The Impact of Macro Base Station Densification and High Order Sectorisation on the Energy Consumption of 4G LTE Access Networks

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ABSTRACT

A detailed analysis of the energy efficiency of an LTE macro radio access network is presented in this paper. Two deployment scenarios are evaluated: the 3-sector macro base station densification and the deployment of higher order sectorised base stations. Our objective is to find the most energy efficient deployment path when increasing the capacity of the LTE networks. The energy consumption gain (ECG) is used as a metric for evaluating the energy consumption of the network in this paper. The radio base station power consumption is estimated by using a realistic power consumption model developed by the authors in a previous publication. The obtained results have shown that 3-sector macro base station densification is more energy efficient than deploying 6-sector base stations. However, when a progressive adaptive sectorisation technique is implemented in the sectorised macro base stations, the option of the deployment of 6-sector macro base stations becomes more energy efficient than the densification of 3-sector base stations.

Keywords: RAN, Energy Efficiency, Sectorised networks, Energy Consumption Gain, Power consumption model, LTE.

1. Introduction

Given the continuing increase in the demand on the wireless networks services, the wireless networks have grown in the number of new subscribers, and in the number of deployed networks. This growth is accompanied by an increase in the network energy consumption. Today, the information and communication technology (ICT) sector consumes about 4% of the global energy consumption [1]. The energy bill has become a significant portion of the operational expenditures (OPEX) of mobile network operators. Also, ICT has a share of 2% of global CO2 emissions [2]. Therefore, the energy efficiency of cellular networks has become an important issue for the network operators. The objective of this paper is to find the right deployment strategy, which can improve both the network capacity and the network energy efficiency of a macro radio access network.

Antenna sectorisation and base station densification are the two key techniques which have been used extensively in the 2G, 3G and the 4G Libyan mobile networks. They have the advantage of improving both the coverage and capacity of radio access networks (RANs). However, deploying these techniques comes with the price of increasing the network power consumption. This is because densification means an increase in the number of deployed base stations, which requires more power to operate them. Also, increasing the number of sectors in a base station leads to an increase in its power consumption by a factor equals approximately to the number of deployed sectors. The authors will evaluate the energy consumption of the network, when these two techniques are implemented in order to find how operators might chose the most efficient option to achieve the target network capacity.

Many publications have studied the impact of these two options on the network energy efficiency, independently from each other. However, to the best of our knowledge, none have compared the energy efficiency between them. The authors of [3] and [4] have investigated the network densification impact on the energy efficiency, the results of [3] have shown that when the overhead power is omitted from the analysis, small macro cell size deployment is more energy efficient than large cell size. On the contrary, when the overhead power is included in the analysis, large macro cell deployments become more energy efficient [4]. The same results have been obtained by the authors of [5] when the base station overhead power is included in the analysis.

Cellular networks are often dimensioned according to the peak traffic requirement. Therefore, a large part of the network resources remains idle during the low traffic periods of the day, which leads to unnecessary energy consumption. Adaptive sectorisation has been proposed in the literature to solve this issue, where the radio base station site is reconfigured to have fewer and larger beamwidth sectors during low hours of traffic load. It has been proposed in [6] as a potential energy efficiency enabler technique for mobile networks, the authors have tested their solution for different scenarios. Their results have shown that it can save up to 30% of power compared to a 3-sector always active base station, with only a drop of 7.6 % in network throughput. The authors of [7] have also proposed an energy-aware adaptive sectorisation strategy to improve the energy efficiency in LTE networks. Each base station is able to adapt itself to the temporal traffic variation by switching off one of its sectors and changing the beamwidth of the two remaining sectors to maintain the required coverage level. Their results have shown that 21% of energy savings can be achieved, when one sector is switched off during the low traffic load periods.

In this paper, the authors investigate the impact of macro base station densification and high order sectorisation on the energy efficiency of an LTE macro cell RAN. The energy comparison is carried out between two deployment options, the first option is to densify the 3-sector macro network, the second option is to deploy 6-sector base stations. The network energy consumption gain (ECG) is calculated for both deployment options, with reference to using only omnidirectional base stations in the network as a common benchmark. The impact of implementing the adaptive sectorisation on the network energy efficiency is also evaluated. In contrast to the previous publications [6-8], more adaptive sectorisation schemes are evaluated in this paper by using a typical daily traffic model and more accurate sectorisation gain values. A base station power model developed in [9] is used to estimate the radio base station power consumption at an ambient temperature 23 °C.

