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Power Efficient Systems in Wireless Communication

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Abstract: It is commonly known that mobile communication networks will have an increasing ecological and economic impact worldwide, and recently, initiatives to reduce the energy consumption of network operation and reduce the carbon footprint of these networks have gained momentum. Thus, climate and cost issues now shift the research focus of wireless communications to energy consumption and energy efficiency. Two approaches can be followed: Incremental improvements of existing systems or a clean slate re-design with a fundamental change of paradigms. We describe two such initiatives and discuss their differences. The paper aiming for a reduction of the overall energy consumption of 4G mobile broadband networks by 50%, regarding network aspects and individual radio components from a holistic point of view. The literature often states that small cells will reduce transmit power. We have shown that with realistic macro base stations (BS) power models smaller cell sizes increase the total power consumption. Heterogeneous deployments with macro cells and small cells are beneficial for indoor or can be alternatives to a densified macro only deployment. Relaying is a well-known technique to improve data transmission in cell-edge or to provide coverage in new areas. Installation of new relays nodes instead densifying the macro only network can be 30% more energy efficient. The main goal of our apporach is to reduce the power consumption of cellular networks by 50%. These technologies include deployment strategies, network management concepts, radio resource management techniques and some proposals for future architectures that are inherently designed to be energy efficient.

Keywords: Energy Efficiency, Green House Emissions, mobile communication networks, small cells, energy aware mana gement, Information & Communications Technology.

I. INTRODUCTION

Research and development in various engineering and industrial sectors is beneficial for mankind and essential in order to get better socio-economic effects. But as we are getting more and more advanced in technology the GHG (Green House Emissions) are increasing. So global warming is becoming a very big issue. With no contentions, ICT (Information & Communications Technology) sector is one of the very important sectors which is necessary for the growth of a society. Aside from emissions associated with deforestation, the largest contribution to man-made GHG emissions comes from power generation and fuel used for transportation. As ICT systems have evolved they helped in decreasing the pollution because before this development people had to use transportation systems to transfer information. The ICT sector has transformed the way we live, work, learn and play. From mobile phones and micro-computer chips to the internet, ICT has consistently delivered innovative products and services that are now an integral part of everyday life. ICT has systematically increased productivity and supported economic growth across both developed and developing countries. But as it is getting bigger and bigger it has also started using a lot of energy which again results in emission of CO2 and other GHGs.

In a case study conducted by "The Climate Group", which is an independent, not-for-profit organization, which brings together a global coalition of the world's most powerful governments, brands and public figures across Asia, Europe and North America, it is stated that the global information and communications technology (ICT) industry accounted for 530 $MtCO_2e$ in 2002 and 830 $MtCO_2e$ in 2007. This is approximately 2% of the global carbon dioxide (CO2) emissions and about equivalent to those of global aviation [1]. In telecom sector the CO2 emission has increased from 150 $MtCO_2e$ in 2002 to 300 $MtCO_2e$ in 2007 and is expected to reach 350 MtCO2e in 2020. This study shows that at present broadband penetration is less but by 2020 its penetration will become very much making it a large contributor to CO2 emission.

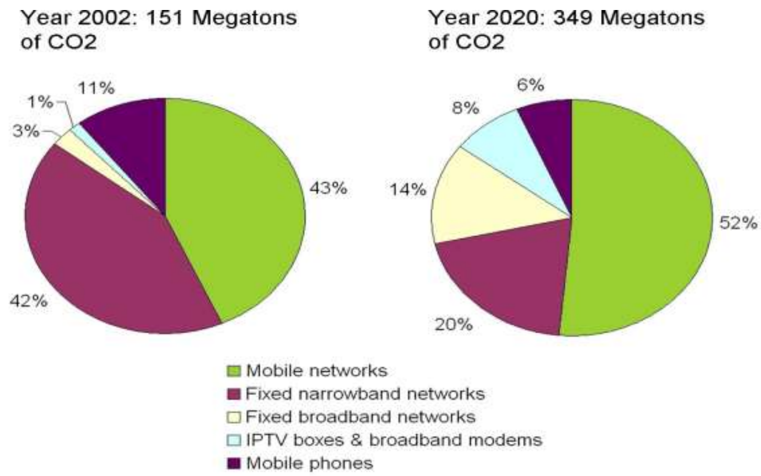

Figure 1. Contribution of mobile communications to the CO_2 footprint of telecommunication industry in 2002 and estimated for 2020 [1]

In the coming future, as the number of subscribers will increase, the number of base stations will also increase. So, for next generation mobile networks the energy consumption of the network infrastructure is expected to rise even stronger and, at growing energy prices, makes up for a significant fraction of the operational costs of operators. Now operators have started implementing air cooled systems instead of using air-conditioners. But still a lot of further improvement is required to increase the efficiency of systems. To address this problem lot of research work is going on.

