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A Framework for Energy Efficiency Evaluation of LTE Network in Urban, Suburban and Rural Areas

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Abstract: Energy Efficiency (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 environment effects and economic issues for wireless network operators. In this paper, we highly focus on the EE evaluation of LTE BSs. Then, the parameters that are affecting the EE and the coverage area of LTE BS in different scenarios are investigated. EE analysis has been done using few key performance indicators including coverage size (C), area power consumption (APC), energy efficiency and area energy efficiency (AEE). The network performance in term of EE for all the three urban, suburban and rural terrains are compared and assessed. The simulation results show that the LTE BSs have better AEE in urban environment with cell size less than 750 m. For cell radius more than 750 m and 1500 m, the LTE performance becomes better in suburban and rural environments respectively. Also, it is obvious that there is a strongly influence of traffic load 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 while the APC decreases as traffic load decreases.

Key words: energy efficiency, LTE, macro base station

INTRODUCTION

As the number of cellular and wireless networks as well as the number of mobile users explodes, energy efficiency has become a major concern. Indeed, the energy consumption problem in the Information and Communication Technology (ICT) sector has become crucial during the past years. On the one hand, ICT is expected to play a key role in reducing the energy consumption in many sectors such as transportation, power, agriculture, etc., which are the major contributors to the rise of global Carbon DiOxide (CO_2) emission. As an instance, a recent study (EU ENSURE Project, 2010) estimates that ICT can reduce up to 25 percent energy consumption in the transport sector and about 30 percent in the manufacturing sector. Moreover, ICT is expected to significantly improve the efficiency of energy generation and distribution through the concept of smart grid. On the other hand, ICT especially mobile industry itself is also a contributor of CO2 emission through network operations, mobile equipment's etc.

According to (Global Action Plan, 2007) ICT equipment is responsible for about 2 ~ 10 percent of the world energy consumption. Indeed, these facts have attracted a keen interest among the research community in the field of energy efficient ICT, triggering the appearance of a popular terminology – green communication. Furthermore, due to the above mentioned reasons, there is now a worldwide effort towards energy efficient solutions, evidenced through several large-scale initiatives (Alcatel Lucent Bell Labs, 2010; EU TREND Project, 2010; Mobile Virtual Centre of Excellence, 2010; Nokis Siemens Networks, Feb. 2010)

More specifically, green communication is an innovative research area to find radio communication and networking solutions that can greatly improve energy efficiency as well as resource efficiency of wireless communications without compromising the QoS of users. It not only contributes to global environment improvement but also achieves commercial benefits for telecommunication operators. To meet the challenges of increasing energy efficiency in communication systems, it is imperative to resort to paradigm-shifting technologies, such as energy efficient network architectures, energy efficient wireless transmission techniques, energy efficient networks and protocols, smart grids, etc. Some recent efforts towards achieving green communication solutions include (Ashraf *et al.*, Aug. 2011; Mancuso and Alouf, Aug. 2011; Niu *et al.*, Nov. 2010; Zhang *et al.*, June 2011).

Furthermore, in order to achieve real green wireless and cellular communications, the energy efficiency of both networks and mobile devices needs to be addressed evenly.

The energy conservation aspect of the constituent networks and mobile devices has become a topic of great interest. In this paper, we address a few issues within the topic of energy efficiency in LTE wireless mobile.

Moreover, the impact of different deployment strategies on power consumption of cellular networks is

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investigated in (Richter *et al*., Sept. 2009). Their simulation results suggest that under full traffic load the use of micro BSs has a moderate effect on the area power consumption of a cellular network and it strongly depends on the offset power consumption of both macro- and micro-BSs

Generally, it is assumed that the traffic load variations have small influence on the power consumption of BSs (Blume *et al*., 2010) and (Oh *et al*., 2011). (Wang and Shen, 2010) analyzes the energy efficiency and area energy efficiency *AEE* of two-tier networks with macro and pico-cells. In their study, the maximum achievable data transmission rate for each user is obtained with the knowledge of receiving *SNR*.