The rest of the paper is organized as follows: section 2 describes the sectorisation capacity gain, section 3 presents the radio base station power consumption model. The analysis and the methodology are presented in section 4. In section 5, the results and the discussion of the results are presented. Finally, section 6 summarizes the conclusions of the paper.

2. Sectorisation capacity gain

Deploying sectorised base stations improves the network capacity, and can theoretically offer a gain in the capacity equal to the number of site sectors. However, in reality this increase is not proportional to the number of sectors due to the interference leakage between the adjacent sectors of the same site. The sectorisation capacity gain G is expressed in this paper as shown in (1).

$$G = \frac{sectored\ site\ average\ capacity}{omni\ site\ \ average\ capacity} \quad (1)$$

The values of *G* when the number of sectors is increased progressively from 1 to 6 sectors are obtained from a MATLAB based static system level simulation, which has been carried out in our previous work in [10]. The simulation configuration parameters are shown in table 1. The signal to interference and noise is calculated by considering the interference of the first two tiers. The average cell capacity is calculated by averaging the users bit rates, where the users are assumed to be all indoor, and uniformly deployed inside the cell. The obtained results for *G* are shown in Figure 1.

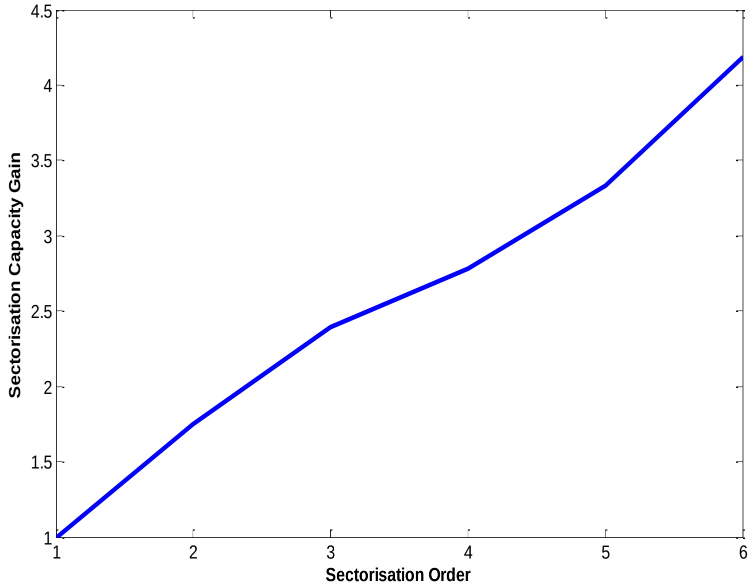

Figure 1. Sectorisation capacity gain

Table 1: *System level simulation configuration parameters*

Parameter	**Omni Macro Cell**
Frequency(MHz)	2000
Bandwidth(MHz)	20
RF Power(dBm)	46
Cell Radius(Km)	[0.3-2]
Antenna Gain(dBi)	15
Shadowing margin(dB)	8.7
Penetration loss(dB)	20
Path loss model(dB)	ITU Macro URBAN

3. Radio base station power consumption

Knowing the accurate power consumption of the RAN is a necessary step for estimating its energy efficiency. 60% to 80% of a cellular network energy is consumed by the radio base stations (RBS) [11]. A number of RBS power consumption models are available in the open literature. Significant generic models were developed in [12] and [13] based on measurements taken from specific vendor's equipment. In this paper, the enhanced version of the Green Radio (GR) RBS parametric power consumption model is used to estimate the power consumption of the macro base stations. This model has been developed by the first and third authors of this paper in their previous publication in [9].
The overall average power consumption of an RBS is modelled as the sum of the power consumption of the sub units of the base station, as expressed in (2).

$$P_{site} = P_{cool} + P_{bh} + P_{rect} + n_s \cdot n_t \cdot (P_{bb} + P_{trx} + P_{pa}) \ . \qquad (2)$$

In (2), the terms P_{site}, P_{cool} and P_{bh} denote the power consumption of the RBS site, the cooling unit and the backhaul, respectively and the terms P_{rect}, P_{bb}, P_{trx} and P_{pa} denote the power consumption of the power supply unit, baseband processing unit, RF transceiver circuitry, and the power amplifier PA, respectively. The parameters n_s and n_t refer, respectively, to the number of sectors per RBS site, and the number of transmitting antennas per sector. The power consumption in the cooling and power supply units is calculated as a percentage of the sum power consumption of the power amplifier, RF transceiver, and baseband processing unit. The method of modelling the power consumption of each unit has been fully explained in [9]. Figure.2 shows the average power consumption of a macro base station when the number of sectors is varied from one to 6 and at full load and ambient temperature of 23 °C. Table 2 shows the values of the parameters of the power model used to plot Figure 2.

