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Energy Consumption Assessment of Mobile Cellular Networks

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ABSTRACT : *The increase in energy consumption of mobile cellular networks has now become a concern not only because of increase in the cost of energy on the part of mobile network operators but also because of its adverse effect on the environment due to global warming. Also with 5G technologies like Machine to Machine (M2M) and Internet of things being developed, there is even going to be a greater increase in the energy consumption of mobile cellular networks. Hence there is a need to develop energy efficient solutions and strategies. A key aspect of these strategies is the development of suitable metrics that can be used to quantify and compare the energy consumption of mobile cellular networks. In this research, the Energy Consumption Gain (ECG) metric is used compare the energy efficiency of the various Radio Access Technologies (RATs) in Zurich, Switzerland. Relevant Mobile network data set comprising all the Radio Access Technologies (RAT) in Zurich, Switzerland was obtained and analyzed using a combination of ArcGIS ArcMap 10.1 and Microsoft excel 2013 software. The outcome is that the LTE RAT is the most energy efficient because it consumes less power than all the other RATs.*

KEYWORDS –*Base Transceiver Station (BTS), Energy Consumption Gain (ECG), Energy Efficiency, Radio Access Technology (RAT)*

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I. INTRODUCTION

The mobile communication industry is one of the fastest growing sectors of the Information Communication Technology (ICT) sector. This rapid growth is as a result of the ever increasing number of mobile subscribers, exponential rise in the number of mobile devices and the advancement in mobile application development. This has resulted in the increase in the amount of mobile traffic demanded. Also with the emerging 5G technologies like the Machine to Machine (M2M) communication, there is going to be even higher demand for mobile data services. All these result in the increase of energy consumption of the mobile network.

The ICT sector is said to contribute about 10% of the global energy consumption and this figure is projected to increase by a factor of two (2) every ten (10) years [1]. 0.5 % of the energy consumption in the ICT sector is contributed by the mobile communication networks and this value is also expected to increase further. The increase in the energy consumption of mobile cellular network has two negative consequences which are environmental degradation and increase in network operating cost on the part of mobile network operators. In recent years, attention has been drawn to the area of global warming. It has been estimated that the ICT sectors accounts for about 2% of the total volume of greenhouse gas emission out of which the mobile communication networks is said to contribute 0.2% to the world wide greenhouse gas emission. Also, with the ever increasing demand for mobile data service, this figure is expected to increase. The increase in the energy consumption of cellular networks has also resulted in more electricity bills for mobile network operators thereby leading to an increase in the cost of running or operating the network [2].

Therefore it has become necessary to develop new techniques and technologies that will help reduce the energy consumption of mobile networks. There are certain areas that need to be considered in order to develop energy efficient solutions. They include: design of energy efficient network architecture, development of new techniques for network deployment, spectral efficiency techniques, proper choice of backhaul connectivity and the development of energy efficiency metrics [3]. For this research work, the emphasis is on assessment of the energy consumption of mobile cellular networks using energy efficiency metrics.Energy efficiency metrics are used to compare the energy consumption performances of components, equipment and systems or networks. A few energy efficiency metrics have been developed, however, there is yet to be a generally agreed upon metric to be used in for evaluating the energy efficiency at a network or system level.

II. BASE STATION SITE POWER CONSUMPTION MODEL

Since the energy efficiency metrics of a mobile cellular network cannot be formulated with an understanding of the power consumption of the various components or subsystems of the base station, a brief review of base station components is considered in this session as well as the power models that exist.

The mobile cellular network consists of three distinct parts namely the user devices, the Radio Access Network and the core network [4]. The Radio Access Network (RAN) consumes the highest percentage of the energy with the base station accounting for about 60-80% of the total energy consumption of the radio access network [5]. Since the base station is the major contributor to the energy consumed in the radio access network, there is a need to investigate the energy consumed in the base station site in order to enable proper evaluation of the energy efficiency of the network.

