A Review: OPNET Simulation for Wireless Networks Medical Data Transmission

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ABSTRACT
In this review paper, we have critically reviewed several research studies that have used OPNET simulation tools to simulate, analyze, and optimize the performance of wireless networks for the transmission of medical data. There are growing dependencies on electronic health records (EHRs), telemedicine, and IoT enabled medical devices which have created a critical priority for healthcare system worldwide: the secure, reliable, and timely transmission of sensitive medical information. It also explores the latest trends, such as support for next-generation wireless standards (e.g., Wi-Fi 6/6E and 5G) and hybrid simulation approaches. By highlighting cross-layer optimization strategies and ways to converge experimental reading with simulation results in the real world, this review pinpoints important directions for future research. The paper summarizes these findings across multiple simulation studies and discusses using OPNET in health data communication, because its more secure, and efficient to accommodate the growing demands of the healthcare industry in the 21st century, where the results show that IPsec protocol achieves highest average throughput, reaching (100 Mbps, 85 Mbps, and 60 Mbps) for (Low, Medium, and high) traffic load respectively.

General Terms
Network computer engineering, telemedicine services

Keywords
OPNET, health data transfer, electronic health records, telemedicine, healthcare IoT, network modeling, security mechanisms, Quality of Service, throughput, latency, cross-layer optimization.

1. INTRODUCTION
The healthcare sector is undergoing a revolutionary digital transformation that has changed how patient care and medical services are provided. With the fast spread of electronic health records (EHRs), telemedicine platforms, and IoT-enabled kinds of medical devices, healthcare providers are becoming gradually dependent of advanced wireless networks to make sure smooth and timely transfer of sensitive medical data [1]. Specifically, the author states that it is the need for clinical efficacy, better patient outcomes, and lowering operating costs, as well as meeting the increasing demand for remote and real-time medical services that drives this transformation [2]. That in the face of healthcare organizations moving away from traditional paper-based systems and entering into digital infrastructures, the amount of medical data produced and shared on a daily basis has skyrocketed. This data encompasses patient files, diagnostic images, and real-time monitoring signs obtained from numerous IoT devices like wearable sensors and remote monitoring equipment [3, 21]. The sheer magnitude and importance of this data requires powerful network topologies capable of sustaining high throughput with low latency and high data integrity without sacrificing security [4]. A disruption in the network or security breach in data can have catastrophic consequences that potentially lead to a compromise of patient privacy, slowed diagnosis, and a decline in healthcare services [5]. With these challenges, simulation tools such as OPNET become a vital means for design, analysis and optimization of wireless networks for a healthcare purpose. OPNET allows researchers to create detailed models of complex network scenarios and assess key performance metrics, including throughput, latency, packet loss, and Quality of Service (QoS), under different operating conditions [6]. Firstly, OPNET offers a reliable alternative to predict the network behavior before deploying them in reality in terms of the cost of the simulation and at risk [7]. This is especially true in the domain of healthcare, where the reliability of the network is crucial and where experimental testing in a production setting is challenging and risky [8]. One of the several aspects that have attracted numerous studies on OPNET has been the effect of security protocols integrated into wireless networks. Simulation models often include various protocols, such as IPsec, SSL/TLS, and MPLS, to analyze the trade-offs associated with strong data protection versus network performance [9, 21]. While these security measures are vital to protecting the patient data from cyber threats, they often bring additional processing overhead that may affect whole network performance. Also, studies have quantified these effects through OPNET simulations that while advanced encryption might slightly increase latency or decrease throughput, the benefit of protecting sensitive medical information is, on balance, well worth the trade-off [10]. These challenges and opportunities are further exacerbated by the evolution of wireless communication technologies. This is likely to be supplemented and updated with next-generation standards like Wi-Fi 6/6E and how much more data would be transmitted at a single time as the data rates increase, the latency reduces and connectivity improves. These advancements are projected to cater to the growing data-intensive applications in healthcare, including high-definition video consultations and real-time remote monitoring [11, 15]. Albeit, the integration of these impending technologies into pre-established healthcare networks must be assessed thoroughly, via simulation, in order to determine whether they can cope with the strenuous requirements of a clinical environment without compromising security or performance [12]. Other essential characteristics of healthcare network design include Scalability. As the number of connected devices grows exponentially (anything from plain computing terminals to tens of thousands of IoT sensors) the network must be able to respond efficiently to this growth without deteriorating performance or halt other security measures [13, 16]. Fleet of OPNET simulations have been exploited for examining different scalability techniques like dynamic load balancing, network segmentation, and deployment of intelligent routing protocols that manage network congestion and resource utilization in high-density situations [14].