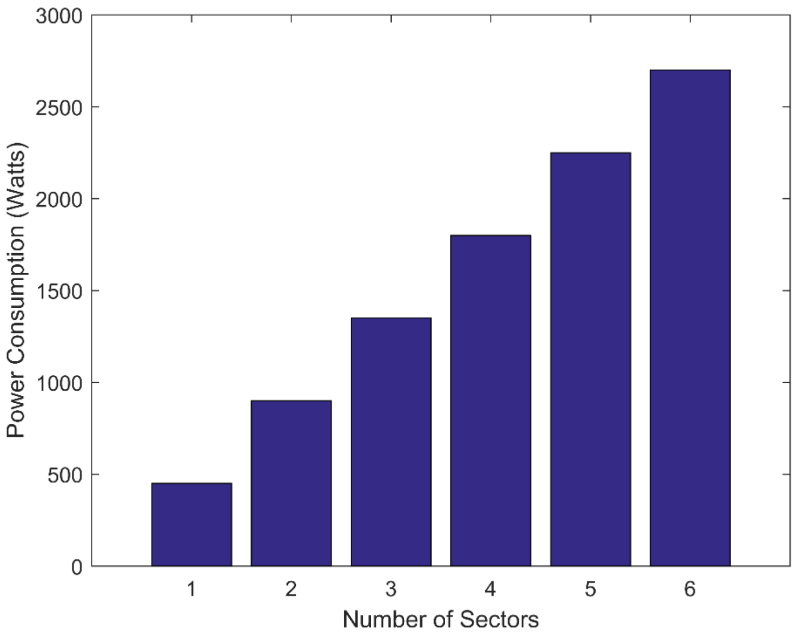

Figure 2. Macro RBS Power consumption

Table 2: *Power Consumption Model Parameters*

Parameter	Value
Transmit Power Per Sector (W)	40
Bandwidth (MHz)	20
Transceiver Unit (W)	13
Processing Unit (W)	30
Fibre Backhaul (W)	10
PA Efficiency	30%
Antenna Feed Cable Loss (dB)	-3

A simpler form of the power model is usually used by writing the power model as the sum of a load independent static part and a load dependent dynamic part, as given by (3). P_{oh} refers to the load independent overhead part and P_{rh} to the load dependent radio head part. The term α denotes the base station normalised average load ranging from 0 to 1. In cellular networks like LTE, the load includes both traffic and control data, while the traffic data maybe zero at times, there is always some level of signalling and control data present in the base station.

$$P_{in} = P_{oh} + \alpha . P_{rh} \quad (3)$$

4. Analysis and the methodology

The average power consumption of an LTE RBS can be written as in (3), where both P_{rh} and P_{oh} can be obtained from the base station power model shown in (2). If the observation time is T_{oh} , the consumed energy in the omnidirectional RBS, and sectorised RBS can be calculated by using (4) and (5). The omnidirectional RBS will be used as a reference when evaluating the energy consumption gain for both the three and six sector deployments. Note that the subscript letters “o” and “s” in (4) and (5) refer to the omnidirectional and sectorised base stations.

$$E_o = T_{oh}.(P_{oh,o} + \alpha_o . P_{rh,o}) \quad (4)$$

$$E_s = T_{oh}.(P_{oh,s} + \alpha_s . P_{rh,s}) \quad (5)$$

Where α_s denotes the average load traffic when the sectorised RBS is used, and α_o is the average traffic load when omnidirectional base stations are used.
The Energy consumption gain (ECG) [14] is used as the Figure of merit for the energy efficiency; it can be calculated as the ratio of the network energy when only omnidirectional base stations are used to the energy when sectorised base stations are used as shown in (6).

