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REVIEW ARTICLE

TCP Performance Enhancement in IoT and MANET: A Systematic Literature Review

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Abstract – TCP operates as a unicast protocol that prioritizes the reliability of established connections. This protocol allows for the explicit and acknowledged establishment and dissolution of connections, the transmission of data without loss of context or duplication, the management of traffic flows, the avoidance of congestion, and the asynchronous signaling of time-sensitive information. In this research, we use the Systematic Literature Review (SLR) technique to examine and better understand the several methods recently given for enhancing TCP performance in IoT and MANET networks. This work aims to assess and classify the current research strategies on TCP performance approaches published between 2016 and 2023 using both analytical and statistical methods. Technical parameters suggested case study and evaluation settings are compared between MANET and IoT to give a taxonomy for TCP performance improvement options based on the content of current studies chosen using the SLR procedure. Each study's merits and limitations are outlined, along with suggestions for improving those studies and areas where further research is needed. This work outlines the basic issues of TCP when it is used in IoT and MANET. It also highlights the recent approaches for TCP performance enhancement, such as machine Learning-based approaches, multi-path TCP, congestion control, buffer management, and route optimization. It also provides the potential for future research directions into the effectiveness of TCP performance in IoT and MANET. The major findings of this review are to provide a thorough understanding of the latest techniques for enhancing TCP performance in the IoT and MANET networks, which can be beneficial for researchers and practitioners in the field of networking.

Index Terms – Transmission Control Protocol (TCP), Mobile Ad Hoc Network (MANET), Internet of Things (IoT), Retransmission Timeout (RTO), RTT (Round Trip Time), Congestion Control (CC), Acknowledgement (ACK).

1. INTRODUCTION

Postel introduced Transmission Control Protocol (TCP) in RFC 793 [1] as a connection-oriented transport layer protocol. Due to the lack of a CC mechanism, TCP Tahoe was introduced by Jacobson et al. in 1988 [2]. TCP Tahoe controls network traffic with an adaptive window-based congestion management technique in accordance with the additive increase multiplicative decrease (AIMD) paradigm. Van Jacobson made tweaks to it in 1990, changing it to TCP Reno [3]. Since it is a connection-oriented protocol, TCP establishes a logical channel for information to go from sender to receiver. All the necessary pieces of information are then sent along this route. When only one logical channel is used between the sender and receiver for the entire message, reliable data transmission is facilitated by an acknowledgement mechanism and retransmission of damaged or missing frames. TCP [4] is a stable, transport layer protocol that was developed in wired networks in which the BER (bit error rate) is substantially less than 1% and the end nodes are static. Through its transmission acknowledgement (ACK) and retransmission procedures, TCP ensures data reliability. Each data packet received from the sender must be acknowledged by the receiver as having arrived safely. A selective ACK or a cumulative ACK might be transmitted back to the sender to indicate that the packet has arrived safely at the receiver's side. Out-of-order (OOO) packets are those that are received before their proper place in the sequence. The receiver transmitted back a duplicate acknowledgment (DACK) when it receives a packet out of sequence [5].

The reliability of TCP and its traffic control and congestion control mechanisms have made it the most prevalent transport layer protocol on the Internet. TCP serves as the most extensively used protocol alongside application layer protocols such as "File Transfer Protocol (FTP), Hyper Text Transfer Protocol (HTTP)", email and remote access (Telnet) traffic, and by various other applications. TCP, the transport layer protocol was primarily designed with a focus on wired networks. It must be enhanced due to the growth of mobile computing devices that use wireless technologies. The congestion window (cwnd) is handled by the TCP sender and

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limits the data segments count that may be transmitted without being acknowledged. Based on the acknowledgements it receives from the TCP receiver, the sender modifies the cwnd size. Because of congestion, packet loss is the most typical issue with TCP over wired connections. To combat this issue, TCP makes use of a congestion management mechanism that interprets packet loss as a symptom of congestion and takes action to alleviate the situation. High BER in wireless networks is often the result of signal noise conditions, suggesting that TCP, which was developed for wired networks, may not be well suited to this environment.

The IoT is an emerging technology that facilitates communication and data exchange among heterogeneous devices through a network. Various sensor nodes operate as interconnected IoT devices, serving diverse purposes such as transportation, home automation, environmental surveillance [6], and infrastructure administration [7]. Data transfer across heterogeneous IoT devices uses a number of IoT protocols, including MQTT, AMQP and HTTP, CoAP, and XMPP. Effective communication among IoT devices utilized in applications is made possible by these protocols. The transmission rates of IoT devices vary, leading to notable network congestion and posing several challenges in the transfer of data between sensor nodes. The diagram depicted in figure 1 displays the IoT application protocols that are utilized for the purpose of transmitting data. It illustrates the essential role of TCP in the IoT application protocol.

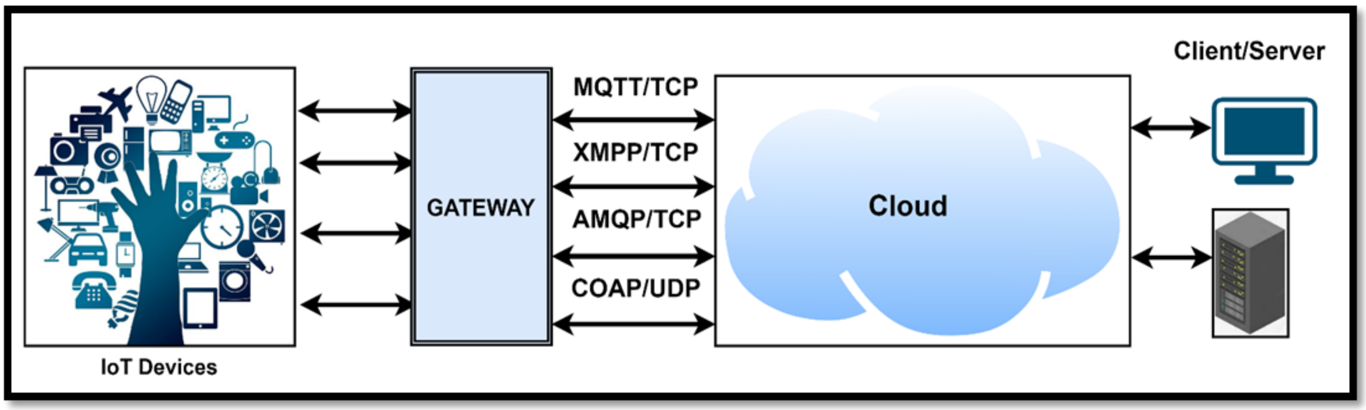

Figure 1 IoT Application Protocols

Beyond the research of Mobile Ad hoc Networks (MANETs), which has been the most popular, wireless communication technology has developed as one of the most enabling and adaptable technologies. In 2002, the Internet Engineering Task Force (IETF) initially suggested the phrase "mobile ad hoc network" (MANET) is an infrastructure-less network. Infrastructure-less networks are those without a pre-existing infrastructure, such as base stations or access points. In other words, the MANET's network cell is decentralized, meaning it does not need a fixed cell, allowing the nodes in MANETs to move arbitrarily as shown in figure 2. With the ability to build networks that are self-maintaining and self-configuring without the need for centralized cell support, MANETs are well suited for use in a wide range of crucial fields, including emergency recovery, military conflicts, disaster recovery, etc. Because of developments in end-user technology like mobile, portable, and other devices, wireless communication has a significant impact on disaster and rescue operations. The communication cell is either missing or broken at this level, or the previously installed network may not be capable to handle the large volume of traffic. The solution is MANET since it functions as a temporary network and can be established and destroyed quickly wherever it is needed, regardless of time. Regarding wireless communication, there are two methods: one uses centralized infrastructure to facilitate communication. Our legacy mobile networks, such as WLAN, UMTS, and GSM, integrate into an infrastructure network but need access points to interact. The opposite strategy, which excludes the use of a central cell, involves no central means for communication. Every node functions as a central device in and of itself. A MANET is a form of communication in which there is no central cell.

Figure 2 MANET

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Utilizing the standard TCP protocol will have an adverse impact on the efficiency of MANET and IoT. This is because TCP congestion management blames queue overflow for any packet loss. Proxy nodes are chosen in the proxy acknowledgement scheme based solely on hop count values. In order to ensure link stability and congestion avoidance, it is important to check the link availability and load during the proxy node selection phase. Even more importantly, the chosen proxy nodes are immutable and will not alter at any point throughout the transmission.

1.1. Motivation of the Paper

A wide range of studies has been done in the area of IoT, MANET, WSN [8], and Ad hoc networks for TCP performance enhancement and is still in the developing field. However, while analyzing TCP performance, it was found that there was no SLR that could explain the various aspects and functionality of TCP and its performance under different network scenarios. The prime focus of the systematic review is to present not only an in-depth analysis but also a comprehensive summary of the prior research work conducted in this specific field. This systematic review presents an approach that is based on the SLR methodology and provides a procedure that is well-defined for extracting and analyzing the findings in order to generate a comprehensive survey regarding the TCP performance in various network scenarios. The objective of this study is to consider papers from 2016 to 2023 related to TCP performance enhancement in IoT and MANET.

1.2. Contribution of the Paper

The main contributions of this review work are given below:

- Presenting an SLR method for TCP performance enhancement.
- Analysis of a number of parameters used to improve TCP performance in IoT and MANET for quality of service provisioning (QoS).
- The strengths/Merits and disadvantages/limitations of each selected approach are discussed.
- Addressing a discussion of existing issues of TCP in the area of IoT and MANET.
- Providing future research directions in the area of IoT and MANET for TCP performance enhancement.

1.3. Outline of the Paper

After the introduction section, this review paper is organized as follows: The related work is discussed in section 2. Section 3 outlines the research selection criteria, inclusion and exclusion process for related work as well as the formulation of research questions. In section 4, we describe the TCP performance enhancement in IoT and MANET that has not been systematically analyzed until now. Discussions on the research questions as well as analysis of them in section 5. Section 6 concludes the paper.

2. RELATED WORK

Many researchers have carried out comprehensive research on the performance improvement of TCP over IoT and MANET. The early TCP was applicable only to wired networks that experienced a severe drop in performance when used in IoT networks and MANET. The reason for this is that TCP is constrained by a number of aspects in MANET and IoT, including route failure, exposed terminals, channel contention, and hidden terminals.

A comparative analysis of TCP variants with a distinct reactive routing protocol has been published by Abu-Zant et al. [9]. A comparison is conducted by repeatedly executing a simulation scenario using NS2. TCP variants perform comparably with both the DSR and AODV routing protocols. The various TCP variants have not significant effect on the routing protocol. TCP-Vegas outperforms the other two protocols in terms of packet loss, throughput, and jitter. The results reveal that DSR is superior to AODV in terms of performance analysis.

The loose-coupled and close-coupled TCP optimization methods, both developed by Zhu et al. [10], are two examples of radio-aware TCP optimization. Using the client estimated rate and information from lower levels, the TCP parameters are regulated in the loose-coupled approach. Close coupled is a method that modifies the standard TCP congestion control method to provide support for the TCP request and grant processes.