To quantify the energy consumed by a base station site it is important to know the various subsystems or equipment that make up the base station site and their contributions to the total site power consumption. There seven major subsystems that are present in a base station site [5] are: Power amplifier (PA), Radio Frequency (RF) transceiver, antenna and feeder cable, the processing unit, backhaul, cooling unit and the power supply unit and backup batteries. Irrespective of the size, type or shape of the base station site, they all have these components installed.

2.2 RELATED WORKS ON POWER CONSUMPTION MODELS

Developing models that can quantify the power consumption of a base station site is an ongoing research area. A review of various kinds of power consumption models that can be applied to all base station types is carried out in this section.

A linear power consumption model that relates the average power radiated in a BTS site to the average power consumed was proposed in [6]. The model is made up of two parts, the first parts deals with the effect of average RF radiated power on the overall BTS power consumption while the second part is the power consumed independent of transmit power. The impact of backhauling on the power consumption of heterogeneous networks was considered in [7] and a power consumption model which is an extension of [6] was developed by including the effect of backhaul. In [8] a sophisticated power model which maps the RF power radiated to the power supplied to a BTS site was proposed. This model takes all the components of BTS site into consideration except the power consumption of the backhaul. A parameterized base station power consumption model was introduced in [9]. It builds upon the model developed in [8] by including two other parameters: power amplifier output range and transmission bandwidth. In [10] a non-linear power consumption model has been proposed which can be used to evaluate the power consumption of LTE base stations. This model has the ability to accommodate a large set of parameters, however it is quite complex to apply. Another generic model was proposed in [11] using these parameters: power consumed by the RF module, system module, feeder cable loss and RRH and site cooling. It also takes into account the fixed and load dependent aspects of BTS power consumption. The Green Radio (GR) project also developed simple analytic power model similar to [11] that comprises all the BTS site subsystems. It considers the load dependent and independent power consumption as well as the impact of backhaul. This model is simple to implement and can be used to compute the power consumption of all base station types.]. A new power consumption model was also developed by IMEC [12]. This power consumption model can accommodate a wide variety of network scenarios and can be applied to all base station types under different operation conditions. The future power consumption of base stations can also be estimated using this model.

III. ENERGY EFFICIENCY METRICS

There are basically two ways of defining energy efficiency metrics. First, it can be defined as the ratio of the energy output to the energy input. Secondly, it can be defined with respect to performance in which case the energy efficiency is considered to be the ratio of a given network performance to the energy consumed in order to obtain that performance [3].

Energy efficiency metrics can be specified at three different levels namely:

- Component level (for wireless equipment subsystems e.g. power amplifier, antenna, etc.)
- Equipment level (e.g. base stations and wireless terminals)
- System or network level (for a group of equipment that form a network) [3].

Energy efficiency metrics play a major role in the quest to develop energy efficient solutions whether at the component, equipment or system level. They include:

- They enable us to evaluate and compare of the energy consumed in different components, equipment, systems or networks.

- They enable us set research targets that will guide us in our quest for energy efficient techniques and technologies.
- Energy efficiency metrics helps to examine the network architecture in order to detect certain parts of the network that consumes more energy thereby enabling their replacement with more energy efficient ones.
- They also help to quantify the gains obtained by adopting or utilizing energy efficient techniques in the design of networks [13].

According to [3] at the component level, most of the energy efficiency metrics have been fully developed but energy efficiency metric definition at the equipment and network level is not easy and straightforward. In the next section a review of the energy efficiency metrics used in literatures is carried out.

3.1 RELATED WORKS ON ENERGY EFFICIENCY METRICS

One of the most widely applied EE metric is the bit per joule metric. It is defined as the ratio of total volume of data transferred to the energy consumed within a given time interval. Its unit is in bits/joule or bits per second per watt. It is expressed mathematically as [14]:

$$EE = \frac{overalldatarate}{Totalpowerconsumed} = \frac{R_T}{P_T} \quad (bits/joule\ or\ bps/W)$$

