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Energy Efficiency Enhancement of Next Generation Mobile Systems- An Hybrid Approach

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Abstract: - The surge in mobile users and online applications, particularly video streaming, is indeed fueling a significant increase in global data traffic. To accommodate this growth while ensuring fast data rates, it's crucial to optimize data transmission with limited resources. Balancing high data throughput with lower power consumption is essential for network efficiency without compromising Quality of Service (QoS).

In our research, we focus on enhancing data transmission efficiency between base stations and multiple users. Our approach revolves around transmitting data only when there's a demand or explicit user request, a strategy aimed at conserving power. By doing so, we achieve substantial energy savings, leading to decreased energy consumption and improved energy efficiency.

Central to our methodology is an optimized power control transmission mechanism. This ensures that data rates and QoS requirements are met while maximizing energy efficiency (EE). By dynamically adjusting power levels based on transmission needs, we strike an optimal balance between throughput and power consumption.

Our findings underscore the significance of adaptive power control strategies in modern wireless networks. By intelligently managing resources and minimizing unnecessary transmissions, we pave the way for sustainable network growth and enhanced user experiences.

Keywords: Energy Efficiency, Quality of Service, Data throughput.

1.   Introduction

The escalating demand for data, driven by the rapid increase in mobile users worldwide, presents a formidable challenge for network providers. With data consumption growing by nearly 40% compared to the last five years, the strain on network resources is substantial. To address this challenge, it's imperative to design energy-efficient networks that can meet the demand for high data throughput while adhering to Quality of Service (QoS) requirements.

The concept of On-Demand data transfer plays a crucial role in achieving this balance. By establishing connections and transferring data only when necessary, energy consumption is minimized, leading to enhanced energy efficiency. This approach not only mitigates environmental concerns associated with energy consumption but also helps manage the escalating costs of network operations.

Furthermore, employing On-Demand Power Control techniques ensures that data rates and QoS expectations are optimized. By dynamically adjusting power levels based on transmission needs, network efficiency is maximized, resulting in an optimal utilization of limited resources.

In summary, the development of energy-efficient networks capable of providing high data throughput while maintaining QoS standards is essential to meet the growing demand for data. Leveraging On-Demand data transfer and Power Control techniques represents a significant step towards achieving this goal, ensuring sustainable network growth in the face of escalating data demands.

2.   Literature Review

The pursuit of enhanced Transmitted Energy Efficiency and data throughput within the constraints of limited network resources has been a focal point of global research efforts. Researchers have explored various methods to achieve these objectives, including Transmit Power Control. Regulating the transmitted power helps optimize energy efficiency. This approach ensures that the required signal strength is maintained while minimizing unnecessary power consumption.

Small Cell Technology: Implementing small cell networks enables more efficient use of available spectrum and resources. By reducing the coverage area of each cell, small cell technology can alleviate congestion and enhance energy efficiency.

Massive MIMO (Multiple-Input Multiple-Output): Leveraging multiple antennas at both the transmitter and receiver ends, massive MIMO technology maximizes spectral efficiency and enhances energy efficiency by improving signal quality and reducing interference.

Power Consumption Reduction: Efforts to reduce overall power consumption are essential for improving energy efficiency. This can involve optimizing hardware components, implementing energy-saving algorithms, and adopting energy-efficient protocols.

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The overarching goal of improving energy efficiency is not only to mitigate
environmental impact but also to minimize energy costs associated with network operation. Achieving energy efficiency without compromising Quality of Service (QoS) standards is paramount. Research has delved into various aspects of this challenge, including: Orthogonal Frequency Division Multiple Access (OFDMA): OFDMA-based LTE systems offer a flexible framework for accommodating diverse user QoS requirements. By efficiently allocating resources based on user demand, OFDMA systems can maintain QoS, while maximizing energy efficiency. Resource Allocation Schemes: Developing optimal resource allocation schemes is critical for maximizing energy efficiency. These schemes dynamically allocate network resources such as bandwidth, power, and time slots to users based on their requirements, ensuring efficient utilization of limited resources.

3. System Description

The utilization of on-demand power allocation relies on effective coordination between the base station and the mobile users accessing the network. Additionally, coordination between cells and base stations is crucial for optimizing network performance. Let's consider a scenario where we have a set of mobile users and a Macro Base station,as illustrated in Fig 1.

To efficiently manage the available bandwidth, we divide the total channel bandwidth into smaller sub-bands, each containing a set of subcarriers. This division helps mitigate interference between different frequency bands. Each sub-band is allocated a separate subcarrier to ensure interference-free transmission.

