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Quality of service optimization for 4G LTE upload and download throughput

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ABSTRACT

Demand for mobile data services and people's dependence on 4G LTE networks continue to increase. However, the quality of service (QoS) of this network still requires improvement, especially regarding the effect of QoS on throughput at specific frequencies. The research gap lies in the lack of in-depth analysis of the impact of QoS parameters on network performance at frequencies of 2,100 MHz and 2,300 MHz. This study evaluates the effect of QoS parameters, such as delay, jitter, and packet loss, on throughput in 4G LTE networks at both frequencies. The research methodology uses an experimental approach with throughput, delay, jitter, and packet loss measurements in various network conditions. The results showed that delay (17.2174 ms to 37.0322 ms), jitter, and packet loss significantly influence throughput, ranging from 624.5 Kbps to 1,322.4 Kbps. The 2,100 MHz frequency tends to show better performance than 2,300 MHz. This study concludes that optimizing QoS parameters, especially delay and jitter, can significantly improve 4G LTE network performance. These findings provide practical contributions for mobile operators in improving network quality and customer satisfaction and open opportunities for further research on other frequencies or newer network technologies.

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1. INTRODUCTION

The demand for mobile data services is increasing globally, along with the need for fast and stable connectivity. Nauman *et al.* [1] noted that internet traffic is dominated by multimedia content, which increases quality of service (QoS) and quality of experience (QoE) requirements. With more connected devices, such as smartphones and internet of things (IoT), the demand for better connectivity is increasingly urgent [2], [3]. Maulana *et al.* [4] mentioned that advances in network technology increase the need for efficient, stable, and secure connectivity. Fifth generation (5G) technology, with higher speeds and lower latency, is also accelerating the increase in demand [5], [6]. Siddiqi *et al.* [7] added that applications such as augmented reality require more efficient transportation protocols. This emphasizes the need for network technology innovation to meet high bandwidth demands. 4G LTE networks have become the backbone of mobile data services with high speed and large capacity compared to previous generations. However, QoS still needs to be improved to meet the evolving needs of users. A key challenge is the management of diverse data traffic, including real-time, such as video streaming and voice over internet protocol (VoIP), as well as non-real-time, such as file downloads [8]. Afzal *et al.* [8] showed that low-latency scheduling mechanisms can improve the QoS of real-time traffic, while Madi *et al.* [9] emphasized the importance of delay-based packet scheduling for efficiency. Erunkulu *et al.* [10] noted that although 4G LTE overcomes many of the limitations of 3G, signal loss model optimization and data rate improvement are still needed for better coverage and higher QoS. In addition, Hassoulas *et al.* [11] highlighted the importance of continuous network evaluation in coping with the increasing demand for multimedia services. With advanced signal optimization and scheduling techniques, 4G LTE can meet the increasingly high expectations of users. QoS parameters, such as delay, jitter, and packet loss, significantly influence network throughput, a key indicator of data service performance. Delay (latency) measures the data delivery time, where an increase in delay can decrease throughput [12]. Jitter, the variation in delay, disrupts data flow, especially in real-time applications such as video streaming and VoIP [13]. Packet loss, the loss of data packets due to congestion or transmission errors, also contributes to decreased throughput as it requires retransmission. Sangeetha *et al.* [14] emphasized the importance of integrated QoS management in minimizing these three parameters. Attia *et al.* [15] added that QoS-based scheduling algorithms could optimize throughput on time-sensitive services. Service providers can maximize throughput, improve network performance, and increase user satisfaction by effectively managing delay, jitter, and packet loss. Several studies have investigated the relationship between QoS and throughput in 4G LTE networks, but only a few focus on specific frequencies such as 2,100 MHz and 2,300 MHz. Research has been conducted on the relationship between QoS and throughput on 4G LTE networks. However, the focus on specific frequencies, such as 2,100 MHz and 2,300 MHz, is still limited. QoS parameters such as delay, jitter, and packet loss significantly affect throughput [16]. This gap emphasizes the need for more focused research on the effect of 2,100 MHz and 2,300 MHz frequencies on QoS and throughput [17]. The frequency of 2,100 MHz in 4G LTE networks shows better throughput performance than 2,300 MHz, especially on delay and jitter parameters [18], [19]. The 2,100 MHz frequency provides more optimal results for throughput and QoS, while the 2,300 MHz frequency is more susceptible to delay and jitter [20]. 2,100 MHz frequency stability in data transmission reduces packet delivery delay and variation [17]. Samsuzzaman *et al.* [21] mentioned that lower frequencies, such as 2,100 MHz, have better signal penetration and stability, increasing overall throughput. In contrast, although the 2,300 MHz frequency offers greater bandwidth, interference and signal loss often cause increased delay and jitter, so its QoS is not comparable to the 2,100 MHz frequency [20]. These findings suggest that the 2,100 MHz frequency is superior in supporting time-sensitive applications such as video streaming and voice calls. Further research is needed to improve QoS at higher frequencies [17].