Liu et al. [11] developed a transparent protocol optimization that recognizes on-the-fly protocol optimization in a network device to enhance TCP's throughput performance. It remains fully compatible with the latest TCP version without requiring any end-host modifications or specialized hardware. Better bandwidth usage is achieved with the improved protocol.

TCP with cross-layer information has been recommended by Bhatia et al. [12]. Whenever contention, congestion, or route failure occurs, the cross-layer information-based messages notify CTCP explicitly to respond in the appropriate manner. Significant improvements are attainable through the utilization of cross-layer parameters for the purpose of differentiating between the packet loss that is brought on by congestion or route failure. But the impact of poor channel conditions on TCP was not addressed in this work.

The mechanisms for adjusting the TCP congestion window have been described by Larsen [13]. Layer-specific solutions to TCP problems in MANET are also provided. Multiple TCP variants are introduced, and several approaches to enhancing

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TCP performance are discussed. The functioning of TCP in MANET has been studied by Ahmed et al. [14]. Simulation experiments are used to examine the impact of BER on TCP. Different routing protocols were inferred to use distinct paths for data transmission based on experimental outcomes.

The performance of TCP Reno in a different MANET topology has been analyzed by Papanastasiou et al. [15]. Effect on TCP throughput, the interplay of route buffering, and transport agents have all been investigated. TCP Reno has the lowest performance of the three TCP variants across a variety of network topologies and traffic volumes. Specifically, TCP Vegas and TCP New Reno have shown impressive throughput performance.

The latest AIMD algorithm was developed by Almobaideen et al. [16], as a new TCP variant i.e. TCP Karak. This algorithm takes into account the number of DACKs received upon a timeout and uses that information to determine the extent of multiplicative decrease. Particularly, it specifies the point from where the slow-start mechanism should start recovering the congestion window size. Mobile wireless networks are notoriously unstable, but TCP Karak can adjust to these changes and distinguish between different types of loss, such as those caused by congestion, link failures, bit errors, and so on. According to the simulation results, TCP Karak has obtained a high throughput and goodput than TCP New Reno under a wide range of traffic loads, bit error rates, and mobility speeds.

There are major problems with TCP throughout the entire protocol stack in MANETs. TCP congestion control does not differentiate between congestion losses and transmission error losses. Congestion in the network often leads to packet loss in TCP. In MANET, packet loss occurs mostly due to connection failure and not congestion. However, TCP misinterprets this as congestion and uses its congestion management mechanism. When using a MANET, there are a number of potential causes for packet loss. However, modern TCP variants automatically assume packet loss is due to congestion caused by buffer overflow, and hence use the corresponding congestion management approach regardless of the actual cause.

3. RESEARCH SELECTION METHOD

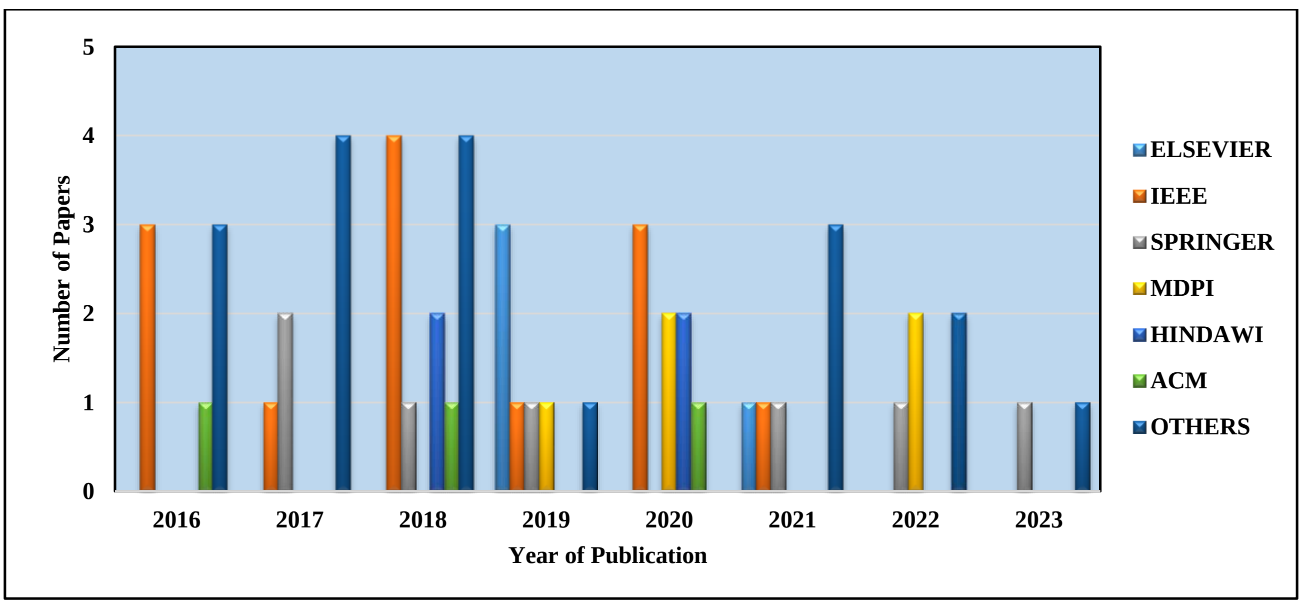

Figure 3 Distribution of Research Papers by Different Publishers

This section provides a review based on the SLR technique as an evaluation of a research study for categorizing the performance of TCP. The subsequent exploration string was defined by considering the alternatives and other synonyms of the essential key components:

- (“TCP” OR “Transmission Control Protocol”) AND (“IoT” OR “Internet of Things”)
- (“TCP” OR “Transmission Control Protocol”) AND (“MANET” OR “Mobile Ad hoc Network”)

Figure 3 illustrates the distribution of the research papers in online databases from various publishers such as Elsevier, Hindawi, IEEE, MDPI, Springer, ACM, etc. from the year 2016 to 2023. In this classification, some electronic databases like Science Direct and IEEE Xplore are used in the SLR method. Firstly, 346 papers are selected after duplicate

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removal. Out of these 54 peer-reviewed papers were considered by applying inclusion and exclusion criteria.

This SLR paper describes the analytical questions in section 3.1, regarding the aims of this research. Then the inclusion criteria and exclusion criteria for the concluding research selection were applied [17]. In terms of the number of papers that have been published, we only look at journal articles and conference papers since these are the studies that have been subjected to peer review for the TCP performance in IoT and MANET networks. The prime objective of this study is to conduct a survey on methods for enhancing TCP performance in the context of IoT and MANET.

3.1. Research Questions

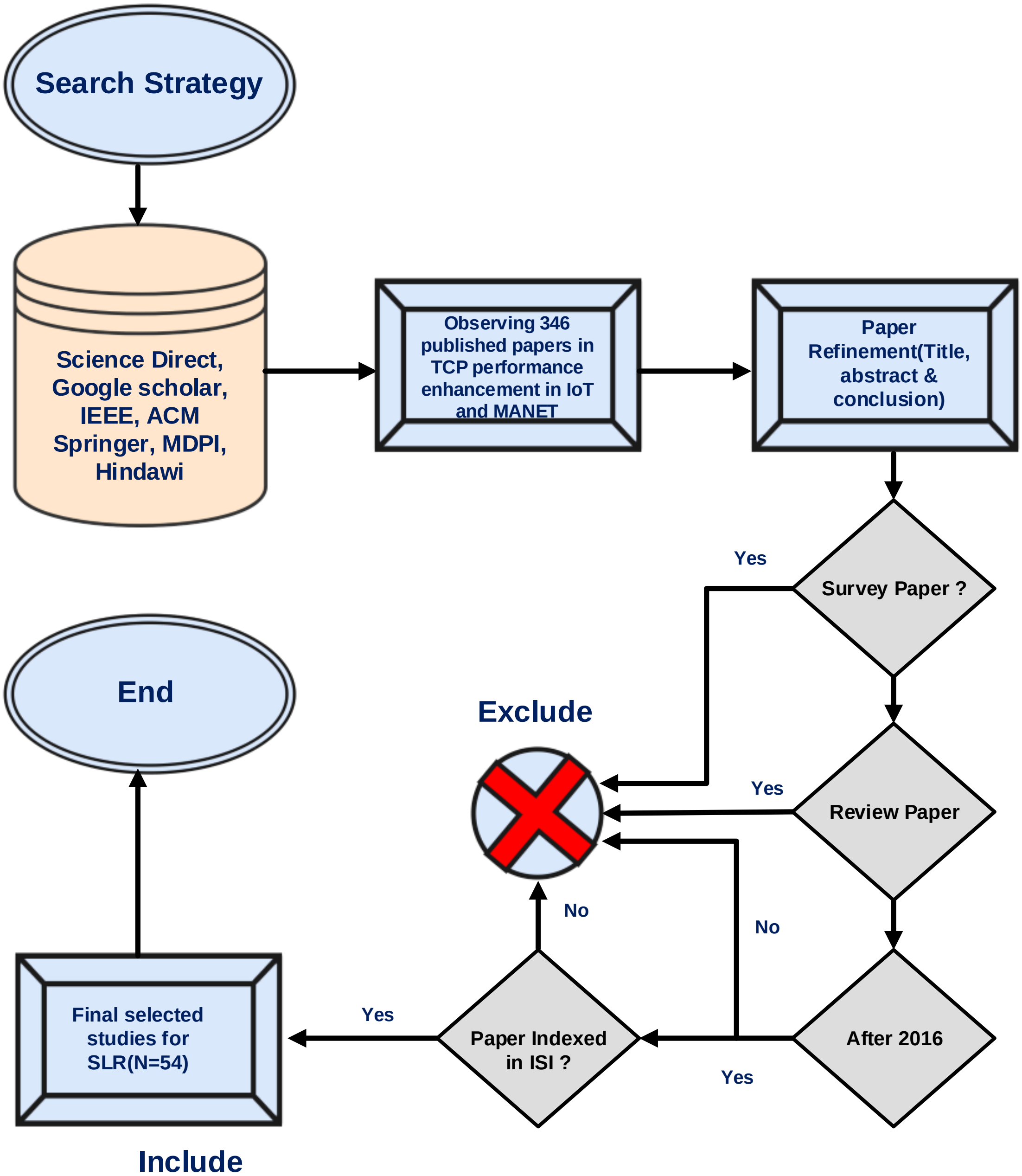

Figure 4 The Selection Criteria and Evaluation Framework of Research Papers

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The motive of this research is to conduct a survey on how TCP performance can be improved over IoT and MANET, a total of eight research questions have been formulated to cover the related ideas and problems that are associated with this topic. This paper provides some of the potential answers to the following research questions (RQ) that can be gathered from this study:

- RQ 1: What are the most significant QoS parameters to consider when analyzing the performance of TCP in a MANET network?
- RQ 2: What are the most significant QoS parameters to consider when analyzing the performance of TCP in an IoT network?
- RQ 3: How are the paper publications related to TCP performance in IoT and MANET distributed throughout the year?
- RQ 4: How are the various paper publications related to TCP performance in different journals in the area of MANET and IoT spread throughout the years?
- RQ 5: Which tools or platforms are commonly used in the process of evaluating the performance of TCP?
- RQ 6: What are the open issues and existing challenges that TCP faces in IoT? What are the probable solutions to alleviate these issues?
- RQ 7: What are the open issues and existing challenges of TCP in MANET? What are the probable solutions to mitigate these issues?
- RQ 8: What are the potential future research directions into the effectiveness of TCP performance in IoT and MANET?