In this context, it's essential to assume that the base station possesses perfect Channel State Information (CSI). This means that the base station has accurate knowledge of the channel conditions, enabling it to make informed decisions regarding power allocation and resource management.
With this setup, effective coordination between base stations and mobile users, as well as inter-cell and inter-base station coordination, becomes paramount. By leveraging the perfect CSI, the base station can dynamically allocate power and resources based on real-time channel conditions and user demand, thereby optimizing energy efficiency and ensuring Quality of Service (QoS) requirements are met.

Overall, the integration of on-demand power allocation with coordinated resource management strategies facilitates efficient utilization of network resources, ultimately enhancing network performance and user experience.
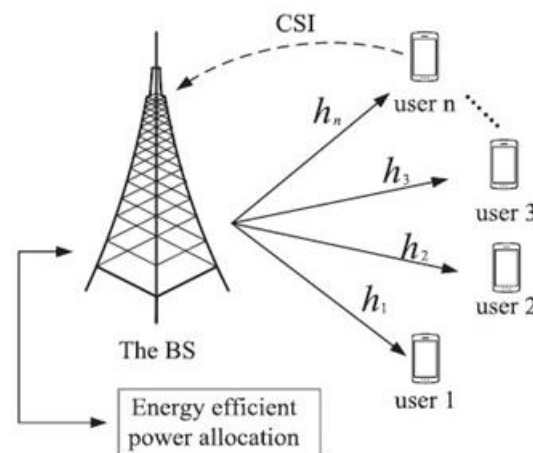
3.1. Signal model

Fig 1: A Communication Network with one Macro cell Base Station with no of mobile users.[1]

If we have i mobile users and i sub-channels, the output for the ith channel and the ith user can be represented as follows:
Let's denote:
x_i = input signal for the ith user
h_i = channel frequency response for the ith channel and
y_i = as the output signal for the ith channel and the ith user.

Then, the output y_i for the ith channel and ith user can be expressed using the concept of linear convolution in the frequency domain:

yi=hi∗xi
Where:

- $***$ denotes convolution,

In practical scenarios, this convolution operation accounts for the effect of channel fading, noise, and interference on the transmitted signal, resulting in the received signal at the receiver end. The output signal yi represents the received signal for the ith user after passing through the channel.

Also yi is given by

$$yi = \sqrt{pi.hi}.xi + Ii + No \quad . \quad (1)$$

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

Where

$$Ii = \sqrt{\alpha i}.pi.hi \; .xi \ldots\ldots\ldots\ldots ..(2)$$

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

where
p = Transmitted Power
x = Input
N_0 = Noise
I= Adjacent channel frequency Interference.

Then, the data rate or the throughput is given by

$$Ri = B \log 2 \left(1 + \frac{S}{N}\right) \qquad (3)$$
$\forall i \in \{1,2,3\ldots\ldots n\}$

Where B = Bandwidth
S/N = Signal to Noise ratio

3.2. Power model
The total power consumption of a base station is given by
PC =Pamp + Pcircuit   (4)

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.

The Pcircuit is assumed to be constant, hence the total power Consumption is a variable term depending totally on the Power consumed by the Power amplifiers in the trans-receiver circuits

3.3. Energy Efficiency model
The Energy Efficiency (EE) of a base station is given by the ratio of Data rate or throughput and the total power consumed i.e

$$EE = \frac{Ri}{PC} \qquad (5)$$

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

Where   R = data rate or throughput
& PC = Total power consumed

3.4. Quality of Service model :-
The Quality of Service (QOS) is given by

$Qi = 1-1/2 \exp [(-Ri-Rth) / Rth]$ (6)

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

where Ri = data rate or data throughput for i 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

$EE(D) = EE_i \cdot Qi$ (7)

where $i \in \{1,2,3\ldots\ldots n\}$

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

EE_i = The total Energy Efficiency of i users

Qi = Quality of Service of i users.

The max $EE(D)$ is defined as

$EE(D)_{max} = \sum_{i=1}^{n} B\log 2(1 + Ptransmitted) / (PCi)$

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.

Therefore for $EE(D)max$, we control the max power transmitted in order to achieve a max Energy Efficiency while decreasing the 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 i=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 $EE(D)_{max}$, Qi

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, PCi = 0.2W and a max transmit power Pt max = 10W for 3,5 & 10 Users resp.
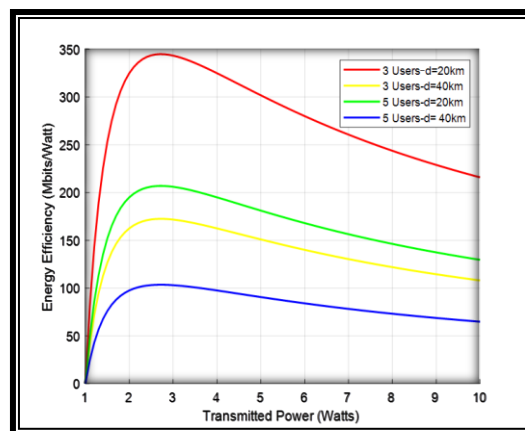

