Analysis and Evaluation of Energy Consumption over 4G Network

Md Mamun Ur Rashid[1*], Tadele Belay Tuli[2]

[1]Lecturer, National Institute of Textile Engineering and Research (NITER), Dhaka, **BANGLADESH**
[2]Department of Electromechanical Engineering, Addis Ababa Science and Technology University, **ETHIOPIA**

[*]Corresponding Contact:
Email: mamun.rashid.duet@gmail.com

ABSTRACT

The mobile communication network cuts 0.5 percent of today's global energy consumption. Among all other constrains, energy is the most critical concern to deploy any communication network. The demand of power for wireless networks increases dramatically. By applying three novel approaches, we can minimize the power consumption of 4G wireless networks such as optimal power scheduling (OPS) for base stations, packet delay scheduling (PDS) and sleep mode for variable traffic density (SMVTD). This paper presents energy consumption issues over the 4G wireless network and its associated constraints such as finding the optimal radio base stations to reduce the energy and cost for the entire system. Within same network coverage area if we optimize the number of base stations, then it will be a hallmark to minimize the energy cost. We have considered the various element concerning the 4G network and responsible parameters for energy consumption. We also studied the different mode of variable traffic density in 4G network.

Key words:

4G, LTE, BTS, sleep mode, packet delay, traffic density

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INTRODUCTION

There are some advanced features and benefits offered by fourth-generation networks (4G) such as real-time voice and video conferencing, video streaming, games, and best effort web browsing. Conventional design suffers from bandwidth shortage and high-cost base station sites have produced current cellular systems based on third-generation (3G) and 4G (LTE) standards. LTE offers extraordinary speed in data transfer and continuous-connected capabilities. In sophisticated antennas in which multiple input and multiple output (MIMO) technology implements the different scheme, attain the highest data rates through higher order modulation and coding. The higher data transmission or reception in the other hand consumes more powers; this in turn, creates quick battery drainage. To support battery operated mobile devices, LTE networks support power saving modalities, and mobile devices could work for a long period with one-time full charge Tombazet al. (2011), Guo et al. (2013), Paloheimo et al. (2006).

There are three main factors which responsible for more energy consumption over the 4G wireless networks. The higher number of base stations, packet delay scheduling, and traffic density. However, there are three main elements in the 4G wireless networks such as spectrum cost, infrastructure cost, and energy cost. The most critical concern in this paper is optimization and minimization of energy cost in such network. Because energy is the vital element to drive the whole system. Instead, we should take a "clean state of art" approach, which will resolve the energy consumption problem and make sure optimal power consumption for the broadband access network that meets user requirements at lowest total cost. On the other hand, it is significant to consider how various cost factors and constraints such as energy, infrastructure investments, and spectrum affect the design.

Several studies have been done to realize the mobile traffic modeling of handheld devices. In work, truly used 4G devices and 4G setup to turn up with application characteristics. Authors Richter et al. inspected the impact of social networking on 3G systems (Richter and Fred, 2010). The researchers, Tombaz et al. (2011) established a power model for network activity on three different types of networks namely Wi-Fi, GSM, and 3G and showed that each had a different model of how energy consumes for network activity (Tombaz et al., 2011). Based on this model, they settled an algorithm called *Tail Ender* which saves energy spent at the tail of any network traffic activity by reducing the amount of time spent in an active state after transfer is complete. In this paper, we have investigated at the energy consumed for 4G network and it's possible saving strategies which were not inspected before. The scientist Ibrahim and Jawad made power measurements of different apparatuses of different models of smart phones and proposed a battery-based power model named Power Tutor of how diverse components e.g., screen, CPU, the 3G, the Wi-Fi, and GPS consume power on the phone (Ibrahim and Jawad, 2002).