This metric has been applied in many literatures and according to [3] is the will continue to be the basic energy efficiency metric in 4G networks and beyond. Despite the simplicity of this metric, it does not include network coverage hence it cannot be used to assess the energy efficiency of networks having different coverage areas. The notion of Area Power consumption was proposed in [6]. This is obtained by dividing the network average power consumption by the average area covered by the network. Its unit is in watts per square kilometer. It is defined as:

$$\rho = \frac{P}{A} \quad (W/m^2)$$

Where ρ represents the area power consumption, P is the average power consumption and A is the average cell coverage area. It is used in comparing the power consumption in heterogeneous networks with varying site density. The metric is mainly useful under low load conditions whereby network is limited by it coverage. However as observed in [8], this metric needs to be used in conjunction with other performance metrics as it cannot be used to successfully access the energy efficiency of two networks having different capacity or throughput. The concept of area energy efficiency [AEE] was introduced in [15]. It is an extension of the bit per Joule metrics with an inclusion of network coverage area. It is used to evaluate the energy efficiency of a network with respect to its size. The AEE can be defined as the bit/Joule/unit area that a cell can support. It is expressed as

$$AEE = \frac{EE}{A} \quad (bit/joule/m^2)$$

The Energy consumption rating (ECR) [16] metric relates the peak power consumption to the peak amount of data transferred in a given period of time. It is defined as

$$ECR = \frac{E}{T} \quad (W/Gbps)$$

Where E is the maximum energy consumption (Watts) and T is the peak throughput (Gbps). Thus the more efficient system is the one that has a lower value of ECR which implies that it uses less energy for data transfer. Its unit is in watts per Gigabyte per second. The ECR (Energy consumption rate) metrics used in Green radio Project is a slight variant the ECR (Energy consumption rating) because instead of using the peak values of power and capacity, they are replaced with their average values. That is [17]

$$ECR = \frac{averagepowerconsumption}{averagedatarate} = \frac{E}{M} \quad (Joule/bit)$$

They also introduced the ECG metric which is a comparison of the ECR of two system one being the reference system and the other is the one whose energy efficiency needs to be assessed. It is defined as [18]

$$ECG = \frac{E_a}{E_b}$$

Where E_a is the energy consumption of the reference system and E_b is the energy consumption of the system that is been tested.

They also developed the Energy Reduction Gain (ERG) metric which is derived from ECG metric [17], [18]. It is defined as

$$ERG = \left(1 - \frac{1}{ECG}\right) \times 100\%$$

In this research we going to make use of the Energy consumption gain (ECG) metric which is a comparison of the energy consumption of two different systems or networks.

IV. METHODOLOGY

4.1 Metric Presentation

4.1.1 Base Station Site Energy Consumption

The Green Radio model for base station site power consumption [4] is expressed as:

$$P_{bts} = P_{ac} + P_{bh} + n_s \cdot \{P_{ps} + P_{pu}\} + \alpha \cdot n_s \cdot n_a \cdot \left\{P_{trx} + \frac{P_{tx}}{\eta_{pa} \cdot \eta_{cl}}\right\} \quad (1)$$

Where: P_{bts} is the total power consumption of a base station site, P_{ac}, P_{bh}, P_{ps} and P_{pu} represents the power consumption of the air- conditioner, backhaul, power supply and processing unit, n_s denotes the number of sectors in each base station site. P_{trx} and P_{tx} represents the power consumption of the transceiver and power amplifier, n_a denotes the number of antennas, η_{pa} and η_{cl} represents the power amplifier efficiency and the feeder cable efficiency respectively

The energy consumption of a BTS can be expressed as:

$$E_{bts} = P_{rh}T_{rh} + P_{oh}T_{oh} \quad (2)$$

Where E_{bts} denotes the energy consumption of the BTS, P_{rh} and P_{oh} represents the load-dependent (radio head) and the load-independent (overhead) power consumptions respectively. T_{rh} and T_{oh} represents the periods of time in which the radio head and overhead power is consumed. Hence for a Radio access network (RAN) made up of n homogeneous base station sites, its total energy consumption, E_{RAN} can be expressed as:

$$E_{RAN} = n \cdot E_{bts} \quad (3)$$

Substituting the expression for E_{bts} from (2) gives;

$$E_{RAN} = n \cdot (P_{rh}T_{rh} + P_{oh}T_{oh}) \quad (4)$$

Where n is the total number of base stations in the RAN

4.1.2 Energy Consumption Gain (ECG)

The figure of Merit known as the Energy Consumption Gain (ECG) can be defined as the ratio of the energy consumption of two systems or network [17]. It is used to compare the energy consumption of two different systems, networks or configurations. It can be mathematically expressed as:

$$EnergyConsumptionGain(ECG) = \frac{E_{system\ 1}}{E_{system\ 2}} \quad (5)$$

Where $E_{system\ 1}$ is the energy consumption of system 1 and $E_{system\ 2}$ is the energy consumption of system 2.

