ANALYSIS ON BANDWIDTHS OF 6TH GENERATION CELLULAR SYSTEM TO ENHANCE SPECTRAL EFFICIENCY

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Abstract

Channel capacity of any communication system is very important. Data rate, Spectral efficiency, Energy efficiency etc. of any communication system depend on this. Channel capacity of a system depends on bandwidth, signal to noise ratio etc. In this paper we have analyzed spectrum efficiency of 6^{th} generation of mobile communication system for different range of higher frequencies and how it can be optimized. It has found that as we increase bandwidth for 6^{th} generation system (system becomes more costly) spectral efficiency decrease.

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

I. INTRODUCTION

From 1G's simple analog voice services in the 1980s to 5G's lightning fast speeds and Internet of Things-driven connection, wireless communication has seen a significant transformation. Every generation has brought new advancements, and 5G is making smart cities, AR/VR, and industrial automation possible. With features like microsecond latency, flawless worldwide coverage, and speeds of up to 1 Terabit per second, the future 6G networks promise revolutionary breakthroughs. 6G will redefine connectivity and promote digital inclusion globally by utilizing terahertz frequencies, artificial intelligence, and the Internet of Things to enable applications such as autonomous systems, smart ecosystems, and real-time holography.

6G will integrate AI-driven automation, quantum security, and energy-efficient designs, ensuring sustainable and secure communication networks. By overcoming challenges in high-frequency bands, 6G will support ultra-reliable applications such as remote surgeries, immersive VR/AR, and global digital inclusion. Its potential to revolutionize industries like healthcare, education, and entertainment underpins a hyper-connected, smarter, and sustainable future.

II. LITERATURE REVIE

Some important results of 6G communication has summarized as follows:

Ref. No.	Title of the Pages	Findings
[1]	6G Wireless Networks: Vision, Requirements, and Key Technologies	50-100 GHz enables high data rates, but signal loss and line-of-sight limitations impact range. Power, antenna gains, and interference management are crucial for performance.
[2]	Terahertz Communication for 6G Networks	150-200 GHz offers ultra-high speeds but suffers from high signal loss and short range. Dense infrastructure is needed to overcome these challenges.
[3]	Opportunities and Challenges of Sub- THz Communication in 6G	100-150 GHz provides high throughput for IoT but faces challenges with interference and path loss. Optimizing gains and minimizing noise is essential for efficiency.

[4]	Millimeter-Wave and Sub-Terahertz Band for 6G: Spectrum and Propagation Characteristics	50-100 GHz offers high-speed communication but is affected by high attenuation, requiring careful management of noise and interference.
[5]	Channel Modeling and Propagation for Terahertz Communication in 6G	150-200 GHz supports terabit-per-second speeds but is limited by severe path loss, requiring advanced antenna designs and power control.
[6]	Towards 6G: The Role of the 10-20 MHz Frequency Band in Low-Power IoT Applications	10-20 MHz is ideal for long-range, low-power IoT communication with minimal signal loss, but provides lower data speeds.
[7]	The Impact of Frequency Bands on 6G System Design	Higher frequencies like 100-150 GHz offer fast speeds but suffer from high interference and path loss. Lower frequencies like 10-20 MHz offer better coverage at slower speeds.
[8]	Challenges and Opportunities of 6G Wireless Communications: A Survey	100-150 GHz is suitable for smart cities, but interference and noise must be minimized for optimal performance.
[9]	Advanced Antennas and Propagation for Terahertz Wireless Systems	150-200 GHz offers high speeds but requires advanced antenna designs to overcome severe signal attenuation and short-range limitations.
[10]	Low-Power Communication in 6G: The Role of the 10-20 MHz Band"	10-20 MHz is ideal for long-range IoT communication with minimal signal loss, although it offers slower speeds compared to higher frequencies.

III. SYSTEM MODEL

System Models for Advanced Wireless Communication [2]

In modern wireless communication systems, especially with the growth of technologies like 5G and 6G, having a solid understanding of system models is critical for designing efficient, high-performance networks. System models are representations of how signals are generated, transmitted, received, and affected by various environmental factors. As per Figure 2, these models provide the foundation upon which engineers and researchers build and optimize the performance of wireless communication systems.