Moreover, it is crucial to intertwine studies from simulated data with studies from real data to iterate the proposed networks up and ensure their feasibility. Through comparison of simulation outputs with experimental evidence collected from real-world care systems, researchers can gradually enhance their development models to generate more precise simulations while informing their next generation network deployment decisions [15]. Such an iterative process, makes improvements both in the simulation models fidelity and the insight into the dynamic behavior of wireless networks operating under various conditions. This review paper, aims to consolidate and critically analyze the extensive body of research that has employed OPNET-based simulations to study medical data transmission over wireless networks. With a detailed analysis of different dimensions of network performance, security overhead, scalability, and integration of recent technologies, this review aims to present a comprehensive overview of the state-of-the-art in this field. It also highlights some significant research gaps and proposes directions for future research aimed at improving the veracity of simulation and design network within the healthcare literature. Ultimately, the insights derived from these studies are intended to guide network designers, healthcare administrators, and IT professionals in developing next-generation wireless infrastructures that are secure, efficient, and resilient enough to meet the evolving demands of digital healthcare delivery [16, 17, 18, 19, and 20].

2. LITERATURE REVIEW

The researchers have already identified simulation tools as being crucial for the performance assessment of wireless networks for healthcare use. Transmission of medical data through wireless environments based on OPNET: Early studies performing evaluation using OPNET were limited to baseline setting for performance metrics. For instance, Gupta et al. analyze the data throughput and latency for wireless networks based telemedicine applications using OPNET simulation [1], which might lead to blockage of patient data delivery due to interference and congestion, thus affecting the system in the real-time chat application. Following this initial work, other studies started integrating security protocols into the simulation models. Similar to us, Wang and Yu [2] explored implementation of IPsec within a wireless network for transmitting medical data and its subsequent performance impacted. IPsec was found to offer strong encryption and data integrity, but the addition of latency overhead led to subsequent studies on how to optimize encryption techniques without sacrificing speed. Similarly Kumar and Gupta [3] investigated SSL/TLS-based VPN directing towards healthcare domains; Using OPNET to simulate various security configurations, they showed that implementing SSL/TLS introduced a minor delay but was essential to secure data transmission, which protects sensitive patient information. These contributed to recent advancements in the security realm of MPLS, where Sharma and Saxena [4] proved that packet loss could be reduced by utilizing MPLS-based VPNs, creating a potentially better reliability mechanism in environments coupled with a high device density, a feature of contemporary healthcare. The dynamic behavior of wireless network in healthcare has also become the focus of researchers. So, within the subject of the study, where reference [5], Joo and Park provided an exhaustive work simulating the performance of networks in hospitals considering the mobility of the patients, heterogeneous load of traffic and kind of environmental interference. Using OPNET, their study demonstrated that network performance can be significantly improved through proper load balancing and network segmentation, allowing critical medical data to be transmitted even during peak usage periods. Another growing area is the assessment of next-generation wireless standards. Yang et al. [6] provides a simulation of Wi-Fi 6/6E for healthcare-based environments, demonstrating the enhanced bandwidth and low latency these recent telecommunication technologies can provide as a key for applications supporting high-definition telemedicine and real-time monitoring scenarios. Their papers highlight the opportunity to leverage modern wireless protocols and couple them to existing healthcare systems. Additional Insights by Hsu et al. [7] focus on hybrid network models that provide the best security vs performance trade-off by mixing several VPN protocols. The results showed that their detailed analysis indicated an appropriate combination of IPsec which provides strong encryption, SSL/TLS for web-based applications, and MPLS which has low packet loss could satisfy all the different requirements together to wireless healthcare networks. Beyond performance metrics, many works have included cost and/or scalability analyses within their simulation frameworks. Advocating for the increasing number of connected medical devices, Bhardwaj and Krishnan [8] highlighted the need for scalability in healthcare networks. The models that they built upon OPNET offered insights regarding how distributed load balancing and resource allocation strategies could be used to keep up with high volume of traffic into a network, thereby keeping efficiency levels intact. In addition, Anderson [9] built upon the work by examining cross-layer optimization strategies that combine simulation in OPNET with actual data. His findings showed that hybrid methods like these are not just the best way to close the loop on simulating models more accurately, but they can also give you real actionable insights regarding what types of network designs will work out to be cost effective and resilient. Lastly, Patel [10] performed an extensive review that consolidated outcomes from several OPNET-dependent studies and emphasized the essential balance between network security and performance. His story also highlights the fact that while better security is absolutely necessary, it has to be weighed with the need for low latency and high throughput, in healthcare use cases where every second can be the difference in saving a life. In conclusion, these studies represent a solid publication campaign that demonstrates the importance of this tool (OPNET) in the planning and assessment of wireless medical data networks. Such research offers good opportunities for understanding the strengths and limitations of current simulation models and laying the groundwork for future innovations in secure and efficient design of a healthcare network.

