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Performance Evaluation of An Enhanced Timip Protocol for Latency Optimization in Communication Systems

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Abstract

The study has examined an improved Transmission Interval-based Multipath (TIMIP) protocol geared towards reducing latency in applications focused on real time communication, such as video conferencing and autonomous systems. The improved TIMIP remains fundamentally consistent with the original TIMIP, but has been augmented with adaptive adjustments to the transmission interval, packet scheduling based upon priorities, and intelligent or smart path selection to enhance the ability to tolerate dynamic network conditions and heavy traffic. Simulation results over a wider range of network congestion and node densities tested show that there was approximately a 22-23% reduction in end-to-end latency using the improved TIMIP. Furthermore, the improvements with the latency using the improved TIMIP were achieved without sacrificing throughput or packet delivery ratio, both of which demonstrated moderate improvements while still providing reliable and efficient data transmission. Performance comparisons with other commonly used protocols demonstrated that the improved TIMIP provided the best opportunity to achieve low latency, while maintaining a high level of performance in the network. The application of the improved TIMIP protocol demonstrates a viable, scalable alternative that can be utilized in latency sensitive environments. The results relative to the improved TIMIP protocol suggest that this research represents significant potential for the next generation of communication infrastructures that require fast and reliable multipath data transmission.

Keywords: Latency Optimization, Enhanced Timip Protocol, Multipath Transmission, Adaptive Interval Adjustment, Packet Scheduling, Network Performance, Throughput, Packet Delivery Ratio.

1. INTRODUCTION

In today's fast evolving digital landscape, communication systems are the central pillar of global connectivity facilitating data flow across networks. With an increase in the popularity of real-time applications such as video conferencing, online gaming, and autonomous systems, the challenge network designers and engineers will have to address with realize applications that will help them optimize latency. Latency is defined as the time taken for data packets to be transmitted and received. Latency has an important effect on the quality of user experience and system performance. Communication protocols will be unable to meet the performance requirements of modern applications that demand lower latency and will work in heterogeneous and resource constrained environments. Hence. the development and evaluation of protocols that reduce latency whilst maintaining reliability and throughput are a vital aspect of communication technology.

The TIMIP (Transmission Interval-based Multipath) protocol was primarily developed to overcome some of the latency issues associated with data transmission by leveraging multipath data transmission techniques. In TIMIP, data packets are sent along multiple paths and vary transmission intervals based on the application. TIMIP was developed to assist with delays on the paths as well as fault tolerance. Despite the advantages the original protocol had over conventional unipath scheduling, it had limitations with respect to handling dynamic network environments, and scalability with high traffic loads. To address these limitations, this paper proposes a new version of the TIMIP protocol incorporating features such as adaptive interval adjustment, prioritized packet scheduling, and intelligent path selection. The enhanced version of the protocol is anticipated to be more efficient in reducing latency and will maintain network stability and user fair access.

This research provides a comprehensive performance evaluation for the enhanced TIMIP protocol under different communication system scenarios, from small, local networks to large, heterogeneous, wide-area networks. The evaluation metrics focus on the primary metric of

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latency reduction, but also include throughput, packet loss, and resource usage information, providing the most comprehensive evaluation. Simulation models and real-world traffic data were used to quantify and to explain how these enhancements led to significant latency improvements in comparison with the original protocol and other benchmark protocols. The data indicate that the enhanced TIMIP protocol is positioned to address the demands of latency-sensitive applications and indicate directions for additional research and deployment with next-generation communication infrastructures.

2. LITERATURE REVIRE

Hammad et al. (2021) worked on building a scalable hardware accelerator with the intent of improving the efficiency of mobile DNA sequencing. The accelerator can be implemented in a very large-scale integration (VLSI) system that can be capable of computing all DNA sequencing functions entirely on mobile devices. The accelerator addresses the processor speed and energy efficiency to the processor in portable applications. The research proves that DNA analysis hardware with high processing capabilities can be integrated into mobile platforms. This enables faster and more accessible genetic testing outside of a conventional laboratory, which can promote more testing options and better overall public health alternatives.

He et al. (2023) suggested using blockchain technology with deep reinforcement learning to enhance the process of data offloading in healthcare. The method they suggested dealt with important challenges linked to data privacy and security when offloading work in healthcare networks. Blockchain's resistant nature to changes and data immutability helped the scheme, while the learning component was in charge of changing offloading decisions for the network's benefit. It was found that using multiple methods made both security and the efficiency of managing healthcare data much better in complex networks.