Figure 4 depicts the evaluation and selection criteria that were created for the research work. The exclusion phase consists of omitting non-English papers, non-peer-reviewed papers, book chapters or books, and low-quality studies that did not provide any scientific explanations and technical information.

The following inclusion criteria are taken into account in order to map the research that was eventually chosen:

- Papers were accessed and published online between 2016 and 2023.
- Papers that focus on TCP performance in IoT and MANET.
- Papers that provide information regarding QoS factors (such as Throughput, Packet Delivery Ratio, Packet Loss Ratio, Delay, etc.)

The following exclusion criteria are taken into account while mapping the final set of studies:

- Papers not focusing explicitly on the performance of TCP in IoT and MANET.
- Papers that are duplicates and not relevant to the proposed taxonomy.
- Review and survey papers are not included in the studies.
- Papers that are not written in the English language.
- Papers not indexed in ISI.

4. TCP PERFORMANCE

A technical review of the chosen TCP performance enhancement in MANET and IoT for the current studies according to the applicable SLR process is presented in this part. The parts that follow provide an illustration of the various methods of TCP performance optimization, one of which is geared toward MANET and the other toward IoT. In addition, several studies will be compared with one another in a number of different aspects, including the primary context that has been described, the case studies, the benefits, the drawbacks, and finally the individual outcomes.

4.1. Enhancement of TCP in MANET

TCP performance in MANET has been an area of research for many years, as it has unique characteristics that can affect the performance of TCP. Numerous investigations have been carried out to assess the efficacy of TCP in MANETs and to suggest remedies for enhancing its performance. The following are the recent MANET-based research endeavors undertaken for TCP performance enhancement.

One of the key issues affecting TCP performance in MANETs is the frequent changes in the network topology, which can result in routing loops, packet loss, and increased delay. To resolve this issue, various routing protocols have been suggested that can adapt to the dynamic topology of MANETs, such as AODV, DSR, and OLSR. These routing protocols can help to reduce the impact of routing loops and packet loss on TCP performance.

Thuneibat [18] provided an accurate portrayal of the unpredictable behaviors exhibited by nodes within an Ad hoc network. They constructed and implemented a simulation-based system to evaluate AODV concerning TCP and UDP. The simulation's results map the values of latency, jitter, and throughput for these scenarios against simulation time.

Another author, Taha et. al [19] used the AODV routing protocol and several multimedia apps to assess how well TCP and UDP function in a MANET. The researchers concluded that TCP was the most appropriate for the investigational scenario due to its high throughput and PDR.

The impact of malicious node behavior on AODV-based MANETs has been addressed by Malik et al. [20] through a

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comprehensive examination of the operation of the Blackhole attack and the AODV routing protocol. The simulation findings revealed the throughput, delay, and normalized routing load of TCP and TCP Vegas under AODV and Blackhole AODV. The achieved throughput value for TCP and TCP Vegas decreases noticeably as blackhole AODV's node count rises. Blackhole attacks on TCP increase the normalized routing load and end-to-end delay significantly. TCP Vegas was unsuccessful to improve performance.

The TCP variants New Reno and Vegas, as well as the Full TCP protocol, have been examined by Das et al. [21] utilizing the grid topology-based routing protocols DSR, AODV, and DSDV. The simulation results obtained using the NS2 demonstrate that the FullTCP outperforms Newreno and Vegas regardless of the routing protocol employed. Furthermore, DSDV protocols offer superior performance.

Hanin et al., [22] offered a novel optimization strategy to improve TCP-based decision-making. The purpose of this study is to evaluate and determine the optimal routing protocol for TCP in a MANET with the goal of enhancing the quality of service (QoS) while mitigating the effects of packet loss, and retransmissions, and minimizing energy consumption. The results of this research significantly improved the TCP performance in MANETs.

Sarkar et al. [23] improved the performance of TCP over MANETs under conditions of channel noise. They suggested a new transport layer protocol called TCP-LoRaD. It solves the issue of packet loss problems that are caused by congestion management techniques of TCP. Extensive simulations were run under realistic scenarios to verify TCP effectiveness.

Sivakumar et al. [24] proposed COLMACL to increase network throughput and solve the congestion management issue in MANET. Through the use of this method, the average data transmission rate is increased while the average queuing latency is decreased. The congestion management issue is addressed by TCP's Convex Optimized Lagrange Multiplier-based Algebraic Congestion Likelihood (COLM-ACL). In MANET, the rate of data transfer is regulated via convex optimization. Thus, a mobile node's optimal rate is determined by the dynamic improvement of Lagrange Multipliers along its path with the queue factor.

Vivekananda et al. [25] compared TCP, UDP, and SCTP's performance using NS2 for a number of quality criteria. In ad hoc networks, simulation results demonstrate that SCTP outperforms TCP and UDP regarding jitter, throughput, PDR, delay, and loss rate.

Three metrics including stability of node, energy, and signal intensity have been employed in fuzzy logic systems by Hanin et al. [26]. They have developed a cross-layer-based strategy to guarantee an effective diagnosis of packet loss and find an appropriate solution. The NS3 simulation results showed that this research generally boosts TCP performance in MANET. Throughput may be improved by reducing packet overhead and power consumption.

An adaptive proxy acknowledgement scheme and a cross-layer-based congestion detection scheme for TCP in MANET were proposed by Kumar et al. [27]. This mechanism uses metrics for the link-layer transmission queue length and link availability to select proxy nodes along the source and destination. These are used to determine which nodes should be used. Verifying the missing TCP sequence allows for the detection of local congestion. The efficiency of the frame transmission is used to determine end-to-end congestion. The results of simulations demonstrate that the proposed method ensures connectivity as well as a transmission that is unaffected by congestion.

Nigar et al. [28] presented a solution to address the fairness concern in MANETs at the transport layer. Their approach involved identifying the optimal TCP variants for MANETs through the utilization of a widely recognized routing protocol. The throughput fairness of several TCP variants is performed through a simulation experiment using NS-2. TCP Reno performs best when using the DSDV routing protocol. In contrast to the other forms of the preexisting routing protocols, TCP Cubic also shows improved throughput. When compared with other TCP variants, TCP Vegas obtains unfair performance on different routing protocols.

Sharma et al. [29] introduced a modified version of Hybrid-TCP that incorporates the increment parameter rate, which is determined by the signal strength and noise factor, to accurately determine the retransmission time. Performance analysis shows that the Modified Hybrid-TCP variant performs better than traditional TCP variants.

The primary purpose of Patel et al. [30] study is to investigate the response of various TCP implementations to distinct mobility models in MANET. TCP Westwood NR possesses the ability to ascertain the quantity of available bandwidth for a specific connection. The aforementioned is a sender-side modification to the TCP. In wireless environments, the most commonly observed issue is the loss resulting from link failure, while other TCP versions often struggle with the efficient utilization of available bandwidth. In order to make the most effective use of available resources, TCP Westwood NR can be modified to perform calculations that determine the available bandwidth for a specific connection upon the reception of each ACK.

Several techniques aim to produce a delayed or proxy acknowledgement to minimize congestion control. Zin Oo et al. [31] proposed a technique called PACK (proxy acknowledgement) to improve the efficiency of TCP connections in MANETs. The PACK technique is

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incorporated in various TCP variants. Diverse network topologies are employed to investigate disparities in performance between static and mobile ad hoc environments. The results of the simulation indicate that PACK exhibits superior performance when compared to PART in the context of TCP variants. The utilization of PACK over PART when used with TCP variants has demonstrated a notable enhancement in throughput and a reduction in packet loss of up to 60 percent within a grid topology.

Rao et al. [32] have introduced a scheme called Smart Acknowledgment Distributed Channel Access. This method involves the utilization of a unique Access Category (AC) specifically designated for data-only TCP acknowledgement packets, which are then given the highest priority. Thus, the delay during packet transmission can be minimized. Additionally, the packet's confirmation can be sent immediately. The optimization of TCP performance can be achieved by considering various parameters such as transmission rate, number of hops, and Channel Occupied Ratio, and by optimizing the delay window size accordingly.

Pusuluri et al. [33] have proposed a feedback technique, TCP-F or Feedback-based TCP intending to optimize TCP performance. This technique enables the source to differentiate Route Failure Notification packets, thereby allowing it to stop packet transmission and freeze its timers. They conducted a comparative analysis of TCP's performance in ad-hoc networks with and without feedback. The network's performance is assessed through various metrics such as throughput, routing overheads, and time delay for different numbers of nodes.

The notion of an antijam communication system based on pseudo-noise signals and MANET architecture has been proposed by Volkov et al. [34]. MANETs performance is highly dependent on interference produced by the devices and their environments. UDP protocol usage, which is inefficient in light of redundancy, increases network load. Numerous current interferences were taken into account, and the TCP protocol's potential application in MANET was examined. The TCP protocol's overall performance in a challenging interfering scenario was demonstrated in this mechanism.

Sunitha et al. [35] presented an innovative technique that utilizes cuckoo search optimization to choose the optimal Base RTT value. Additionally, their suggested algorithm dynamically considers the slow start method based on real-time estimations of existing bandwidth and adjusts the decrease or increase rate in the congestion avoidance stage for a specified network environment. When compared to other methods, the suggested algorithm can efficaciously prevent packet losses and achieve the highest throughput.

Govindarajan et al. [36] developed the "Enhanced TCP NCE" protocol intending to reduce the occurrence of erroneous identification of non-congestion events and improve the corresponding response mechanism. The simulation results indicate that the enhanced TCP-NCE protocol enhances performance.

Zhang et al. [37] introduced a data delivery approach that utilizes multipath TCP and prioritizes quality of experience (QoE). They proposed a novel hidden Markov model (HMM) that utilizes optimal-start multipath routing to accurately predict the future network connection state of a mobile node, based on its previous connection state. MPTCP is used to simultaneously transfer data over several MSD interfaces and enhance the MPTCP subpath construction process. They investigated and enhanced the multihop routing technique. The results demonstrate that their methods can provide better network traffic load balancing and more effective usage of many subpaths than utilizing traditional MPTCP alone.

Sharma et al. [38] introduced a novel approach called CL-ADSP, which serves as a flexible and adaptable method for transmitting data through multiple paths in multipath TCP. The utilization of a multi-path data transfer policy's dual concept is executed in an efficient manner. The findings of the simulation indicate that the CL-ADSP method is efficacious in enhancing throughput, reducing file transfer time with minimal delay, and mitigating the number of timeout packets.

Modified TCP New Reno's performance analysis for MANETs was completed by Shenoy et al. [39]. In order to conduct a comparison study, the MD phase of TCP New Reno for the MANET congestion window was only reduced by 20%, as opposed to the 50% that was previously present. Compared to the previous strategy, this led to better performance related to throughput and packet delivery rate.

