A Survey on Energy Efficient Wireless Communication in Cellular Networks

Suganya Rajendran, C.Jaya suriya

***Abstract*—The explosive growth of high data rate in wireless networks has resulted in a tremendous increase in energy consumption. Energy efficiency in wireless networks has drawn increasing attention of the research communities. High energy consumption has a significant impact on the environment due to the associated CO_2 emission. Moreover energy costs can account for as much as half of a mobile service provider's annual operating expenses. Energy consumption of a cellular network is becoming important interms of both operational costs and environmental impacts. This paper presents a brief survey on some of the works that has been already done to achieve energy efficiency in cellular networks. This paper discuss the techniques such as cell zooming, internetwork cooperation, IDLE mode procedure for femtocell base stations, DBSOS with CoMP and RTP, three stage stackelberg game using backward induction method and also compares the performance metrices of these techniques.**

***Index terms*— Energy efficiency, cellular networks**

I. INTRODUCTION

In recent years with the introduction of android and iPhones, the success of social networking giants such as facebook there has been tremendous increase in demand for data rate. Such unprecedented growth in cellular industry has resulted in high energy consumption [1]. Energy consumption has become one of the important issues in the world. Moreover high energy consumption in wireless communication directly lead to the growth of CO_2 emissions. The CO_2 emissions produced by wireless cellular networks are equivalent to those from more than 8 million cars [2]. This emission negatively influence the quality of air and increase green house effect, weather changes, loss of ecosystem and cause potentially hazardous health effects for people. So it has been recognized as the major threat to environment [3]. Inorder to cope with global warming and facilitate sustainable development energy efficient systems are needed. It has been reported that data volume in telecommunication increases approximately by an order of 10 every 5 years. This results in an increase of energy consumption approximately by 16-20 percent per annum. The energy costs can account for almost half of mobile service provider's annual operating expenses [4]. The energy costs can account for almost half of mobile service provider's annual operating expenses [4].

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Thus optimizing energy efficiency in wireless communication not only reduces the environmental impacts but also helps to reduce the network the energy cost.

Rapidly rising energy price has led to a trend of studying energy efficiency aspect of cellular networks [6]. The main contributor to green house gas emission in the cellular network is the base stations [7]. Base station consumes maximum portion of the energy used in the cellular networks. The power consumed by the base station includes two parts. First part is the static power which is the power consumed by an empty base station and the second part is the dynamic power, which gets added to the static power depending upon the load condition. Largest amount of gas emission occurs in base stations. One possible solution to reduce this energy consumption is to consider cellular network deployment based on both macrocell and small cell base stations. Fig.1 shows the simple cellular network with the joint deployment of macrocells and small cell base stations. The small cells used here can be femtocell or pico cells. The macrocell base stations provide large coverage and consumes high transmission power whereas the small cell base stations also called as home base stations provides less coverage area and consumes less power. They are also efficient in providing high data rates and prolonged battery life. Joint deployment of macrocells and small cells in a network can reduce energy consumption up to 60% when compared to thenetwork with macrocells [8]. The heterogeneous deployment of base stations is an important technique for improving energy efficiency in cellular networks.

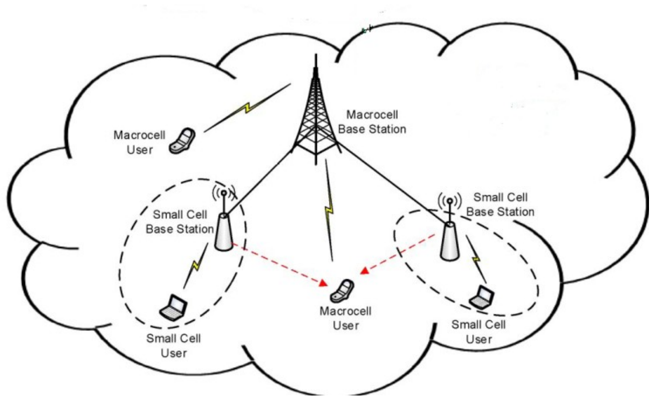

Fig.1: Heterogeneous cellular network

The rising energy costs & carbon footprint have led to an emerging trend of addressing the "energy efficiency" aspect of cellular networks. This paper presents a brief survey on some of the works that have been already done to achieve energy efficient communication in cellular networks.