Antenna Models

Antenna models serve as the backbone of how signals are transmitted and received. Antennas are responsible for directing energy in specific patterns that affect coverage, interference, and overall signal quality.

Geometric Single-Beam Models

A geometric single-beam model is one of the simplest types of antenna models, providing the basic parameters necessary to understand antenna radiation.

Propagation Models

Propagation models are essential for understanding how signals degrade as they travel through the environment. They account for various factors such as path loss, shadowing, and fast fading, which can significantly impact the quality of communication.

Path Loss [1]

Path loss is the reduction in the signal strength as it propagates from the transmitter to the receiver. In wireless networks, path loss increases with the distance between the two points. The loss is more pronounced at higher frequencies like mm Wave and sub-THz bands used in 5G and 6G, as these frequencies are absorbed by environmental elements such as trees, buildings, and even the air itself.

Shadowing and Fast Fading [4]

Shadowing occurs when large objects like buildings or terrain obscure the signal, causing fluctuating signal strength over a large area

MBS architecture in 5G NR

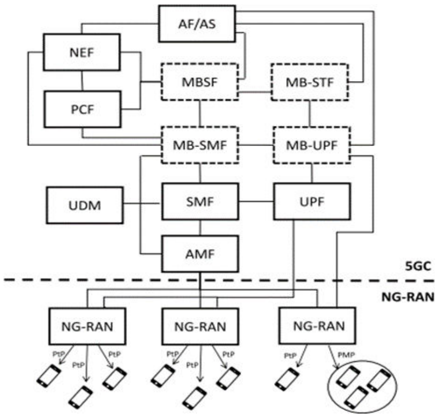

Figure 1: System model

The 5G MBS architecture, shown in Figure 2, introduces key components:

MB-SMF: Manages multicast/broadcast sessions and QoS.

MB-UPF: Anchors and routes multicast data

MBSF: Connects 5G features with legacy systems and coordinates content delivery.

MB-STF: Optimizes data transport with tasks like splitting and error control.

IV. RESULT AND DISCUSSION

This section presents the results of simulations exploring how scaling factors (SF), bandwidths, and user fraction (UF) affect spectral efficiency (SE) of next-generation wireless system. Spectral efficiency is a critical metric for measuring how efficiently a wireless network utilizes its available bandwidth to transfer data. Simulations are conducted with following parameters as per literature [15]:

Scaling factor = 0.20 to 0.80, Bandwidth =10 MHz to 200 GHz, and explore their effects on spectral efficiency of this system. The primary focus is on bandwidth of the system.

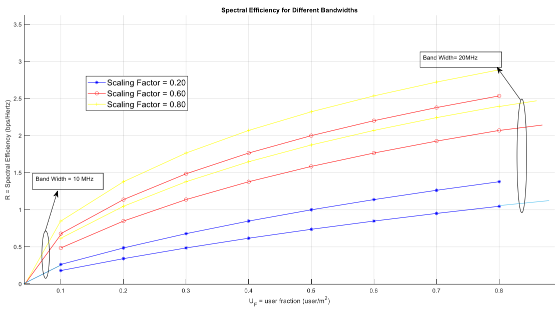

Fig-2: Spectral efficiency vs user fraction for bandwidths 10 MHz and 20 MHz

In figure-1, We have done analysis on spectral efficiency vs user fraction for different bandwidths (10 MHz and 20 MHz) and scaling Factor It has found that as user fraction increases spectral efficiency increases. It has observed that as scaling factor increases for fixed value of user fraction and bandwidth spectral efficiency increases. It can be verified from figure that as band width of system increases for fixed scaling factor and user fraction spectral efficiency decreases. Comparison of spectral efficiency at user fraction = 0.70 i.e. 70% for different bandwidths as per figure no-1.