The understanding of how QoS affects throughput on mobile networks, including 4G LTE and 5G, is still limited. Despite significantly impacting throughput, Bouraqia *et al.* [22] showed that network dimensioning often ignores QoS parameters such as delay and jitter. The importance of QoS in network planning is emphasized in optimizing system capacity, especially for real-time services. Siriwardhana *et al.* [23] noted that 5G offers improved QoS over 4G LTE, with the ability to handle more users and increase throughput for applications such as augmented reality and IoT. Haile *et al.* [13] added that QoS is affected by delay, jitter, and packet loss, which all contribute to throughput. However, specific research on the impact of QoS parameters on throughput in specific frequencies or new technologies such as 5G is still limited. Further research is needed to optimize QoS parameters in various network scenarios and technologies. The effect of QoS parameters on throughput in 4G LTE networks at multiple frequencies and network conditions has not been fully explored. Rappaport noted that lower frequencies, such as 900 MHz, offer better coverage but less optimal throughput than higher frequencies, such as 2,100 MHz [24]. Zappone [24] showed that carrier aggregation technology could increase throughput, but the results vary depending on the frequency. El-Saleh [20] revealed that interference at 2,300 MHz can cause throughput degradation, especially in congested network conditions. This finding indicates the importance of considering frequency and network conditions to achieve optimal QoS. The comparison of throughput performance at 2,100 MHz and 2,300 MHz frequencies in 4G LTE networks still requires further study [20]. In contrast, Isabona *et al.* [25] noted that the 2,100 MHz frequency provides more stable throughput performance under varying network conditions. Mishra and Natalizio [26] emphasized the importance of QoS management to maximize throughput, especially in dense networks, highlighting that delay and jitter can hinder the performance of 2,300 MHz frequencies in complex situations. The relationship between QoS parameters such as delay, jitter, and packet loss with throughput at 2,100 MHz and 2,300 MHz frequencies in various network scenarios is poorly understood [20]. Joung and Kwon [27] showed that delay and jitter significantly affect throughput in IntServ and DiffServ scenarios but did not compare the two frequencies. El-Saleh [20] emphasized the importance of QoS in measuring delay, jitter, throughput, and packet loss but did not provide specific analysis for 2,100 MHz and 2,300 MHz frequencies. Giordani *et al.* [28] found that poor connections disrupt communication but did not mention particular frequencies. Piran *et al.* [29] highlighted the importance of jitter and packet loss in maintaining QoS but did not compare these two frequencies. Khan *et al.* [30] proposed a QoS-based scheduling scheme to improve throughput without specific frequency details.

These findings indicate the need for more focused research to understand the QoS and throughput comparison between 2,100 MHz and 2,300 MHz frequencies. QoS optimization strategies to improve throughput at 2,100 MHz, especially under high traffic conditions, are still not fully understood.

