# ENERGY-EFFICIENT DESIGN CONSIDERATIONS FOR 6G WIRELESS COMMUNICATION NETWORKS

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**ABSTRACT**

The upcoming sixth-generation (6G) wireless communication systems promise unprecedented speed, ultra-low latency, and massive device connectivity. However, these advancements come at the cost of increased energy consumption, posing challenges to sustainability and operational efficiency. This paper presents an analytical framework for understanding the energy efficiency of 6G systems. By modeling critical parameters such as signal-to-noise ratio (SNR), bandwidth, number of users, and transmission power, and utilizing MATLAB-based simulations, we have evaluated their impact on network energy efficiency. Our findings highlight that optimizing these parameters can significantly improve energy performance, paving the way for sustainable 6G implementations. The results reinforce the need for intelligent, energy-aware network designs and present strategies for achieving higher energy efficiency in future wireless communications

## I. INTRODUCTION

The upcoming sixth-generation (6G) wireless communication systems promise unprecedented speed, ultra-low latency, and massive device connectivity. However, these advancements come at the cost of increased energy consumption, posing challenges to sustainability and operational efficiency. This paper presents an analytical framework for understanding the energy efficiency of 6G systems. By modeling critical parameters such as signal-to-noise ratio (SNR), bandwidth, number of users, and transmission power, and utilizing MATLAB-based simulations, we have evaluated their impact on network energy efficiency. Our findings highlight that optimizing these parameters can significantly improve energy performance, paving the way for sustainable 6G implementations. The results reinforce the need for intelligent, energy-aware network designs and present strategies for achieving higher energy efficiency in future wireless communications.

Key words: 6G cellular system, Spectral efficiency , Channel capacity, Tera Hz frequency

## II. LITERATURE REVIEW

Recent literature has explored multiple dimensions of energy efficiency in 6G networks. Zhang et al. presented a foundational overview of 6G architecture and enabling technologies [1], while Saad et al. investigated critical use cases and design objectives for next-generation networks [3]. Liu et al. proposed optimized transmission models aimed at reducing energy consumption [5], and Wu and Zhang introduced the concept of intelligent reflecting surfaces (IRS) to enhance wireless energy efficiency [6]. Moreover, various studies have underscored the potential of artificial intelligence (AI), reconfigurable intelligent surfaces (RIS), and low-power hardware components in driving sustainable 6G implementations [3], [6], [8], [10], [12]. Despite these advancements, there remains a lack of comprehensive, simulation-driven analyses that examine how variations in key network parameters impact energy efficiency of 6G wireless communication system. This gap forms the central motivation for the present study.

## III. SYSTEM MODEL

We consider a generalized 6G network consisting of a base station, multiple users, and IRS-assisted transmission. The system model of 6G is shown in Figure:1 1incorporates:

- Base Station (BS): Allocates power and spectrum
- User Equipment (UE): Devices include smartphones, sensors, and wearables
- Intelligent Reflecting Surfaces (IRS): Meta-materials enhancing propagation
- Channel Model: Includes noise, fading, and interference
- Power Circuitry: Accounts for transmission and processing energy

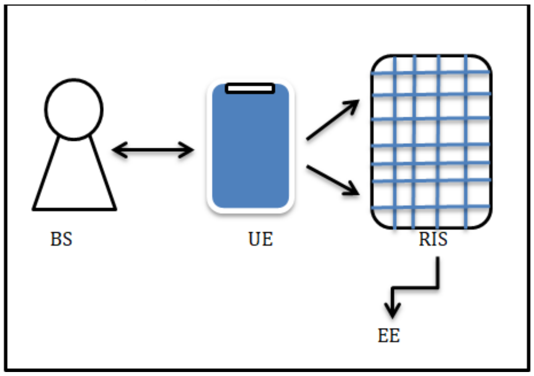


Figure-1: System model of 6G

Data transmission follows user-to-BS routing, adjusted by IRS, with dynamic resource allocation to minimize power waste. Energy efficiency (EE) is calculated using:

EE = (K * B * log2(1 + SNR)) / P_total [ 5 ]

P_total = P_transmit + P_circuit [11]

Where:

K = number of users

B = bandwidh BS

SNR = signal-to-noise ratio

P_total = P_transmit + P_circuit

"**Power of a circuit**" refers to the electric power drawn by the electronic parts and integrated circuits in a system. Transceivers, processors, and antenna arrays are included. The target is generally ultra-low-energy designs, making use of new materials and integration to minimize consumption and heat, vital for high-frequency applications.

"**Power transmit**" refers to the electromagnetic power transmitted by the transmitting antenna to deliver information wirelessly. This power is maximized with techniques such as beamforming and large-scale MIMO to counter signal attenuation. It can also encompass smart surfaces for steering the signal and sensing and communication integration for efficient wireless power delivery, guaranteeing effective signal delivery.