$$ECG = \frac{E_o}{E_s} \quad (6)$$

The ECG value is greater than one when the sectorised RBS is more energy efficient than the omnidirectional RBS. The most energy efficient sectorised deployment is the one which has the greatest ECG value. The ECG’s of the 3-sector and 6-sector deployment options are calculated when the same offered traffic volume, and observation time are assumed for the two deployment options. The 6-sector RBS offers higher sectorisation gain *G* than the 3-sector. Hence, a smaller number of 6-sector sites than the 3-sector sites is needed to deliver the same offered traffic, and to serve the same target area. From (4), (5) and (6), the ECG of a single sectorised RBS, can be written as in (7).

$$ECG_{RBS} = \frac{P_{oh,o}+\alpha_o.P_{rh,o}}{P_{oh,s}+\alpha_s.P_{rh,s}} \quad (7)$$

As networks are dimensioned according to the peak traffic load values, the average traffic loads will be equals in the two sectored deployment options and in the reference network. Omnidirectional sites are assumed in the reference network. The network ECG can be calculated as in (8).

$$ECG_{RAN} = \frac{N_o}{N_s}.ECG_{RBS} \quad (8)$$

All the sites have the same coverage area for a homogeneous RAN. Therefore, the ratio of the number of omnidirectional sites to the sectorised sites is given by (9).

$$\frac{N_o}{N_s} = \frac{R_s^2}{R_o^2} \quad (9)$$

Where R_s and R_o represent, respectively, the radius of the omnidirectional and sectorised sites. From (8) and (9), the sectorised network ECG can be written as in (10).

$$ECG_{RAN} = \left(\frac{R_s}{R_o}\right)^2.ECG_{RBS} \quad (10)$$

The network ECG is calculated for both the 3-sector and 6-sector deployment options. When the 3-sector ECG is greater than the 6-sector ECG, this means the densification is the more efficient option, and vice versa.
Given the temporal and spatial variation of the offered traffic load, part of the RBS capacity remains unused most of time, which causes unnecessary energy consumption. The adaptive sectorisation technique is implemented to improve the RBS ECG, where the number of sectors and the antenna beamwidth can be changed according to the traffic load. For instance, if the peak traffic load in 6-sector RBS is normalized to one, and the sectorisation gain of 6-sector RBS equals 4.2 and equals 2.7 for 3-sector RBS, the 6-sector RBS can be switched to 3-sector mode when the normalised traffic load is less than 0.64. It can be also switched to an omnidirectional mode when the normalized traffic load is less than 0.23. The observation time T_{oh} will be divided into three time slots: T_1, T_3 and T_6, these slots refer respectively to the time intervals of omnidirectional, 3-sector and 6-sector modes. The ECG of an adaptive 6-sector RBS with reference to a non-adaptive 6-sector RBS can be expressed as in (11).

$$ECG_{adaptive} = \frac{(P_{oh,6}+\alpha.PR_{rh,6}.).T_{oh}}{\sum_{i=1,3,6}(P_{oh,i}+P_{rh,i}.\alpha_i).T_i} \quad (11)$$

Where α is the average daily traffic load, α_i is the average traffic load when the RBS number of active sectors is *i*. The terms $P_{oh,6}$ and $P_{rh,6}$ refer to the overhead power and radio head power of a 6-sector

RBS, $P_{oh,i}$ and $P_{rh,i}$ refer to the overhead power and radiohead power when the RBS number of active sectors equals i. Switching between the different modes can be done dynamically depending on the offered traffic value. Other schemes of adaptive sectorisation can be implemented to save even more power by switching off and activating the RBS sectors progressively one by one from 3 to 2 and from 2 to 1 in 3-sector RBS. Similarly, from 6 to 5, 5 to 4, 4 to 3, 3 to 2 and 2 to 1 in the 6-sector RBS.

5. Results and discussion

A. RAN energy efficiency evaluation

In this section, the energy efficiency of both 3-sector and 6-sector network deployments are evaluated with reference to an omnidirectional RBS deployment benchmark. The ECG of the two deployments is evaluated when the same coverage area and the same offered traffic load are assumed. The number of the required sectorised base stations, and the omnidirectional base stations are estimated by using a MATLAB based static system level simulator developed by the authors. The simulator is used to find the coverage radius of the sectorised and omnidirectional sites and then the RAN ECG is calculated by using (10).