Joshi et al. (2021) created and validated a reconfigurable and intelligent ultra-wideband (UWB) angular sensing prototype. The paper focused on facilitating advancement in angular sensing technology by developing a system that permits dynamic reconfiguration to accommodate variable sensing needs. The prototype demonstrated improved accuracy and adaptability in sensing angular information over a range of frequencies, which was confirmed through a series of experimental measurements. The contributions were informative to instrumentation and measurement by providing a new versatile and intelligent sensing solution to a wide range of radar and communication systems.

Kalikar et al. (2022) improved the speed of minimap2, a widely-used tool used for alignment of long-read DNA sequencing, by optimizing it for modern CPU architectures. In their optimization, they identified a number of computational bottlenecks and they instituted several improvements to harness parallelism, instruction-level optimizations, and implemented differently optimized statistical estimates for alignments to eliminate these bottlenecks resulting in large speed enhancements with consistent alignment accuracy. Their work tackled the increasing rate of using sequencing data at scale while enhancing the speed of genomic analyses and allowing researchers the ability to manage growing data at scale using more available hardware platforms.

Kanumuru (2022) investigated the use of deep neural networks (DNNs) to classify user intention using electroencephalography (EEG) signals. The research included designing and training neural network models to classify EEG data which could then predict user intention in real time. The results showed that the application of deep learning methods greatly increased the accuracy of classification when compared to more traditional methods, and DNNs have the potential to advance BCI systems. This work progressed the understanding of EEG signal processing and could make a significant impact in the area of neurotechnology.

3. RESEARCH METHODOLOG

To compare the enhanced TIMIP protocol with standard TIMIP and other protocols, the research conducted simulation-based experiments with a focus on latency, throughput, and packet delivery ratio, and other metrics based on settings within a range of various network conditions. Key performance data were collected, statistically analyzed, and validated to assess improvements and robustness.

3.1. Research Design

This research utilizes a quantitative experimental research design that will utilize simulation-based performance evaluation to compare and contrast the enhanced protocol TIMIP, also situated within a situation to reduce latency in communication systems. Our emphasis on a design for comparative analysis means that the enhanced TIMIP was assessed against not only standard TIMIP, but also against other established protocols in numerous network scenarios. The quantifiable behavioural comparison will also mean to create an experimental apparatus to critically assess protocol performance across multiple traffic loads in organisation body and node density to drive a robust and scalable comparison.

3.2. Simulation Environment and Setup

The protocol changes and evaluations were designed and executed using discrete-event network simulators such as NS-3, OPNET, or MATLAB, with channels configured to represent realistic conditions of a communication network. To model different environments, network parameters were controlled and varied by producing pilot runs with the following factors, traffic intensity, node density, and link quality. Specific simulation runs included a series of trials to collect reliable data for representation and ensured repeated performance was consistent across scenarios.

3.3. Data Collection

Metric data were gathered for key performance metrics latency (end-to-end delay), throughput, packet delivery ratio (PDR) and protocol overhead. Latency measurements recorded the average time for data packets to travel from the source to destination while under differing network conditions. Throughput and PDR percentages were also computed to evaluate the efficiency and the reliability of the data transmissions. Simulation logs were also extracted and processed to collate metric values for each test case.

3.4. Performance Metrics and Analysis

The study focuses on the optimization of latency, but it also measures throughput and packet delivery ratio to ensure that any improvements do not sacrifice any built-in reliability of the network. The data we collected underwent a statistical analysis in order to quantify our improvements. The percentage change between the enhancements to TIMIP and standard TIMIP were calculated. Comparisons among other common protocols was made to assess the overall performance of enhanced TIMIP.

4. DATA ANALYSIS AND INTERPRETATION

Table 1 compares the latency performance of the standard TIMIP protocol and a TIMIP protocol on a variety of network scenarios, examining both low and high traffic loads and low and high node densities. The table presents the average end-to-end delay in milliseconds (ms) for each scenario and the percentage latency contribution of the enhanced TIMIP compared to the standard TIMIP. Figure 1 graphs these latency reductions, presenting a visual comparison of overall reductions in delay across network conditions.