In this study, a theoretical model of energy efficiency that reinforces the key deployment solutions in LTE cellular networks considering three types of environments has been derived and the network performance in terms of *EE* has been evaluated.

MATERIALS AND METHODS

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 base station at a distance of d and angle θ from the main lobe of the antenna can be calculated as (Tesfay *et al*., 2011):

$$P_{rx}(d,\theta,\Psi) = P_{tx} - \left(PL(d) + \kappa + A_h(\theta)\right) + \Psi_{dB} \tag{1}$$

Where P_{tx}, P_{rx} and d denote transmit and receive power, and propagation distance respectively. The random variable Ψ is used to model slow fading effects and commonly follows a log-normal distribution, i.e., the variable 10 $\log_{10}$ □ follows a normal distribution. The antenna pattern $A_h(\theta)$ depends on the mobile's location relative to the base station. In addition to path loss and shadowing, another factor which affects the channel quality is penetration loss for users indoors we assume 20 dB of attenuation to account for outdoor-indoor penetration loss, denoted by κ. The path loss *PL* in decibels (dB) for a distance *d* can be expressed into three different categories, namely urban, suburban and rural areas (Technical Specification Group Radio Access Network, 2010) they take into account distance, line-of- sight existence, antenna height, average building height.

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 meter, and f_c is the carrier frequency in GHz. After $d_{BP,}$ the path loss is founded via:

$$PL = 40.0\, log_{10}(d) + 7.8 - 18.0\, log_{10}(h'_{BS}) - 18.0\, log_{10}(h'_{UE}) + 2.0\, log_{10}(f_c) \tag{3}$$

where h'_{BS} and h'_{UE} are the effective antenna heights at the BS and the user Equipment (UE).

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 in the following form:

$$PL = 20\, log(40\pi d f_c/3) + min\left(0.03h^{1.72},10\right) log_{10}(d) - min\left(0.044h^{1.72},14.77\right) + 0.002\, log_{10}(h)d \tag{4}$$

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

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

here *h* is building height in meter.

Cell Coverage Area:

The coverage of a cellular system 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 (Goldsmith, 2005):

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

where:

$$a = \frac{P_{min} - P_{rx}(R)}{\sigma_{\Psi dB}} \tag{7}$$

and

$$b = \frac{10\alpha\, log_{10}(e)}{\sigma_{\Psi dB}} \tag{8}$$

Where α denote to path loss exponents and σ_{dB} is the standard deviation of shadow fading (Goldsmith, 2005).

The receiver sensitivity P_{min} is the minimum power received at which a throughput requirement is fulfilled. The throughput will be equal to or higher than 95% of the maximum throughput for a specified reference measurement channel and can be expressed as(Sesia *et al*., 2011):

$$P_{min} = kTB + NF + SINR_{req} + IM - G_d \tag{9}$$

Where *kTB* represents the thermal noise level in a specified noise bandwidth *BW*, where $BW = N_{RB} * 180$ (kHz) in LTE. N_{RB} is the number of resource blocks (RB) and 180 kHz is the bandwidth of one *RB*. *NF* is the prescribed maximum noise figure for the receiver. *SINR* is the signal to interference plus noise ratio requirement for the chosen modulation and coding scheme (*MCS*). *IM* is the implementation margin and the G_d represents the diversity gain (Sesia *et al*., 2011). The value of G_d depends on the specific implementation and the propagation conditions and 3dB is used as an example in this paper. 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 (*IM*) is added to reflect the difference in *SINR* requirement between theory and practicable implementation (Sesia *et al*., 2011).

Power Model:

In (Richter *et al*., Sept. 2009) and (Tombaz *et al*., 2011), the average power consumption of a base station is modeled as a linear function of average radiated power which is given by:

$$Pc_i = L\,.N_{sec}\, N_{ant}\,(A_i P_{tx} + B_i) \tag{10}$$

where *L* 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 average total power per base station and the power fed to the antenna, respectively. The coefficient A_i accounts for the part of the power consumption that is proportional to the transmitted power (e.g., radio frequency (RF) amplifier power including feeder losses), while B_i denotes the power that is consumed independent of the average transmit power (e.g., signal processing, site cooling, backhaul) (Richter *et al*., Sept. 2009).