THEORY

Before 4G

The evolution and history of mobile service from the first-generation (1G) to fourth-generation is illustrates as follows:

A. First generation (1G)

In the 1970s the first generation of wireless cellular technology, known as 1G is introduced. The first generation mobile service was based on analog systems and operated for voice communication mainly. The wireless standards for this generation used plain FDMA and TDMA. Several principles are Mobitex, DataTac, ETACS, and TACS.

B. Second generation (2G)

In the 1980s the second generation (2G) systems were designed and are still widely applicable in developing countries mainly for voice calls based on digital technology. These 2G systems provided circuit switched data communication services at low speed (Sharif et al., 2015). The second-generation mobile communication systems starts to revolutionize the communication protocols and standard to enhance the applications. It expands rapidly to every corner of the globe. The second generation standards are GSM, iDEN, D-AMPS, etc.

C. 2.5G

The in-between wireless technology that bridges 2G and 3G is called 2.5G. The naming is assigned to refer to packet switching domain in addition to the circuit switching domain. However, the naming is not scientifically formulated reasonably it uses for marketing purpose. 2.5G system provides some of the 3G features (e.g., it is packet-switched) and can use some of the existing 2G infrastructures (Khan et al., 2009).

D. Third generation (3G)

For high-speed data transfer and multimedia applications rates required to meet the growing demands in network capacity, 3G standards started evolving. The systems in this standard are essentially a linear enhancement of 2G systems. They are based on two parallel backbone infrastructures, one consisting of circuit switched nodes, and another is packet oriented nodes. The third-generation (3G) has been launched in several parts of the world, but the success story of 2G is hard to repeat. Figure 1 shows the evolution of 4G technology and its related data rates.

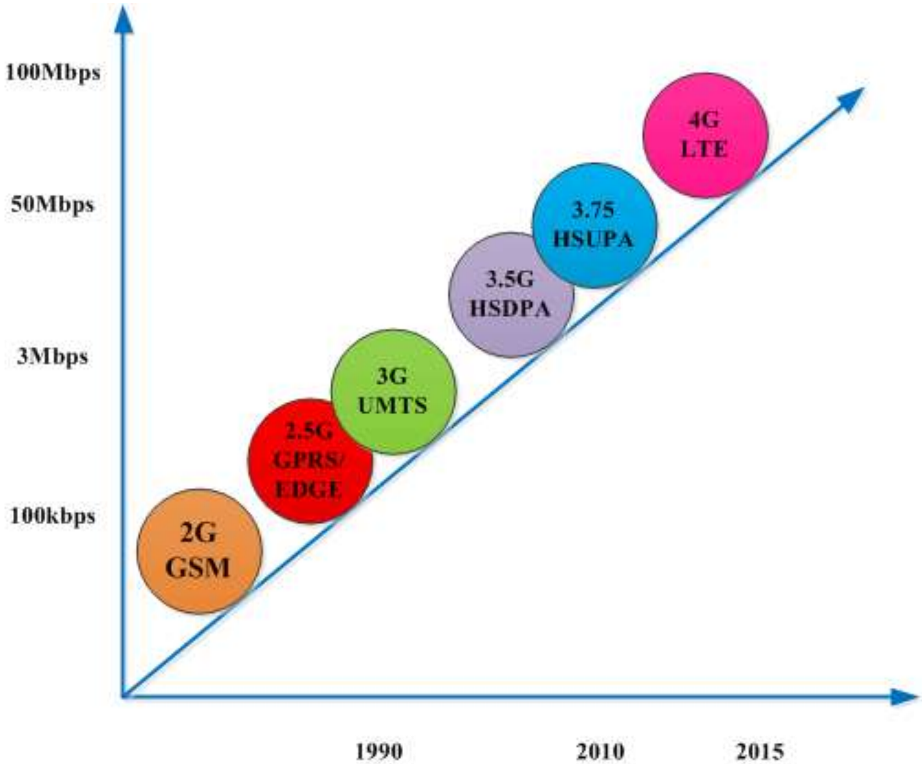

Figure 1: Evolution of 4G Technology (Santhi et al., 2003)

Features of 4G Technology

A. High performance

Rich multimedia content across wireless networks with 3G will not be able to take advantages some industry experts' opinion. 4G will feature extremely high-quality video quality comparable to HD (high definition) TV compared to 3G. Downloads at the wireless platform the speeds reaching 100 Mbps, i.e., 50 times of 3G, are possible with 4G (Frattasi et al., 2006).