This paper will investigate the energy efficiency limit that is theoretically and practically achievable whilst providing high capacity and uncompromised QoS. The target of our study is to enhance the energy consumption of mobile systems by a factor of at least 50%. It is adviced to the development of a new generation of energy efficient equipment, components, deployment strategies and energy aware network management solutions. The other project is Green touch. It is a consortium of leading Information and Communications Technology (ICT) industry, academic and non-governmental research experts dedicated to fundamentally transforming communications and data networks, including the Internet, and significantly reducing the carbon footprint of ICT devices, platforms and networks. It has analyzed the fundamental limits of global communication systems. It turns out that fundamental physical limits would allow designing a system that is several orders of magnitude more efficient than today's systems.

II. TRADE-OFFS

As it is stated above that the energy consumption of wireless networks is increasing day by day, so we need to implement some changes in our wireless networks to cut short on our energy consumption. But before studying about the possible changes, first we need to know about the fundamental tradeoffs which are there in wireless communication. These tradeoffs [2,3,4] provide the limiting factors for the changes to be implemented. The four basic tradeoffs in wireless communication are given below.

A. DEPLOYMENT EFFICIENCY-ENERGY EFFICIENCY (DE-EE) TRADE-OFF

Deployment cost and network performance are two very important factors in wireless networks. The deployment cost consists of both, capital expenditure and operational expenditure. For radio access networks, capital expenditure mainly includes infrastructure costs, such as base station equipment, backhaul transmission equipment, site installation, and radio network controller equipment. The key drivers for operational expenditure, on the other hand, are electric bill, site and backhaul lease, and operation and maintenance cost. This is one dimension. Other one is energy efficiency. As the deployment cost increases we can deploy more and more number of base stations thus making the cell size smaller. If the cell is small then we need to feed less power to support cell edge users. So with less power we can support more number of users, thus we can say that energy efficiency is increasing but on the other hand we are putting more money for implementation. On the other side of coin, if we use less cost then, we will be putting less number of towers so cell area becomes larger which results in feeding more power on both tower and user side such that last user at boundary of cell can also transmit and receive. Overall we can say that we are consuming more power so our energy efficiency is decreasing. Here we observe that energy efficiency increases with increase in cost thus making deployment efficiency poor.

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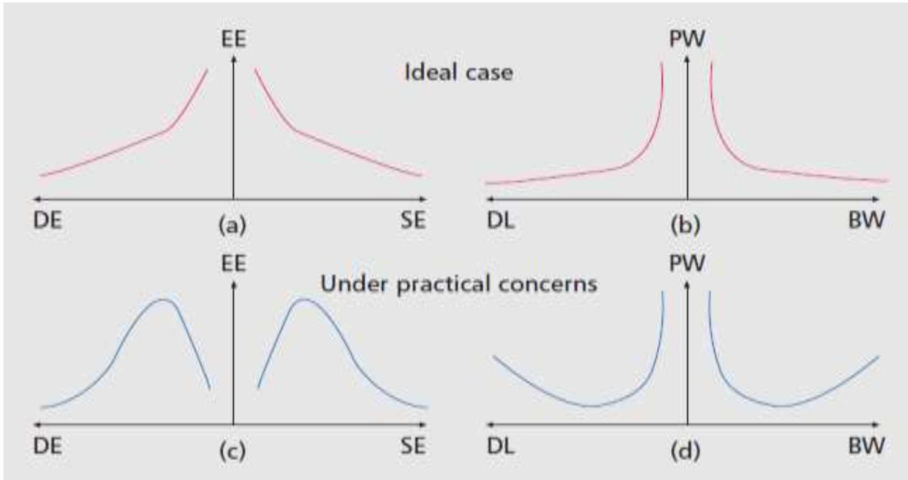


Figure 2. Fundamental trade-offs graphs between respective trade-off dimensions

It is observed that as deployment efficiency is increasing, energy efficiency is decreasing. In upper graph ideal conditions were considered when there are no losses but in practical conditions sketch comes out to be different. Practical limitations which result in such changes in graph are filter losses, power amplifier losses, circuit losses and other practical hardware conditions. In practical graph, it is observed that as DE becomes less than a practical value then again EE starts decreasing. So this graph shows that we need to choose some optimal point where we gain from both dimensions. This shows that we can decrease cell size but up to some certain limit, because after that limit extra overhead starts resulting in less energy efficiency.

