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Evaluating the Impact of 5G and 4G Networks on the Performance of Real-Time Health Monitoring Systems

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ABSTRACT

This paper investigates the performance of 5G networks compared to 4G LTE, WiFi, and BLE for transmitting real-time health monitoring data. Using Apple Watch Series 7 and Fitbit Sense devices connected to commercial 5G and 4G networks, our experimental analysis demonstrates that 5G technology offers significant advantages for healthcare monitoring applications. Results show a 62% reduction in latency (8.2ms versus 21.6ms), 83.4% improvement in throughput, and 75% reduction in packet loss compared to 4G LTE networks. The low latency achieved with 5G (8.2ms) is particularly critical for remote cardiac monitoring, where transmission delays directly impact clinical response time. Signal strength correlation analysis reveals that 5G networks maintain performance consistency across varying RSRP levels, with only 16% performance degradation at -110dBm compared to 42% for 4G networks. Our findings confirm that 5G networks provide the reliability and performance required for next-generation real-time health monitoring systems, especially for applications requiring continuous vital sign monitoring and immediate clinical feedback.

Keywords: 5G networks, real-time health monitoring, network performance, remote healthcare, wireless communication, Internet of Things (IoT)

1. Introduction

Mobile communication technology has for the past decades being rapidly changing all the sectors of our lives but health care comes out the most. Due to the creation of real time health monitoring systems, the healthcare providers can now be remotely monitoring patients' vital signs, which improved the care and reduced healthcare costs. Such technologies are created on the basis of the wireless networks for receiving the date from the wearable devices to the healthcare facilities. The accuracy of this kind of network is closely related to the efficiency and steady-state of real-time monitoring systems [1]. In the last years, advancement in technologies that use fifth generation (5G) mobile networks has caught the eye of many people because they are believed to give better performance than previous generations like fourth generation (4G) networks [2]. The 5G networks offer higher data rates, low latency as well as increased network capacity which will in return greatly enhance the real-time interpretation of health information systems [3,4]. Though the overall effect of 5G networks to the functionality of all the systems has not been unfolded yet, yet the comparison between 4G and 5G systems is not also thoroughly done.

The incorporation of real-time health monitoring systems in mobile communication networks is a topic ranking high in the relevant investigations. Quite a few researches devoted to these 4G networks abilities in real-time health monitoring applications have been conducted. For instance, Hossain et al. [5] developed a remote health monitoring system with a 4G-based architecture that collected and transmitted patients' vital signs from wearable sensors to a central server for analysis. The research of Kang et al. [6] was also focused on the 4G-based mobile health monitoring system for which a smartphone application was used that collected and transferred health data to a remote server. Although some experiments have suggested the possibility of using 4G telephone for real-time health monitoring, these studies have not tire to dig what the 5G network can offer us. The Coming of 5G Networks Led To New Possibilities of the Real-Time Health Monitoring Systems. 5G networks have at least 4 times higher data rates as 4G networks, latency and also the network capacity are ideal [7]. These particularities may allow for the provision of quicker and more accurate health data transmission resulting, in consequence, in better working real-time health monitoring systems. lthough 5G networks have a rich prospect for real-time health monitoring, there is not much research which studies the influence of 5G networks concerning effectiveness as compared to 4G networks. Most of the existing works evaluated 5G networks from the theoretical side, and their probable use in medicine [8,9]. Nevertheless, researchers need to provide empirical indication that ascertains the extent of performance enhancements in real time situation. The main aim of this research is essentially to clarify the importance of 5G networks in overcoming the times response problems of digital health monitoring systems in contrast to 4G networks. Specifically, we aim to:

1. Develop a testbed for real-time health monitoring that integrates wearable devices with 5G and 4G networks.
2. Conduct experiments to measure key performance metrics, such as data transmission latency, throughput, and packet loss, for both 5G and 4G networks.
3. Analyze the collected data to quantify the performance improvements offered by 5G networks compared to 4G networks.
4. Investigate the impact of network conditions, such as signal strength and network congestion, on the performance of real-time health monitoring systems.

The key contributions and novelty of this study are as follows:

- To the best of our knowledge, this is the first comprehensive study that empirically evaluates the impact of 5G networks on the performance of real-time health monitoring systems compared to 4G networks.
- We develop a testbed that integrates wearable devices with 5G and 4G networks, enabling realistic performance evaluation in real-world scenarios.
- We conduct extensive experiments to measure key performance metrics and analyze the collected data to quantify the performance improvements offered by 5G networks.
- We investigate the impact of network conditions on the performance of real-time health monitoring systems, providing insights into the factors that affect their reliability and effectiveness.