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 (Watt/km^2) is introduced as the total power consumption in a reference cell divided by the corresponding reference area (Richter *et al*., Sept. 2009) and (Fehske *et al*., 2009):

$$APC = \frac{P_C}{A_{macro}} \tag{11}$$

Here A_{macro} is the macro reference area which can be expressed as (Richter *et al*., Sept. 2009) and (Fehske *et al*., 2009):

$$A_{macro} = \frac{3\sqrt{3}}{2} d^2 \tag{12}$$

It was shown that for a hexagonal deployment the area power consumption metric yields an optimal cell size (Richter *et al*., Sept. 2009).

Energy Efficiency:

Energy efficiency (*EE)* which is defined as the ratio of total amount data delivered and the total power consumed measured in bits per joule (Chockalingam and Zorzi, 1998), is represented by:

$$EE = \frac{R_T}{PC_T} \tag{13}$$

where PC_T is the total power consumed and R_T is the total data rate which can be calculated using the modified Shannon's formula as (Holma and Toskala, 2009).

$$R_T = \eta_{BW} \ \eta \ BW \ \log_2(1 + \frac{SNR}{\eta_{SNR}}) \tag{14}$$

where 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 1.6~2 dB off from the Shannon capacity bound because the η_{SNR} is not constant and changes with the geometry factor (*G*-factor). It was shown that this impact can be accounted for using the fudge factor, η, multiplying the η_{BW} parameter. It is worth mentioning that we use $\eta = 0.9$ ($\eta_{BW} \times \eta = 0.75$) and $\eta_{SNR} = 1.0$ for our simulation (Mogensen *et al*., 2007). In order to assess the *EE* the network relative to its size, the notion of Area Energy Efficiency (*AEE*) which is defined as the bit/Joule/unit area is introduced. The *AEE* for a certain base station can be expressed as (Wang and Shen, 2010)

$$AEE = \frac{EE}{A_{macro}} \tag{15}$$

RESULTS AND DISCUSSION

In this section, the parameters that are affecting the cell size and *EE* of LTE macro BS are investigated. The impact of these parameters on coverage and energy efficiency is shown for different modulation and coding schemes.

Simulation Procedure:

We assume a single LTE macro base station that covers a hexagonal shaped area. The cell size is determined according to minimum received power level constraints. The receiver sensitivity is calculated based on sufficient *SINR* for the specified 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 while the received power level is estimated according to the path loss model described in 3GPP TR 36.814 (Technical Specification Group Radio Access Network, 2010). 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 static power consumption which is independent on traffic load while the second part depends on the traffic load. The simulation parameters are based on 3GPP recommended macrocell model with a carrier frequency of 2.6 GHz, different antenna height and user height of 1.5 m. The 2.6 GHz spectrum band is used since this is the band allocated to future LTE operators in Malaysia (Malaysian Communications and Multimedia Commission Annual Report, 2011). Other parameters can be found in Table 1. Effective environment height (which is subtracted from the actual antenna height for BS and User Equipment UE to find their effective antenna heights) and standard deviation of shadow fading are assumed to be equal to 1m and 4 dB respectively. *IM* of 2.5 dB is assumed for all QPSK modes, while 3dB and 4dB are generally expected for 16QAM and 64QAM respectively. However, the typical assumptions for the *SINR* values for different *MCS* that are used in our simulation assumptions equal the ones in (Sesia *et al*., 2011). The proposed simulation model for evaluating the *EE* in LTE macro BS in different environments is shown in Fig. 1