Based on the condition of the MANET environment, Al-Maaitah [40] updated the timeout calculation method to produce more precise retransmission times. The network status is determined by the change in the time between the first and second ACK. In order to address the situation when there are insufficient duplicated acknowledgments to trigger fast retransmit, it also suggests lowering the minimum required duplicated acknowledgments from three to two. A discrete simulator was utilized to conduct a series of experiments with varying traffic loads and mobility speeds in order to assess the efficacy of the suggested approach (AT-ER) in comparison to TCP New Reno. The findings suggest that the implementation of AT-ER leads to a rise in the throughput of TCP New Reno in the context of MANET.

Molia and Kothari's [41] discussion has predominantly focused on the conventional TCP variants and varied losses in MANETs. The cross-layer techniques and layered approaches of TCP for MANETs are explicated. This study presents an analysis of multiple TCP variants based on loss differentiation, loss avoidance methodologies, and loss

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prediction. The primary objective of this study is to identify existing challenges associated with TCP in MANETs, as well as explore prospective ways for future enhancement.

Molia and Kothari have proposed TCP-RLLD, which stands for TCP with Reinforcement Learning-based Loss Detection [42]. The process of differentiation is a comprehensive solution at the transport layer that is employed to anticipate the main causes of packet loss. TCP-RLLD is designed to supersede TCP's default behavior of interpreting any loss as a congestion loss in order to avoid an unnecessary reduction in transmission rate. Multiple TCP variants are evaluated along with TCP-RLLD for Mobile Adhoc Networks.

Deshpande et al. [43] have presented a new algorithm to mitigate TCP's fundamental limitations. The first component includes methods for resolving route failures, node failures, packet losses, and whole throughput improvement, while the name of the second part, called "Adept Route Yielding Algorithm," determines the most efficient path along which the current node can forward packets. The two approaches, which are deployable and functionally independent of one another, have been determined to produce superior results and have been given the name "Feedback-based Adaptive Speedy Transmission Control Protocol."

Sunitha et al. [44] have developed a trust-aware routing protocol for choosing the best route over MANET. According to this protocol, the direct and indirect trust values are used to calculate the trust value for each node. The best path in the network is then determined by selecting the one with the lowest routing cost metric value. Once the best path has been chosen, data packets are delivered along the best path. Due to mobility or congestion, a data packet during transmission may be discarded or reordered.

Huang [45] re-designed the TCP congestion control over MANET and suggested the QUIC-TCP algorithm. Using the Lyapunov method, the algorithm constructed a TCP fluid model in order to accomplish global convergence and stability.

Tabular data (Table 2) summarizes the aforementioned articles and highlights the most crucial metrics for assessing TCP performance improvements in MANET networks. Figure 5 displays the detailed analysis of parameters considered to provide QoS at the MANET. Table 1 provides a comparison of these studies for evaluating the performance of TCP. The parameters consist of packet delivery rate, average packet loss, throughput, packet loss rate, delay, routing overhead ratio/normalizing routing load, jitter, and noise ratio.

Table 1 Classification of Recent Studies and Other Information in the Enhancement of TCP in MANET

Research	Merits	Limitation and Future Scope
Thuneibat [18]	This article compares AODV QoS parameters with the simulation time for TCP and UDP using NS-2.	Among the issues that are not addressed here is a comparison of available routing protocols. This simulation system will be used with different routing protocols in future work.
Taha et al. [19]	This article compares the performance of TCP and UDP protocol on MANET networks with AODV routing protocol for multimedia applications.	This work recommends the use of the AODV protocol for situations involving emergencies and rescue operations because of its remarkable performance in terms of PDR, throughput, and Delay.
Malik et al. [20]	Performance of TCP and TCP Vegas in the context of AODV and Blackhole AODV, utilizing metrics such as average throughput, end-to-end delay, and normalized routing load.	Only the existing works are compared.
Das et al. [21]	TCP variants such as New Reno and Vegas, as well as the Full TCP protocol, are investigated using grid topology and AODV, DSR, and DSDV routing protocols.	It is a heuristic that does not guarantee improved performance in all scenarios. It is unable to immediately accept the new path. Packet sequencing necessitates the addition of bytes to the header.
Hanin et al. [22]	The TCP protocol has been updated with a new improvement that makes use of fuzzy logic to predict packet loss and prevent congestion.	It would be fascinating to adapt this study for use in a real-world scenario (emulation).
Sarkar et al. [23]	This article sheds some light on TCP performance in noisy channels over MANETs.	Future development could include TCP-LoRaD in the design of the IoT to save human life in an emergency scenario.

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Kumar et al. [24]	The COLM-ACL technique of TCP is used to enhance the network throughput and congestion control rate.	The study is limited to the COLM-ACL technique.
Vivekananda et al. [25]	Evaluated the performance of TCP, UDP, and SCTP based on various quality metrics types using ns2.	SCTP's multistreaming features can inspire a variety of future research, including multipoint streaming with reliability in heterogeneous networks.
Hanin, et al. [26]	Cross-layer optimization is used to improve TCP decision-making in response to modifications to IEEE 802.11 MAC.	In the future, there may be an attempt to upgrade TCP and routing protocols in order to accommodate the constraints of the Internet of Things clients.
Kumar et al. [27]	This article accomplishes inter and intra-level congestion tests to identify MAC and network layer congestions and modifies the proxy based on network conditions.	TCP performance can be negatively impacted by interference's hidden terminal effects; as a result, there has been a restriction placed on the maximum sending window size.
Nigar et al. [28]	The utilization of the DSDV routing protocol exhibits superior performance with TCP Reno in comparison to alternative TCP variants. The TCP Cubic routing protocol exhibits a higher throughput compared to alternative protocols.	TCP Vegas obtains an unfair throughput when compared to other TCP variants.
Patel et al. [30]	TCP utilizes Internet Protocol so that it is compatible with satellite networks. With its congestion control and filter implementation, Westwood NR of TCP can achieve great performance in MANET.	It is possible to enhance dependency on currently utilized data relative to previously obtained data. Thus, filter performance can be enhanced.
Rao et al. [32]	SADCA is a strategy for improving TCP performance in MANETs.	The packet drop rate and packet loss may grow as the number of nodes increases. As a result, performance suffers.
Pusuluri et al. [33]	Proposed a TCP-F(feedback) for enhancing the overall TCP performance. It gives a simple solution to minimize the issues caused by regular path breaks in MANETs.	As mobility increases, traffic overhead is incurred while assessing unnecessary routes.
Volkov et al. [34]	TCP is a reliable choice when it is essential to maintain the integrity and sequence of the data being transmitted, as well as to conserve energy.	This is not appropriate for use in real-world applications. As a result, additional improvements are required.
Sunitha et al. [35]	Dynamic TCP Vegas optimizes network utilization and lowers network congestion by altering the transmitting rate with the help of accurate Base RTT calculation.	Rerouting consumes additional resources and is unable to recognize RTT updates when changes occur in the network. It was unable to increase end-to-end performance in the context of mobility, multipath routing, congestion, error, and reordering.
Govindarajan et al. [36]	The protocol called "Enhanced TCP NCE" was developed to reduce the occurrence of false identification of non-congestion events and improve the response time to such events.	This is merely a reconsideration of the classification of non-congestion events. It will not take into account the identification of congestion events.
Zhang et al. [37]	This study presents a Quality of Experience (QoE)-driven multipath Transmission Control Protocol (TCP)-based data delivery model in MANETs.	This protocol will not result in an improved quality of experience at the application level.

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Sharma et al. [38]	“CL-ADSP” utilized a delay-variation-based adaptive fast retransmission policy.	The scheme does not deal with the issues of security. This scheme can be extended to adapt the Internet heterogeneity.
Shenoy et.al [39]	TCP algorithm's MD phase decreases the congestion window (cwnd) by 50% in case of packet loss.	This study did not offer a new routing protocol.
Al-Maaitah et al. [40]	It comes to making TCP capable of sensing network conditions and identifying the true cause of loss. It alters the timeout calculation method to get a more precise retransmission time based on the MANET environment state.	Because the window size is not determined by the network state, the sender and receiver are unaware of each other's status.
Molia et al. [41]	The purpose of this study is to identify prevailing issues associated with TCP in MANET and propose viable remedies, in addition to outlining prospective avenues for further research.	The loss handling issue can be tried to solve using Artificial Intelligence and Data Mining approaches.
Deshpande et al. [43]	In MANETs, the performance of the modified CC method for the TCP was significantly better than that of the standard TCP.	Before planning for real-world implementation, these observations were checked and validated using other technologies like OMNET++ to make the conclusions platform-independent and definitive.
Sunitha et al. [44]	Designed a new protocol for enhancing the efficiency of TCP in MANETs through the implementation of packet reordering.	It is also necessary to implement it at each and every intermediate node. Inappropriate for an environment with high levels of mobility.
HUANG et al. [45]	The QUIC-TCP as CC algorithm was introduced and its performance under various schedulers was evaluated.	This method requires a large amount of computational data on the transmitting end, thereby restricting its applicability in multi-hop networks with limited resources.

Table 2 Comparison of the Performance Matrix Parameter in the Enhancement of TCP in MANET

Research	Packet Delivery Ratio (PDR)	Average Packet Drop Rate	Throughput	Packet loss rate	Delay	Routing Overhead Ratio/normalizing routing load	Jitter	Noise ratio
[18]			✓		✓		✓	
[19]	✓		✓		✓			
[20]	✓		✓		✓	✓		✓
[21]	✓			✓		✓		
[22]			✓	✓		✓		✓
[23]	✓		✓		✓			
[24]		✓	✓		✓			
[25]	✓		✓	✓	✓		✓	

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[26]			✓	✓		✓		
[27]	✓	✓	✓		✓	✓		
[30]	✓		✓			✓		
[31]			✓	✓	✓	✓		
[32]	✓		✓		✓			
[33]	✓		✓			✓		
[34]			✓	✓	✓		✓	
[35]			✓	✓				
[36]			✓		✓			
[37]	✓		✓	✓	✓	✓	✓	
[38]	✓	✓	✓	✓	✓	✓		
[39]	✓		✓		✓		✓	
[40]	✓		✓					
[41]	✓		✓					
[43]	✓	✓	✓		✓	✓		✓
[44]			✓					
[45]			✓	✓	✓			✓

