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Energy Efficient 5G Mobile Communication System Using Transmit Power Control and Small Cell Technique

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Abstract : In the realm of next-generation wireless technology, the surge in data traffic poses formidable challenges for communication networks. Addressing these challenges, requires a focus on energy efficiency, particularly in the context of 5G networks where network resources are finite. This paper delves into maximizing energy efficiency by synergizing Demand Power control with the deployment of multiple small cells.

Our investigation aims to optimize energy efficiency while ensuring robust data throughput without compromising Quality of Service (QoS). We explore the dynamics of data transmission between the base stations of multiple small cells and their respective users. Data transmission occurs only in response to demand or user requests to the small cell's base station.

The strategic deployment of small cells allows users to connect to the nearest cell, enhancing the Signal-to-Noise ratio and consequently improving energy efficiency while reducing energy consumption. Optimal power control ensures that the required data rate and QoS are maintained, leading to maximal Energy Efficiency (EE).

The utilization of multiple small cells results in notable enhancements across various metrics. Energy Efficiency (EE), data throughput, and QoS all witness significant improvements compared to a single macrocell at the transmitter base station.

Keywords*: *Energy Efficiency, Quality of Service, Data throughput, Small Cells.

1. Introduction

In the coming years, global concerns such as energy shortages and climate change are driving the need for more sustainable solutions, particularly in the face of the skyrocketing number of mobile users and bandwidth-intensive applications. To meet the demand for high-quality service, there's a pressing need for high data rates, which in turn leads to increased energy consumption.

To address these challenges, service providers are turning to innovative approaches like demand power control and the strategic deployment of small cells within macrocells. By expanding coverage and enhancing signal strength, these techniques improve system capacity and overall user experience while also mitigating energy usage.

Energy consumption poses a significant operational cost for service providers, making it challenging to balance the need for high data throughput with cost limitations. As a result, the focus is shifting towards energy-efficient networks as a crucial aspect of green communication strategies.

Demand power control enables data transmission between base stations and multiple users on an as-needed basis, a process known as On-Demand data transfer. This approach not only saves energy but also enhances energy efficiency by ensuring resources are utilized only when necessary. When coupled with multiple small cells, this technique optimizes energy efficiency while maintaining desired data rates and Quality of Service levels.

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2. Literature Review

In the context of wireless communication systems, a critical challenge lies in meeting the escalating demand for data rates while maintaining energy efficiency for sustainable, green communication. To address this challenge, a range of techniques has been devised to minimize power consumption, with one particularly effective method being the reduction of the distance between base stations and users.

By shortening the distance between base stations and users, signal quality is significantly enhanced. This is achieved by enabling mobile users to associate with either macrocell base stations or small cell base stations. Such association not only improves signal quality but also aids in optimizing energy consumption.

In a notable study by the authors in [8], a novel approach was proposed, combining joint cell association with different bandwidth allocation schemes for Heterogeneous Networks (HetNets). The objective of this approach is to maximize network efficiency by intelligently allocating resources across different types of cells within the network. [5],[11]–[17].

Researchers worldwide have concentrated their efforts on subchannel allocation and power control [5], [11]–[13], [15]–[17], particularly within the context of single-cell networks [14]. Various methods have been explored to enhance Transmitted Energy Efficiency and data throughput, given the constraints of limited network resources [1]-[4].

Fundamentally, improving Energy Efficiency entails controlling transmitted power, leveraging small cell technology, and employing massive MIMO [1],[12],[13],[17]. These approaches represent the cornerstone strategies for enhancing Energy Efficiency and optimizing data throughput amidst the challenges posed by finite network resources.

Efforts to decrease power consumption are crucial for bolstering Energy Efficiency. The primary goal of Energy Efficient transmission extends beyond environmental preservation to cost reduction. Extensive research has been dedicated to enhancing Energy Efficiency while preserving Quality of Service (QoS) [1],[3],[4].

In [16], research delves into Orthogonal Frequency Division Multiple Access (OFDMA)-based LTE systems, ensuring user QoS while optimizing Energy Efficiency. This highlights a key area of investigation aimed at balancing Energy Efficiency and QoS requirements in wireless communication networks.

A multitude of resource allocation schemes have emerged to maximize Energy Efficiency [3],[4],[5],[13],[17]. These schemes represent a diverse array of strategies aimed at optimizing resource utilization to achieve the highest possible Energy Efficiency.

3. System Description

The primary objective of on-demand power allocation is to optimize coordination between the base station and the user requesting mobile network access. Additionally, effective inter-cell and inter-base station coordination is highly desirable.

Small cells utilize the same frequency spectrum as the macrocell. A total of j mobile users are randomly distributed within the coverage area of s small cells. Let Gj represent the average channel power gain between the macrocell base station and the jth user. Gsj denotes the downlink channel gain between the sth small cell base station and the jth user, while Psj represents the transmit power from the sth small cell base station to the jth user. Poj represents the transmit power from the macrocell base station to the jth user. Since each user is assigned a unique subchannel, users connected to small cells only experience interference from the macrocell base station. Conversely, macrocell transmissions encounter interference from the small cell base stations.