B. SPECTRUM EFFICIENCY-ENERGY EFFICIENCY (SE-EE) TRADE-OFF

Spectrum efficiency means how many bits are transmitted per second per hertz of frequency. As we embed more and more number of bits our spectrum efficiency increases but we also need to feed more power to the system. So there is a negative relationship between spectrum efficiency energy efficiency. Here we use Shannon's capacity formula to find out the relationship. It states that

$$\mathbf{R = Wlog_2\left(1+\frac{P}{WN_o}\right)}$$

Where R is the achievable transmission rate, W is the bandwidth, P is the power and N_o is the power spectral density of noise. By using this Shannon's capacity formula relationship between SE and EE is found out, which is given by

$$\eta_{EE} = \frac{\eta_{SE}}{(2^{\eta_{SE}}-1)N_o}$$

By using this equation ideal graph is obtained. But when practical conditions such as filter losses, power amplifier losses, circuit losses etc. are considered then practical graph is obtained which again shows that we need to use some optimal point to gain maximum advantage.

C. BANDWIDTH-POWER (BW-PW) TRADE-OFF

Bandwidth and PW are the most important but limited resources in wireless communications. From Shannon's capacity formula, the relation between transmit power and signal bandwidth for a given transmission rate, R, can be expressed as

$$\mathbf{P = WN_o\left(2^{R/w-1}\right)}$$

Again for this equation also there are ideal and practical graphs shown in fig.1. Ideal graphs are drawn without considering any losses whereas practical graphs are drawn for observation in practical scenario, in which all the losses make some significant factor.

D. DELAY-POWER (DL-PW) TRADE-OFF

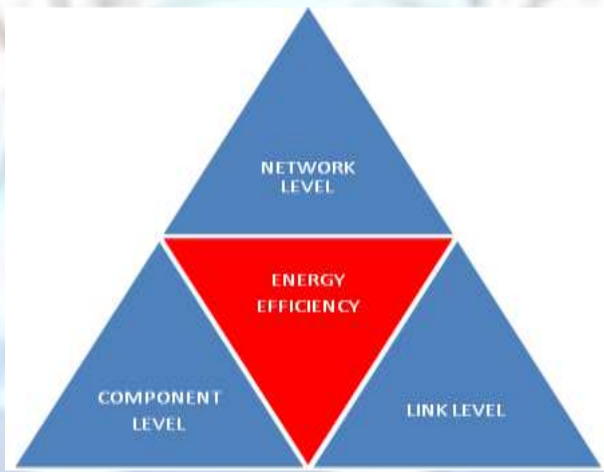
DL, also known as service latency, is a measure of QoS and user experience and is closely related to the upper layer traffic types and statistics. As a result, the design of transmission schemes shall cope with both channel and traffic uncertainties, which makes the characterization of DL-PW tradeoff more complicated. Future networks must deal with various applications and heterogeneous DL requirements. Therefore, in order to build a green radio, it is important to know when and how to trade tolerable DL for low power. To understand relationship between delay and power Shanon's law is used. It provides a graph between DL and PW. That graph is shown in fig.1 in both ideal and practical conditions. The relationship between DL and PW comes out to be

$$P_b = W N_o t_b \left(2^{1/t_b W} - 1\right)$$

Where P_b is the power per bit and t_b is the time per bit. By using this equation ideal graph can be drawn.

III. LEVEL BASED APPROACH FOR ENERGY EFFICIENCY

There are basically three levels to study for changes in our existing wireless communication system. We will study all three approaches one by one.



A. NETWORK LEVEL

Network level is one of the levels at which we can implement various changes which can result in increasing the energy efficiency of networks. This level helps in conserving efficiency while transmitting signal from tower to user or from user to tower. As it is known that most of the energy is consumed at BTS so it becomes the main focus point when it comes to conserve energy. Ideas important for increasing EE are discussed below.