B. Interoperability and easy roaming

The fourth-generation wireless network 4G provides a global standard that provides global mobility. Various wireless access networks typically differ regarding data rate, coverage, latency, and loss rate. This concept is referred to as service personalization (Richter et al., 2010).

Figure 2 shows the key feature of 4G network.

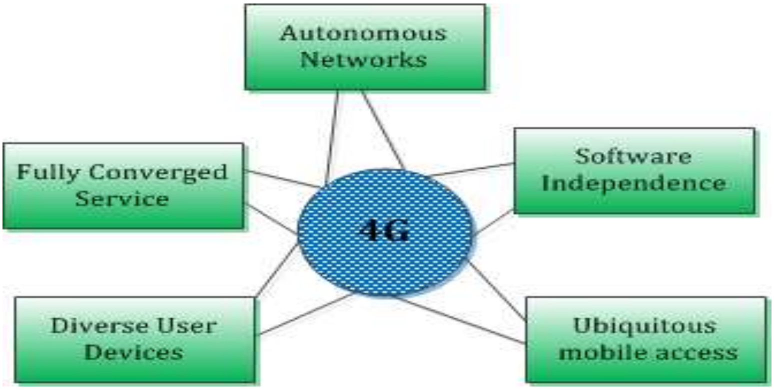

Figure 2: Key Features of 4G Network (Santhi et al., 2003)

C. Fully converged services.

The user can access the network from different platforms such as cell phones, laptops, etc. In 4G which delivers connectivity intelligent and flexible enough to support streaming video, VoIP telephony, Web browsing, e-commerce, still or moving images, e-mail and location-based services through a wide variety of devices.

D. Low cost

4G systems are low-priced network compared to 3G, it can be built atop existing networks and will not require operators to completely retool and will not require carriers to purchase costly extra spectrum. In addition, 4G is cost efficient along with spectrally efficient.

E. Scalability

One of the most challenging aspects of the mobile networks is the scalability. It refers to capability to handle ever increasing number of users and services. Since an all IP core layer of 4G is easily scalable, it is ideally suited to meet this challenge. Table 1 shows the series of mobile generation and their features.

Table-1: Series of Mobile Generations and their Features (Santhi et al., 2003)

Technology	**1G**	**2G**	**2.5G**	**3G**	**4G**
Design Began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2010
Services	Analog Voice	Digital Voice	Higher capacity	Higher capacity, broadband data up to 2mbps	Completely IP based, speed up to hundreds of MBs
Standards	NMT	GSM	GPRS EDGE	WCDMA, CDMA	Single standard
Bandwidth	1.9kpbs	14.4kpbs	384kpbs	2Mbps	200Mbps

Modeling of Power Consumption

The average radiated power of any base stations is given by the given equation (Richteret al., 2010) (1):

$$P = aP_{tx} + b \quad (1)$$

Here P and Ptx denoted the average total power per base station and the power fed to the antenna, respectively. Coefficient a accounts for the part of the power consumption while b denotes the power that is consumed independent of the average transmit power. The total power consumption of the network is calculated by considering the density of base stations, back haul and traffic density. However, the backhaul power is neglected in most of the literatures. This paper presents the detailed power consumption model that puts into account both network power and back hauls.