ISSN: 2278 – 1323

In section II different methods used to achieve energy efficient communication in cellular networks is discussed. Section III deals with the performance evaluation of the discussed methods. Section IV concludes the paper.

II. METHODOLOGY

The main source to green house gas emission caused by cellular networks originates more precisely from the base stations [7].The power consumed by the base stations varies with time. It depends on whether the base station is in operational mode or non operational mode. If the base station is in operational mode the power consumption varies depending on the traffic mode (low traffic or peak traffic mode). Energy consumption by base stations can be reduced by using energy aware components in the base stations and by energy aware network deployment strategies. In recent years the number of cellular base stations has been increased to many millions due to the growing demand for mobile communication technology. Such unsubstantial growth in number of base stations causes sudden increase in green house gases in addition to higher energy costs to operate them [1]. Various methods that helps to reduce energy consumption is discussed in this section.

1. Cell zooming

In general cell size in a cellular network is fixed based on some estimated traffic load. But the traffic load will not be fixed, it will have fluctuations. If the traffic load increases beyond the expected capacity, then there is possibility that some mobile users will be unable to get services. To overcome these situations cell zooming method is used. In this method the cell size is adaptively adjusted according to traffic conditions. Following steps are used to adjust the cell size[9].

- Adjusting 'physical parameters' such as transmit power (increased in case of zoom out and vice versa) ,antenna height and antenna tilt of base stations.
- 'Cooperation' among base stations i.e., cooperatively transmit to or receive from base station
- Deploying 'Relay Stations' near the boundary of two neighbouring cells which can relay traffic from the cell with heavy load to the cell with light load.
- 'Switching off' the base stations when the traffic load is light. In this case the base station which is switched off (sleeping mode) will zoom into 0 and its neighbour cells will zoom out to provide coverage. Switching off the base stations will also reduce energy consumption.

The techniques explained above is shown in figure.2

Two types of algorithms namely centralized algorithm and distributed algorithms are used to achieve these techniques [9]. Here the main goal of centralized algorithm is to switch off the base stations during low traffic load conditions and achieve coordination among the base stations. By this algorithm the cell zooming server will collect information about all channel conditions and user requirements in the network and performs resource allocation and cell zooming functions in a centralized way. Centralized algorithm requires more signaling overhead.To reduce the information exchange and signaling overhead distributed cell zooming algorithm is used. No coordination among base stations is needed in this algorithm, hence much signaling overhead is reduced. It has been reported that cell zoomig centralized algorithm performs better compared with distributed algorithm[9].

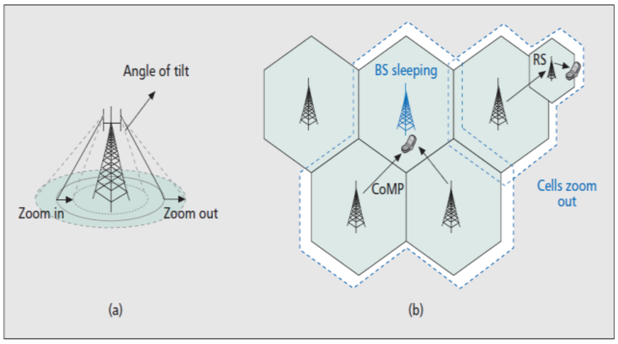

Fig.2: Techniques to implement cell zooming: a) cell zooms in or zooms out with physical adjustments;b) cell zooms out through BS cooperation and relaying.

Cell zooming techinque helps to reduce energy consumption in cellular networks. It also saves lot of energy by switching off the base stations during low traffic load. But it requires the help of additional mechanical equipments to adjust physical parameters such as antenna height, antenna tilt of base stations, base station cooperation and relaying techniques which is not supported by current cellular networks.

Cell zooming may cause inter-cell interference i.e.,when the neighbourig cells zooms out together, it wiil create inter-cell interference. Cell zooming may also cause coverage holes i.e., when cells zooms in or zooms out there is possibility that users in certain areas of the network will be unable to get service.