Table 1: Values of spectral efficiency at user fraction = 0.70 i.e. 70%for different Bandwidths (**10 MHz,20 MHz**)

S.no	**Scaling factor**	**Spectral Efficiency for 10 MHz**	**Spectral Efficiency for 20 MHz**
1	0.20	1.263	0.951
2	0.60	2.378	1.926
3	0.80	2.722	2.242

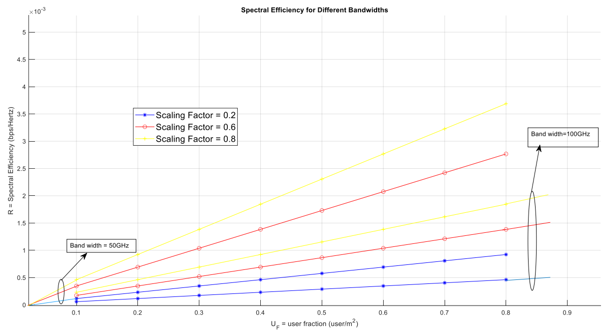

Fig-3: Spectral efficiency vs user fraction for bandwidths 50 GHz and 100 GHz

Similarly for figure-3,We have done analysis on spectral efficiency vs user fraction for different bandwidths (50 GHz and 100GHz) and scaling factors. It has found that as user fraction increases spectral efficiency increases. It has observed that as scaling factor increases for fixed value of user fraction and bandwidth spectral efficiency increases. It can be verified from above figure that as band width of system increases for fixed scaling factor and user fraction spectral efficiency decreases. Comparison of spectral efficiency at user fraction = 0.70 i.e. 70% for different Bandwidths is shown in table-2.

Table 2 : Comparison of spectral efficiency at user fraction = 0.70 i.e. 70% for different Bandwidths (**50 GHz,100 GHz**)

S.no	**Scaling factor**	**Spectral Efficiency for 50GHz**	**Spectral Efficiency for 100GHz**
1	0.20	0.807	0.403
2	0.60	2.421	1.211
3	0.80	3.227	1.614

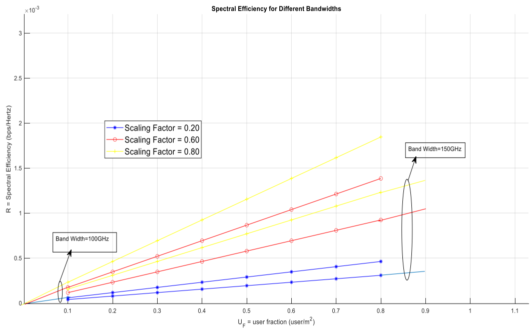

Fig-4: Spectral efficiency vs user fraction for bandwidths 100 GHz and 150 GHz

For figure-4, we have done analysis on spectral efficiency vs user fraction for different bandwidths (100 GHz and 150 GHz) and scaling factors. It has found that as user fraction increases spectral efficiency increases. It has observed that as scaling factor increases for fixed value of user fraction and bandwidth spectral efficiency increases. It can be verified from figure-4 that as band width of system increases for fixed scaling factor and user fraction spectral efficiency decreases. Comparison of spectral efficiency at user fraction = 0.70 i.e. 70% for different Bandwidths is shown in table-3 .

Table 3 : Values of spectral efficiency at user fraction = 0.70 i.e. 70% for different Bandwidths (**100 GHz, 150 GHz**)

S.no	**Scaling factor**	**Spectral Efficiency for 100 GHz**	**Spectral Efficiency for 150 GHz**
1	0.20	0.403	0.269
2	0.60	1.211	0.807
3	0.80	1.614	1.076