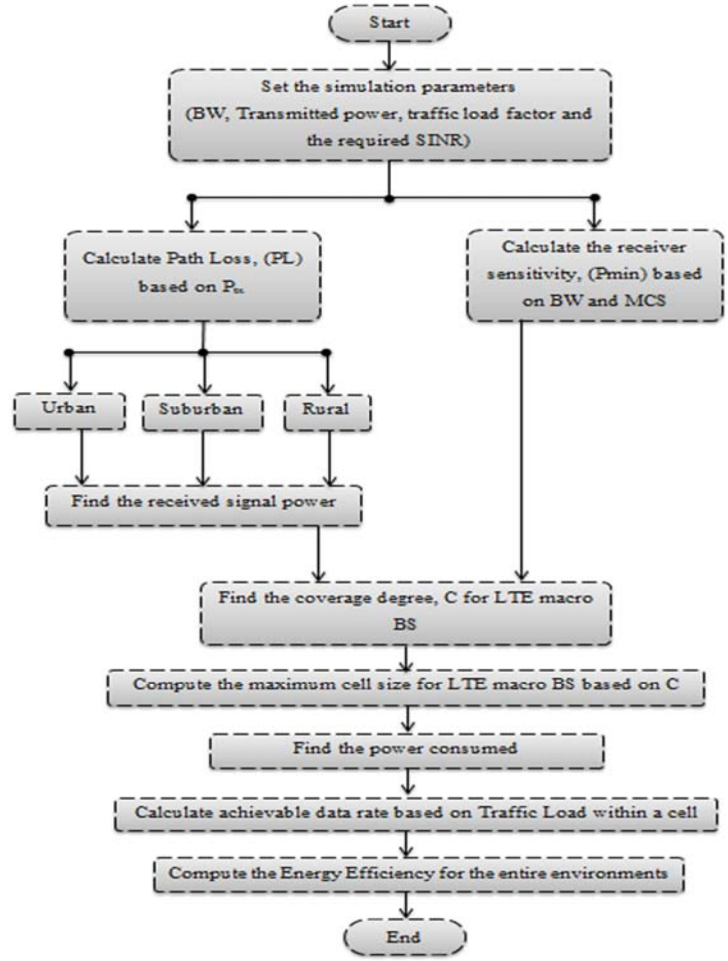

Fig. 1: Flow chart of the proposed simulation model

Table 1: Simulation Parameter

Parameter	Value
Bandwidth @ Carrier frequency	10MHz @ 2.6 GHz
Penetration loss	20 dB (Sesia *et al*., 2011)
Macro propagation model	Urban, Suburban and Rural
Macro antenna pattern (horizontal)	$A(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right]$
Thermal noise	-174dBm/Hz (Sesia *et al*., 2011)
Noise figure	9 dB (Sesia *et al*., 2011)
Shadowing standard deviation	4 dB
Coverage degree, C	95%
Power consumption parameters for macro BS	Ai= 21.45, Bi= 354.44 (Tombaz *et al*., 2011)

Simulation Results:

Coverage Analysis:

The area covered by each sector of a base station is calculated so that the received signal level is above the minimum required signal levels, P_{min} which are founded to be around -93.96dBm, -91.38dBm and -91.39dBm for urban, suburban and rural respectively. The calculation of the expected received signal level was based on (1). Moreover, the cell radius of LTE macro BS is calculated to achieve minimum coverage degree of 95% based on the required SINR and the receiver sensitivity as well as MCS. The received power depends on the allowed path losses and the downlink transmitted power. The accumulated path losses for 2.6 GHz in urban, suburban and rural terrains are shown in Table 2 with P_{tx} of 46dBm, MCS: 1/3 QPSK and BW equal to 10MHz for all scenarios.

Table 2: Path Losses for 2.6 GHz in urban, suburban and rural

Distance(m)	Urban Path Loss (dB)	Suburban Path Loss (dB)	Rural Path Loss (dB)
100	78.5725	71.3512	68.0841
500	106.6711	99.4498	96.1827
1000	118.7297	111.5084	108.2413
1500	125.7791	118.5578	115.2907
2000	130.7796	123.5583	120.2912

As it is expected the rural environment have path loss less than the urban and suburban environments. Also, urban environment having the higher path loss as compare to suburban and rural environments. Figure 2 shows the coverage degree versus the distance of the UE from LTE BS for three different environments. The maximum cell radius of LTE macro BS that achieve a minimum coverage degree ,*C,* of 95% are determined to be 1475.7m, 1718.1m and 2074.9m for urban, suburban and rural environments respectively. It is clear that the coverage area increases as the cell radius decrease for all types of scenarios as demonstrated in Fig.2.