Srivastava *et al.* [31] showed that handover algorithms can improve QoS and throughput in LTE but did not specifically discuss 2,100 MHz or 2,300 MHz frequencies. Wong *et al.* [32] proposed a delay-based scheduling scheme to improve multimedia service throughput, but its application at 2,100 MHz frequency has not been analyzed. Wu *et al.* [33] emphasized the importance of optimizing traffic-sharing techniques to improve network quality, while Piran *et al.* [29] found that throughput, delay, jitter, and packet loss significantly affect QoS without focusing on specific strategies for certain frequencies. Research on WiFi offloading is not relevant to the LTE context. The lack of research linking QoS parameters with throughput at specific frequencies indicates the need for further research, especially for high traffic conditions at 2,100 MHz frequencies [20]. QoS in 4G LTE networks, especially in throughput, still requires improvement, especially at critical frequencies such as 2,100 MHz and 2,300 MHz [31]. Although previous research has addressed QoS, in-depth studies on the impact of parameters such as delay, jitter, and packet loss on throughput at these two frequencies are still limited [29]. This understanding is essential to help mobile operators optimize their networks to meet the growing data demand [34]. This research aims to evaluate the effect of QoS parameters on throughput at 2,100 MHz and 2,300 MHz frequencies under various network conditions and compare their performance [17]. The main focus is identifying the frequency with the best throughput performance and providing QoS optimization recommendations, such as delay and jitter reduction, to improve service quality [35]. The results are expected to show that QoS parameters significantly influence throughput, with 2,100 MHz frequencies expected to perform better than 2,300 MHz. These findings can help mobile operators improve network performance to support a better user experience with fast and stable connectivity.

2. RESEARCH METHOD

This research uses experimental methods to evaluate the effect of QoS parameters on throughput in 4G LTE networks. Data were collected through measurements of QoS parameters, such as delay, jitter, and packet loss, as well as throughput at two main frequencies, 2,100 MHz and 2,300 MHz. Various network conditions were set up to reflect variations in data traffic density levels, and measurements were taken using instruments that record data in numerical format for further analysis. Experiments were conducted by alternately configuring the network at both frequencies, and each test was repeated to ensure the validity of the results. The data obtained was analyzed to determine the relationship between QoS parameters and throughput, and a comparison of throughput performance between 2,100 MHz and 2,300 MHz frequencies was conducted to identify the better-performing frequency. The analysis results are used to provide recommendations for QoS optimization, especially on the most influential delay and jitter parameters, and the research findings are interpreted to guide mobile operators in improving network performance and customer satisfaction.

3. RESULTS AND DISCUSSION

3.1. Throughput parameter processing results upload and download methods frequency 2,100 MHz and 2,300 MHz

Figure 1 analysis of the physical throughput on the uplink channel (P.U.S.C.H.) shows that most users (46.73%) experience moderately high throughput, with a significant concentration in the 6,000-60,000 kbps range. This finding is in line with previous studies showing improved mobile network performance. However, the presence of measurements in the lower throughput range indicates unevenness in service quality. This study did not consider factors such as interference and distance from B.T.S.; further investigation is needed to identify the causes. These results have important implications for operators in optimizing resource allocation, especially in areas with weak coverage. Future research can be conducted by expanding the data coverage to different geographical locations and device types and analyzing the data over a more extended period to identify long-term trends.

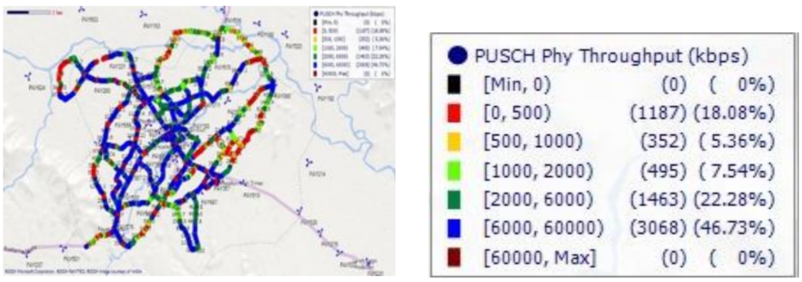


Figure 1. Throughput parameter processing results upload method frequency 2,100 MHz

Figure 2 analysis of the physical throughput on the uplink channel (P.U.S.C.H.) shows a predominance of measurements in the lower value range, with 68.19% of measurements falling below 2,000 kbps. This finding indicates potential constraints in delivering high-speed data services on the uplink channel. Factors such as interference, distance from B.T.S., and environmental conditions are thought to be the leading causes. These results have significant implications for network operators in identifying areas that require capacity enhancement and optimizing network settings. This study has limitations regarding time and location coverage and factors that should have been considered. For future research, it is necessary to conduct a more comprehensive analysis by expanding data coverage and considering other factors that can affect throughput, such as the type of device and application used.