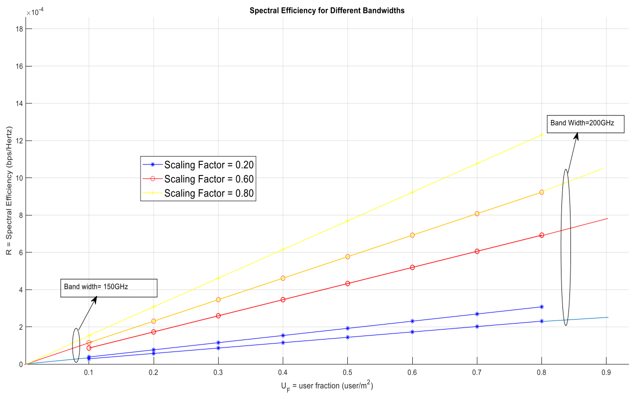

Fig-4: Spectral efficiency vs user fraction for bandwidths 150 GHz and 200 GHz

Table 3 : Values of spectral efficiency at user fraction = 0.70 i.e. 70% for different Bandwidths (**100 GHz,150 GHz**)

S.no	**Scaling factor**	**Spectral Efficiency for 150 GHz**	**Spectral Efficiency for 200 GHz**
1	0.20	2.269	1.9
2	0.60	5.2	6.80
3	0.80	9.4	7

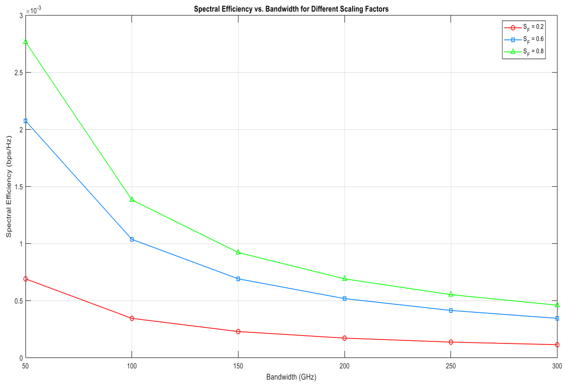

Fig-5: Spectral efficiency vs Bandwidth for different scaling factors at user fraction of 0.70 i.e. 70%

In figure-5, we have done analysis on spectral efficiency vs Bandwidth for constant user fraction of 0.7 and different scaling factors i.e. 0.2,0.6 and 0.8 . It has found that as band width increases spectral efficiency decreases very fast initially but later this decrease is slow or almost constant. It has observed that as scaling factor increases for fixed value of user fraction and bandwidth, spectral efficiency increases . It can be verified from figure-5 that as band width of next generation system increases for fixed scaling factor and user fraction spectral efficiency decreases.

The analysis of spectral efficiency in 6G wireless networks highlights the significant influence of key parameters such as scaling factors, bandwidth, and user fraction (UF) on network performance. Our findings of optimizing these parameters to maximize spectral efficiency and data transmission rates are as follows:

Impact of Scaling Factors: Higher scaling factors result in improved signal strength, which directly leads to higher spectral efficiency and better data rates. This is particularly beneficial in scenarios where network capacity is critical, such as high-density environments or data-intensive applications.

Bandwidth and Spectral Efficiency: The analysis has clearly shown that as we increase the band width, significantly spectral efficiency decreases. Larger bandwidths allows for more data to be transmitted over a given frequency range, which is crucial for meeting the demands of next-generation technologies like 6G. The results validate the need for ultra-wideband communication to support high-data-rate services, including autonomous systems, real-time immersive experiences, and massive IoT deployments.

User Fraction and Network Performance: Increasing user fraction generally improves spectral efficiency, as it leads to better utilization of available bandwidth. However, beyond a certain threshold, network congestion can reduce performance due to increased interference. This finding highlights the importance of dynamic resource allocation and efficient interference management in high-density networks.

V. CONCLUSION

The results have been revealed that the combination of higher scaling factors and reasonable bandwidth leads to optimal performance. This synergy between signal strength and bandwidth is vital for achieving the desired spectral efficiency and data rates in 6G networks, where the need for fast, reliable communication is ever-growing.

In conclusion, 6G systems will require careful optimization of scaling factors, bandwidth, and user fraction to deliver the high-performance, low-latency, and high-throughput capabilities as demanded by future applications. For future prospect optimization w.r.t any parameter may be done to get maximum value of spectral efficiency of this system.

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