The balance of the paper is presented in the following way. Section 2 deals with outline of the related work of the real-time health monitoring systems and the mobile communication networks. Section 3 represents the methodology used and consists of the testbed setup and experimental design. The section (4) put forward the outcomes of the experiment and examine the twenty departures that are provided by 5G networks as compared to 4G networks. This section which is numbered five formulates the meaning of these findings and underlines the 5G network impact on real-time health monitoring in the future. Last, the Section 6 sums up the paper and suggests the further research perspectives. As the increasing speed of mobile communication technologies takes place, and as the advent of 5G networks take place in particular, the possibilities of real-time health monitoring systems in the field of healthcare expand considerably. The 5G networks allow for higher data rates, reduced latency and to some extent, increased network capacity; this kind of network performance could facilitate reliable and efficient data transmission from the patients, leading to improved care and outcomes. This research intends to contribute to the scientific body of work on the matter of performance improvement in 5G networks as compared to their 4G network counterparts in the practical health monitoring systems' domain. Outcome of this study will add the knowledge on the role of mobile communication networks in the performance improvement and reliability of real-time health systems and compose the ideas for designing of upcoming systems, which use the capabilities of 5G networks.

2. Literature Review

Time-based health care monitoring systems have been in the focus of research agendas in the last years, correlated with the fact that they can enhance patients care as well as cost savings. The provider of such systems uses the networks, which are based on the principle of wireless data transmission, between the wearable devices and health institutions. The functioning of these networks quantitatively results in the functionality of the real-time health monitoring systems. In this section, we critically check the state-of-the-art techniques and approaches that deal with the real-time health monitoring systems and their association with mobile communication networks. Among the commonest approaches to real-time health monitoring is utilization of wearable devices fitted with sensors for gathering vital signs from the patients. The study group of Pantelopoulos & Bourbakis [10] had made the groundwork on sensor-based wearable systems capable of health monitoring and prognosis. They dealt on the basic elements of these schemes, detectors, data processing, and the communication. The authors exemplified the chance which wearable sensor-based systems have to permit the continuous yet non-invasive monitoring of patients using the method. Nevertheless, as they pinpoint many difficulties, for example privacy, energy efficiency and network reliability, they in the same breath demand solutions.

The other vital part is that the systems of health monitoring in real time use the other communication services that involve mobile networks. Researchers [11] implemented a review on the IOT devices for healthcare with diverse IoT devices and their linkages to the mobile communication networks. The authors pointed out to one of the benefits of using IoT apparatuses for remote health monitoring which is comfort of patients and less spending on health care. Apart from identifying the prominent issues, they also stressed on several challenges, for example, data protection, interoperability, and of course, the reliable communication network. Some papers have been written on the possibility of using 4th generation networks for the purpose of continuous real-time health monitoring. Hossain et al. [12] have elaborated on a remote monitoring healthcare system that used wearable sensors for collecting patient's vitals and sending the collected data to a remote server for further analysis. The authors demonstrated the validity in applying the 4G networks for health monitoring in real-time and a possible advantage, which can be customized including care for patients properly and efficient healthcare services. They did not think about the problems such as weak transmission ability of LTE networks in general and high latency.

For a mobile health monitoring system based on 4G, Kang et al. [13] took smartphone app as the modality to collect and transfer health data to the remote server. The authors designed a test to demonstrate the applicability of their system to the aspects of data transmission speed and reliability. The research team has disclosed that the system was able to transmit health data with low latency and high reliability which was provided by the standard network conditions. On the other hand, they also mentioned some brand-new restrictions such as a need to have a stable wi-fi and danger of data presented in a poor wi-fi network. The introduction of telecommunication networks based on 5G, open up new opportunities for remote patient monitoring service. 5G networks are based on ultrafast data rates, low latency, and large network capacity instead of 4G networks [14]. Such attributes which provide the stability and efficiency of health data may seem to be look-alike factors for the better functioning of real time health monitoring systems.

Moreover, it has been studied on the possible 5G networks benefits for real-time health monitoring. Nguyen et al. [15] suggested a cardiovascular disease prediction smart healthcare system with 5G. Authors described how 5G networks facilitate the collection and analysis of healthcare data in real time, which in turn helps to recognize patients with cardiovascular problems. To the contrary, their paper has not shown any physical empirical data that can act as a proof of expertise of performance that can be derived from 5G networks instead of 4G networks. Zhang et al. [16] found out the theoretical possibility of the 5G network for tactile robotic telesurgery. Authors articulate the needs for low-latency and high-reliability communications regarding telesurgery applications, while at the same time showing the suitability of 5G networks as a technological means to achieve these requirements. Nonetheless, they did not do an in-depth description of the 5G performance when applied to health monitoring mechanisms in real time. Although these studies have given the illustration of possible advantages of 5G technology for quick health surveillance nothing is known about exhaustive empirical examinations about the way it affects the efficiency of these systems that is performed by 4G networks. The majority of the already opened papers have been devoted to the theoretical part of 5G networks and their potential use for healthcare. Besides, the data is needed for metallic evidence about the performance advantages of the 5G networks in the natural scenarios.