Fig 2: Pt max Vs EE(D)max

Fig 2 shows Pt max Vs EE(D)max with d= 20km and d=40km for one Macro Cell Base Ststion

i) In fig 2,, it shows that the On-Demand Energy Efficiency -EE (D)max is 350 M bits / W for 3 Mobile Users at a distance d= 20km

ii] The On-Demand Energy Efficiency- EE (D)max reduces to 175 M bits / W for 3 Users for a distance d= 40km

iii] If the no of mobile users increases then EE (D)max decreases to 200 M
bits / W for 5 Mobile Users at a distance d = 20km

iv] Further the EE (D)max decreases to 100 M bits / W for 5 Mobile Users at a distance d = 40km

Thus the Energy Efficiency-EE (D)max achieved is high i.e. 350Mbits/W for a transmitted Power of 1W to 10W by controlling On-Demand Transmit Power ,increasing the Energy Efficiency.
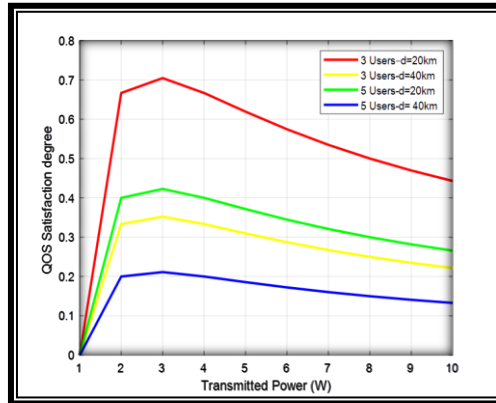

Fig 3: Pt max Vs QOS degree with d=20km and d= 40km for One Macro cell Base Station.

Fig 3 shows the transmitted power Vs the Quality of Service.(QOS) satisfaction degree. which lies between min 0 and max 1 value.

i) In the fig 3, it shows that QOS satisfaction degree is max i.e. 0.7 for 3 Mobile users at a distance d = 20km

ii) The QOS satisfaction degree decreases to 0.35 for 3 Mobile users, when the distance increases to d = 40km

iii) Whereas the QOS satisfaction degree for 5 Mobile users is 0.2 for 5 Mobile users for a distance d = 20km

iv) The QOS satisfaction degree is min at 0.42 for 5 Mobile users for a distance d = 40km

Thus the QOS satisfaction degree achieved is highest i.e. . 0.7 for 3 Mobile users at a distance d = 20km for a transmitted Power of 1W to 10W
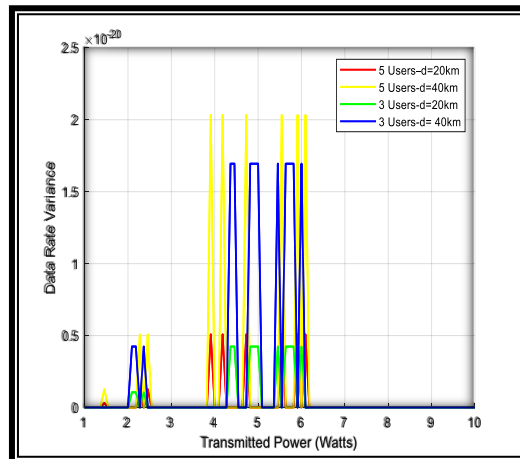

Fig 4: Pt max Vs Date rate variance with d= 20km and d = 40km for one Macro Cell Base Station.

i) In fig, 4, it shows that the data rate variance is min i.e. $0.45 * 10^{-20}$ for 3 Mobile users for a distance d = 20km

ii) Which increases to $0.5 * 10^{-20}$ for 5 Mobile users for a distance
d = 20km at Pt = 3 W

iii) The data rate variance is
$1.75 * 10^{-20}$ for 3 Mobile Users for
d = 40km

iv) It increases to max. $2.0 * 10^{-20}$ for 5 Mobile Users for d = 40km

6. Conclusion

Using On-Demand Transmit Power Control for transmitting data bits from the base station to end users maximizes energy efficiency while maintaining optimal Quality of Service and data rates, primarily by regulating power consumption in power amplifiers.

Simulated results demonstrate that Energy Efficiency peaks at 350 M bits / W for 3 Mobile Users at a distance d= 20km for one macro cell base station with On-Demand transmit power control, surpassing continuous power transmission from base stations to users. Additionally, Quality of Service satisfaction is max i.e. 0.7 for 3 Mobile users at a distance d =   20km across a significant power transmission range from 4W to 10W.

Furthermore, date rate variance is minimal at maximum transmitted power, ensuring a stable data bit rate for end users.

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