2. Internetwork cooperation

This is the method in which each user cooperate with each other in transmitting data packets to the base station. By this method each user will be fixed with both short range communication network(eg:bluetooth, Wi-Fi) and a long range communication network(eg:celluar network)[11].Short range communication network consumes less energy since it covers local-area and it is a peer-to-peer communication while the long range communication networks i.e., cellular networks provide wider coverage and consumes higher energy. First each user will exchange the data packets through the short range communication network over an industrial, scientific and medical (ISM) band instead of using cellular band. This helps

ISSN: 2278 – 1323

to save the spectrum resources. After exchanging, the packets are send to the base station with the help of their antennas.

When there are more than two users, pairwise grouping is performed. Multiple users are divided into multiple user pairs and each user pairs proceed the inter-network cooperation independently. This technique helps to improve the energy efficiency of cellular transmissions by using short range communication network to assist the cellular transmissions. This technique significantly outperforms in terms of energy consumption when the inter user distance is not too large. But when the inter-user distance increases beyond a certain value i.e, when the cooperating users are far away from each other energy consumption will be higher because of lack of user cooperation.

3.IDLE mode procedure for femtocell base station

This technique enables switching off of unnecessary hardware components when not involved in an active call based on user activity detection. So that wastage of energy can be minimized. It provides an energy efficient solution for controlling idle or sleep mode behaviour of femtocell BSs by enabling the IDLE mode procedure in femtocell BSs. The femtocell BS includes a low power sniffer capability that detects the active call from a mobile to the macrocell. When a user is involved in an active call, the sniffer will detect a rise in the received power.

Figure.3 shows the flowchart of the IDLE mode procedure for femtocell BS. When no user is involved in an active call this IDLE mode procedure allows the femtocell BSs to switch off all of its pilot signal transmissions and only the hardware components required to keep the femtocell connections alive are kept in active mode. The femtocells in the IDLE mode switches to ACTIVE mode when an active call is detected from a registeed UE i.e., it activates all of its pilot signal transmissions. The active mobile in the range of femtocell then reports the pilot measurement of femtocell to the macrocell and if the mobile is allowed to access the femtocell, it will be handed over to the femtocell. After the completion of the call, the femtocell switches back to the IDLE mode and again disables the processing and pilot signal transmissions

4. Dynamic Base Station Opration Scheme(DBSOS) with CoMP and Real Time Pricing(RTP)

Here the problem of energy consumption and electricity price decision is formulated using a two level stackelberg game also called as leader follower game. The two levels used here is a smart grid level and a cellular network level.Smart grid is the power grid which provides electricity to the cellular networks. The retailers in the smart grid level acts as the leaders. The base stations in the cellular network level acts as the followers. First the smart grid level is considered.

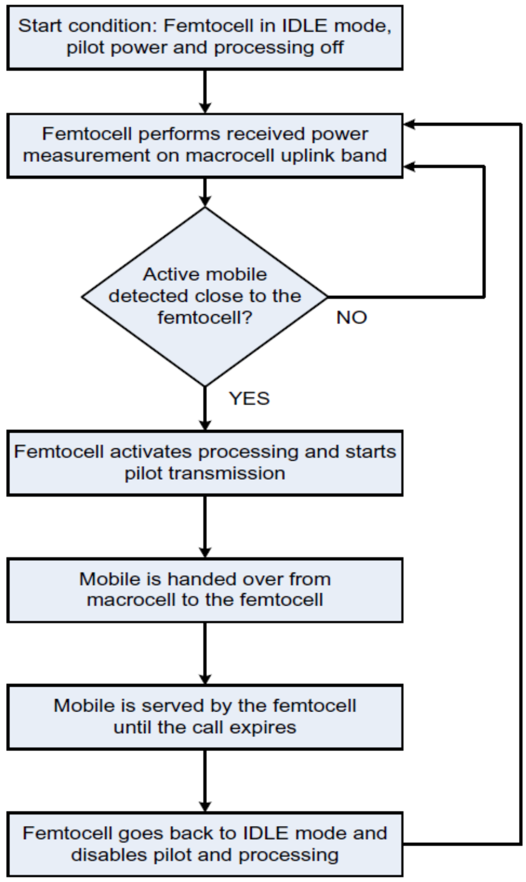

Fig. 3: Flowchart of the IDLE mode procedure for femtocell BS

A.Smartgrid level

In the smart grid level among various price models such as critical peak pricing (CPP), time of use (TOU), real time pricing (RTP), RTP is used because if renewable energy resources are used in the smart grid, the amount of electrical energy produced will not be a constant & it will vary depending up on the weather conditions. Real time pricing (RTP) is the method in which the retailers offered electricity price can be changed according to the variations in the cost of energy supply. RTP for demand side management (DSM) is considered which helps to reduce the green house gas emission and also decrease the electricity cost for consumers. Each retailers will act independently and aims to achieve high profit. Since each retailers compete with each other to be seleced by the base stations in the cellular network , each retailer's profit will get affected by their own electricity cost and the other retailers prices. Retailer r's utility function is expressed as,