$$P = N_{BS}(aP_{tx} + b_r + b_b + y\bar{R}) + d \quad (2)$$

Equation (Richter et al., 2010) (2) includes radio power, br, backhaul power, br which is consumed by the transceiver. NBS represents a number of base stations, the uplink interface, $\bar{R}$ is the data rate per base stations and the power independent of traffic is denoted by d. The power consumption derived from the transmission power can be expanded in equation (3) as;

$$P_c = \frac{aN_{BS}}{A}\left(\frac{N_0}{cG}\left(2^{\frac{\bar{R}tot}{N_{BS}}} - 1\right)\left(\frac{A}{\pi N_{BS}}\right)^{\frac{\alpha}{2}} + b_r + b_b\right) + \frac{d}{A} \quad (3)$$

Expression of equation (Richter et al., 2010) (3) illustrates the relation of area power consumption (P_c) with the amount of spectrum, W and the number of base stations, N_{BS}. The performance of the network is measured in average total throughput, $\bar{R}tot$ per unit area. Two main directions can be set for reducing power consumption in the literature: Installing efficient equipment and employing power saving network deployment strategy. Density of base station will be high at urban and lower at rural areas. This helps to manage the spectrum and reduce the infrastructure cost. However, the methods presented in the literature do not presented the effect of high number of base stations in total power consumption.

PROPOSED SOLUTION

In order to optimize the power consumption over 4G network, we propose three approaches.

A. Optimizing base station power consumption

From equation (3) it is shown that, as the number of base stations increases, the radio power consumption also increases. In order to overcome the increase in power consumption due to the number of base stations, it is necessary to model in a mathematical way. If we differentiate the total power consumption with respect to the number of base stations, and equate to zero then we will find the optimal number of base stations that gives minimum power consumption which is mentioned in equation[18] (4).

$$Pc \to \infty, if \begin{Bmatrix} N_{BS\to\infty} \\ N_{BS} \to 0 \end{Bmatrix}; \qquad => \frac{dP_c}{dN_{BS}} = 0; \qquad (4)$$

Here Pc refers total power consumption and NBS denotes number of base stations. The other factors not mentioned in the literature, if the number of base station increases the total energy and infrastructure cost also increases. When we optimize the number of base stations, then the infrastructure cost will be also optimized. The total cost can be given in a plain equation (5) as;

$$T_{total} = T_{bandwidth} + T_{infrastructure} + T_{energy} \qquad (5)$$

We modeled a new approach over diagram (Fig.1) where we are interested to work on energy minimization because the bandwidth and infrastructure costs are nearly constant.

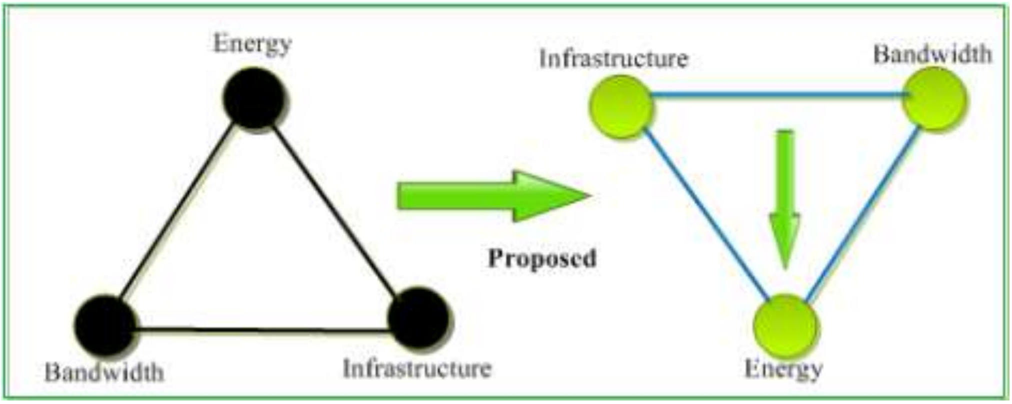

Figure 3: Main constraints of the 4G wireless network (Tombaz et al., 2011)