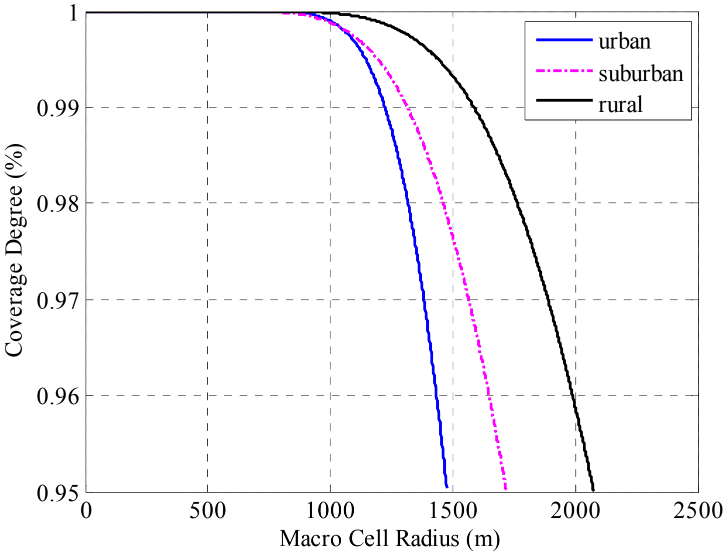

Fig. 2: Coverage degree vs. cell radius for three environments

Power Consumption:

According to (10), the power consumption depends on number of antenna and sectors as well as the traffic load, *L.* In this section we discusses the potentials of saving energy when the consumed power scale with the traffic load changes. The APC of LTE BS decreases as the cell radius increases as shown in Fig. 3. However, if the BS's elements are load adaptive power consumption (scale their power consumption according to the traffic load), the APC will decreases as the traffic load decreases. Also, it can be seen that the APC become almost equal at high load as shown for 90 and 100%load in Fig.3. This reveals the components where their energy consumption increases with the load and those components where their energy potentials of improving the EE of LTE network if their systems/elements are consuming power according and depending on real load.

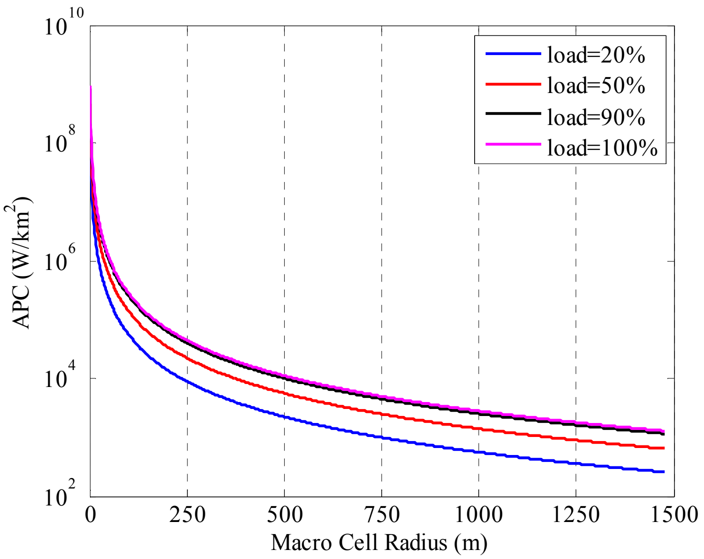

Fig. 3: urban APC versus distance for urban environment

In spite of that the LTE consumes the same power in all environments, the APC for urban area is higher than of the suburban and rural areas due to its small area size compare with the area of suburban and rural areas. Table 3 demonstrates the APC for such networks at light(20%) and at full loads.