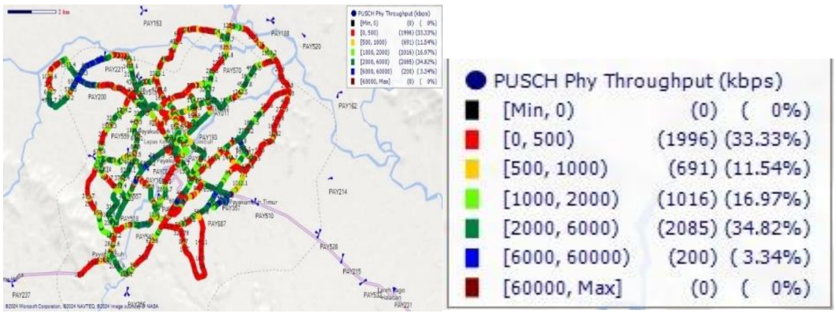


Figure 2. Throughput parameter processing results upload method frequency 2,300 MHz

Figure 3 analysis of physical throughput on the downlink channel (P.D.S.C.H.) shows a relatively even distribution, with a significant proportion of users achieving high throughput above 15,000 kbps. This finding indicates good data service quality on the downlink channel and effective network optimization. However, it should be noted that the absence of data in the range below 1,000 kbps may be due to measurement limitations. These results have positive implications for network operators in maintaining good service quality. Further research can be done by expanding the data coverage, analyzing the influence of other factors such as device type and environmental conditions, and comparing it with the uplink channel to get a complete picture of the network performance.

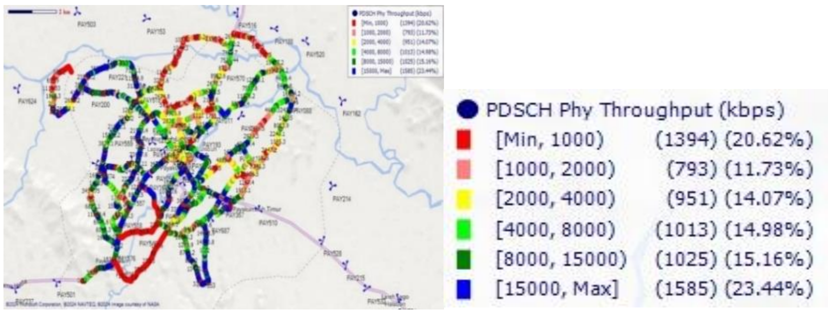


Figure 3. Throughput parameter processing results download method 2,100 MHz frequency

Figure 4 physical throughput analysis on the downlink channel (P.D.S.C.H.) shows a fairly even distribution, with a significant concentration in the mid-range (1,000-4,000 kbps), which accounts for 39.71% of the total data. This finding indicates that most users experience consistent data download speeds. The category with the second highest percentage was the 2,000-4,000 kbps range (21.31%), followed by the 1,000-2,000 kbps range (18.4%). Only a tiny percentage of users experienced throughput below 1,000 kbps (22.3%) or above 8,000 kbps (28.39%). These results have positive implications for network operators in maintaining data service quality. However, it should be noted that the absence of data in the range above 15,000 kbps may be due to measurement limitations or other factors that need further investigation. Further research can be done by expanding the data coverage, analyzing the influence of different factors such as device type, environmental conditions, and interference, and comparing it with the uplink channel performance to get a more comprehensive picture of the overall network performance.