$$U_r = (x_r - c_r)q_r$$

Where, x_r denotes the real time electricity price offered by retailer r, c_r denotes the cost of electricity for retailer r and q_r denotes the amount of electricity procured by the base station from retailer r.The optimal electricity prices to offer to

ISSN: 2278 – 1323

the base station is calculated using the following expression. For retailer r the optimization problem is,

$$\max_{x_r} U_r = (x_r - c_r), \forall r$$

B Cellular network level

Cellular networks are deployed with base stations. The electricity prices offerd by the retailers in the smart grid will be selected by the base stations in the cellular network. Energy consumption and electricity cost depends on the number of base stations in the network. So in cellular networks redundant base stations are switched off during low traffic conditions (e.g: night time). A coordinated multipoint (CoMP) technique is used to provide service for users whose base stations are turned off under light load. The base station will decide how many base stations in the CoMP cluster must be active and how much amount of electricity has to be procured from the retailers to maximize their utility function. The utility function of all the base stations in a CoMP cluster is defined as

$$U_s = \xi\,(U_{const} - \rho_{exp}((P_b - \delta P_{th} + G_{bk})\,K_{bk})) - \sum_{r\in R} x_r\, q_r$$
$$- \sum_{r\in R}(\alpha_r\, q_r^2 + \beta_r q_r)$$

Where, $\alpha_r > 0$, $\beta_r > 0$ and it depends on the pollutant level of retailer r, p_b denotes the service blocking probability,p_{th}, denotes the blocking probability threshold value, ρ, δ, G_{bk} and K_{bk} are the parameters that define the utility function for users. The optimization problem for the base stations in th cluster is,

$$\max_{q_r} U_s$$

The prices decided by the base stations will be passed to the users. A gradient based iterative algorithm is used to achieve this stackelberg equilibrium. There is possibility for inter-cell interfernce in the cellular networks. The stackelberg game does not solve the interference problem.

5.Three stage stackelberg game using backward induction method

In this method the problem of electricity price decision, efficient power allocation and interference management is handled as a three stage stackelberg game as shown in figure.In order to improve the energy efficiency, heterogeneous networks with both small cell and macrocell deployment is considered as shown in figure 1. Because macrocells provide large coverage area, they consume more power and for mutimedia apllication theyare not efficicient in providing high data rates whereas small cells provide high data rates and they consume less power due to small coverage area.

During first stage of the stackelberg game retailers in the smart grid acts as the leaders and the macro cell base station in the network acts as the follower. Each electricity retailers offers real time electricty prices to the small cell base stations and the macrocell base stations based on their profit. Each retailers profit will depend on their own electricity cost

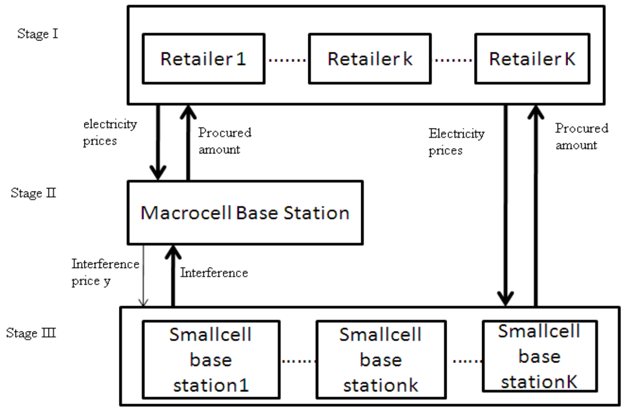

Fig. 4: Three Stage Stackelberg game[4]

and the prices offered by the other retailers. Since both small cells and macrocells are used the profit of retailer n is expressed as,

$$U_n(P) = (p_n - c_n) \times ((P_{mp} + B_{mv}\, p_m)S_{nm} +$$
$$\sum_{l=1}^{L} P_{lp} + B_{lv}\, p_l)S_{nl})$$

