can be concluded that the suburban area achieved better AEE performance due to its suitable cell size compare to urban and rural areas.

Table 2
Training and classification times

Environments	Distance [m]	AEE $\left[\text{bits/s/W/km}^2\right]$			
		20% load	50% load	90% load	Full load
Urban	100	13180	5264	2929	2637
	1000	2416	966.5	536.9	483.2
	1475.7	1041	416.4	231.3	208.2
Suburban	100	10780	4311	2395	2155
	1000	2751	1100	611.4	550.2
	1718.1	1107	442.9	246.1	221.4
Rural	100	7841	3136	1742	1568
	1000	2324	929.6	516.5	464.8
	2074.9	758.1	303.2	168.5	151.6

Table 3
AEE at cell edge for different P_{tx}

Environment	P_{tx} [dBm]		
	43	46	49
Urban	453.7886	208.1916	86.3716
Suburban	482.2614	221.4458	92.0362
Rural	330.7610	151.6243	63.1749

Table 4
AEE at cell edge for different bandwidth

Environment	BW [MHz]					
	1.4	3	5	10	15	20
Urban	8.642	34.101	73.337	208.191	382.168	586.726
Suburban	9.192	36.316	78.206	221.445	407.545	626.886
Rural	6.308	24.962	53.715	151.624	279.118	429.570

Increasing the BW for any type of environment will increase the AEE of LTE macro BS. In fact, the better outcomes can be predicted for suburban area while the urban area comes in the next order and finally the rural area as demonstrated in Table 4 ($P_{tx} = 46$ dBm, 1/3QPSK, full load).

4. Conclusion

One of the most important requirements for wireless communication technologies is to be applicable and universally desirable. AEE for LTE macro BS analysis is the main target for this paper. It is considered as the most important process to achieve mobility within wireless networks. Work evaluation has been done by simulating AEE assessing with different scenarios. Three different environments were chosen for this study including urban, suburban and rural. A framework for evaluating the AEE of LTE network in different environments has been proposed. Using few key performance indicators such as coverage size, area power consumption, energy efficiency and area energy efficiency, the network performance from EE perspective for all the three urban, suburban and rural terrains are compared and evaluated. Although, the LTE BSs have large cell size and good coverage degree in rural areas, the simulation results show that they have better AEE in urban environment with small cell sizes while the AEE becomes better in suburban and rural environments for larger cell radius. Also, it can be concluded that there is a strongly impact of traffic load, bandwidth and transmission power on APC and AEE of LTE macrocell networks. For all the three environments, it has been shown that the AEE of LTE macro BS decreases with increasing the traffic load and this effect becomes the same at high loads. Using the proposed framework, the EE of different deployment scenarios can be evaluated and insights on how to deploy a greener LTE network are provided. The results presented in this work consider only one LTE BS and therefore the impact of the handovers and interference in the LTE network may bring substantial impact on the AEE. These issues have been left for author's future works.

Acknowledgment

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References

[1] P. Misar, "Wireless LTE deployment: How it is changing cell site energy and infrastructure design", in *Proc. 32nd IEEE Ann. International Telecommun. Energy Conf. INTELEC 2010*, Orlando, FL, USA, 2010, pp. 510–514.

[2] A. A. Abdulkafi, T. S. Kiong, J. Koh, D. Chieng, A. Ting, and A. M. Ghaleb, "Energy efficiency of LTE macro base station", in *Proc. 1st Int. Symp. Telecommun. Technol. ISTT 2012*, Kuala Lumpur, Malaysia, 2012, pp. 259–264.

[3] M. Pickavet *et al.*, "Worldwide energy needs for ICT: The rise of power-aware networking", in *Proc. 2nd Int. Symp. Adv. Netw. Telecommun. Syst. ANTS 2008*, Bombay, India, 2008, pp. 1–3.

[4] T. T. Tesfay, R. Khalili, J.-Y. L. Boudec, F. Richter, and A. Fehske, "Energy saving and capacity gain of micro sites in regular LTE networks: downlink traffic layer analysis", in *Proc. 6th ACM Workshop on Perform. Monitor. Measur. Heterogen. Wirel. Wired Netw.*, Miami, FL, USA, 2011, pp. 83–92.

[5] 3GPP TR 36.814 V9.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9)", 3rd Generation Partnership Project, Tech. Rep., 2010 [Online]. Available: http://www.3gpp.org

[6] A. A. Abdulkafi, T. S. Kiong, D. Chieng, A. Ting, and J. Koh, "Energy efficiency improvements in heterogeneous network through traffic load balancing and sleep mode mechanisms", *Wirel. Personal Commun.*, vol. 75, no.4, pp. 2151–2164, 2014.

[7] A. Goldsmith, *Wireless Communications*. New York: Cambridge University Press, 2005.

[8] S. Sesia, I. Toufik, and M. Baker, *LTE – The UMTS Long Term Evolution: From Theory to Practice*, 2nd ed. United Kingdom: Wiley, 2011.

[9] P. Mogensen *et al.*, "LTE capacity compared to the shannon bound", in *Proc. IEEE 65th Veh. Technol. Conf. VTC2007-Spring*, Dublin, Ireland, 2007, pp. 1234–1238.

[10] F. Richter, A. J. Fehske, and G. P. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks", in *Proc. IEEE 70th Veh. Technol. Conf. Fall VTC-Fall 2009*, Anchorage, AK, USA, 2009, pp. 1–5.

[11] S. Tombaz, M. Usman, and J. Zander, "Energy efficiency improvements through heterogeneous networks in diverse traffic distribution scenarios", in *Proc. 6th Int. ICST Conf. Commun. Netw. in China CHINACOM 2011*, Harbin, China, 2011, pp. 708–713.

[12] O. Arnold, F. Richter, G. Fettweis, and O. Blume, "Power consumption modeling of different base station types in heterogeneous cellular networks", in *Future Network and Mobile Summit*, Florence, Italy, 2010, pp. 1–8.

[13] A. J. Fehske, F. Richter, and G. P. Fettweis, "Energy efficiency improvements through micro sites in cellular mobile radio networks", in *Proc. 2nd Int. Worksh. Green Commun.*, in conjunction with *GLOBECOM Workshops 2009*, Honolulu, HI, USA, 2009, pp. 1–5.

[14] A. Chockalingam and M. Zorzi, "Energy efficiency of media access protocols for mobile data networks", *IEEE Trans. Commun.*, vol. 46, pp. 1418–1421, 1998.

[15] W. Wang and G. Shen, "Energy efficiency of heterogeneous cellular network", in *Proc. IEEE 72nd Veh. Technol. Conf. Fall VTC-Fall 2010*, Ottawa, Ontariao, Canada, 2010, pp. 1–5.

[16] Malaysian Communications and Multimedia Commission Annual Report, SKMM-MCMC, 2011 [Online]. Available: http://www.skmm.gov.my/skmmgovmy/media/General/pdf/SKMM_2011.pdf

[17] A. A. Abdulkafi *et al.*, "Energy-aware load adaptive framework for LTE heterogeneous network", *Trans Emerging Tel Tech*, vol. 25, no. 9, pp. 943–953, 2014.

[18] S. N. Shahab, T. S. Kiong, and A. A. Abdulkafi, "A framework for energy efficiency evaluation of LTE network in urban, suburban and rural areas", *Australian J. Basic Appl. Sci.*, vol. 7, no. 7, pp. 404–413, 2013.

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