Table 3: APC of the basic deployment types

Deployment Area	Cell Radius [m]	Site area [Km^2]	APC [Watt\Km^2] at light load	APC [Watt\Km^2] at full load
Urban Macro	1475	5.6578	$10^{2.4087}$	$10^{3.1077}$
Suburban Macro	1718	7.6700	$10^{2.2765}$	$10^{2.9755}$
Rural Macro	2074	11.1863	$10^{2.1127}$	$10^{2.8116}$

Energy Efficiency:

The EE as a function of macro BS' radius with different deployments is shown in Fig.4. It is clearly shown that EE decreases as the macrocell BS' radius increases for all scenarios.

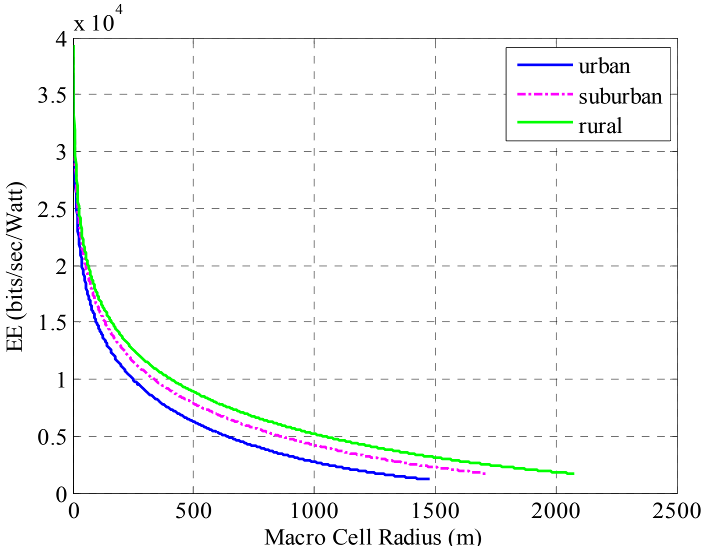

Fig. 4: EE vs. cell radius for three environments

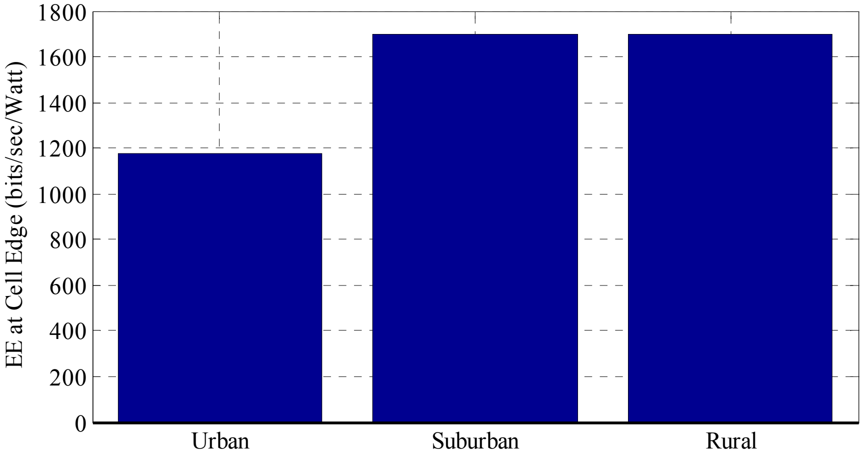

Fig. 5: EE at cell edge for three environments

Also the EE of LTE BS in rural area is better than of these in urban and suburban areas because rural environment has the lowers path losses compare to other environment and hence it has better EE at its cell edges as shown in Fig.5.

While 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 EEs. 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. Thus, the area energy efficiency (AEE) is used to evaluate the EE of LTE network relative to its size. Figure 6 shows AEE versus distance for three environments. It is obvious that AEE decreases as the macrocell BS' 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 m and 1500 m, the LTE performance becomes better in suburban and rural environments respectively.