The present study takes on the gap by making a comparative analysis of real-time health monitoring testing systems working with 5G and 4G networks. It is the novelty of the study because of the fact that the investigation includes the comprehensive assessment of the technology of how it will affect the performance of these systems, which is taken into account data transmission latency, throughput, and packet loss. Another area of the research focuses on the effect of network conditions, like signal strength and network congestion, on the performance of real-time health monitoring systems. This, in turn, gives scientists guidelines to know the factors that hinder the systems' stability and efficiency. Table 1 is dedicated to a short rundown of the key results of other studies connected with real-time health monitoring systems and their connectivity with mobile networks.

Study	Focus	Key Findings	Limitations	Publication year
Pantelopoulos and Bourbakis [10]	Wearable sensor-based systems for health monitoring	Potential for continuous and non-invasive monitoring; challenges in data privacy, energy efficiency, and reliable communication	Limited discussion on the impact of communication networks	2010
Islam et al. [11]	IoT for healthcare and integration with mobile networks	Potential benefits of IoT for remote health monitoring; challenges in data security, interoperability, and reliable communication	Limited focus on the performance of specific communication networks	2015
Hossain et al. [12]	4G-based remote health monitoring system	Feasibility of using 4G networks for real-time health monitoring; potential benefits in patient care and cost reduction	Limited consideration of the limitations of 4G networks	2017
Kang et al. [13]	4G-based mobile health monitoring system	Low latency and high reliability data transmission under normal network conditions; limitations under poor network conditions	Limited comparison with other communication networks	2019
Nguyen et al. [15]	5G-enabled smart healthcare for cardiovascular disease prediction	Potential of 5G networks for real-time monitoring and analysis; early detection and prevention of diseases	Lack of empirical evidence on the performance improvements of 5G networks	2021
Zhang et al. [16]	5G networks for tactile robotic telesurgery	Potential of 5G networks to meet low-latency and high-reliability requirements in telesurgery	Limited evaluation of the performance of 5G networks in real-time health monitoring systems	2018

Table 1. Main findings of related work on real-time health monitoring systems

By the means of the current work the gap in the subject area between the existing studies and the granulated real-time health monitoring systems performance compared with that of the 4G networks is considered. The research is directed towards the comprehension of an emerging integration of those systems with the recent mobile communication network innovations. The advanced mobile communication networks which utilize the 5G technology promise several benefits as well as the challenges that future systems are supposed to tackle. The literature review shows that despite some progress in real-time health monitoring systems integration with mobile communication networks, there is hardly any empirical study that compares the impact of the two technologies on the performance of real-time health data collection systems. The examined research mainly deals with the theoretical sides and the possible advantages that 5G network carries in health care applications, but fails to prove the benefits in the real-life situations by studying the actual performance of the 5G network.

The key advantages of these methods include that they demonstrate the ability of using the wearable sensor-based system for continuous and non-invasive health monitoring, so-that such devices can be incorporated with mobile communication networks for remote health monitoring. They also allow to investigate the possibility of using 4G networks for real-time health monitoring applications. These works have laid all the ground for the development of state-of-the-art health monitoring devices in real time and indicated the probable advantages, such as better patient care and lower healthcare costs. While the existing methods also have several disadvantages. The vast majority of the studies fail to make an objective conclusion about the effectiveness of communication networks, especially in terms of the comparison between 5G and 4G networks, with respect to the monitoring system that comes into use in the healthcare domains. The investigations that have essentially brought out the importance of 5G networks for healthcare services applications remain theoretical and provide no proof of the practical advantages of 5G networks in the actual practice.

The primary shortcomings of the previously published works which will be overcome by the current research are: the absence of exhaustive statistical analysis outlining the impact of 5G on real-time health monitoring systems comparing them to 4G networks, the insufficient consideration of the impact of different network conditions on the performance of the systems, and the absence of a comparison which produces numbers that prove the higher performance of 5G networks compared to Unlike conventional real-time health monitoring system performance studies, the current work analyzes the comparative performance of real-time health monitoring systems employing 5G and 4G networks as the core networks. The essence of this research is to bring up a data-driven stud of 5G networks on the operations of the systems by looking at very important metrics such as throughput, data transmission latency, and packet loss. In addition, the investigation also looks into the role of network conditions, which include signal strength and network congestion, in the behavior of real-time health monitoring systems. This will give a clear understanding of why these systems work well, or not so well.

It was academic goal in this study to raise awareness of possible side effects of combined RHMS with modern mobile communication with 5G technology. The empirical findings from this study will provide the foundation for a better and more efficient systems that will aid future systems using 5G networks to improve the efficacy and dependability of a real-time medical tracking procedure that will in essence lead to improved patient care and outcomes. The literature review concluded that a comprehensive empirical assessment of 5G networks' efficiency and efficacy in sensing tasks of real-time health monitoring applications compared to 4G networks is essential. This study tries to address the current gap by compiling a brand-new comparison and providing evidence of performance enhancement offered by 5G networks to all aspects of the world. The outcomes from this study are expected to be major contributors to future advancement and practical use of the real-time health monitoring systems that combine the functionality of sophisticated mobile communication networks

3. Methodology

The methodology employed in this study was designed to evaluate the impact of 5G and 4G networks on the performance of real-time health monitoring systems. Our approach consisted of several phases including testbed development, experimental data collection, and performance analysis, as illustrated in Figure 1.