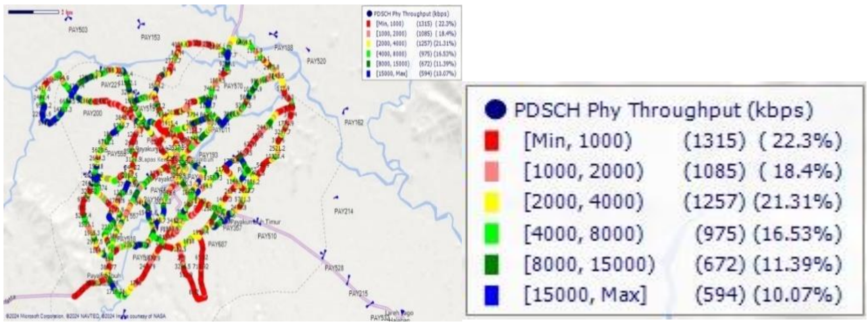
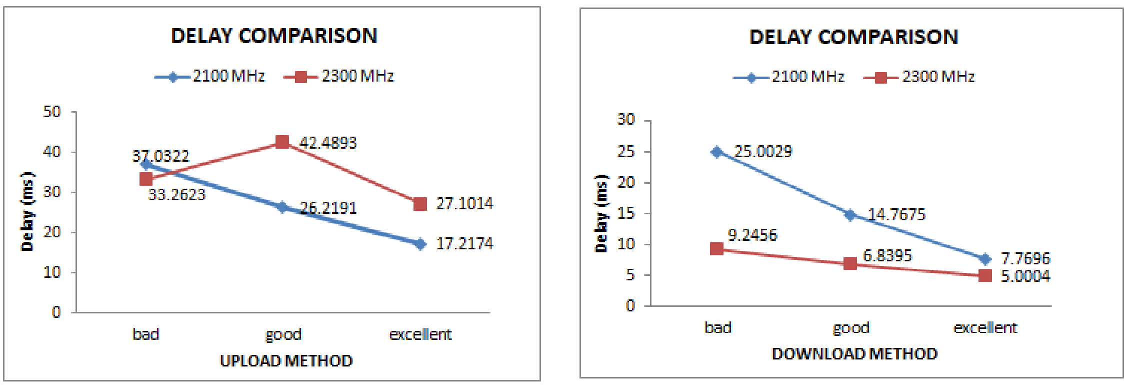


Figure 4. Throughput parameter processing results download method 2,300 MHz frequency

3.2. Delay testing results frequency 2,100 MHz and 2,300 MHz upload and download method

Comparative analysis of delays at 2,100 MHz and 2,300 MHz frequencies shows mixed results, depending on the access method (upload and download). Figure 5 shows the delay values for both frequencies, with Figure 5(a) presenting the delay values for the upload method, and Figure 5(b) showing the delay values for the download method. In general, the 2,100 MHz frequency tends to provide lower delay values, especially in the “good” (26.2191 ms) and “excellent” (17.2174 ms) upload methods compared to the 2,300 MHz frequency (42.4893 ms and 27.1014 ms). However, there is an anomaly in the “bad" upload method, where the 2,300 MHz frequency (33.2623 ms) has a lower delay value compared to the 2,100 MHz frequency (37.0322 ms). The 2,300 MHz frequency generally provides lower delay values in the download method, especially in the “excellent” download method (5.0004 ms). These performance differences may be due to interference, traffic load, environmental conditions, or different network settings at each frequency and access method. These results have important implications for network design and optimization, especially for delay-sensitive applications such as video calls or online gaming. Further research can be conducted by expanding the scope of frequencies and access methods and analyzing the influence of other factors that may affect delays, such as modulation and coding types. It is essential to deeply understand the factors affecting network performance and design optimal solutions for different applications.

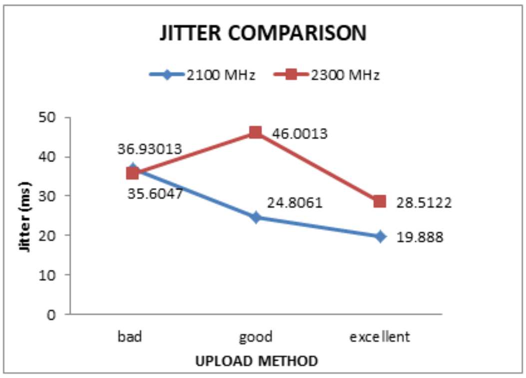


(a) (b)

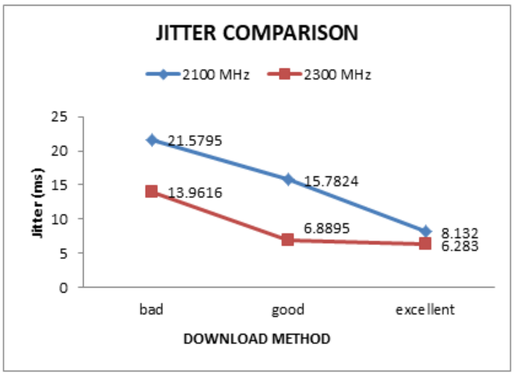
Figure 5. Delay test results of 2,100 MHz frequency and 2,300 MHz frequency (a) upload method and (b) download method