Applying the ECG figure of merit to two different homogeneous RANs, RAN_1 and RAN_2 with each consisting of a number of base stations represented by n_1 and n_2 respectively gives:

$$ECG_{RAN} = \frac{E_{RAN1}}{E_{RAN2}} = \frac{n_1 \cdot E_{bts1}}{n_2 \cdot E_{bts2}} = \frac{n_1 \cdot (P_{rh1}T_{rh1} + P_{oh1}T_{oh1})}{n_2 \cdot (P_{rh2}T_{rh2} + P_{oh2}T_{oh2})} \quad (6)$$

The load activity factor $\alpha = \frac{T_{rh}}{T_{oh}}$ which means that $T_{rh} = \alpha \cdot T_{oh}$ (7)

Substituting (7) in (6) gives

$$ECG_{RAN} = \frac{n_1 \cdot (P_{rh1}T_{rh1} + P_{oh1}T_{oh1})}{n_2 \cdot (P_{rh2}T_{rh2} + P_{oh2}T_{oh2})} = \frac{n_1 \cdot (P_{rh1}(\alpha_1 \cdot T_{0h1}) + P_{oh1}T_{oh1})}{n_2 \cdot (P_{rh2}(\alpha_2 \cdot T_{0h2}) + P_{oh2}T_{oh2})}$$

$$= \frac{n_1 \cdot (\alpha_1 \cdot P_{rh1} + P_{oh1}) \cdot T_{oh1}}{n_2 \cdot (\alpha_2 \cdot P_{rh2} + P_{oh2}) \cdot T_{oh2}} \quad (8)$$

Assuming that the observation period of time when the load-independent power is consumed for both systems is the same i.e. $T_{oh1} = T_{oh2} = T_{oh}$, then equation (8) then becomes:

$$ECG_{RAN} = \frac{E_{RAN1}}{E_{RAN2}} = \frac{n_1 \cdot (\alpha_1 \cdot P_{rh1} + P_{oh1}) \cdot T_{oh}}{n_2 \cdot (\alpha_2 \cdot P_{rh2} + P_{oh2}) \cdot T_{oh}} = \frac{n_1 \cdot P_{bts1}}{n_2 \cdot P_{bts2}} = \frac{P_{RAN1}}{P_{RAN2}} \quad (9)$$

Where $P_{bts} = \alpha_1 \cdot P_{rh1} + P_{oh1}$ is the power consumption of a base station site.

Extending the above formulation in (7) to compute the ECG of two different Radio Access Technologies (RATs), RAT_1 and RAT_2 each made up of heterogeneous base stations types gives

$$ECG_{RAT} = \frac{E_{RAT1}}{E_{RAT2}} = \frac{P_{RAT1}}{P_{RAT2}} \quad (10)$$

Where P_{RAT} in this case is expressed as

$$P_{RAT} = \sum_{i}^{m} n_i P_i \quad (11)$$

Where m denotes the number of BTS site types in the RAT, n_i is the number of each base station type (denoted by i) and P_i denotes the power consumption of each base station type.

Expanding equation (10) gives

$$ECG_{RAT} = \frac{E_{RAT1}}{E_{RAT2}} = \frac{P_{RAT1}}{P_{RAT2}} = \frac{\sum_{i=1}^{m} n_{1i}P_{1i}}{\sum_{i=1}^{m} n_{2i}P_{2i}} \quad (12)$$

Where the first subscripts (1 and 2) in the numerator and denominator is used to differentiate between RAT_1 andRAT_2.