Mixing cell size:-As we have already stated that effort to deploy very large numbers of small base stations may be uneconomical. So we can use mix of cell sizes to cater the problem. The mix of cell sizes is shown in the figure below.

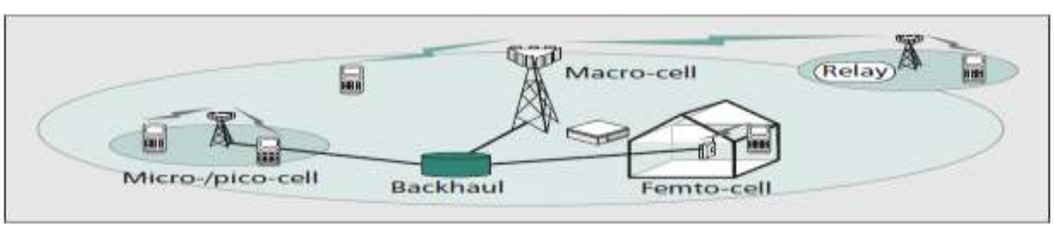


Figure 3. Mix of cell size

As we observe in the figure above, we can use hheterogeneous networks with a hierarchical mix of base stations with different cell sizes with optimal balance of macro-, micro-, pico- and femto-cells. Areas which are having very high density can be covered by smaller cells; whereas the larger cell gives an overall coverage. This optimises on the cost, capacity, quality and energy.

Relay:- Relays split the transmission into smaller hops, where the link between base stations and relays may have better channel quality compared to the direct communication with the user terminals. So this idea can be used in hilly terrains where one BTS can't reach whole of the area. They can also be employed outside the buildings which come in low connectivity zone, so relays are planted where there is strong signal and then that low coverage area is covered by relay. We can intentionally reduce the power transmitted by the tower and relays can be used in every building. As the power used by relay will be very small so we'll be able to conserve energy. As per the literature 2-hop relay is more useful in conserving energy as compared to higher order relays. Some user components may also function as relays. Use of femto-cells is also recommended to increase coverage and decrease power usage.

Sleep mode:- Sleep mode can also be incorporated in every base station. When there is no or very small no of users in a cell then respective base station may go to sleep and there may be cooperation between nearby base stations such that they can expand their cell size and area of BTS in sleep mode can be covered. This idea can be implemented in optimal mix of cell size also. When there are no users micro cells may switch off and coverage may be provided by larger cell but as the number of users in that area start increasing then microcell awakes and starts functioning. Usage of sleep mode can help in a lot of power.

Sectorized antennas v/s Omni-directional antennas:- When traffic density is high then sectorized antennas can be used such that the capacity can be increased by using multiplexing techniques such as space division multiplexing. But when traffic intensity is less then instead of giving feed to sectorized antennas, Omni-directional antennas can be used which will result in consumption of less power because very less power will be used for computation.

Adaptive antennas:- These are the antennas which can change their properties as per the conditions. First property is beam forming. They can also adapt to different modulation schemes depending on channel. For e.g. if channel is good enough then they need to feed less amount of power and vice-versa. Power control schemes can be deployed. And if possible it may trade-off delay with power, means that packets may be received with some delay but less power is required to transmit them.

B. LINK LEVEL

Beam forming and active antennas:-By using this technique antennas can produce sharp beams depending upon position of user. As the signal is to be transmitted in very small angle so very less power will be required. They can also change their tilt angles to change their coverage areas if any of the nearby cells requests for going in sleep mode. By using this technique higher gains can be given to high traffic areas or hotspots thus increasing spectrum efficiency.

Bandwidth adaptation:- In this technique, if there is less traffic then operator may transmit for less frequencies, means he uses less bandwidth instead of using whole and if traffic density increases then it may start using whole of the bandwidth. Transmission for less bandwidth will result in saving the power.

Cell DTX:- This means discontinuous transmission from a base station. It incorporates sleep mode also. If no or very less traffic is there then all or some of the components may go to sleep unless they are awoke by high traffic demand. In case of less traffic less signaling or no signaling can also be used.

Retransmission schemes: - As per this technique, coding schemes can be used such that there are very less number if retransmissions.