3.3. Jitter testing results frequency 2,100 MHz and 2,300 MHz upload and download methods

Comparative analysis of jitter at 2,100 MHz and 2,300 MHz frequencies shows mixed results depending on the access method (upload and download). Figure 6 illustrates the jitter values for both frequencies, with Figure 6(a) presenting the jitter values for the upload method, and Figure 6(b) showing the jitter values for the download method. In general, the 2,100 MHz frequency tends to have lower jitter values in the “good” (24.8061 ms) and “excellent” (19.888 ms) upload methods compared to the 2,300 MHz frequency (46.0013 ms and 28.5122 ms, respectively). However, in the download method, the 2,300 MHz frequency consistently provided lower jitter values, especially in the “bad” (13.9616 ms) and “good” (6.8895 ms) download methods. This difference in performance indicates that proper frequency selection can significantly affect the time variation between packets, an essential indicator of service quality. Factors such as interference, traffic load, and network settings are likely to be the leading causes of this performance difference. The results of this study have important implications for network design and optimization, especially for jitter-sensitive applications such as video calls and audio streaming. Further research can be conducted by expanding the scope of frequencies and access methods and analyzing the influence of other factors, such as modulation and coding types. It is essential to deeply understand the factors affecting jitter and design optimal solutions for different applications.



(a)

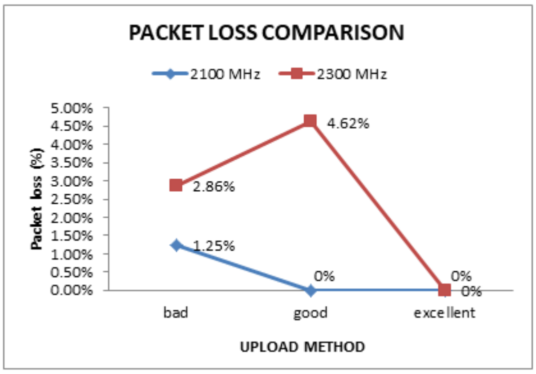


(b)

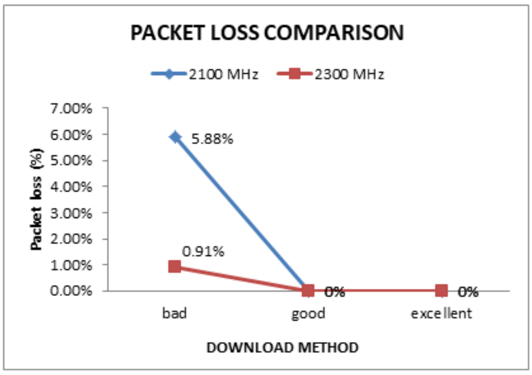
Figure 6. Test results of jitter frequency 2,100 MHz and frequency 2,300 MHz (a) upload method and (b) download method

3.4. Packet loss testing results frequency 2,100 MHz and 2,300 MHz upload and download methods

Comparative analysis of packet loss at 2,100 MHz and 2,300 MHz frequencies shows mixed results depending on the access method (upload and download). Figure 7 illustrates the packet loss percentages for both frequencies, with Figure 7(a) presenting the results for the upload method, and Figure 7(b) showing the results for the download method. Generally, the 2,300 MHz frequency tends to have a lower packet loss percentage, especially on the "bad" download method (0.91% vs. 5.88%). However, on the upload method, the performance of the two frequencies varied more. The 2,100 MHz frequency generally showed a lower packet loss percentage, except in the "good" upload method, where the 2,300 MHz frequency had a higher packet loss percentage (4.62%). This difference in performance indicates that proper frequency selection can significantly affect packet loss rate, an essential indicator of network reliability. Factors such as interference, traffic load, and network settings are likely to be the leading causes of this performance difference. The results of this study have important implications for network design and optimization, especially for data loss-sensitive applications such as video streaming or large file transfers. Further research can be conducted by expanding the coverage of frequencies and access methods and analyzing the influence of other factors, such as modulation and coding types. It is essential to deeply understand the factors affecting packet loss and design optimal solutions for different applications.