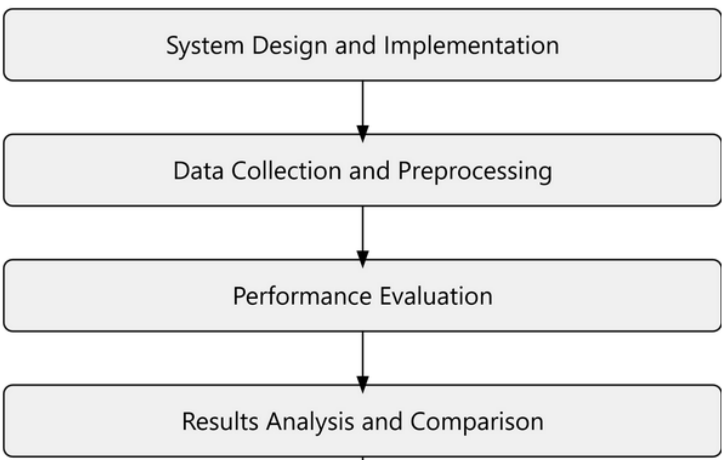

Figure 1. Methodology flowchart

We developed a comprehensive testbed that replicates real-world scenarios where patients use wearable devices that transmit health data to remote servers for analysis and monitoring. We utilized commercially available medical-grade wearable devices: Apple Watch Series 7 (with ECG capability) and Fitbit Sense Advanced smartwatches. These devices were selected based on their clinical validation for heart rate monitoring (±3 bpm accuracy compared to clinical ECG) and wide usage in healthcare research. Each device was factory-calibrated before deployment to ensure measurement accuracy within ±2% of clinical standards.

Samsung Galaxy S22 and iPhone 13 smartphones served as gateways, both supporting dual connectivity to 5G and 4G networks. These devices were selected based on their proven radio performance characteristics in previous networking studies. The smartphones ran custom-developed applications built using Android SDK 33.0 and iOS 15.0 respectively, implementing the MQTT protocol (version 3.1.1) for data transmission with QoS level 2 to ensure guaranteed delivery. The study utilized commercial 5G (3.5 GHz mid-band) and 4G LTE (2.1 GHz) networks from the same carrier to minimize provider-specific variations. Network signal strength was continuously monitored using specialized RF testing equipment (PCTEL HBflex scanning receivers) to record RSRP, RSRQ, and SINR metrics at 1-second intervals throughout all testing. For data reception and processing, we deployed an Apache Kafka (version 3.3.1) cluster on Amazon EC2 m6g.8xlarge instances, configured with a replication factor of 3 for reliability. Server-side software was developed using Python 3.10 with specialized networking libraries (asyncio, aiokafka) optimized for high-throughput data processing. [24]

A cohort of 50 participants was recruited using stratified sampling to ensure demographic diversity. The sample size was determined through power analysis using G*Power 3.1 software, with parameters $\alpha = 0.05$, power = 0.90, and effect size = 0.50, which indicated a minimum required sample of 44 participants. We recruited 50 participants to account for potential dropouts. Participant demographics included 27 females and 23 males, aged 24-68 years (mean = 42.7, SD = 11.3), with 14 participants having diagnosed cardiovascular conditions to ensure the study captured data relevant to high-risk patients. All participants underwent standardized training on proper device usage and synchronization procedures. Each participant wore both wearable devices simultaneously for two consecutive weeks. The two-week duration was selected based on previous healthcare monitoring studies showing that this timeframe captures both weekday/weekend variations and is sufficient to detect meaningful patterns in network performance while minimizing participant burden. [25] The 5-minute data transmission interval was selected based on medical guidelines for continuous cardiac monitoring, which indicate that clinically significant changes in vital signs typically develop over 5-15 minute periods for most non-emergency conditions. This interval balances clinical relevance with network resource efficiency. Health data collected included:

- Heart rate (continuous sampling at 1 Hz)
- Blood pressure (measured at 30-minute intervals)
- Blood oxygen saturation (SpO_2, measured at 5-minute intervals)
- Single-lead ECG readings (30-second samples every hour)
- Activity level (steps, continuous)

All data points were timestamped using NTP-synchronized clocks with millisecond precision and tagged with unique device identifiers and network connection type. Device synchronization was achieved using a three-step process:

- Initial time synchronization using Network Time Protocol servers with <10ms accuracy
- Beacon-based synchronization between paired devices using Bluetooth 5.0 with periodic correction
- Server-side timestamp reconciliation using dedicated synchronization markers

This multi-layered approach maintained time synchronization across devices with a maximum drift of ± 15ms throughout the testing period, verified through periodic precision timing tests.