4. 2 Data Collection

The telecommunication regulatory authority web pages of different countries like Japan, Korea, Sweden, Switzerland were visited and email sent to relevant contacts. Also a search was carried out for journals were relevant data have been used. At the end of the search, the dataset from Zurich canton in Switzerland was obtained. The data set contained all the base stations in Bern which were categorized according to their technologies (GSM, UMTS, and LTE), locations (X Y coordinates) and the total power consumption (represented by power codes $1 < P1 \leq 10W$, $10 < P2 \leq 100W$, $100 < P3 \leq 1000W, P4 > 1000W$ and above).

4.3 Determination of total power consumption of each RAT in Switzerland

To obtain the total power consumption of all base stations belonging to each RAT the following procedure was carried out:

- Grouping the base stations in each RAT according to the power consumption denoted by their power code P1 to P4 using Microsoft excel 2013.
- Assigning of specific values for P1 to P4 (P1=10W, P2=55W, P3 =550W, P4 = 1350W). The values of P1 to P4 for each base station type was selected using the IMEC power model [12] by selecting the base station parameters for earlier years like 2010.
- There after the formula for calculating the total power consumption of a RAT as developed in equation (12) was applied.

V. RESULTS

The tables below show the total power consumption of each of the Radio Access Technology (RAT) in Zurich, Switzerland. The total power consumption of each RAT is displayed in the TABLES 1-3:

Table 1: Total power consumption of GSM RAT

POWERCODE	Powercode value (P_i)	No. of BTS (n_i)	power consumption per power code (n_iP_i)
P1	10	577	5770
P2	55	106	5830
P3	550	982	540100
P4	1350	95	128250
		$\sum_{i=1}^{4} n_i = 1760$	$\sum_{i=1}^{4} n_iP_i = 679950W$

Table 2: Total power consumption of UMTS RAT

POWERCODE	Powercode value (P_i)	No. of BTS (n_i)	power consumption per power code (n_iP_i)
P1	10	114	1140
P2	55	28	1540
P3	550	735	404250
P4	1350	466	629100
		$\sum_{i=1}^{4} n_i = 1343$	$\sum_{i=1}^{4} n_iP_i = 1036030W$

Table 3: Total power consumption of LTE RAT

POWERCODE	Powercode value (P_i)	No. of BTS (n_i)	power consumption per power code (n_iP_i)
P1	10	27	270
P2	55	25	1375
P3	550	836	459800
P4	1350	83	112050
		$\sum_{i=1}^{4} n_i = 971$	$\sum_{i=1}^{4} n_iP_i = 573495W$

The result of the power consumption comparison of the RATs in Switzerland using the energy consumption gain (ECG) figure of merit is presented in TABLE 4. The UMTS power consumption was chosen as the base line RAT because it has the highest power consumption.

Table 4: RAT power consumption comparison using ECG figure of merit

RAT	TOTAL POWER CONSUMPTION (Watts)	ECG
UMTS	1036030	1
GSM	679950	1.523686
LTE	573495	1.80652

The most energy efficient RAT using the ECG metric is the RAT with the highest ECG value. Hence from the ECG result obtained above, the LTE RAT is the most energy efficient since it has the least power consumption among the three (3) RATs. The least energy efficient is the UMTS RAT because it has the highest energy consumption.

VI. CONCLUSION

In this paper, a review of recent energy efficiency metrics and power consumption models was carried out. Relevant data was obtained from Zurich in Switzerland and the data was analyzed in order to obtain the total power consumption of each RAT. The Energy Consumption Gain (ECG) metric was then used to compare the energy consumption of the various RATs. The result obtained showed that the LTE RAT was more energy efficient than the UMTS and GSM with the UMTS RAT being the least energy efficient RAT because it has the highest power consumption. This result is important because it enables us to know the magnitude of the power consumption of each RAT but it is however not sufficient enough to determine the overall energy efficiency of the RATs because it did not take into consideration the throughput as well as the coverage area of the RATs in Zurich. Hence it is recommended that further research should include throughput and coverage area in their energy efficiency assessments of mobile networks.

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