According to the increase in number of base stations, the total cost also increases remaining the band width as a constant figure. However, the infrastructure cost is increasing linearly. Figure 3 indicates the main constraints of a 4G wireless network.

$$T_{total} = f(N_{BS}, B_{width}, I_{str})$$

(6) By considering1both the mathematical model for total cost and power consumption, we can get a threshold of number for base stations based on the applications.

$$P_{c*} = \int_{N_{BS}^*}^{*} f(N_{BS}^*, B_{width}, I_{str}) d_{NBS} \quad \leq \quad P_c(N_{BS}, B_{width}, I_{str}) \ (7)$$

Where; Pc* is a recalculated power with the optimal number of base stations which reduces extra costs and energy (Richter et al., 2010).

B. Packet delay scheduling for minimum energy

To cut the minimum energy we may introduce the packet delay scheduling for this dedicated wireless network. The lazy packet scheduling schemes have been proposed to find optimal transmission schedules for the packets so that energy consumption is minimized with respect to certain delay bounds. In the fair queuing approach dynamic modulation scheme (DMS) is used to transmit the packets in an appropriate time interval (Richter et al., 2010).

$$T_{bit} = \frac{1}{b * R_s} \qquad (8)$$

$$E_{bit} = C_s * \frac{2^b - 1}{b} + C_E * \frac{1}{b} \qquad (9)$$

Where, T_{bit} is average time to transmit one bit and E_{bit} is energy consumed for transmission of one bit. From the equation (8) we can say, data rate is inversely proportional to the average time, which means if the data rate is higher, average transmission time will becomes lower. In addition, delay and energy consumption are correlated and it can be adjusted by changing modulation level. Energy consumption can be decreased by delaying packets in the buffers for an appropriate time.

C. Sleep mode for minimum energy

The growth of demand for mobile data is directly proportional to the corresponding energy consumption. For networks that operate at varying traffic loads, incorporating the sleep mode significantly reduces the energy consumption. Application of sleep mode works by deactivating some cells based on the traffic threshold T_{th} at time t.

$$T_{th} = f * \frac{1}{N_{BS}} \sum_{n=1}^{N_{BS}} R_{traf,n,t} \ : \ R_{traf,n,t} < T_{th} \tag{10}$$

Where $R_{traf,n,t}$ is the 3G packet-switched (PS) data traffic density on a certain cell n. The behavior of the sleep mode is calibrated by a factor f. If the density of the traffic is less than the threshold of the network, sleep mode is deactivated. The calculation of traffic threshold puts the following parameters into account.

- Percentage of coverage probability (%): this is an area where reasonable signal power is reached.
- Throughput (Mbits/s): is the mean throughput of radio access network of a single cell.
- Percentage of Energy Reduction Gain (ERG): the energy reduction subjected to sleep power.

Sleep mode improves the noise interference to signal ratio (SINR) by increasing the mean distances of cell/UE. The percentage of energy reduction gain (ERG) is calculated for different sleep mode thresholds so that operators can easily look for the best configuration which yields the lowest consumption in energy for a minimum of percentage of coverage. Introducing sleep mode for areas with high cell density reduces radio resources during peak off times which significantly results in reduced energy consumption.

CONCLUSIONS

This paper provides an overview of the 4G evolution and some related parameters concerning energy and cost for the network. There are three key constraints to establish any wireless communication network such as infrastructure, bandwidth and energy. The observation of this research is to find the optimal number of base station to minimize the overall cost and energy for a sustainable network. The integration of optimized number of the base stations, packet delay scheduling, and regulating the traffic density is the most convenient and efficient way to minimize the power consumption over the 4G wireless network. The 4th Generation, mobile communication technology, will be advanced and intelligent technology that will connect the whole world seamlessly. The planned 4G mobile communication system will reduce the number of traffic and increase the network stability. Technologies are evolving day by day but the final achievement of 4G mobile communication will depend upon the new services and contents made accessible to users. These new applications must meet user expectations, and give added value to existing offers.

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