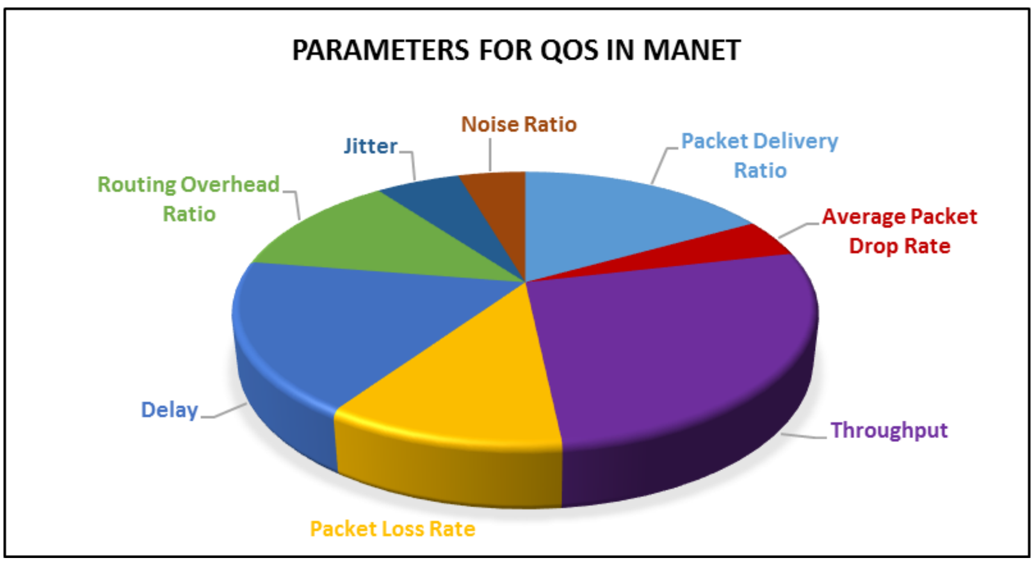

Figure 5 Parameters for QoS in MANET

4.2. Enhancement of TCP in IoT

Due to the large-scale, dynamic, and heterogeneous nature of IoT networks, TCP performance in these networks is a complex and difficult issue. The vast number of devices in IoT networks can cause congestion, and the heterogeneity of those devices can lead to diverse network conditions and communication needs. Furthermore, the dynamic nature of devices in IoT networks may lead to frequent modifications in the network's topology and routing paths, thereby potentially affecting the performance of TCP.

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Several research studies have been conducted to evaluate the effectiveness of TCP in IoT networks and suggest solutions to enhance the reliability and effectiveness of the protocol. These studies have identified several aspects that impact TCP performance in IoT networks, such as the network topology, low bandwidth, the type of traffic, high latency, packet loss, interference, the network load, and the TCP variant that is being used. In addition, numerous optimization strategies, such as CC algorithms, routing protocols, and QoS mechanisms, amongst others, have been proposed as means to enhance TCP efficiency in IoT networks. The following are the recent IoT-based research endeavors undertaken for TCP performance enhancement.

Tyagi et al. [46] conducted an analysis on enhancing the architecture of Compound TCP to facilitate continuous learning and minimize delays in WiFi-based IoT networks. To boost efficiency in all industry 4.0 WiFi networks, this research takes a cross-layer strategy and designs many intelligent APs using cognitive collaboration techniques.

The IoT network is structured using a grid topology that uses the Manhattan distance metric. This topology enhances the network's scalability and flexibility [47]. After the network is established, packet scheduling selects the optimum subflow to minimize the transmission delay using a fitness-based proportional fair (FPF) scheduling. TCP's congestion management comes after packet scheduling. To identify congestion in a TCP-IoT environment, numerous aspects must be taken into account, and an adaptive RTO is estimated to minimize latency and maximize convergence during retransmission.

Lim [48] conducted an analysis of the TCP Congestion Control (CC) method implemented in the uIP stack. This analysis was carried out using grid topology networks. After recognising the necessity for retransmission, the basic uIP TCP protocol adjusts the retransmission timer based on the predetermined Retransmission TimeOut (RTO) before commencing the retransmission procedure. The presence of a hidden terminal problem in ContikiMAC can lead to significant variations in round-trip time (RTT). Consequently, utilizing a retransmission timer that relies on a fixed RTO value may trigger a large number of unnecessary retransmissions. To solve this issue, they have proposed a novel method of retransmission timer management that uses an idea called "weak RTT estimate of CoCoA," as well as "exponential backoffs with variable limits," and "dithering." Using an RDC (radio duty cycling) method, this scheme decreases retransmissions while increasing throughput and fairness.

Aljubayri et al. [49] utilized Opportunistic Routing (OR) to reduce latency in MPTCP by minimizing the total number of transmissions. The utilization of the broadcasting technique in this routing model enhances the delivery rate and reliability of data transmission across networks. It allows for multiple relays to be responsible for transporting data for each subflow. The results indicate that MPTCP systems based on OR exhibit better energy efficiency and reduced startup delay compared to the current state-of-the-art.

Dong et al. [50] developed an integrated multipath scheduler aimed at optimizing energy consumption while maintaining throughput, to promote energy conservation. The novel MPTCP transmission paradigm and the pre-existing energy efficiency model can be employed to approximate the throughput and energy consumption for every route. Therefore, a heuristic scheduling strategy is specified to determine the optimal path for each application. One of the advantages of this method is that it requires less energy to complete a flow. The suggested EE-MPTCP is useful in both home and business IoT environments.

Ji et al. [51] incorporated machine learning algorithms into the management of Multi-Path TCP (MPTCP) paths and introduced a mechanism for automatic learning path selection based on MPTCP, known as ALPS-MPTCP. The system is capable of dynamically selecting pathways of superior quality while concurrently transmitting data. This study creates a simulation experiment to evaluate the quality of paths using four different machine-learning techniques. Based on the timing and precision of the experiments, the random forest method was shown to be the most effective in determining the quality of the paths. In contrast to other algorithms, this particular one exhibits favorable performance characteristics with respect to both speed and accuracy in evaluating the efficacy of a chosen pathway.

Yang et al. [52] presented a novel permutation-based encapsulation technique to address the issues of elevated latency, reduced goodput, and suboptimal resource utilization that are commonly encountered with conventional transport layer protocols in the context of the IoT. This technique aims to facilitate the seamless transmission of packets. Permutation-based data units (PBDUs) can be utilized to transmit additional application-layer data. The PBDUs are in correspondence with the permutation linked to a valid tuple comprising unique packet lengths within a given group. As a result, the throughput is significantly enhanced for a specific amount of resource units in the physical channel. The optimal configuration of this encapsulation, which optimizes the PBDU size, is written in closed form, allowing one to calculate the achievable gains in goodput and latency.

Zong et al. [53] suggested an improved TCP mechanism that integrates a revised TCP Veno mechanism and enhances the quantity of data sent during the slow start stage of TCP Hybla to lessen the impact of long RTT.

This method can distinguish both unpredictable data loss and data loss due to congestion. It is shown that the suggested

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TCP mechanism for a GEO satellite network improves performance, even when random packet losses occur.

Lin et al. [54] enhanced the performance of TCP by implementing suitable rate control at the access point (AP) before the occurrence of congestion. This was accomplished by identifying qualitative relationships among congestion packet loss behaviors and the instantaneous cross-layer network metric measurements (states). In addition, they predicted future congestion in wireless links by analyzing these relationships. Furthermore, modeling and rate control modules were incorporated into this platform.

Verma et al. [55] provided a novel congestion management strategy that adaptively adjusts the transmission rate in response to fluctuations in bandwidth and latency. The suggested method keeps things in a constant condition to minimize packet loss and increase throughput. Additionally, adaptive approaches for keeping fairness with widely implemented TCP Cubic are proposed in this study. According to the findings of the experiments, the newly suggested TCP attains superior performance with respect to both inter-protocol fairness and throughput.

Park et al. [56] investigated TCP's efficiency in low-power, lossy, multi-hop, many-to-one wireless networks (LLNs). The TAiM approach leverages the distinctive characteristics of LLN, which result in a higher and more fluctuating RTT compared to wired or WiFi networks. The TAiM system operates by intervening solely at the LLN border router (LBR) during TCP communication. It achieves objectives by carefully manipulating the round-trip time (RTT) of the flows passing through, without disrupting any packets or the functioning of the existing protocols. Two 30-node TelosB testbeds are used for experiments, and TAiM is only implemented on a Linux-based LBR. The experimental findings showed that the utilization of TAiM facilitates the equitable and effective functioning of TCP, while simultaneously retaining the overall throughput and end-to-end compatibility.

Sun et al. [57] suggested (TCP-SCTP) method to analyze network traffic and modify the TCP approach. The ideal route was chosen by predicting the condition of each network path based on the packet loss rate calculated along that path. This technique improves throughput, and data transmission reliability while drastically decreasing latency and packet loss caused by congestion.

Leung et al. [58] designed a smart TCP sender model with the aim of distinguishing between congestion-related and non-congestion-related problems. The STS framework has been devised to reduce predicted expenses and determine the optimal setting of timer expiration intervals. This model has been practically represented through the development of a novel TCP variant, namely TCP for non-congestive loss (TCP-NCL). The deployment of TCP-NCL requires modifications exclusively to the sender-side TCP, thus facilitating its potential broad adoption in the future. The simulation experiments have shown that TCP-NCL displays robustness against packet reordering and non-congestive packet loss while maintaining acceptable responsiveness in the face of congestive loss.

Gomez et al., [59] examined the most common IoT applications using TCP. Then, analyzed TCP's purported problems in the IoT environment. Based on their work with the IETF to standardize TCP, they provided recommendations for its lightweight implementation and proper functioning in IoT environments. Although TCP has been underutilized in the past, recent developments indicate that it may soon see widespread use in IoT networks.

A method called Adaptive Contention Window (ACW) was developed by Bhavadharini et al. [60] with the intention of improving TCP performance. This was accomplished by reducing MAC overhead and retransmissions, as well as estimating the active queue size and energy level of competing nodes. Moreover, the MAC contention window undergoes dynamic modification in accordance with the active queue size of the node and the remaining energy level of the node. The MAC contention window serves as the basis for the dynamic adjustment of the TCP congestion window. The medium access is effectively distributed using the proposed method, which also ensures an increased network throughput by modifying the MAC ACW. The simulation outcomes indicate that the suggested approach enhances network throughput and concurrently diminishes collision occurrences.

Pokhrel et al. [61] created a complete analytical design for compound TCP in Wi-Fi. This model takes into consideration the flow and CC dynamics of numerous concurrent compound TCP connections along with the MAC layer dynamics that occur from devices receiving variable signal-to-noise ratios. This model can confidently anticipate steady-state throughputs and TCP packet loss probabilities over a wide range of IoT devices with diverse SNRs. It provided a simple adaptive control method for enhancing fairness without negatively impacting overall efficiency.

Toprasert et al. [62], suggested a Markov Decision Process (MDP) to improve existing congestion avoidance strategies. A new CC mechanism for TCP, called TCP-Siam, is being developed to boost performance. As congestion avoidance advances to its next level, the TCP Siam is deployed using a variant of the TCP-Illinois hybrid protocol that takes into consideration the MDP status. TCP-Siam enhances network performance by augmenting the cwnd size in the event of packet loss over a lossy connection in the context of a Wireless Mesh Network (WMN). TCP-Siam enhances throughput, round-trip time fairness, and resource utilization within heterogeneous networks.

Sari et. al [63] investigated the effects of WLAN characteristics on the TCP efficiency within a network topology that may be optimized for an IoT use case. They run the simulations with different WLAN configurations to estimate the TCP throughput for changing data drop and media access rates.