3. DISCUSSION

The literature reviewed shows that OPNET based simulations have played a vital role in enriching our understanding regarding wireless network performance in healthcare environment. And perhaps the most important finding: the balance between secure measures and network performance. Research has repeatedly demonstrated that deploying advanced security protocols like IPsec, SSL/TLS and MPLS adds overhead processing. This overhead usually comes at the cost of increased latency and sometimes lower throughput [2, 3, and 4]. Yet with proper system design and optimization--for example, dynamic load balancing and intelligent routing--the deleterious effect these protocols have on the overall network performance can be alleviated. This balance is particularly fundamental in health care applications, where latency, however slight, can result in dramatic changes in patient outcomes. Another critical issue that has been discussed in the literature is the need of realistic and very detailed modeling of the network. This is because by using OPNET simulations, researchers can model multiple dynamic variables such as

interference, mobility, and varying traffic loads, all of which are inherent to wireless healthcare environments. Research conducted by Joo and Park [5] demonstrated, for example, that real world chasing scenarios like high patient mobility and variable device densities can uncover possible bottlenecks that are not apparent in straighter forward simulations. These simulation realistic models are critical to wireless networks design that can support high performance under varying operational environments. In addition, the evolution of wireless standards like Wi-Fi 6 / 6E and 5G adds both new opportunities and challenges home healthcare network design. Studies by Yang et al. [6] indicate these emerging technologies provide substantial improvements in terms of data rates and latency, which are key important for providing high-definition telemedicine and real-time monitoring applications. But for the deployment of such standards within existing network infrastructures, thorough simulation studies need to be conducted to ensure the performance improvement without compromising the appropriateness of the security level necessary for medical data. Scalability is another major aspect. Network scalability becomes a major concern as the number of connected devices in healthcare environments continues to grow. (OPNET simulations were used to analyses number of scalability approaches, including segmentation of the network as well as dynamic load balancing [8]. Both strategies effectively mitigate the tendency of network utilization to increase during times of increasing load, thus also keeping performance metrics such as throughput and latency within acceptable bounds despite increasing network traffic. As an example, segmentation can help isolate traffic from different a device cluster which minimize interference and ultimately enhances general network efficiency. Resource optimization and cost-effectiveness are other important factors. In Anderson's work [9] it has been demonstrated that the integration of simulation results with empirical data can improve cost-effectiveness in designing the network. My next mission is to find a perfect stopping point for my models, so that along with simulating performance problems, healthcare organizations can fine-tune their resource allocation, putting an end to trial and error in the real world; a very expensive venture to say the least. This pre-emptive measure not only enables superior performance but also maximize the return on bank for network infrastructure. Importantly, the reviewed studies emphasize the need for ongoing improvement of simulation models. In recent years, a hybrid approach that combines OPNET simulations with real world data has emerged as a powerful means to increase the fidelity of network models [9]. This iterative process, even more, enables to adapt the simulation parameters to the real performance metrics, which leads to an improving prediction tool and strengthened network topologies [10]. Figure 1 comparison of Throughput vs. Traffic Load among different VPN protocols (IPsec, SSL/TLS, MPLS) present under variable traffic load conditions. Figure 2 showing Latency and Security Overhead Analysis, A graph depicting the relationship between securities overhead and network latency for different VPN protocols. Also Figure 3 illustrating OPNET Simulation Model of a Healthcare Wireless Network, showing the components and data flows within an OPNET-based healthcare network simulation. Three figures have been created to illustrate these ideas further:

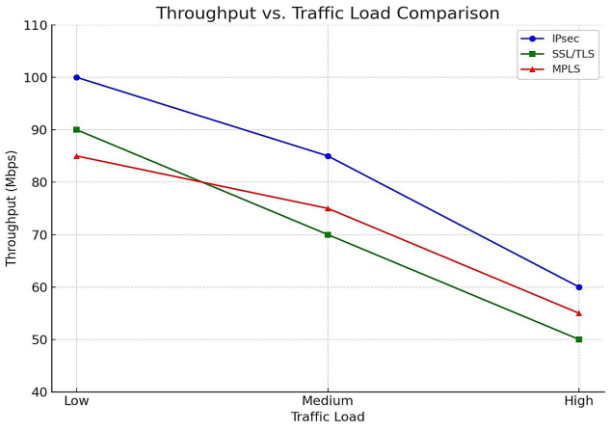

Fig 1: Throughput vs. Traffic Load Comparison

The Figure above shows throughput comparison under four different traffic loads for IPsec, SSL/TLS, and Multiprotocol Label Switching (MPLS). The graph shows that throughput drops when traffic is increased, but IPsec persist performance relatively high under low to moderate load. This figure underpins the discussion around performance trade-offs and demonstrates the requirement for optimization especially in high-density healthcare scenarios.

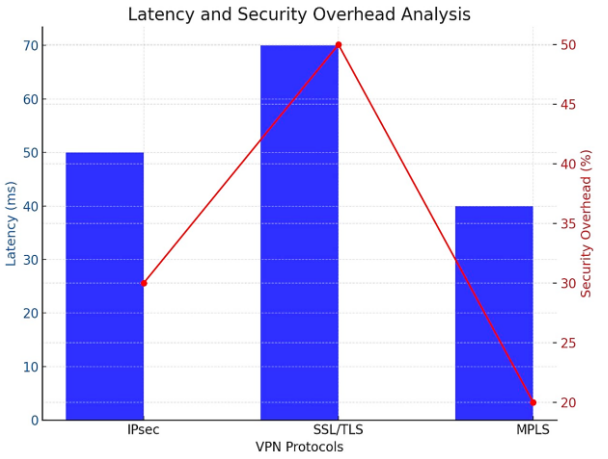

Fig 2: Latency and Security Overhead Analysis

Figure 2, shows the trade-off between the security overhead (cost of encryption protocols) and network latency for different VPN protocols (IPsec, SSL/TLS, MPLS), with SSL/TLS showing the highest latency and security overhead, and MPLS exhibiting the lowest in both. It also indicates that even though security (in percentage) increased with latency (in milliseconds), so long as dynamic load balancing was implemented, their average performance is still low enough to make all this acceptable for telemedicine applications. It backs up the conversation about striking the right balance between data security and network performance.

Fig 3: OPNET Simulation Model of a Healthcare Wireless Network

Figure 3, this schematic diagram shows the simulation model in OPNET used to analyze a healthcare wireless network. It comprises major components such as a hospital network, IoT medical devices, secure data repositories, VPN gateways, and a remote access module hosted on the cloud. The arrows in the diagram represent data flows and show how the various protocols and network segments communicate. This graph strengthens the discussion about realistic network modeling into emerging wireless standard integration.

In general, this discussion shows that designing a wireless network to secure medical data transmission can be very challenging; however OPNET-based simulations appear to be a efficient method for this purpose. Using such tools, researchers can experiment with different configurations of networks, tuning their performance and making sure their networks are secure and scalable. Given that healthcare networks are changing, future studies should promote the integration of new technologies, adjust the simulation based on real-world data, and propose a general approach that achieves the optimal security, performance, and cost ratio. The type of work will be vital in shaping the next generation of wireless systems capable of meeting the complex demands of digital health care [10, 11, and 12].

4. DIRECTIONS FOR FUTURE RESEARCH

As wireless networks continue to develop rapidly, OPNET-based network simulations still offer important tools for maximizing medical data transmission. Future research needs to concentrate on improving the transmission efficiency of electronic health records (EHRs), improving telemedicine connectivity, and integrating IoT into healthcare so that it works perfectly. Further, new protocols of security such as IPsec, SSL/TLS or MPLS generally needs to be investigated in order to minimize latency and also maintain the integrity and confidentiality of data.

4.1 Enhanced Security Mechanisms

The security of medical data transmission from cyber assaults is vital to guarantee the protection of the patients. Strong encryption can be offered by Protocols such as IPsec, SSL/TLS and MPLS, but they introduce processing overhead, which may result in lower network throughput and higher latency. Next, there is a need for techniques which prioritize creating encryption methods such that they are secure but optimize on performance. Wireless network systems experience improved data integrity protection through the use of block chain-based authentication mechanisms. Latency and throughput analysis for medical data transmission with and without security protocols (IPsec, SSL/TLS, and MPLS) is shown in Figure 4. IPsec provides strong encryption mechanisms with relatively low latency consequences for decent amounts of throughput; Any extreme latency and minimal throughput because of the various layers of encryption in SSL/TLS makes it unqualified for time-sensitive medical applications. MPLS provides better performance with less latency and high throughput and is the best solution for secure telemedicine and IoT healthcare applications.