(a)

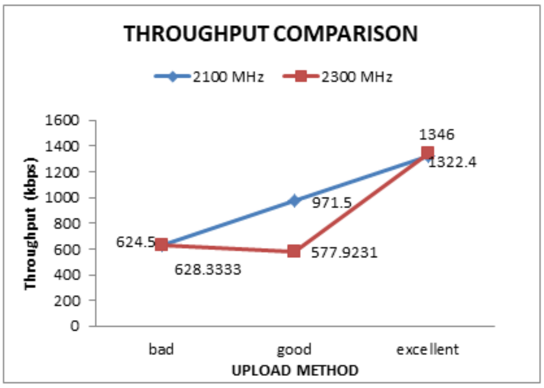


(b)

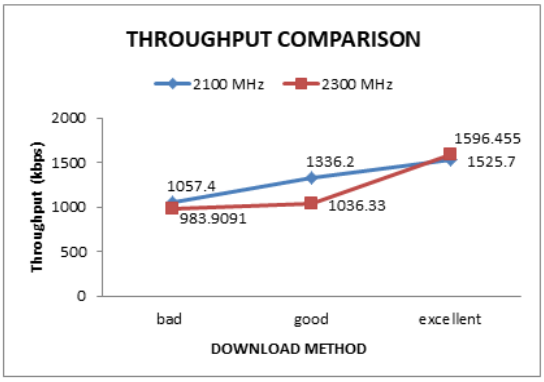
Figure 7. Test results of packet loss frequency 2100 MHz and frequency 2300 MHz (a) upload method and (b) download method

3.5. Throughput comparison results frequency 2,100 MHz and 2,300 MHz upload and download methods

Comparative analysis of throughput at 2,100 MHz and 2,300 MHz frequencies shows that the 2,300 MHz frequency generally provides higher throughput values, especially in the “excellent” download method (1,596.455 kbps). Figure 8 illustrates the throughput values for both frequencies, with Figure 8(a) presenting the results for the upload method, and Figure 8(b) showing the results for the download method. However, the throughput performance varies depending on the access method (upload and download). In the upload method, the 2,100 MHz frequency provides higher throughput values in the “good” method (971.5 kbps), while the 2,300 MHz frequency is superior in the “excellent” method (1,322.4 kbps). This difference in performance indicates that proper frequency selection can significantly affect the data transfer rate. Factors such as interference, traffic load, and network settings are likely to be the leading causes of this performance difference. The results of this study have important implications for network design and optimization, especially for applications that require significant bandwidth, such as video streaming or file downloads. Further research can be conducted by expanding the coverage of frequencies and access methods and analyzing the influence of other factors, such as modulation and coding types. It is essential to deeply understand the factors affecting throughput and design optimal solutions for different applications.



(a)



(b)

Figure 8. Comparison of throughput methods (a) upload and (b) download

3.6. Comparison results of 2,100 MHZ and 2,300 MHZ upload and download frequency

A comparative analysis of QoS performance between 2,100 MHz and 2,300 MHz frequencies shows that the 2100 MHz frequency consistently provides lower delay, jitter, and packet loss rate values. The better QoS performance at 2,100 MHz is positively correlated with a significant increase in throughput. These results indicate that the 2,100 MHz frequency is optimal for applications that demand high-quality service, such as video streaming, video conferencing, and large data transfers. These findings highlight the importance of proper frequency selection in designing cellular networks to meet the needs of diverse user applications.

4. CONCLUSION

The study concluded that QoS significantly influences throughput performance on 4G LTE networks, particularly on the 2,100 MHz and 2,300 MHz frequencies. QoS parameters such as delay, jitter, and packet loss have played an essential role in determining network performance, with the 2,100 MHz frequency generally performing better than the 2,300 MHz frequency. QoS optimization, especially the reduction of delay and jitter, can significantly increase throughput, thus providing opportunities for mobile operators to improve service quality and customer satisfaction. These results answer the gaps in previous research and provide practical guidance for network optimization. In addition, the research opens up opportunities for further exploration, such as analyzing other frequencies or developing newer network technologies such as 5G.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Afrizal Yuhanef	✓	✓		✓	✓	✓		✓	✓	✓			✓	✓
Siska Aulia			✓	✓			✓	✓		✓	✓	✓		✓
Lefenia Indriani			✓			✓	✓		✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

We declare that we have no conflict of interest in relation to the research and publication of this article.

DATA AVAILABILITY

This study did not involve the creation or analysis of new data; therefore, data availability is not applicable. No datasets were generated during the course of this research.

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