The utilization of Q-learning in TCP cwnd adaptation during the congestion avoidance state was investigated by Li et al. [64]. The conventional window alternation was substituted with this approach, allowing the protocol to respond promptly to previously observed network conditions. In addition, it highlights the need for memory in constructing the exploration space and suggests techniques for minimizing this overhead through function approximation. An in-depth simulation analysis revealed that the learning-based approach achieves significantly higher levels of success than the TCP New Reno strategy.

TCP Expo was introduced as a novel TCP variant for high-speed networks and emerging application domains by Vanzara et al. [65]. The TCP Expo protocol incorporates three supplementary parameters, namely cwnd old, and new, and the mean value of both parameters (mid). The execution of the suggested task is bifurcated into two discrete stages, namely, the slow start phase and the congestion avoidance phase. The analysis of TCP Expo's performance under severe congestion conditions was conducted by comparing the cwnd values of the new and old versions. The findings indicate that the suggested approach has the ability to expeditiously recover the cwnd and ssthresh values subsequent to a packet loss.

Gamess et al. [66] have developed a few benchmarking tools. The present study employed certain instruments to evaluate the efficacy of TCP and UDP in both IPv4 and IPv6 for Espressif ESP8266, a cost-effective WiFi microprocessor that features a complete TCP/IP stack and microcontroller functionalities. The authors presented findings on the performance metrics of One-Way Delay (OWD) and throughput, in relation to the utilization of the ESP8266 module as either an end-point device or an access point.

Khan et al. [67] investigated the efficacy of TCP packet surveillance in IoT, the effectiveness of TCP packet surveillance in mitigating the risk of ransomware attacks in IoT, and the efficacy of TCP packet surveillance in data security.

TCP BBR is an algorithm recently introduced by Cardwell et al. in 2016 [68] for the TCP protocol. It is completely obvious that the BDP represents the optimal window size for TCP. In contrast, the majority of TCP algorithms do not prioritize the consideration of Bandwidth Delay Product (BDP). The users augment the value of their congestion window until they encounter packet losses, following which they deliberately surpass the BDP. The authors concentrated their attention on two different types of physical limitations that limit transport performance. The two factors that must be considered are RTprop and BtlBw. During its communication, TCP BBR computes a pair of values. Subsequently, the estimated values are utilized to compute the BDP by multiplying the RTprop with the BtlBw. The resulting BDP is employed to establish the size of the cwnd, which corresponds to the estimated BDP, as indicated in [69].

The TCP Reno and CUBIC TCP algorithms, which are widely recognized for their loss-based approach, have been observed to exceed the optimal congestion window size, commonly referred to as BDP. The result of this is that these algorithms purposefully cause congestion on the network and packet loss. In addition to that, this results in an increase in RTT, which is unnecessary. The term "bufferfloat" is what Cerf et. al [70] use to refer to this unnecessarily lengthy RTT. The implementation of TCP fairness can potentially augment the efficacy of TCP in IoT networks by guaranteeing equitable treatment of all TCP flows.

The works below deal with TCP fairness issues without utilizing BBR. The unfairness in performance between TCP Reno and TCP Vegas was shown in [71] and [72]. In several works, the fairness of Compound TCP in comparison to CUBIC TCP is discussed [73] [74]. These studies indicated that performance fairness is extremely lacking. TCP fairness and TCP BBR are discussed in the works listed below. The fairness of CUBIC TCP in comparison to TCP BBR is assessed by Hock et al. [75]. The researchers then illustrated that CUBIC TCP and TCP BBR operate more effectively with bigger and smaller buffers. Li et al. compared CUBIC TCP and TCP BBR performance over LTE networks [76]. TCP BBR minimized delays substantially more than CUBIC, according to their findings. However, the methods for increasing fairness by dropping packets were not addressed in any of these works.

The following efforts have been made to enhance the TCP's fairness. Several authors have suggested an approach for improving the TCP's fairness that involves dropping packets. The method keeps track of the length of the queue in the bottleneck router and discards packets whenever there is a discernible increase in the length of the queue. The utilization of RED contributes to an increase in TCP fairness [77]. The application of CoDel, as demonstrated by [78] results in an increase in fairness. The functionality of AIMD was utilized very well in these works. To be more specific, upon detection of packet loss, a significant number of TCP algorithms promptly initiate a substantial reduction in the size of their congestion windows. The act of dropping a packet has the effect of decreasing the throughput of the flow that consumes the highest amount of bandwidth. Active packet dropping and

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dynamically controlling queue delay are two methods that have been proposed to advance these methods. These more advanced methods discard bandwidth-consuming packets more aggressively.

Classification of the aforementioned publications and performance metrics for assessing TCP performance improvements in IoT networks are shown in Table 4. Figure 6 displays the detailed analysis of parameters considered to provide QoS in IoT. Table 3 provides a comparison of these studies for evaluating the performance of TCP. The parameters consist of Fairness, RTT, packet delivery ratio, average packet drop rate, throughput, packet loss rate, delay, and Jitter.

Table 3 Classification of Recent Studies and Other Information on the Enhancement of TCP in IoT

Research	Merits	Limitation and Future Scope
Tyagi et al. [46]	Compound TCP was improved, and an analytical model was built to determine how well TCP flows perform in WiFi-based IoT networks.	Slow Start is incapable to measure the throughput of the bulk Compound TCP. In the future, it will be required to conduct a comprehensive time-scale separation analysis to evaluate the delay-adaptation timescales.
Parween et al. [47]	Cross-layer solution for congestion control and effective packet scheduling in IoT networks to improve TCP performance.	In the future, it will be enhanced by offering the security of TCP protocol in an IoT environment.
C. Lim [48]	A new method of retransmission timer management uses an idea called "weak RTT estimate of CoCoA," as well as "exponential backoffs with variable limits," and "dithering."	This work did not consider any other scenario for bursty traffic. The TCP window size is restricted to a single segment.
Aljubayri et al. [49]	OR technique in multipath TCP provides better utilization of IoT network resources.	The proposed OR-based multipath TCP schemes are not suitable for large network topologies.
Dong et al. [50]	A multipath TCP energy-efficient optimization scheduling algorithm for IoT. It enhances network performance and minimizes power consumption.	It's not a good fit for real-time video streaming or cloud computing in the virtual realm.
Ji et al. [51]	A machine learning-based automatic path selection system built on top of multipath TCP is being developed to efficiently and intelligently control the utilization of multiple paths.	The purpose of this study is to explore the utilization of the random forest algorithm in a broad and intricate real-world scenario. MPTCP's path management technique will be improved in the IoT environment.
Yang et al [52]	A unique permutation-based encapsulating technique for uninterrupted delivery of packets to attain higher goodput and lower latency.	Metadata cannot be efficiently encoded and overhead formats cannot be minimized.
Zong et al. [53]	TCP mechanism for a GEO satellite network improves performance, even when random packet losses occur.	The performance improvement is not notably significant under low BER conditions, and there is no apparent benefit in terms of throughput or response time.
Lin et al. [54]	To enhance TCP performance and anticipate forthcoming congestion in wireless networks, it is recommended to enable local rate control on the AP before congestion happens.	The congestion window regressions have a significant role in rate control activities, although their precision is still insufficient.
Verma et al. [55]	In the context of IoT networks, novel TCP CC algorithms have been proposed. The suggested TCP delivers superior performance in terms of throughput as well as inter-protocol fairness.	Due to a lack of consideration for RTO, there is an excessive consumption of bandwidth as well as a high retransmission latency.

Park et al. [56]	Investigated the performance of TCP across multihop many-to-one wireless LLNs, and then offer a TAiM that addresses the unfairness problem of TCP by employing strategies such as "burst distribution" and "packet re-ordering."	This scheme did not consider the TCP's friendliness.
Sun et al. [57]	Both TCP-SCTP and MS-SCTP can boost the throughput and stability of a network while simultaneously improving transmission quality.	MIMO and application slicing techniques will be examined to speed up MS-SCTP data transmission.
Leung et al. [58]	"TCP-NCL" is capable of achieving substantial performance improvements over standard channels, which are error-prone.	This work is not suitable for multiple-source wireless networks. TCP is not utilized for optimal performance in heterogeneous environments.
C. Gomez [59]	TCP has been typically overlooked in IoT network architectures, however, current developments indicate that TCP will be widely adopted in IoT applications.	When monitoring non-critical systems with relatively frequent sensor reading updates, TCP approaches perform less efficiently than their UDP equivalents.
Bhavadharini et al. [60]	An adaptive Contention Window as a means of improving TCP performance. This would be achieved by estimating the active queue size and energy level of contending nodes, thereby reducing MAC overhead and retransmissions.	The physical layer's feedback information was ignored in this study.
Pokhrel et al. [61]	A complete analytical model for "compound TCP" over Wi-Fi that provides precise estimates of the probability of TCP packet loss and steady-state throughputs for IoT devices that have	To account for MU-MIMO in such networks, additional research is required to enhance the model.
Toprasert et al. [62]	"TCP-Siam" augments the coefficient to increase the congestion window and enhance performance whenever packets are dropped owing to lossy links. It functions effectively in heterogeneous	For the wireless mesh network, congestion control at a lower layer may not have been considered during the simulation. The point-to-point wire links are not built for random loss, resulting in a loss.
Gamess et al. [66]	A benchmarking tool for evaluating the performance of TCP and UDP over both IPv4 and IPv6 on the Espressif ESP8266 platform.	It can be extended to other languages and development environments like Lua, PlatformIO IDE, and Zerynth Studio. Also, doing a performance evaluation of the ESP32, an enhanced version of the ESP8266.
Cardwell et al. [68]	The BDP is used to control congestion in BBR, so it can be an important parameter to measure the	Fairness and mobility issues are two of BBR's main open issues.
Sasaki et al. [69]	TCP BBR exhibits superior performance compared to TCP Cubic and TCP New Reno with respect to the trade-off between throughput and	Under certain conditions in the network, BBR has difficulty maintaining fairness between flows.