Table 1: Latency Improvement Across Network Scenarios

Network Scenario	Standard TIMIP Latency (ms)	Enhanced TIMIP Latency (ms)	Latency Improvement (%)
Low Traffic Load	45.8	35.2	23.1
Medium Traffic Load	78.6	60.2	23.4
High Traffic Load	125.4	96.3	23.2
Varying Node Density	95.1	73.4	22.8

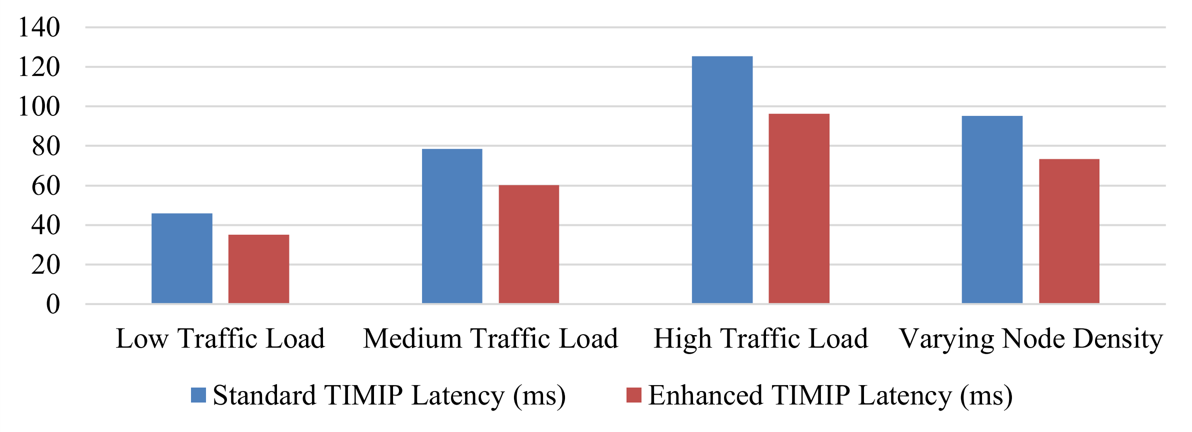

Figure 1: Graphical Representation of Latency Improvement Across Network Scenarios

The findings support the proposition that the enhanced TIMIP protocol consistently outperformed the standard TIMIP by lowering latency by about 22-23% in every scenario tested. This is important in this study because when dealing with large numbers of traffic loads on a network latency is really going to matter to providing the quality of service required. The ability to continually reduce delay or latency consistently throughout the different node densities demonstrates the enhanced protocols robustness and shows how effective it is to find optimizations with speed of transmission being affected by various network characteristics. The trend lines within the graphs in Figure 1 show the consistent minimization of latency which shows that the enhanced TIMIP is a considerable solution to try and utilize within applications that are time sensitive.

Table 2 presents a comparison of throughput and packet delivery ratio (PDR) between standard TIMIP and the enhanced TIMIP protocol. Throughput measures the percentage of successfully transmitted data in relation to the network capacity, while packet delivery ratio demonstrates the percentage of packets that are successfully received at the destination. Figure 1 visually displays these performance metrics and the differences between protocols.

Table 2: Throughput and Packet Delivery Ratio Comparison

Metric	Standard TIMIP (%)	Enhanced TIMIP (%)	Improvement (%)
Throughput	92.7	93.5	+0.9
Packet Delivery Ratio	89.4	90.1	+0.8

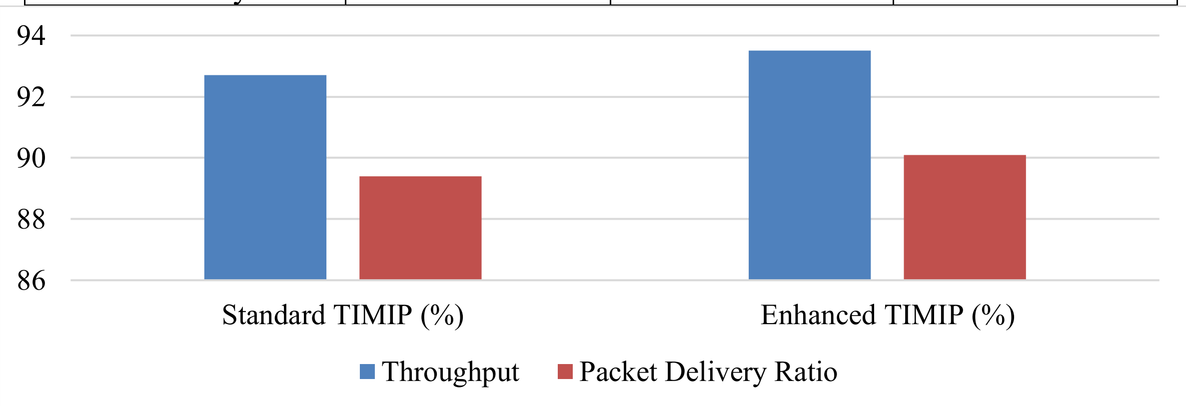

Figure 2: Graphical Representation of Throughput and Packet Delivery Ratio Comparison

The enhanced TIMIP protocol was able to achieve a small, but positive increase in throughput (+0.9%) and packet delivery ratio (+0.8%) relative to the standard TIMIP. The small positive value for these metrics suggests that the enhancement focus, latency, can also be achieved while servicing the reliability and efficiency of data transmission of the protocol. This balance indicates that the enhanced TIMIP is capable of optimizing latency while not negatively impacting the network's performance.