To meet the required coverage and the QoS requirement, the site radius must not exceed the maximum allowed distance, in the uplink as well as in the downlink and 95% of cell coverage requirement is used in the simulator. Figure 3 shows the average area capacity density results for the various deployment options, the ratio $\left(\frac{R_S}{R_o}\right)$ is calculated for both the 3-sector and 6-sector site deployments at each target area capacity density. The results for the network ECG are given in Figure 4 and show that the 3-sector deployment option is more energy efficient than the 6-sector option, for all area traffic demand densities ranging from 10 to 180 Mbit/s/km^2. Therefore. densifying the macro 3-sector base stations seems to be more energy efficient than upgrading the network into 6-sector sites.

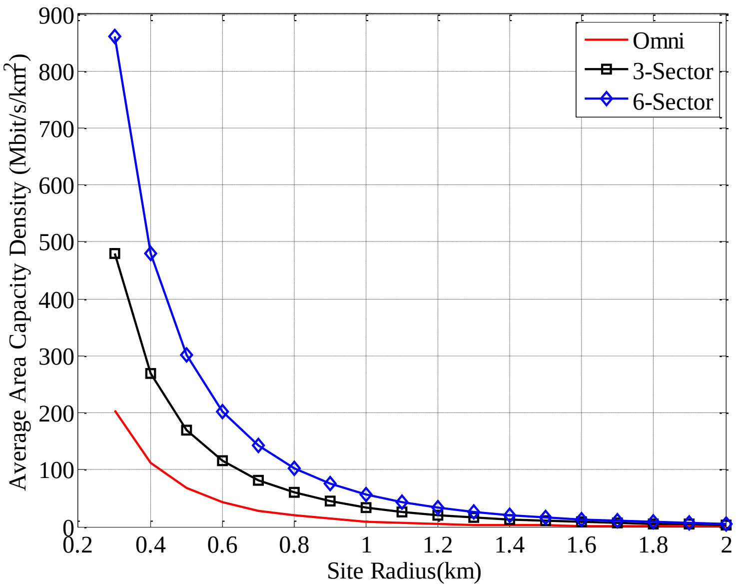

Figure 3. The Area Capacity Density

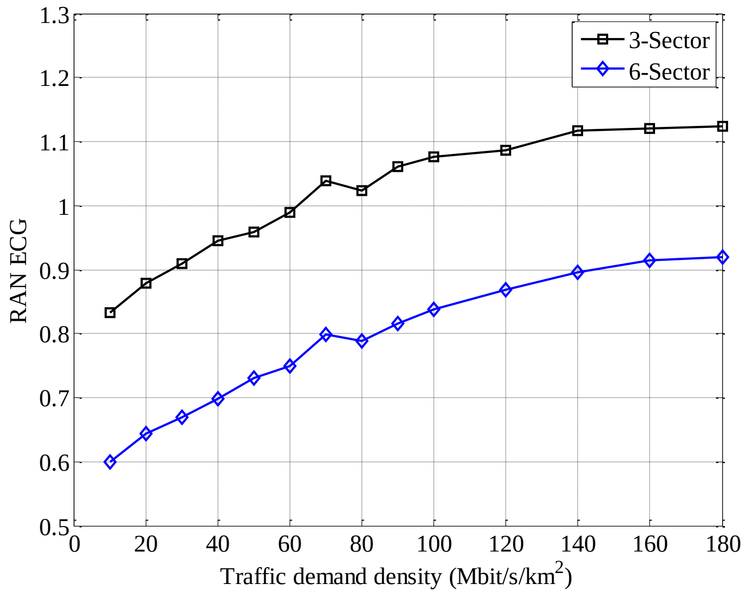

Figure 4. RAN ECG

B. Adaptive sectorisation

The ECG of sectorised RBS can be improved by implementing an adaptive sectorisation technique. Different schemes of adaptive sectorisation can be implemented in order to adapt the number of active sectors to the average traffic load in the network. The ECG for an adaptive 6-sector RBS can be calculated by using (11) for an observation period of one day and by using the traffic profile shown in Figure 5.