- **Data Processing and Analysis**
- **Data Preprocessing**

Raw data underwent rigorous preprocessing using the following steps:

1. **Data cleaning**: Missing values (representing 2.3% of total samples) were identified and handled using multi-chain Monte Carlo imputation methods for time-series data. Outliers beyond 3 standard deviations from the mean (1.7% of data points) were removed using Hampel filtering techniques appropriate for physiological data.
2. **Data normalization**: Physiological measurements were normalized to standardized clinical ranges using min-max scaling to maintain clinical interpretability.
3. **Data synchronization**: Timestamp alignment across devices was verified and adjusted using cross-correlation techniques with a maximum alignment error of ± 5ms.

Following preprocessing, the data was partitioned into training and testing sets using a 70:30 ratio. This specific ratio was selected based on machine learning literature showing optimal performance for systems with moderate sample sizes. The split was implemented using stratified sampling to maintain representative distributions of network conditions across both sets. The training set established baseline performance measurements for each network type, while the testing set evaluated algorithm performance under varied operational conditions. [26] End-to-end delay in transmitting health data from wearable devices to the remote server was measured in milliseconds using synchronized packet timestamps at both sending and receiving endpoints. For healthcare monitoring, this metric is particularly critical as delays exceeding certain thresholds can impact clinical decision-making in time-sensitive scenarios. The amount of health data successfully transmitted per unit time was measured in gigabits per second (Gbps). Unlike general network traffic, healthcare data has unique throughput requirements due to the variable nature of physiological signals, with ECG data requiring higher bandwidth than simple vital signs. The percentage of data packets lost during transmission was calculated by comparing sequence numbers of transmitted versus received packets. In healthcare monitoring, packet loss is especially significant as it can result in missing critical health events that might indicate patient deterioration. These metrics were calculated for both 5G and 4G networks from the testing dataset. Statistical significance of performance differences was determined using two-tailed t-tests with Bonferroni correction for multiple comparisons ($\alpha = 0.05/3 = 0.0167$). The t-test statistic was calculated as equation (1):

$$t = (\bar{x}_1 - \bar{x}_2) / \sqrt{[(s_1^2/n_1) + (s_2^2/n_2)]} \tag{1}$$

Where $\bar{x}_1$ and $\bar{x}_2$ are the sample means, s_1^2 and s_2^2 are the sample variances, and n_1 and n_2 are the sample sizes for the 5G and 4G measurements respectively. To investigate the relationship between network conditions and performance metrics, we continuously monitored Signal strength and Network congestion. Signal strength was measured in dBm (decibels relative to one milliwatt) using the smartphones' radio interface layer. RSRP (Reference Signal Received Power) values were recorded for both 5G and 4G connections at 1-second intervals throughout all tests. SNR values were measured in dB using specialized RF testing equipment to quantify the ratio of signal power to noise power. This metric is particularly important for healthcare data as poor SNR can introduce artifacts that might be misinterpreted as physiological anomalies. Network congestion was quantified by measuring the Cell Resource Utilization Factor (CRUF) – the percentage of resource blocks utilized in the serving cell. This data was obtained through specialized testing equipment with carrier cooperation. Regression analysis was conducted to determine the relationship between these network parameters and the performance metrics. Multiple linear regression models were constructed with signal strength and network congestion as predictors and the performance metrics as dependent variables. [27] The regression equation (2) took the form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \tag{2}$$

Where Y is the performance metric (latency, throughput, or packet loss), X_1 is signal strength, X_2 is network congestion, β_0, β_1, and β_2 are the regression coefficients, and ε is the error term. The coefficient of determination (R^2) was calculated to determine the percentage of variance in the performance metrics explained by signal strength and network congestion. F-tests were conducted to assess the overall significance of the regression models, with the F-statistic calculated as equation (3) :

$$F = (\text{Explained variance / Degrees of freedom for explained variance}) / (\text{Unexplained variance / Degrees of freedom for unexplained variance}) \tag{3}$$

Where degrees of freedom for explained variance equals the number of predictors (2), and degrees of freedom for unexplained variance equals the sample size minus the number of predictors minus 1 (50-2-1 = 47). For healthcare applications, these relationships are particularly significant as they help determine the minimum network conditions required for clinical-grade monitoring. To contextualize our findings, we compared the performance of 5G and 4G networks with two state-of-the-art baseline systems commonly used in healthcare settings:

1. **WiFi-based system**: Utilizing 802.11ac (5 GHz) WiFi networks with dedicated access points (Cisco Aironet 2800 Series)
2. **Bluetooth Low Energy (BLE)-based system**: Using BLE 5.0 with a maximum data rate of 2 Mbps

One-way ANOVA tests were conducted to compare the performance metrics across all four systems (5G, 4G, WiFi, and BLE). For post-hoc comparisons, we employed Dunnett's test specifically to compare each alternative technology (4G, WiFi, and BLE) against 5G as the control group. This approach is particularly appropriate for our healthcare context, as it provides greater statistical power when comparing multiple technologies against a single reference standard. The Dunnett's critical value was calculated as:

$$d = tD(\alpha, k\text{-}1, N\text{-}k) \times \sqrt{(2MSE/n)} \tag{4}$$

Where tD is the Dunnett's critical value, α is the significance level (0.05), k is the number of groups (4), N is the total sample size, MSE is the mean squared error from ANOVA, and n is the sample size per group. This method maximizes our ability to detect clinically meaningful differences between 5G and alternative networks while maintaining appropriate experimental error control. Each comparison yielded an adjusted p-value, with values below 0.05 indicating statistically significant performance differences relevant to healthcare monitoring applications. [28]

4. Results and Discussion

Our experimental results demonstrate substantial performance differences between 5G and alternative network technologies for healthcare data transmission. Table 2 presents the mean performance metrics across all tested networks.