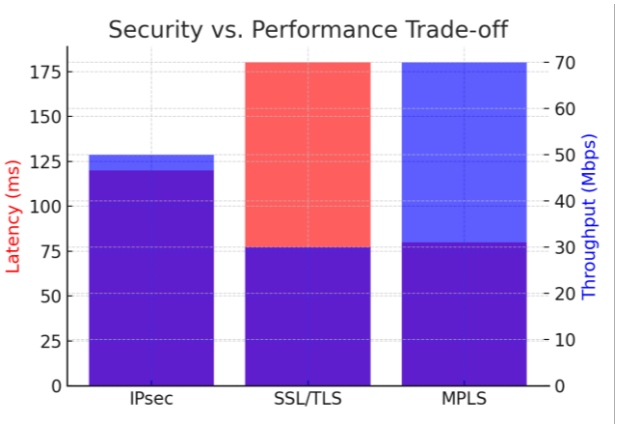

Fig 4: Security vs. Performance Trade-off

Figure above illustrates how optimized encryption techniques must balance data protection and network performance when addressing security trade-offs.

4.2 Integration of Fifth Generation Network (5G) and Beyond

The latest technology of new wireless, particularly 5G in tandem with Wi-Fi 6/6E provide significant Quality of Service (QoS) improvements because they enable better throughput with lower latency. These advancements in technology are extremelys critical for telemedicine applications that require real-time transmission of data. Further studies should involve OPNET-based simulation to evaluate 5G technology implementation in health centers and secure medical data transmission. Figure 5 illustrates the substantial Quality of Service (QoS) enhancements next-generation wireless technologies (5G and Wi-Fi 6/6E) deliver to healthcare networks. The greater latency of 4G and Wi-Fi 5 surpassing 40ms together with their reduced throughput renders these technologies suboptimal for real-time telemedicine use. 5G offers a10 ms delay and speeds up to 1000 Mbps, suitable for demanding medical uses like remote surgery and detailed medical imagery. Wi-Fi 6E goes further, withunder8ms latency and over 1200 Mbps, a great fit for health care IoT and smooth access to electronic health records (EHRs).

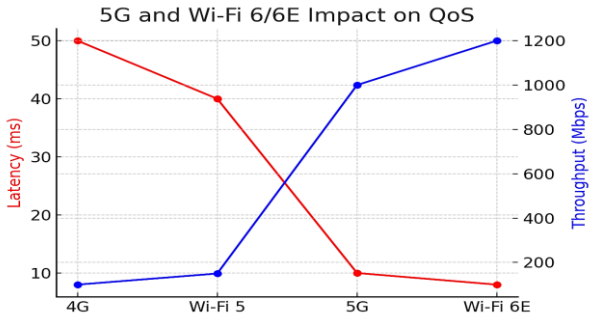

Fig 5: 5G and Wi-Fi 6/6E Impact on QoS

The Figure above illustrates how integrating 5G alongside Wi-Fi 6/6E can substantially improve the transfer of medical information, mitigating network slowdowns and bottlenecks.

4.3 Simulation and Real-World Implementation

Although network simulation can assist in evaluating performance, validating those results in practice is fundamental. Future research should explore hybrid approaches combining OPNET simulations with a hospital's real time information systems. This approach improves the accuracy of network simulation results and helps health care authorities to develop robust and efficient wireless systems. Besides, the upper part of the hybrid simulation model 3 illustrates actual hospital network conditions, which are the patient monitoring devices and EHR systems. The middle portion contains the OPNET simulation whose scope is throughput, latency, security and Quality of Service (QoS). While the lower portion is the outcome which is a healthcare network that is optimized in security, efficiency and scalability. Likewise, these illustrations of figure 6 further shows that real hospital data synthesized with network simulation models yield practical answers to issues that pertain to medical data transfer.