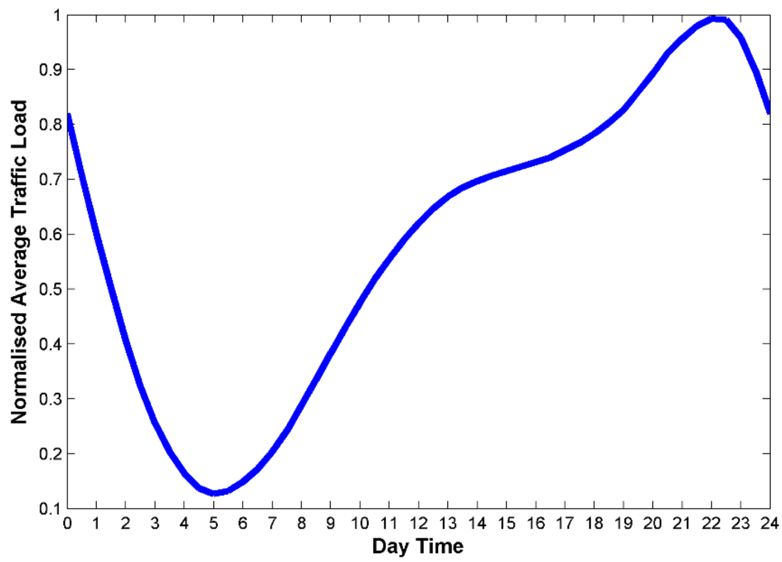

Figure 5. The daily traffic profile

The average traffic load value for this profile is calculated to equal 0.6. The non-adaptive 6-sector RBS is taken as a reference for the ECG calculation. Table 3 shows the ECG results when implementing the adaptive sectorisation in 3-sector and 6-sector sites. For 3-sector RBS sites two schemes have been evaluated: the first is to switch dynamically between 3 and one sectors according to the traffic load. The second scheme is the progressive adaptive sectorisation, where the 3-sector RBS can be switched dynamically between 3-sector, 2-sector and omnidirectional mode. The same schemes can be applied on 6-sector RBS site where the RBS can be switched between 6-sector, 3-sector and omnidirectional mode. A progressive adaptive sectorisation technique is also applied where the 6-sector RBS can switch dynamically between 6 different modes (6, 5, 4, 3, 2, 1 active sectors).

Table 3 *Adaptive Sectorisation ECG*

Sectorisation Type	ECG of 3-sector RBS	ECG of 6-sector RBS
Non-Adaptive	1	1
Adaptive	1.07	1.18
Progressive adaptive	1.14	1.42

The obtained results show clearly in Figure 6 that more energy savings are achieved by using the progressive adaptive sectorisation. For instance, non-progressive adaptive sectorisation improves the ECG by 18% when applied to 6-sector RBS sites, whereas the progressive adaptive sectorisation improves the ECG by 42%. Importantly, as seen clearly from Figure 6, the deployment of 6-sector sites becomes more energy efficient than the densification of 3-sector sites when the progressive adaptive sectorisation scheme is implemented.