Table 4 Comparison of the Performance Matrix in the Enhancement of TCP in IoT

Research	Packet Delivery Ratio (PDR)	Average Packet Drop Rate	Throughput	Packet loss rate	Delay	Fairness	Jitter	Round Trip Time(RTT)
[46]			✓	✓	✓	✓		✓
[47]			✓	✓	✓		✓	✓
[48]	✓		✓			✓		✓
[49]		✓	✓		✓			

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[50]			✓	✓				✓
[51]			✓	✓	✓	✓		
[52]		✓	✓					
[53]			✓	✓				✓
[54]		✓	✓	✓	✓	✓	✓	✓
[55]		✓	✓	✓	✓	✓		✓
[56]			✓		✓	✓		✓
[57]			✓	✓				
[58]	✓		✓	✓	✓	✓		✓
[59]			✓		✓			✓
[60]	✓	✓	✓					
[61]			✓	✓	✓	✓		✓
[62]			✓			✓		✓
[66]			✓		✓			
[68]			✓	✓	✓			✓
[69]		✓	✓		✓	✓		✓

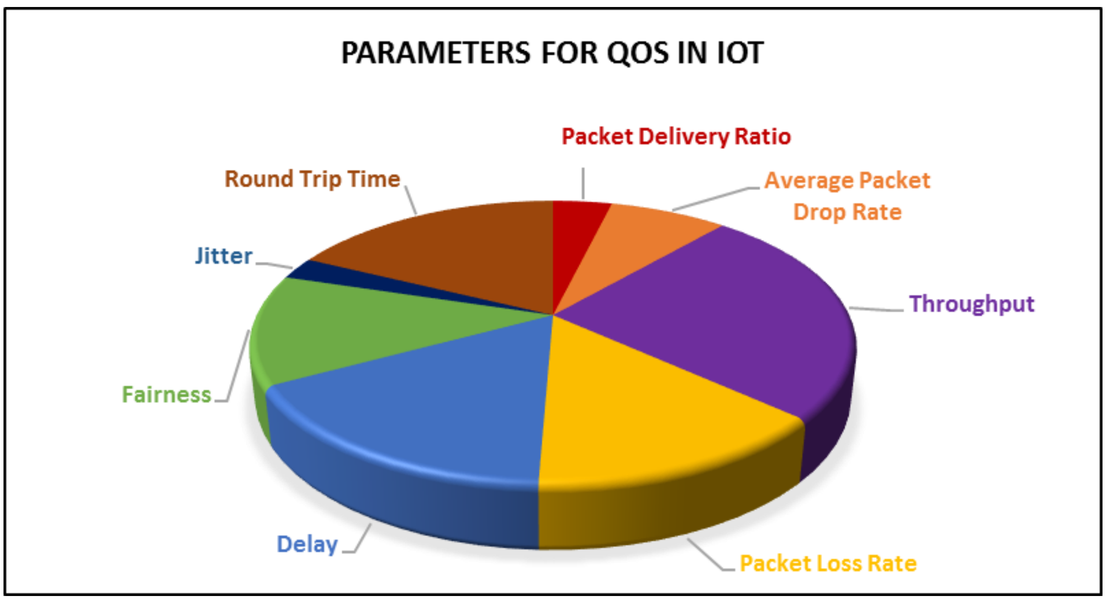

Figure 6 Parameters for QoS in IoT

5. DISCUSSION AND ANALYSIS

In the previous sections, we described the review methods for the TCP performance in IoT and MANET. In this section, a graphical representation of statistical data for in-depth analysis and discussion of various parameters is presented. In addition, the following analytical reports pertaining to the planned research questions in section 3 were presented:

RQ 1: What are the most significant QoS parameters to consider when analyzing the TCP performance over the MANET network?

Table 2 displays the QoS parameters that were evaluated while focusing on enhancing TCP performance in MANET. Figure 5 provides a detailed analysis. The majority of the reviewed literature had a strong emphasis on enhancing the TCP performance in MANET. On the other hand, others enhanced TCP performance by reducing latency, jitter, noise ratio, routing overhead, and packet loss rate while increasing throughput and PDR.

RQ 2: What are the most significant QoS parameters to consider when analyzing the performance of TCP in an IoT network?

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Table 4 displays the QoS parameters that were evaluated while focusing on enhancing TCP performance in IoT, while Figure 6 provides a detailed analysis. The majority of the reviewed literature had a strong emphasis on enhancing the TCP performance in IoT. On the other hand, others enhanced TCP performance by reducing latency, jitter, and packet loss rate while increasing throughput and PDR.

RQ 3: How are the paper publications related to TCP performance in IoT and MANET distributed throughout the year?

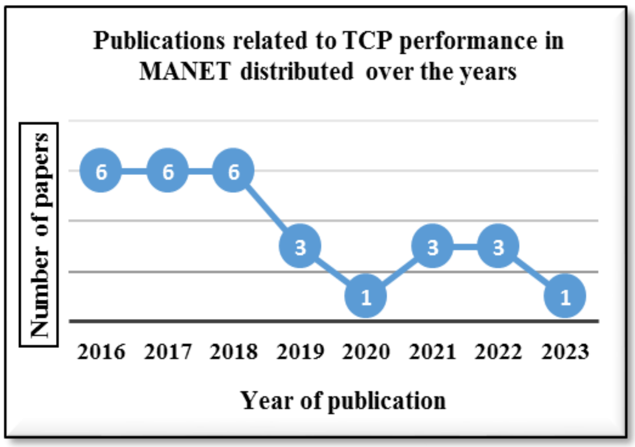

Figure 7 Dispersion Rate of Publications by Year for MANET from 2016 to 2023

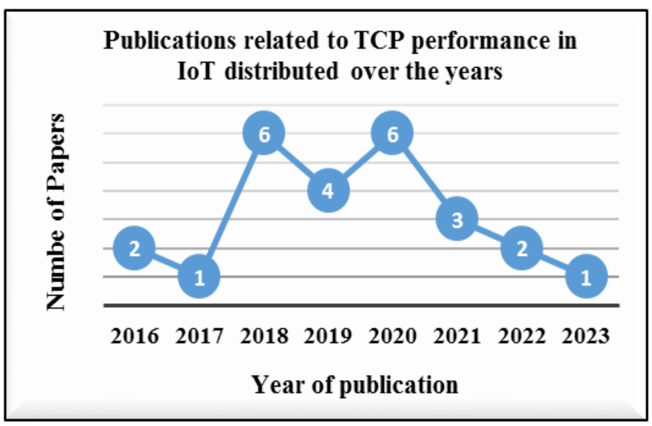

Figure 8 Rate of Publication over the Years for IoT from 2016 to 2023

Figures 7 and 8 depict the annual growth rate of TCP performance enhancement publications in the field of IoT and MANET, respectively. The paper publications related to TCP performance are distributed over the years after 2016. To analyze and obtain a comprehensive understanding of the domain, the selected papers primarily concentrated on the TCP performance enhancement over IoT and MANET. The growing rate of paper publications in TCP performance may be useful to future academicians in analyzing the research trend so that they can focus solely on their research accordingly in the future years.

RQ 4: How are the various paper publications related to TCP performance in different journals in the area of MANET and IoT spread throughout the years?

Based on the SLR, the majority of the research has been published in reputable journals such as Elsevier, Springer, IEEE, Hindawi, ACM, and MDPI. 55% of the published research came from magazines, conferences, and workshops, while the remaining 45% was published in reputable journals.

Table 5 Name of the Popular Journals

Publisher Name	Journal Name	Number of Publications Per Journal
ACM	IEEE/ACM Transactions on Networking	1
Elsevier	Internet of Things Journal	1
Elsevier	Computer Communications	1
Elsevier	Future Generation Computer Systems	1
IEEE	Journal of Communications and Networks	1
IEEE	IEEE Access	1
MDPI	Sensor	3
IEEE	IEEE Internet of Things Journal, IEEE Internet Computing	3
MDPI	Electronics	2
Springer	Cognitive Informatics and Soft Computing, Wireless Personal Communication, Wireless Networks, Cluster	4
Springer	Recent Advances in Artificial Intelligence and Data Engineering, Progress in Intelligent Computing Techniques: Theory, Practice, and Applications	2
Hindawi	Security and Communication Networks, Mobile Information Systems	2
Hindawi	Wireless Communications and Mobile Computing	2

Table 5 shows the top journals from top publishers that have been identified based on their TCP performance in the IoT and MANET fields. These journals include the Internet of Things Journal, Computer Communication, and Future Generation Computer Systems. The researcher is capable of identifying the popular journal that regularly publishes the most recent findings from research, establishing a research group, and properly communicating submissions. In favor of searching in renowned databases, it is possible to conduct an efficient search by examining relevant topics in a reputable journal.

RQ 5: Which tools or platforms are commonly used in the process of evaluating the performance of TCP?

Figure 9 depicts the tools or platforms that were utilized in TCP performance research in order to provide researchers with an idea for potential future work. NS-2, NS-3, MATLAB, OPNET, Raspberry Pi, etc. are some of the simulation tools that can be used to implement TCP performance in IoT and MANET. NS-2 is the most extensively used simulation tool for analyzing the performance of TCP in IoT and MANET. Around 51% of the work was evaluated and implemented using NS-2 for TCP performance enhancement. Approximately 17% of the work was evaluated and implemented using NS-3. Around 4% used OPNET simulator, iperf & nc and 2% used ESP8266, MATLAB simulator, and Raspberry Pi.

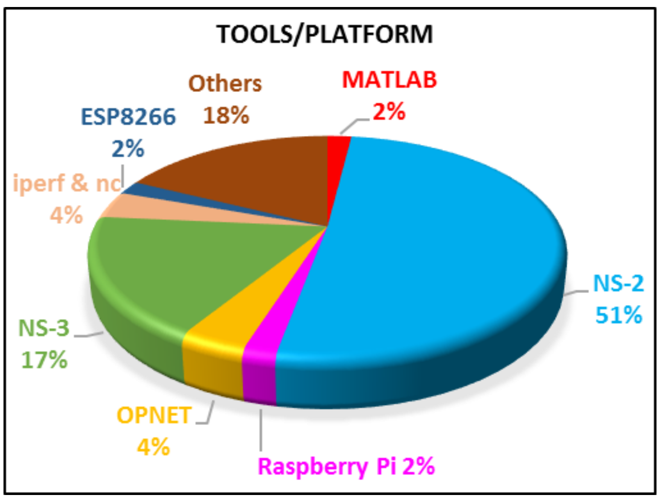

Figure 9 Tools/Platforms Used for Implementation and Evaluation of TCP Performance

RQ 6: What are the open issues and existing challenges that TCP faces in IoT? What are the probable solutions to alleviate these issues?

TCP is still utilized as the transport layer protocol for the IoT, but its performance has degraded over time when utilized over such networks [79]. It is only due to the nature of the IoT which is full of challenges given below:

- Congestion and packet loss are the primary problems that arise in IoT environments [80]. It is a widely known issue that TCP performs sub-optimally when there are non-congestion losses. Several TCP variants i.e. TCP Tahoe, Reno [81], New Reno [82], Vegas [83], Westwood [84], etc. have been proposed to alleviate this issue.
- The header overhead issue of TCP in IoT networks refers to the problem of the large size of TCP headers relative to the payload size of data packets. This can result in increased network congestion, increased latency, and reduced network throughput due to increased packet fragmentation and retransmission. To address the header overhead issue of TCP in IoT networks, several approaches have been proposed. One approach is to use header compression techniques such as Robust Header Compression (ROHC) or Header Compression for IPv6 (HCIPv6) and the TCP/IP header compression algorithms defined in RFC 1144 [85]. These compression techniques reduce the size of the TCP header by removing redundant information and compressing the remaining information. The technical aspects of TCP header compression are well-established, but the decision to use it in a specific IoT deployment is still an open issue that requires careful consideration and evaluation of the specific requirements and constraints of the network and devices involved.
- In IoT networks, high latency can be a significant issue for TCP connections, particularly for real-time applications that require low-latency communication. In IoT networks, where devices may have limited resources and operate in low-power and high-latency environments, TFO can be useful for addressing latency issues. TCP Fast Open (TFO) is a protocol extension for TCP that is designed to reduce the latency of establishing a TCP connection [86]. However, it is important to note that TFO is not a complete solution for addressing high latency in IoT networks. Other factors, such as network congestion, signal interference, and limited bandwidth, can also contribute to latency issues. Additionally, TFO may not be appropriate for all types of IoT applications, particularly those that require high levels of security or that transmit sensitive data.
- Since TCP is unicast; hence it cannot be used as a transport-layer multicast protocol. To address the Multicast Incompatibility issue of TCP in IoT networks, several approaches have been proposed. One such modification is the use of TCP-Friendly Multicast Congestion Control (TFMCC) [87] and Other TCP modifications include the use of the Explicit Multicast Congestion Notification (EMCN) [88] protocol.
- Numerous IoT link-layer protocols employ ARQ; if a link continues to suffer quality degradation, then the link-layer ARQ method may perform retries, which will result in an increase in end-to-end delay and may also cause spurious TCP retransmissions [89].