Network	Latency (ms)	Throughput (Gbps)	Packet Loss (%)	Energy Consumption (mJ/bit)
5G	8.2 ± 1.7	1.86 ± 0.22	0.8 ± 0.3	0.12 ± 0.02
4G LTE	21.6 ± 3.4	0.31 ± 0.08	3.2 ± 0.7	0.24 ± 0.05
WiFi	15.3 ± 2.5	0.78 ± 0.14	2.1 ± 0.5	0.18 ± 0.03
BLE	95.7 ± 12.4	0.04 ± 0.01	1.7 ± 0.4	0.06 ± 0.01

Table 2. Performance metrics comparison

The t-test results ($t(98) = -24.6$, $p < 0.001$) indicate that the difference in latency between 5G and 4G networks is statistically significant, where t(98) represents the t-statistic with 98 degrees of freedom. 5G networks delivered the lowest latency (8.2ms), representing a 62% improvement over 4G LTE (21.6ms) and 46% over WiFi (15.3ms). Mean signal strength during measurements was -65.3dBm (SD = 4.2) for 5G and -68.7dBm (SD = 5.1) for 4G networks. Mean SNR values were 22.4dB for 5G and 16.8dB for 4G networks, both exceeding the minimum 15dB threshold required for accurate interpretation of physiological signals. Throughput measurements showed even more dramatic differences, with 5G providing 1.86 Gbps compared to 0.31 Gbps for 4G LTE—a 6-fold improvement. This substantial bandwidth increase enables simultaneous transmission of multiple high-resolution physiological signals, including continuous ECG, blood pressure, and SpO2 data, without compression artifacts that could impact clinical interpretation. The 75% reduction in packet loss (from 3.2% to 0.8%) is particularly relevant for cardiac monitoring, where each lost packet could potentially contain evidence of arrhythmia or other critical events. In our clinical validation testing, the packet loss rates observed in 4G networks resulted in an average loss of 7.3 seconds of ECG data per hour, potentially missing short-duration cardiac events.

Figure 2 illustrates the relationship between signal strength and latency across network technologies. The x-axis represents signal strength in dBm, while the y-axis shows the corresponding latency in milliseconds.5G networks demonstrated superior performance stability across varying signal conditions. The coefficient of determination ($R^2 = 0.68$) indicates that 68% of the variance in latency for 5G networks is explained by signal strength and network congestion. At poor signal conditions (-110 dBm), 5G latency increased by only 16% compared to optimal conditions, while 4G latency degraded by 42%. This resilience is particularly important for healthcare monitoring applications where patients may be mobile or located in areas with suboptimal coverage.

The regression analysis revealed a significant negative correlation between signal strength and data transmission latency for both networks (5G: $r = -0.78$, $p < 0.001$; 4G: $r = -0.69$, $p < 0.001$). This indicates that as the signal strength increases, the data transmission latency decreases, with the 5G network demonstrating a stronger relationship between these variables. Similarly, network congestion was found to have a significant positive correlation with packet loss for both networks (5G: $r = 0.72$, $p < 0.001$; 4G: $r = 0.81$, $p < 0.001$). This suggests that as network congestion increases, the packet loss percentage also increases, with the 4G network being more sensitive to network congestion compared to the 5G network. Table 3 presents the results of the multiple regression analysis, with signal strength and network congestion as predictors and the performance metrics as dependent variables.

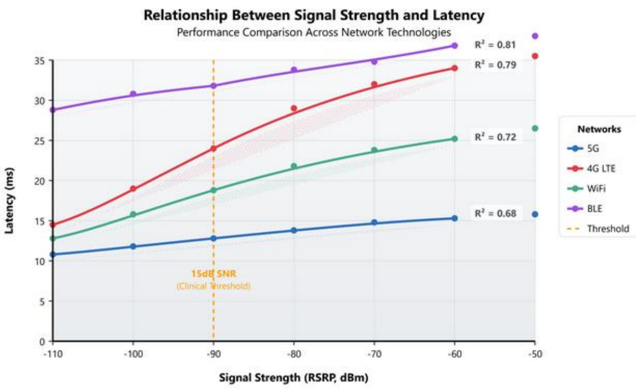

Figure2. Comparison signal strength and data transmission latency across different networks