C. COMPONENT LEVEL

In order to improve the total energy efficiency of cellular networks, special attention needs to be paid to the different base station components, as they are the main contributors to the total energy consumption. This follows two main tracks: One is to optimize the components themselves, such as for example the power efficiency of transceivers, and the other one is to enable power saving measures defined on the network level. Some of the ideas at component level are as follows

Power amplifier efficiency:- A huge potential for energy saving is related to the power amplifiers, which consume the largest part of power in the base station (Fig. 6). The undistorted transmission of signals with significant peak-to-average power ratios (PAPR) requires to operate the power amplifiers on average levels way below their maximum signal amplitude. This reduces the power efficiency, since a simple power amplifier is optimized for maximum output power. The recent evolution of mobile communication systems from GSM to the Long Term Evolution of 3GPP leads to a continuous rise of the PAPR, which will be further increased by using multicarrier and multi-standard solutions.

Cell dependent transceivers:- These are the adaptive transceivers which adapt as per the requirement of cell. They may increase their area, may go in sleep mode, may change their modulation scheme, may change their packet size etc. As they are adaptive so they can help in conserving lot of energy in low loss situations.

Low loss antennas:- Evaluations for improving the efficiency of printed antennas provide a solution for the topic on Low Loss Antennas. Taking benefit on new low loss dielectric materials and taking care on the element configuration and inter-element spacing, improvements of the efficiency from 70-90% (state-of-the-art) to 90-95% are expected. This track has been considered as most promising as it provides a tangible loss reduction in planar antennas without inter-dependencies to other solutions. As low loss dielectrics are there so feeder losses also get reduced.

IV. RESULT

In this paper we try to analyze one aspect i.e. role of Mix of different cell size in the power efficient systems. In this we have considered all cells as square cell for the mathematical simplification. A simple cell structure is explained below-

We know that

$$Path\ loss\ \propto d^n$$

In ideal case, maximum transmitted power required for cell for one user

$$P_{1/user} = kR^n$$

k– constant for proportionality.

n = 2, path loss exponent for free-space.

$$P_{1/user} = kR^2$$

Fig.4. Basic cell structure used for analysis.

We have considered the one test scenario with random distribution of subscribers at specified time in the particular cellular region as represented below, where dots represent the subscriber while square represents the minimum size of cell described above.

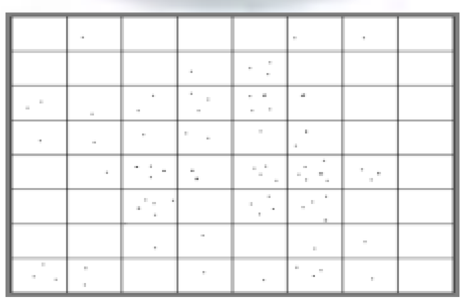


Figure 5. Test case scenario

Each cell is supported by the exactly one base station. Each base station consumes certain amount of power in processing, cooling, etc. This power is assumed to be constant and load independent i.e. base station will consume that much amount of power whether it is idle, partial loaded or fully loaded. That amount of power of considered as P_{idle}.

Relay techniques improves the base station range a lot. Apparently for base station the cell radius is constant and has to provide only same amount of power as subscriber is on cell boundary. But relay helps to provide signal to subscriber well beyond the cell radius with same power utilized by base station. Relay require some power to perform is considered as P_{relay}.

Following four scenarios are analyzed:

1. Total region is covered in 4 cells each having the 4R as diagonal length. Hence we have only 4 base stations and idle power consumed by them is $4P_{idle}$.

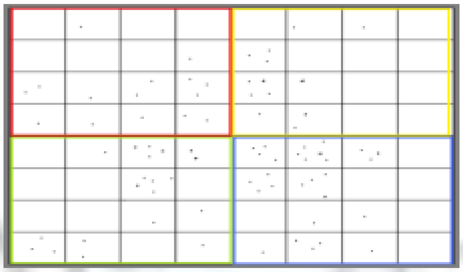


Figure 6. cell scenario

No. of cells = 4
Base station idle power = P_{idle} and therefore

$$P_{4/user} = 16kR^2$$

For 75 users distributed as per above scenario is shown as

$$P_{Total} = 1200kR^2 + 4P_{idle}$$

2. In 2nd scenario we use small cells each having diagonal of R. Hence total area is covered under 64 cells covering all 75 subscribers at the instant. We have 4 base stations and hence idle power consumed by them is $64P_{idle}$. Later we applied the sleep mode to deactivate the empty cells. Hence idle power consumption is reduced to the $36P_{idle}$ saving $28P_{idle}$ amount of power.