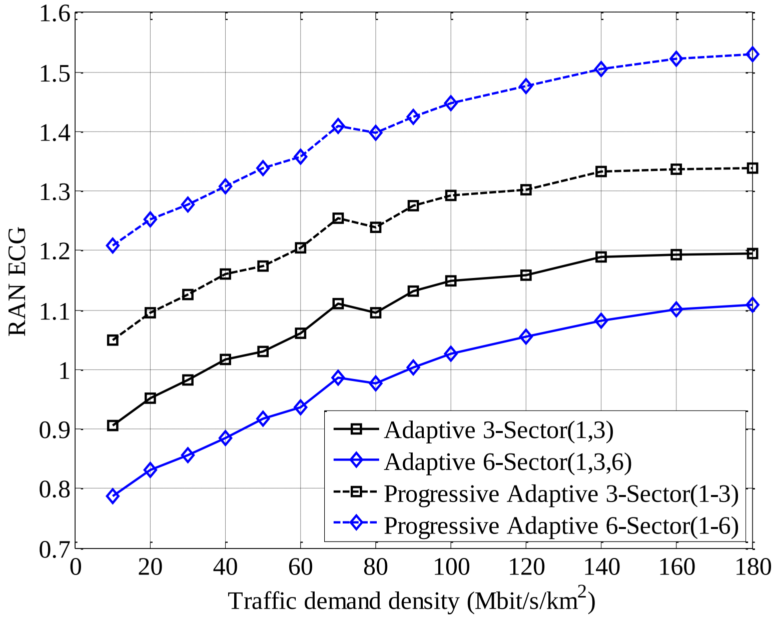

Figure 6. RAN ECG with adaptive sectorisation

6. Conclusion

Our aim in this paper was to find the most energy efficient deployment option for cellular network operators to increase the capacity of their macro RANs. The two evaluated deployment options were either to densify the 3-sector base stations, or to upgrade the network to 6-sector base stations. Our results have shown that densifying the 3-sector base stations is the most energy efficient deployment option when designing the network to meet the peak traffic load. Moreover, different schemes of adaptive sectorisation have been evaluated for the two cases of 3 and 6 sector deployments. The proposed adaptive sectorisation schemes include switching between one and three active sectors mode in 3-sector RBS and between one, three and six sectors mode in 6-sector site. These schemes have improved the network ECG by 7% and 18 % in the 3-sector and 6-sector deployments, respectively. Importantly, greater improvement is achieved when the progressive adaptive sectorisation technique is implemented. The ECG improvement in 6-sector deployment was 42% with reference to non-adaptive mode. Hence, the 6-sector deployment option becomes the most energy efficient option for the network operators when the progressive adaptive sectorisation is used.

References

[1] M. Pickavet, W. Vereecken, S. Demeyer, P. Audenaert, B. Vermeulen, C. Develder, *et al.*, "Worldwide energy needs for ICT: The rise of power-aware networking," in *Advanced Networks and Telecommunication Systems, 2008. ANTS '08. 2nd International Symposium on*, 2008, pp. 1-3.

[2] H. Klessig, A. J. Fehske, and G. P. Fettweis, "Energy efficiency gains in interference-limited heterogeneous cellular mobile radio networks with random micro site deployment," in *Sarnoff Symposium, 2011 34th IEEE*, 2011, pp. 1-6.

[3] B. Badic, T. O'Farrrell, P. Loskot, and J. He, "Energy Efficient Radio Access Architectures for Green Radio: Large versus Small Cell Size Deployment," in *Vehicular Technology Conference Fall (VTC 2009-Fall), 2009 IEEE 70th*, 2009, pp. 1-5.

[4] J. He, P. Loskot, T. O'Farrell, V. Friderikos, S. Armour, and J. Thompson, "Energy efficient architectures and techniques for Green Radio access networks," in *Communications and Networking in China (CHINACOM), 2010 5th International ICST Conference on*, 2010, pp. 1-6.

[5] S. Tombaz, S. Ki Won, and J. Zander, "Impact of densification on energy efficiency in wireless access networks," in *Globecom Workshops (GC Wkshps), 2012 IEEE*, 2012, pp. 57-62.

[6] L. G. Hevizi and I. Godor, "Power savings in mobile networks by dynamic base station sectorization," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2011 IEEE 22nd International Symposium on*, 2011, pp. 2415-2417.

[7] Q. Yinan, M. A. Imran, and R. Tafazolli, "Energy-aware adaptive sectorisation in LTE systems," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2011 IEEE 22nd International Symposium on*, 2011, pp. 2402-2406.

[8] W. Guo, J. M. Rigelsford, L. Ford, and T. O'Farrell, "Dynamic basestation antenna design for low energy networks," *Progress In Electromagnetics Research C*, vol. 31, pp. 153-168, 2012.

[9] Arbi, A., O'Farrell, T., Zheng, F. C., & Fletcher, S. C. (2017). Toward green evolution of cellular networks by high order sectorisation and small cell densification. In *Interference Mitigation and Energy Management in 5G Heterogeneous Cellular Networks* (pp. 1-28). IGI Global.

[10] Arbi, A., & O'Farrell, T. (2015, June). Energy efficiency in 5G access networks: Small cell densification and high order sectorisation. In *2015 IEEE International Conference on Communication Workshop (ICCW)* (pp. 2806-2811). IEEE.

[11] D. Lister, "An operator's view on green radio," *Keynote Speech, GreenComm*, 2009.

[12] G. Auer, V. Giannini, C. Desset, I. Godor, P. Skillermark, M. Olsson, *et al.*, "How much energy is needed to run a wireless network?," *Wireless Communications, IEEE*, vol. 18, pp. 40-49, 2011.

[13] M. Deruyck, W. Joseph, and L. Martens, "Power consumption model for macrocell and microcell base stations," *Transactions on Emerging Telecommunications Technologies*, 2012.

[14] H. Hamdoun, P. Loskot, T. O'Farrell, and J. He, "Survey and applications of standardized energy metrics to mobile networks," *Annals of telecommunications-annales des télécommunications*, vol. 67, pp. 113-123, 2012.