3.1. signal model

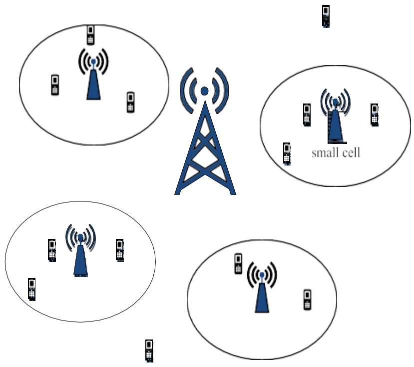

Fig. 1. Small Cell Network [1].

A] On Demand model

If there are j mobile users and j subchannels, the output for the jth channel and the jth user is given by

$$Yj = \sqrt{pj}.hj.xj + Ij + No \qquad (1)$$

$\forall j \in \{1,2,3\ldots\ldots n\}$

Where $Ij = \sqrt{}\alpha j.pj.hj\ .x$ (2)

$\forall j \in \{1,2,3\ldots\ldots n\}$

P = Transmitted Power

x= input

N_0 = Noise

I=Adjacent channel frequency Interference.

Then, the data rate or the throughput is given by

$$Rj = B\log(1 + \frac{S}{N}) \qquad (3)$$

$j \in \{1,2,3\ldots\ldots n\}$

where B = Bandwidth

S/N = Signal to Noise ratio

B] Small cell model

$$\mathrm{SINR}(\Upsilon) = \mathrm{Poj.Gkj}/\sigma 2\mathrm{n} + \mathrm{Psj.Gsj} \quad .. \quad (4)$$

Where

Poj = Power transmitted by the macro cell

Gj = Macrocell Channel Gain

σ2n = variance of noise

Psj = Transmitted Power by the small cell

Gsj = small cell channel gain.

3.2. Power model

The total power consumption of a base station is given by

PC = Pamp + Pcircuit (5)

PC = Total Power Consumed

Pamp = Power consumed by the Power amplifiers

Pcircuit = Power consumed by the other circuit blocks such as the digital to analog converter, filters, mixer etc.

Since Pcircuit is assumed to be constant, the total power consumption varies solely based on the power consumed by the power amplifiers in the transceiver circuits.

3.3. Energy Efficiency model

The Energy Efficiency (EE) of a base station is defined as the ratio of the data rate or throughput to the total power consumed.

$$EE = Rj/Pc \quad \ldots. \quad (6)$$

Where R = data rate or throughput

& PC = Total power consumed

3.4. Quality of Service model

The Quality of Service (QOS) is given by

$$Qj = 1 - \frac{1}{2}\exp\left[\frac{(-Rj-Rth)}{Rth}\right]$$

$\forall j \in \{1,2,3\ldots\ldots n\}$ (7)

where Rj = data rate or data throughput for

j users

& Rth = Threshold value of the data rate set.

Hence the Quality of Service is dependent on the data rate obtained which is compared to the threshold value or the set value of the data rate.

3.5. On-Demand Energy Efficiency Model

The On-Demand Energy Efficiency is given by

$$EE(D) = EEj.Qj \quad (8)$$

$\forall j \in \{1,2,3\ldots\ldots n\}$ (8)

Where EE(D) is the On-Demand Energy Efficiency

EE_j= The total Energy Efficiency of j users

Qj =Quality of Service of j users.

The max EE(D) is defined as

$$\text{EE(D) max} = \sum_{k=1}^{n} \text{Blog2}\ (1 + \text{Ptransmitted})/(\text{Pcj})$$
(9)

Where B= channel bandwidth

Hence in order to achieve max EE(D), the power transmitted should be maximum and the Power Consumption should be minimum.

To achieve maximum Energy Efficiency (EE(D)max), we regulate the maximum transmitted power to maximize energy efficiency while reducing power consumption.

4. The On Demand Power Control Algorithm

Steps:

1. Initialize the time t=max and set t=0
2. Initialize the transmitted power $P_t = 0$
3. Initialize the requirement of the users j=0
4. Sense the requirement of the user by setting the particular user=1
5. Update the value of P_t for the particular user
6. Compute $EE(D)_{max}$, Qk according to (7),(8)and (6) resp
7. Compare the P_t with the P_t max(max threshold value)
8. If $P_t < P_t$ max, then
9. $P_t = P_t$ max
10. Repeat for all users
11. update t=max

5. Simulation results

The simulation is done considering a Base station with n=10 subcarriers, a total bandwidth B= 10 MHz, PCj = 0.3W and a max transmit power Pt max = 10W for 3 & 5 Mobile Users resp for 2 small cells.