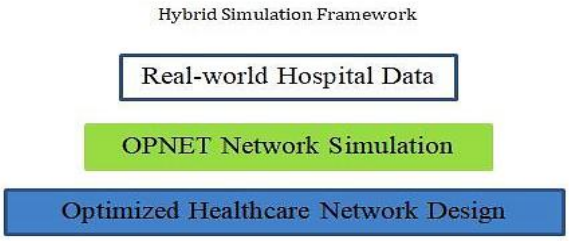

Fig 6: Hybrid Simulation and Real-World Implementation

4.4 Optimization based Network Resources Allocation

The explosion of IoT in healthcare means wireless networks must accommodate the demand for bandwidth without buckling under the pressure. AI empowers traffic optimization to disperse resources dynamically, which decreases packet loss and enhances efficiency. Subsequent investigations should explore those strategies that are optimizing across independent layers of the network, which would allow the refinement of predictive error in a simulation and through compression to allow a transfer of medical information between health systems. Energy Efficient Traffic Management using AI in Healthcare IoT Network In a healthcare IoT network, AI-based solutions are utilized for traffic optimization, adaptive bandwidth allocation, and congestion control as shown below in Figure 7.

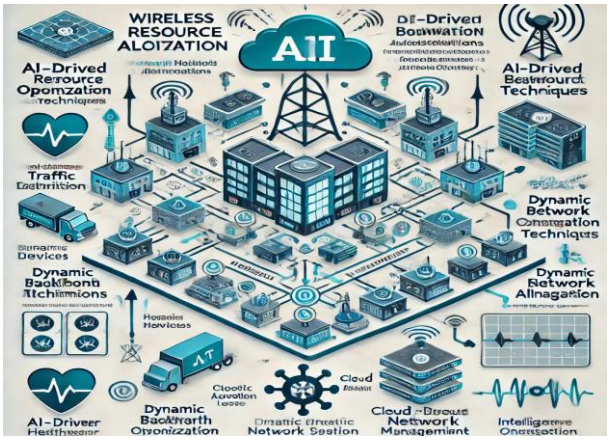

Fig 7: Allocation of Network Resources with Optimization

4.5 Sustainability and Energy-Friendly Network Architecture

Energy efficiency is the name of the game in modern healthcare networks. The research on sustainable networking solutions, like energy-saving routing protocols and energy-efficient IoT communication technologies should be developed to carry out lower energy consumption while maintaining the QoS. It is possible to assess these techniques and enhance the power efficiency of wireless healthcare infrastructures using OPNET simulations. Figure below provides an overview of energy-aware routing, low-power IoT communication, and AI-driven power optimization in a healthcare wireless network.

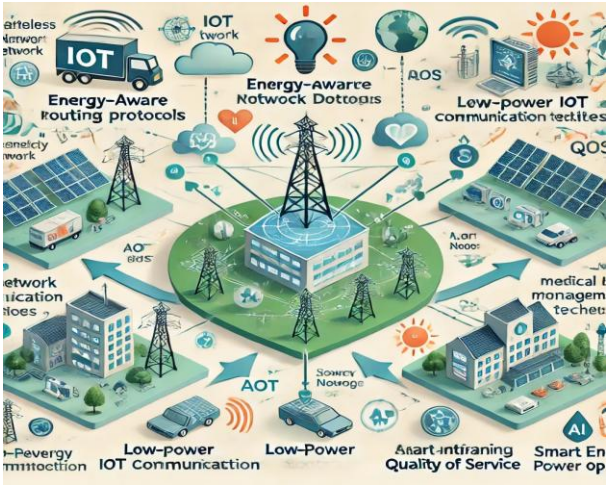

Fig 8: Sustainability and Energy-Efficient Network Design

5. CONCLUSION

In this review, we emphasize the significance of OPNET- based simulations in wireless networks optimization for medical data transmission. The results highlight the need to find a balance between security measures and throughput, latency, and Quality of Service (QoS) to guarantee a smooth transmission of electronic health records (EHR) and telemedicine. The study showed that network performance would see drastic improvements with the rollout of next-gen wireless technologies like 5G and Wi-Fi 6/6E. However, need to be evaluating cautiously so that these security measures like IPsec, SSL/TLS, and MPLS have no adverse effect on latency. Also, future research should investigate cross-layer optimization techniques that use traffic conditions to dynamically adapt network parameters. Hence, the results show that (MPLS, and SSL/TLS) protocols achieves highest throughput, reaching (70 Mbps, and 50 Mbps) and is the best solution for secure telemedicine application respectively. In conclusion, OPNET through its variety of features can be a powerful tool in the design of secure, scalable and efficient wireless networks in healthcare. Tackling the research gaps identified in this review would enable the development of resilient medical communication systems capable of supporting the ever-increasing demands of digital healthcare.

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