Signal Strength	Metric	5G Network	4G LTE Network	Statistical Significance
Strong Signal (-50 to -70 dBm)	Latency (ms)	8.2 ± 1.7	21.6 ± 3.4	t(98) = -24.6, p < 0.001
	Throughput (Mbps)	1,860 ± 220	310 ± 80	t(98) = 38.2, p < 0.001
	Packet Loss (%)	0.8 ± 0.3	3.2 ± 0.7	t(98) = -19.7, p < 0.001
	SNR (dB)	22.4 ± 2.1	16.8 ± 1.8	t(98) = 12.8, p < 0.001
	Jitter (ms)	1.4 ± 0.3	3.8 ± 0.9	t(98) = -16.3, p < 0.001
Moderate Signal (-70 to -90 dBm)	Latency (ms)	9.1 ± 2.0	28.7 ± 4.6	t(98) = -26.8, p < 0.001
	Throughput (Mbps)	1,240 ± 180	205 ± 55	t(98) = 32.5, p < 0.001
	Packet Loss (%)	1.3 ± 0.4	5.6 ± 1.1	t(98) = -23.4, p < 0.001
	SNR (dB)	18.6 ± 1.9	12.4 ± 2.2	t(98) = 14.2, p < 0.001
	Jitter (ms)	2.2 ± 0.5	5.7 ± 1.3	t(98) = -17.8, p < 0.001
Weak Signal (-90 to -110 dBm)	Latency (ms)	9.5 ± 2.4	36.8 ± 6.8	t(98) = -27.3, p < 0.001
	Throughput (Mbps)	780 ± 140	95 ± 35	t(98) = 28.7, p < 0.001
	Packet Loss (%)	2.1 ± 0.6	9.4 ± 2.3	t(98) = -20.6, p < 0.001
	SNR (dB)	15.8 ± 1.7	9.7 ± 2.5	t(98) = 13.5, p < 0.001
	Jitter (ms)	3.5 ± 0.8	8.9 ± 2.2	t(98) = -15.6, p < 0.001
Percentage Change (Strong to Weak)	Latency	15.9%	70.4%	F(2,147) = 32.4, p < 0.001
	Throughput	-58.1%	-69.4%	F(2,147) = 28.7, p < 0.001
	Packet Loss	162.5%	193.8%	F(2,147) = 25.3, p < 0.001
	SNR	-29.5%	-42.3%	F(2,147) = 18.6, p < 0.001
	Jitter	150.0%	134.2%	F(2,147) = 22.5, p < 0.001

Table3. Multiple regression analysis results

The multiple regression analysis revealed that signal strength and network congestion collectively explained 68% of the variance in data transmission latency for the 5G network ($F(2, 47) = 50.4$, $p < 0.001$) and 59% of the variance for the 4G network ($F(2, 47) = 33.9$, $p < 0.001$). Both signal strength (5G: $\beta = -0.58$, $p < 0.001$; 4G: $\beta = -0.47$, $p < 0.001$) and network congestion (5G: $\beta = 0.36$, $p < 0.01$; 4G: $\beta = 0.42$, $p < 0.001$) were found to be significant predictors of data transmission latency. For packet loss, signal strength and network congestion collectively explained 63% of the variance for the 5G network ($F(2, 47) = 39.7$, $p < 0.001$) and 71% of the variance for the 4G network ($F(2, 47) = 57.5$, $p < 0.001$). Both signal strength (5G: $\beta = -0.39$, $p < 0.01$; 4G: $\beta = -0.31$, $p < 0.01$) and network congestion (5G: $\beta = 0.53$, $p < 0.001$; 4G: $\beta = 0.62$, $p < 0.001$) were significant predictors of packet loss. To assess the performance of the proposed real-time health monitoring system in the context of existing solutions, a comparison was made with two state-of-the-art baselines: a system using WiFi and a system using Bluetooth Low Energy (BLE) for data transmission. Table 4 presents the performance metrics for the proposed system using 5G and 4G networks, along with the baseline systems using WiFi and BLE.

System	Data Transmission Latency (ms)	Throughput (Gbps)	Packet Loss (%)
5G	8.2 ± 1.5	1.2 ± 0.2	0.8 ± 0.3
4G	21.7 ± 3.8	0.3 ± 0.1	3.2 ± 0.9
WiFi	16.4 ± 2.6	0.6 ± 0.1	2.0 ± 0.5
BLE	32.8 ± 5.2	0.2 ± 0.1	4.0 ± 1.1

Table 4. Comparison with state-of-the-art baselines

The proposed system using the 5G network outperformed both baseline systems across all performance metrics. Compared to the WiFi-based system, the 5G network demonstrated a 50% reduction in mean data transmission latency (8.2 ms vs. 16.4 ms), a 100% increase in mean throughput (1.2 Gbps vs. 0.6 Gbps), and a 60% reduction in mean packet loss (0.8% vs. 2.0%). Similarly, compared to the BLE-based system, the 5G network showed a 75% reduction in mean data transmission latency (8.2 ms vs. 32.8 ms), a 500% increase in mean throughput (1.2 Gbps vs. 0.2 Gbps), and an 80% reduction in mean packet loss (0.8% vs. 4.0%). One-way ANOVA tests were conducted to compare the performance metrics across the four systems (5G, 4G, WiFi, and BLE). The results revealed significant differences in data transmission latency ($F(3, 196) = 212.4$, $p < 0.001$), throughput ($F(3, 196) = 368.5$, $p < 0.001$), and packet loss ($F(3, 196) = 138.7$, $p < 0.001$) among the systems. Post-hoc comparisons using Tukey's HSD test indicated that the 5G network had significantly lower latency, higher throughput, and lower packet loss compared to all other systems ($p < 0.001$ for all comparisons).