Where, price vector P (P = { p_1 , . . . p_n }) denotes the other retailers electricity prices, p_n denotes the real time electricity price offered by retailer n, $c_n$denotes its own electricity cost, P_{mp} denotes the non-transmit power of macrocell base station m and P_{lp} denotes the non-transmit power of small cell base station l. The optimal electricity price can be obtained by the following expression,

$$\max_{p_n \geq c_n} U_n(P)$$

On receiving this price information the macrocell base station will decide from which retailer to procure electricity and efficiently allocates the power based on the electricity prices. During second stage macrocell base station acts as the leader and the small cell base station acts as the follower.Inorder to increase the spectrum efficiency both the macrocells and small cells share the available spectrum. This may cause cross-tier interference. To overcome this interference effect, in stage 2 macrocell base station offers an interference price to the small cell base station. During third stage the small cell base stations will decide from which retailer to procure electricity and will allocate the power among the SCBS depending upon the interference price offered by the MBS and the electricity prices offered by the retailers. An iterative algorithm is used to achieve the stackelberg equilibrium.according to this algorithm,

IV. PERFORMANCE ANALYSIS

Cell zooming technique which adaptively adjust the cell size based on the fluctuations in the traffic load, not only reduces the problems of traffic imbalance but also improves the energy efficiency. This method saves large amount of

ISSN: 2278 – 1323

energy when the traffic load is light. Using this method energy efficiciency of upto 20-40% can be achieved. But cell zooming can cause problems such as inter-cell interference and coverage holes. Next we have discussed the method, internetwork cooperation, this investigates the multiple network access interface with user cooperation to improve the energy efficiency. This technique consumes less energy when the inter-user distance is not too large, but when the cooperating users are close to base station or the users are far away from each other this technique consumes more power. Next method uses IDLE procedure along with normal operation of femtocell base station. This energy saving procedure allows the femtocell base station to switch off its radio transmissions and associated transmissions when not involved in an active call. This technique can provide energy consumption reduction of approximately 37.5%. Next method is the Dynamic Base Station Operation scheme(DBSOS) with CoMP and real time pricing, which considers not only the energy efficient communication but also the dynamics of the smart grid in designing the cellular networks. This technique can cause a significant reduction in operational expenditure and CO_2 emissions in wireless cellular networks. The operation of base stations in this method depends not only on the service blocking probability but also on the prices offered by the smart grid. So DBSOS with CoMP in the smart grid reduces the operational expenditure by about 27% and also the CO_2 emission remains constant (approximately 1.85tonnes/year)with the prices offered by the smart grid. But this technique is designed for homogeneous network with macrocells. In method, three stage stackelberg game using backward induction method, inorder to improve energy efficiency heterogeneous deployment of both small cells and macrocells along with smart grid is considered.The use of both small cells and macrocells can create cross tier interference. The macrocell base station charges the small cell base stations to avoid the interference between the small cell users and the macrocell users. Both the macrocell base station and the small cell base stations adjust the amount of electricty they consume by performing energy efficient power allocation. Cognitive radio technology is used in this method. So each BS will be aware of the available spectrum. It has been reported that if the operator dynamically manages its spectrum by dynamically moving the users to a particular active bands, about 50% of power can be saved [1]. When compared to DBSOS with CoMP, this method reduces the electricity cost and CO_2 emission by about 31.09%. In this method CO_2 emission decreases with the increase in lowest price offered by the retailers in the smart grid which remains constant in the previous method.

V. CONCLUSION

This research paper addresses the energy efficiency of cellular networks which is becoming more important interms of both environmental impacts and operational costs. An effort has been made to concentrate on comparative studies based on reducing energy consumption without affecting the performance of the wireless cellular communication. In this paper several techniques are analyzed. A three stage stackelberg game using backward induction method is consider to provide better performace when compared to the other methods. This method solves three problems such as electricity price decision, power allocation and interference management in an efficient manner and also causes greater reduction in energy efficiency and CO_2 emission.

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ISSN: 2278 – 1323

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ISSN: 2278 – 1323