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- The well-known RTO algorithm is used by TCP [90]. But, this method was not created with IoT applications in consideration. The CoCoA [91], however, was created for IoT applications. In spite of the fact that it is founded on the TCP RTO algorithm, it additionally makes use of weak RTTs, dithering, an aging mechanism, and variable backoff factors. Several other algorithms have been proposed to alleviate this RTO issue are CoCoA+ [92], CoCoA++ [93], CACC [94], Improved Adaptive Congestion Control [95], FASOR [96], etc.
- TCP has frequently been viewed by the IoT community as a complex protocol. The protocol complexity of TCP in IoT networks is a significant issue that can impact the performance and scalability of the network. The complexity of the TCP protocol can arise from various factors, such as the overhead of the protocol, the number of control messages exchanged, and the processing requirements of IoT devices. Several researchers have proposed many low-overhead TCP variants that reduce the amount of protocol overhead and control messages required to manage TCP connections. Examples include TCP-LP [97] and TCP-BBR. Many researchers have proposed adapting the TCP protocol to better suit the requirements of IoT networks. One potential approach involves the utilization of machine learning algorithms to optimize TCP parameters by taking into account the prevailing network conditions and available device resources.

RQ 7: What are the open issues and existing challenges of TCP in MANET? What are the probable solutions to mitigate these issues?

TCP encounters numerous issues over MANET. It was designed in the first place for secure wired connections or wireless networks with a fixed architecture, both of which minimize the number of propagation losses. TCP suffers from degradation in MANET for a variety of reasons, including:

- Route partition and breakage occur due to the dynamic nature of MANETs. One solution is to use proactive routing protocols such as OLSR [98], which maintain a routing table at each node, even if there is no data to be transmitted. This reduces the time required to discover routes and avoids delays caused by route discovery. Another solution is to use reactive routing protocols such as AODV [99], which discover routes only when needed, thus reducing network overhead.
- The hidden node terminals problem occurs when two or more nodes cannot detect each other's transmissions due to being out of range. One solution is to use CSMA with CA mechanisms, such as the IEEE 802.11 standard. High BER occurs due to the wireless nature of MANETs, which are prone to interference and signal attenuation. One solution is to use error-correcting codes such as FEC or ARQ to correct or retransmit lost packets [100]. Another solution is to use adaptive modulation and coding (AMC) [101], which adjusts the transmission parameters according to the channel quality to improve reliability.
- In MANET, nodes move around, and the network topology changes frequently, leading to high latency and packet loss. TCP utilizes end-to-end acknowledgement as a means of guaranteeing reliable data transfer. However, the occurrence of frequent packet loss can result in retransmission timeouts and longer data transfer times. One solution is to use delay-tolerant protocols such as the Bundle Protocol (BP) [102], which can cope with intermittent connectivity and high delays by forwarding bundles through intermediate nodes. Another solution is to use CC mechanisms such as TCP Vegas or TCP Westwood, which adjust the cwnd based on the measured RTT and packet loss rate.
- Fairness is an important issue with TCP Variants over MANET. Some TCP variants in MANET may exhibit unfair behavior, resulting in some flows dominating the network resources while others are starved of bandwidth. This can occur due to differences in the CC mechanisms used by the TCP flows, leading to one flow sending more packets than another. By employing solutions such as ECN [103], bandwidth estimation, congestion control algorithms, cross-layer approaches, and load balancing, it is possible to improve fairness and optimize network performance in MANET.
- MANETs have limited bandwidth, and when nodes move toward each other, congestion occurs, leading to packet drops and increased latency. One solution is to use TCP variants with CC mechanisms that can adapt to changing network conditions, such as TCP SACK [104], TCP New Reno, or TCP CUBIC [105]. Another solution is to use adaptive routing protocols that can dynamically adjust the network topology to avoid congestion, such as the AODV protocol.
- In MANET, nodes are typically battery-powered, and TCP's high packet retransmission rate can quickly deplete the battery life of the nodes. One solution is to use energy-efficient MAC (Media Access Control) protocols such as IEEE 802.11 Power Saving Mode (PSM) [106], which minimizes power consumption by allowing nodes to switch to sleep mode when idle. Another solution is to use energy-aware routing protocols that can route packets through nodes with more battery life.
- MANET nodes are vulnerable to various types of security threats, such as Denial of Service (DoS) attacks and misbehavior. A potential solution involves the implementation of secure routing protocols, such as Secure

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AODV (SAODV) [107] and Secure Efficient Ad hoc Distance Vector (SEAD) [108], which use digital signatures and encryption to authenticate nodes and prevent attacks. Another solution is to use intrusion detection systems (IDS) [109] that can detect and respond to attacks in real time.

- The functioning of TCP algorithms is dependent on the interpretation of packet loss as a signal of network congestion. In the context of shadow nodes, packet loss may arise as a result of collisions or other factors, leading TCP algorithms to interpret it as a buffer overflow on the intermediate node. This can result in unnecessary retransmissions and congestion, reducing network performance and efficiency. By implementing solutions such as adaptive rate control, dynamic path selection, cross-layer optimization, and hybrid protocols, it is possible to enhance network performance and efficiency in the existence of shadow nodes.
- The routing path in a MANET from the source node to the destination node may differ from the path taken by the data packets from the destination node back to the source node. This phenomenon is referred to as asymmetric routing, and it can present a significant challenge for communication protocols that are based on TCP. By implementing solutions such as explicit acknowledgment messages, multipath routing, selective acknowledgments, and cross-layer optimization, it is possible to minimize the impact of asymmetric routing and enhance the reliability and efficiency of the network.
- In MANET, packets can be lost due to various reasons such as link failures, node mobility, interference, and congestion. When a packet is lost, the TCP decreases the congestion window in half because it assumes the window is too large. This leads to a decrease in the sending rate, which can result in lower network throughput and increased delay. To address this issue, TCP variants have been proposed that use different techniques to handle unacknowledged packets, such as TCP Westwood, and explicit feedback mechanisms like ECN and SACK.
- In MANET, delayed ACK packets can result in an inaccurate estimation of the communication line delay, which can result in poor network performance. TCP variants have been proposed that use different techniques to handle delayed ACK packets, such as TCP New Reno, SACK, and FACK [110]. These techniques can help to enhance the performance of TCP over MANET by minimizing congestion and improving network throughput.
- In a MANET, the existence of multiple paths connecting two nodes may lead to the transmission of data packets in a non-sequential order. This phenomenon can have adverse effects on the network's performance, leading to increased power consumption, congestion control activation, and overall degradation of the system's efficiency. Numerous potential solutions to this issue have been suggested, including the implementation of sequence numbers, selective retransmission, and explicit feedback mechanisms. The implementation of these techniques can effectively optimize the performance of TCP in MANETs by reducing unnecessary retransmissions and mitigating congestion control activation.
- The dynamic nature of MANETs can make it difficult for TCP to make an accurate assessment of the channel's status. However, different solutions to this problem have been proposed, such as cross-layer design approaches. TCP variants are designed for MANETs such as TCP-ELFN (Explicit Link Failure Notification) [111] and TCP-Vegas, and adaptive routing protocols such as AODV and DSR [112]. The implementation of these solutions can potentially enhance the efficiency of TCP in MANETs by furnishing precise insights into the network's condition and facilitating well-informed determinations regarding congestion control.

RQ 8: What are the potential of future research directions into effectiveness on TCP performance in IoT and MANET?

TCP performance enhancement in IoT and MANET is a crucial research area as these networks are highly dynamic and heterogeneous in nature. This section addresses potential future directions after conducting an analysis of the pre-existing problems and research gaps.

- Cross-layer optimization: It involves collaboration among different layers of the protocol stack to enhance the performance of the entire network. In the case of TCP in IoT, cross-layer optimization can be achieved by integrating routing and transport layer protocols to reduce packet loss and delay.
- Adaptive congestion control: Due to their sensitivity to packet loss, traditional CC algorithms, such as TCP Reno and TCP New Reno, are not suitable for IoT and MANET environments. Adaptive CC algorithms that can adjust their behavior based on network conditions, such as network load and link quality, can improve TCP performance in these environments.
- Machine learning-based approaches: They can be used to predict network conditions and adapt TCP performance accordingly. For instance, reinforcement learning algorithms can be used to train TCP to adapt to changing network conditions and optimize its performance.
- Multipath TCP: It allows TCP to send and receive data over multiple paths simultaneously. MPTCP can improve TCP performance in IoT and MANET by utilizing

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multiple paths to reduce congestion and increase throughput.

- Energy-efficient TCP: Energy efficiency is a critical concern in IoT and MANET environments where nodes are often battery-powered. Energy-efficient TCP algorithms can reduce energy consumption by minimizing unnecessary transmissions and adjusting the transmission rate based on node battery level.
- Security-aware TCP: Security is a critical concern in IoT and MANET environments where nodes are often untrusted and vulnerable to attacks. Security-aware TCP algorithms can ensure the integrity and confidentiality of data transmission by incorporating security measures such as encryption and authentication.

Overall, future research in TCP performance enhancement in IoT and MANET should focus on developing adaptive, energy-efficient, and secure TCP algorithms that can operate effectively in highly dynamic and heterogeneous network environments.

6. CONCLUSION

This review presented SLR-based research on enhancing the performance of TCP over MANET and IoT. Throughout this review, a comprehension understanding of TCP, MANET, and IoT was accomplished, along with considerations of open issues. In this review work, we showed the SLR-based procedure by using the exploration query on a total of 346 publications that had been published between the years 2016 and 2023. Finally, we analyzed 54 publications that focused on enhancing the performance of TCP over MANET and IoT. Regarding the SLR-based technique, it's possible that we haven't gone through all of the previous research and examined it. Consequently, the research that provided review, and survey articles was not included. In this review, we conducted an in-depth investigation of the TCP performance enhancement strategies by analyzing the findings of over 100 authors and studies. In spite of the growing number of studies in this field, it is not possible to guarantee that all of the studies were covered, because the research was limited to the years 2016 to 2023. The vast majority of the studies that have been carried out to evaluate the performance of TCP have done so by measuring throughput, delay, and the ratio of packets delivered. This Systematic literature review focuses on the conceptual aspects of TCP performance in the IoT and MANET environments. Moreover, this research will assist researchers and specialists in conducting subsequent analyses of their general understanding of this field.

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