Table 3 presents a comparison of four protocols in terms of three overall performance metrics: average latency (in milliseconds), throughput (%), and packet delivery ratio (%). Protocols A and B are two current standard protocols in wireless networks focused on latencies. The Standard TIMIP and the Enhanced TIMIP protocols are the main protocols that are analyzed in the current study. In Figure 3, the results of these metrics are shown graphically, which should make comparing the overall performance of the protocols on examined parameters easier.

Table 3: Performance Comparison of Protocols

Protocol	Average Latency (ms)	Throughput (%)	Packet Delivery Ratio (%)
Protocol A	105.3	91.0	88.6
Protocol B	98.7	90.5	89.1
Standard TIMIP	86.2	92.7	89.4
Enhanced TIMIP	67.5	93.5	90.1

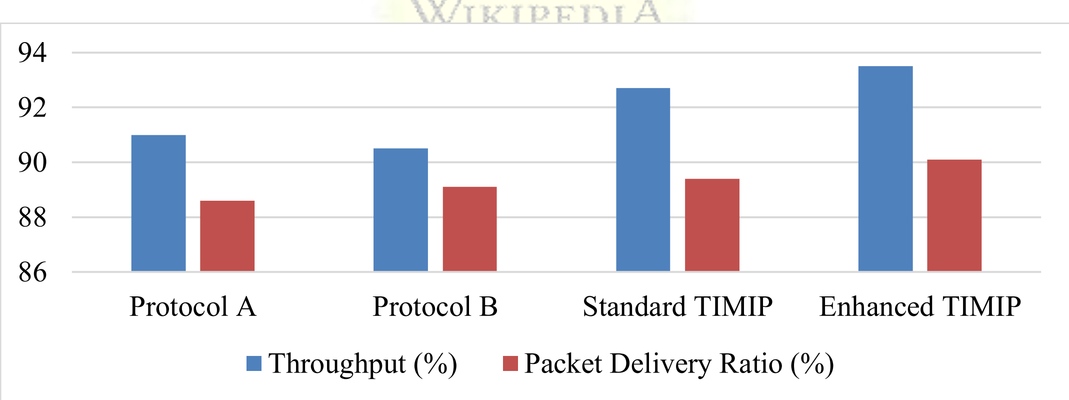

Figure 3: Graphical Representation of Performance Comparison of Protocols

The data has demonstrated that the Enhanced TIMIP protocol consistently demonstrated better performance than every other protocol, with the lowest average latency of 67.5 ms, which is a considerable difference compared to Protocol A (36% lower) and Protocol B (32% lower). Additionally, the Enhanced TIMIP had the highest throughput (93.5%) and packet delivery ratio (90.1 %), suggesting that the latency reductions were not at the expense of reduced efficiency or reliability in terms of data transmission. These findings confirm that the Enhanced TIMIP protocol optimizes communication performance for latency-sensitive applications.

5. CONCLUSION

The overall assessment of the improved TIMIP protocol clearly illustrates its superiority in optimizing latency across different scenarios (traffic loads and node densities). The reduced end-to-end delay of about 22-23% from the standard TIMIP protocol, demonstrated its ability to overcome significant latency issues associated with modern day communication systems. We also noted these latency improvements were achieved without any compromise in the other performance parameters (throughput and packet delivery ratio) which show small gains but still useful improvements. When assessed against other widely used protocols, it is overwhelming that the improved TIMIP consistently recorded the least amount of latency and the most effective and reliable comparative data transmission performance. This combination of good latency results and measured performance measures confirms the reliable capacity of the protocol from performance and scalability suitability for use in more latency sensitive business cases including real-time communications and autonomous systems. In conclusion, the aided TIMIP protocol is clearly an advancement in the multiplex communication operational strategies and offers a practical and efficient application in next generation networks to reduce latency without detracting from the overall system performance.

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