The traffic load is another important factor that effects 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 vs. cell radius for urban environment under different loads shown in Fig. 7. It is clear that the AEE decreases as the traffic load increases. In fact, the AEEs become almost equals as the traffic loads increased as shown in Fig. 7 the curve with traffic load 90% is very closed to the curve with full traffic load scenario. The same AEE performance can be concluded for suburban and rural areas when varying the traffic load.

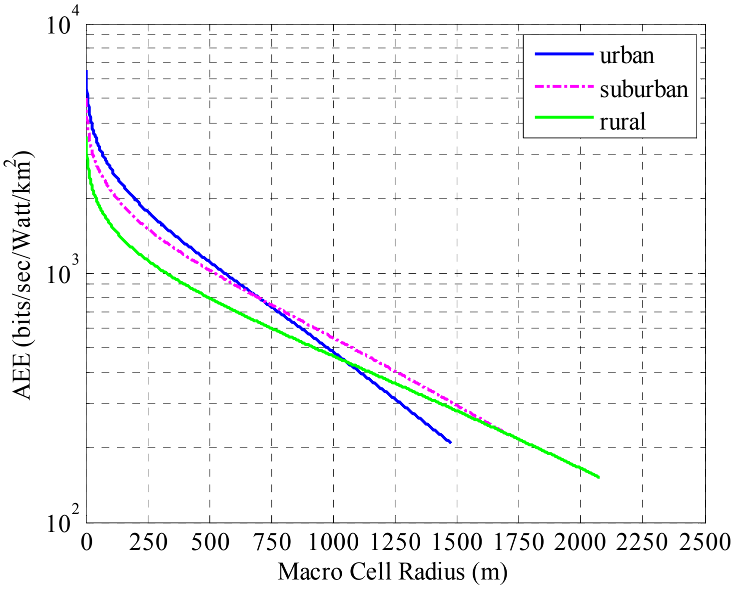

Fig. 6: AEE vs. cell radius for three environments

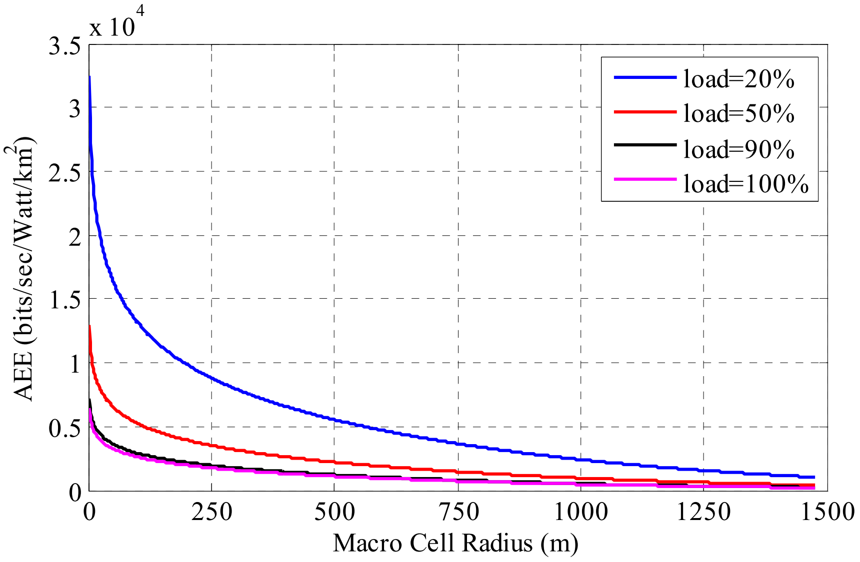

Fig. 7: AEE vs. cell radius for urban environment under different loads.

Conclusion:

In this paper, we have proposed a framework for evaluating the EE of LTE Network in different environments, namely urban, suburban and rural areas. Using few key performance indicators such as coverage size (C), area power consumption(APC), energy efficiency and area energy efficiency (AEE); the network performance from EE prospective 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 the LTE BSs 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 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 while the APC decreases as traffic load decreases. Using our proposed framework, the EE of different deployment scenarios can be evaluated and hence providing insights on how to deploy a greener LTE network.

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