### 3.1 Methodology and Equations

We use the Shannon capacity formula and standard energy models. Simulations are performed in MATLAB over varying SNR levels, user counts, bandwidths, and transmission power. Key formulas include:

SNR (linear) = P_transmit / P_noise

SNR (dB) = 10 * $\log_{10}(1 + SNR)$

Data Rate = B * $\log_2 (1 + SNR)$

Total Power = P_transmit + P_circuit [11]

## IV. ANALYSIS AND RESULTS

This section presents the results of simulations exploring how SNR, Bandwidths, and User count and transmission power affect energy efficiency (EE) of next-generation wireless system. Energy efficiency is a critical metric for measuring the cost of transmission of a bit i.e. 0 or 1. The simulations are conducted with following parameters:

B = 1MHz to 10 MHz , SINR= 0. 5 - 40 dB , Number of Users =1 to 10, Transmission power = 0..5 to 2 watts

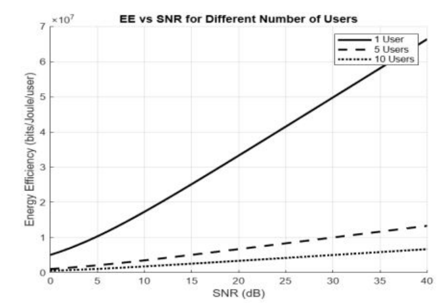


Figure-2: Energy efficiency vs SNR for different number of users

The Figure2 shows that energy efficiency (EE) has decreased as the number of users increases from 1 to 10, even across rising SNR levels. This is mainly due to higher contention for resources, increased interference, and greater signaling overhead, all of which reduce the system's ability to transmit data efficiently.

Although higher SNR improves EE, the benefits are offset by the energy costs of supporting more users, leading to an overall decline in performance.

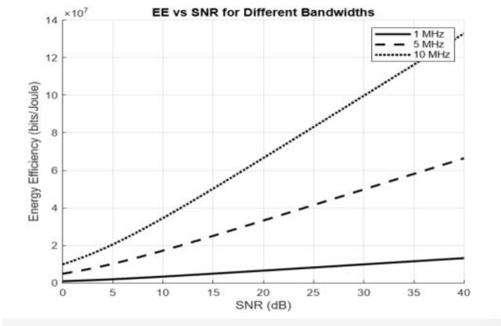


Figure-3: Energy efficiency vs SNR for different bandwidths

The Figure-3 shows that energy efficiency (EE) improves with increasing bandwidth, particularly at higher SNR levels. Wider bandwidths (e.g., 5 MHz and 10 MHz) allow for higher data rates, enabling more efficient use of power. At higher SNR, the system can fully exploit the available bandwidth, resulting in significantly better EE compared to narrower bandwidths like 1 MHz.

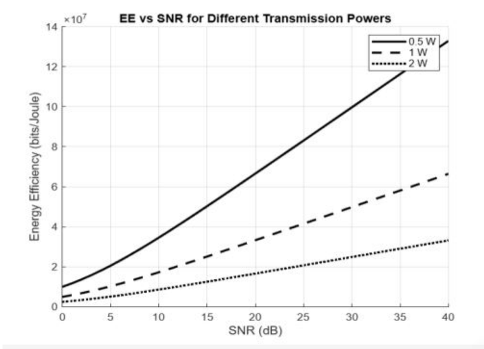


Figure-4: Energy efficiency vs SNR for different transmission powers

Figure-4 shows Energy efficiency vs SNR for different transmitted powers. The graph indicates that energy efficiency (EE) decreases with increasing transmission power (from 0.5 W to 2 W), despite higher SNR. This is because the capacity gains from higher power exhibit diminishing returns, while power consumption increases linearly. As a result, the additional energy spent yields relatively small improvements in throughput, leading to lower overall EE at higher transmission powers.

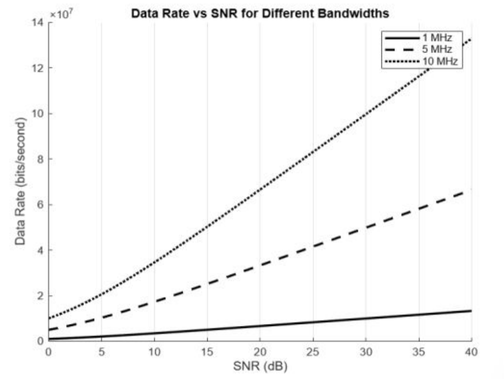


Figure-5: Data rate vs SNR for different bandwidths

The figure-5 shows that data rate increases significantly with both SNR and bandwidth. Wider bandwidths enable more data to be transmitted per unit time, resulting in higher rates. This trend aligns with Shannon's capacity formula, which states that data rate grows logarithmically with SNR and linearly with bandwidth, confirming theoretical expectations.

## V. CONCLUSION AND FUTURE WORK

Our analysis shows that system parameters such as SNR, bandwidth, transmission power and number of users have significant influence on 6G system's energy efficiency. Intelligent power control, dynamic bandwidth allocation, and low-power hardware are essential for building sustainable networks. Future work should explore AI-driven energy optimization,Energy harvesting systems, Cross-layer energy-aware design.

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