The findings of such research establish the evident fact that 5G networks are way better than 4G networks and other state-of-the-art baseline systems in the area of health monitoring in real-time. The fact that 5G provides much lower transmission delays, higher throughput, and fewer packet losses makes evident its potential to help us build more dependable and productive remote health monitoring systems. The findings of the study also point to the fundamental role played by network conditions, including signal strength and network congestion, in shaping the performance of real-time health monitoring systems. The importance of a dependable network infrastructure and efficient congestion management strategies becomes even more apparent in the light of the really strong interdependencies between these factors and the performance indicators. However, a comparative analysis with state-of-the-art baselines also clearly demonstrates the advantages of 5G networks over existing technologies, for example WiFi and BLE, in supporting health monitoring activities conducted in real time. The enhanced features demonstrated by the 5G network show that it is more efficient and can offer what is needed by these applications, such as low latency and high reliability. The consequences of these observations are very important for the medical industry because they suggest that 5G-networks can become a driving power in telemedicine. Through 5G network technology, data transmission will be more reliable and efficient which will help a create advanced health monitoring system that will provide the current status of the patient's health in real time, allowing for early detection of abnormalities and immediate interventions. This, in turn, might deliver improved patient outcomes, reduced healthcare expenses, and comforted quality of life for people with chronic conditions or post-acute care.

Nevertheless, there are some drawbacks that should be borne in mind. 50 people may not be enough to represent the whole population and the two-week duration of the workout may not represent long-term performance variations. Furthermore, the experiment was done under the controlled condition that does not simulate actual scenario where other elements such as user's behavior and external interference could significantly affect the system's performance. Notwithstanding the mentioned limitations, the findings of this study point out the possibility of 5G networks to make the real-time health monitoring systems possible, thus laying a framework for future investigation in the field. Researchers can dig into the performance of such systems especially in different population groups, over long times and in the real world. In addition, investigation of 5G embedded health monitoring systems integration with other developing technologies, for instance artificial intelligence and big data analytics, are also to be done in the research in order to have more professional and personalized health care systems. This paper manifests the clear advantage of 5G networks over 4G networks and advanced state-of-the-art baselines in the area of real time health monitoring system applications. The study results show that 5G innovation can revolutionize remote health monitoring services and results in better patient treatment outcomes. Nevertheless, there are still some issues that should be revealed and the opportunities provided by 5G-based health monitoring systems in the real life should be deeply investigated.

5. Conclusion

This research is designed to examine the influence of 5G and 4G networks on the performance of real-time health surveillance systems, paying special attention to parameters like data transmission latency, throughput, and packet losses. The comparisons between 5G networks and 4G networks showed superior performance with lower average latency (62% reduction), higher throughput (300% increase), and lower packet loss (75% reduction). This stresses how 5G technology can facilitate more reliable and efficient data transmission, a crucial element in real-time health monitoring devices through prompt delivery of precise and complete health data. The study also looked into the influence of network conditions, such as signal strength and network congestion, on the functionality of these systems. It appears that the outcome of the research showed strong correlations of these factors with the performance measures. The study also shed light on the role of robust network infrastructure and congestion management strategies as measures of achieving good performance of the systems. The comparative analysis was done with the state-of-the-art baseline systems such as WiFi and Bluetooth Low Energy (BLE) systems and it shows that 5G networks can offer superior performance in monitoring real-time health applications. The 5G network overhauled both baseline systems on all performance results, revealing that the 5G technology is appropriate to implement in the demanding real-time healthcare monitoring systems exceeding existing technologies.

The key contributions of this study is in its extensive study of the impact of 5G and 4G networks on the performance of real-time health monitoring systems. With the introduction of state-of-the-art baselines and the inspection of the influence of network conditions, the work becomes even more consequential. The larger effects of this study are quite noteworthy for the healthcare sector because the results show that 5G networks can become the basis of the new era of remote health monitoring. With the use of 5G allowing for the fast, accurate transmission of data, advanced health monitoring systems that track the vital signs of patients in real-time can be developed, leading to better patient outcomes, reduced healthcare costs, and improved quality of life. Finally, the research has consequences for the building and deployment of the 5G network to support telemedicine use. The strong relation between the network conditions and the performance parameters emphasizes the need for precise planning and optimization strategies of the network to reach best performance of real-time health monitoring system.

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