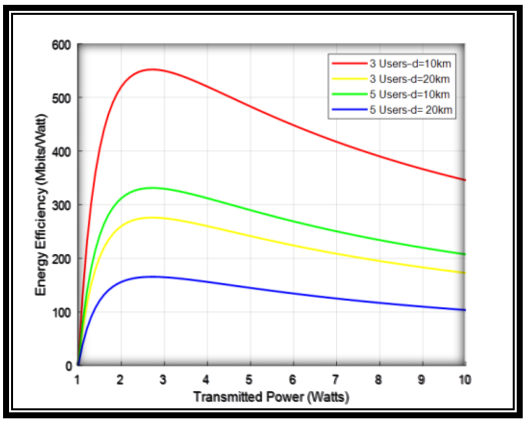

Fig 2: Pt max Vs EE(D)max- 2 Small cells

Fig 2 shows Pt max(W) Vs EE(D) max using 2 small cells with B= 10 MHz, **PC**j= 3W, Pnoise = 0.25W and a max transmit power (Pt max) >= 1 W to 10W for 3 & 5 Mobile Users respectively along with on Demand transmit Power control for variable distances of d= 10Km and d = 20 Km

In fig, 2, It shows that

i) EE(D) max =550 Mbits / W at Pt =2.5W for 3 Mobile users for a distance d= 10km

ii) While it decreases to 330 M bits / W at Pt =2.5W for 5 Mobile users for a distance d= 10km

iii) For 3 Mobile users, EE(D)max =275 M bits / W for 3 Mobile users for a distance d= 20km

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iv) While it decreases to EE(D)max =165 M bits / W for 5 Mobile users for a

distance d= 20km

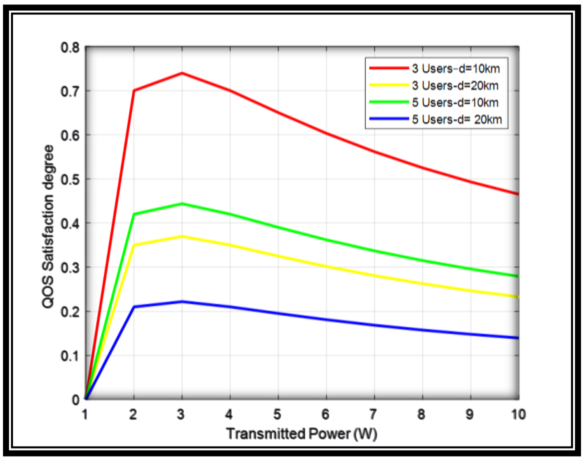

Fig 3: Pt max Vs QOS degree-2 Small cells for d = 10km and d = 20km

Fig 3 shows Pt max(W) Vs Quality of Service(QoS) degree using 2 small cells along with on Demand transmit Power control.

The results obtained are as follows :-

i) It shows that QOS degree is max

0.75 for 3 Mobile Users for d= 10km

ii) While it decreases to 0.45 for 5 Mobile Users for d= 10km

iii) For a distance d= 20km, QOS degree is 0.37 for 3 Mobile Users

iv) For 5 Mobile Users, with a distance d= 20km, QOS degree is 0.22

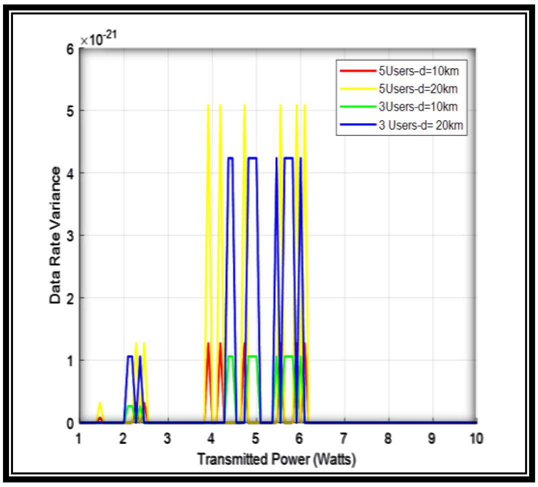

Fig 4 : Pt max Vs Data rate variance- 2 Small cells:-

Fig 4 , shows Pt max(W) Vs Data rate variance using 2 small cells along with on Demand transmit Power control.

Fig 4 shows that

i) It shows that Data rate variance min is 1.0 $*10^{-21}$ for 3 Mobile users at d = 10km

ii) While it increases to 1.2 $*10^{-21}$ for 5 Mobile users at d = 10km

iii) For a distance d= 20km, the data rate variance is 4.2 $*10^{-21}$ for 3 Mobile users

4] Data rate variance min is 5.0 $*10^{-21}$ for 5 Mobile user, for a distance d= 20km

6. Conclusion

Thus, we have observed that employing an on-demand power control strategy and utilizing multiple small cells for data transmission can maximize energy efficiency. This is achieved by maintaining optimal quality of service and data rate while primarily controlling the power consumption of the power amplifiers.

From the simulated results, it can be proved that the Energy Efficiency achieved is max ie 550 Mbits / W at Pt =2.5W for 3 Mobile users for a distance d= 10km by using 2 small cells instead of one macro cell base ststion using On-Demand power control transmission as compared to the continuous power transmission taking place from the base stations to the users.

Also the QOS satisfaction degree achieved is high & is constant at QOS degree is max 0.75 for 3 Mobile Users at a distance of d= 10km

The bit rate variance is also less for small cell Base station ,ensuring a stable data bit rate for the End Users.

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