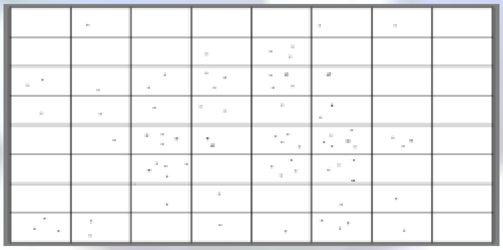


Figure 7. cell scenario

No. of cells = 64
Base station idle power = P_{idle} and therefore

$$P_{1/user} = kR^2$$

For 75 users distributed as per above scenario is shown as

$$P_{Total} = 75kR^2 + 64P_{idle}$$

And when the sleep mode is activated

$$P_{Total} = 75kR^2 + 36P_{idle}$$

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3. In 3rd scenario we analyzed the adaptive cell size, some of them having diagonal as R, 2R, 3R and so on. Hence we deduced 14 cells of different size for given scenario instant for 75 subscribers. Now we have optimized the base stations to 14 and hence total idle power consumed by them is $14P_{idle}$.

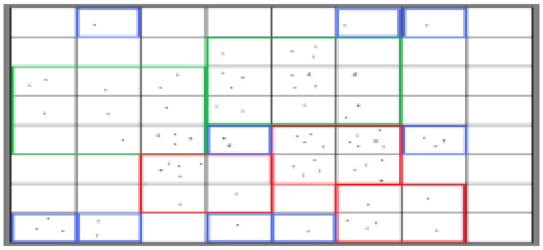

Figure 8. cell scenario

No. of cells = 64

Base station idle power = P_{idle} and therefore

$$P_{1/user} = kR^2$$
$$P_{2/user} = 4kR^2$$
$$P_{3/user} = 9kR^2$$

For 75 users distributed as per above scenario is shown as

$$P_{Total} = 405kR^2 + 14P_{idle}$$

4. In this scenario we have implemented the adaptive cell size along with the relaying. Relays enable us to reduce the number of cells by increasing the scope of cell with marginal amount of increase in power P_{relay}. In this case the number of cells reduced to 9 and the idle case power and relay power is $9P_{idle}+P_{relay}$.

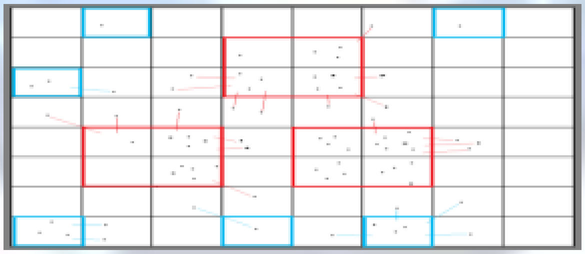

Figure 9. cell scenario with relay.

No. of cells = 9

Base station idle power = P_{idle} and Relay power = P_{relay} therefore

$$P_{1/user} = kR^2$$
$$P_{2/user} = 4kR^2$$

For 75 users distributed as per above scenario is shown as

$$P_{Total} = 243kR^2 + 9P_{idle} + P_{relay}$$

So we have seen that power consumed at base station is depends on the size of cell, idle power for base station and relay power if relay is implemented.

By splitting the cells into smaller cell size, we reduce the transmission power but as number of base station is increased which increases the overall base station idle power. Hence the if base station idle power is negligible compared to transmission power then it is recommended to reduce the cell size but if not the case then we have to find optimum cell size which will balance the mix of transmission power and idle base station power. Same time we have to consider the amount of interference due to small cell size. Overall usage of power is further reduced by the switching off base stations which have no subscriber attached to them which is termed as sleep mode.

Another approach is adaptive cell size which leads to the variable cell size as per the subscriber distribution in the region. These optimize the number of cells required and try to minimize the cell size. This eventually reduces the transmission power and idle power considerably. Application of relays reduce number station much more with marginal increase due to relaying power which overall reduces total power. To compute the optimum cell size and cell allocation to subscriber also increase the processing power for same which is also important and need to be taken into consideration.

V. CONCLUSION

We can conclude that we can obtain the optimum cell size mix for the region which can reduce the total power. To calculate the optimum cell size mix we need to consider the path loss exponent, size of cell, idle base station power and relaying power. For such complex computation the computational power should also be considered.

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