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RESEARCH ARTICLE

A Novel Dynamic Message Time Synchronization Protocol for Real Time Data Exchange in Vehicular Ad Hoc Networks

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Abstract – Vehicular Ad Hoc Networks (VANETs) have become a vital technology to improve road safety and traffic control. In the context of VANETs, precise time synchronization among vehicles is paramount to enable effective real-time data exchange. This research introduces a novel Dynamic Message Time Synchronization (DMTS) protocol designed to optimize timing message coordination in large-scale VANETs. DMTS employs an intelligent selection mechanism to identify the most suitable time synchronization nodes, significantly reducing the number of transmitted timing messages. To ensure robust synchronization, the protocol periodically readjusts the clock offset of interconnected vehicles, enhancing synchronization accuracy. Leveraging a bidirectional timing message synchronization approach, the Maximum Likelihood (ML) estimation for clock offset design is derived, assuming a Gaussian noise model. Through comprehensive simulation analyses, the effectiveness of the DMTS protocol is validated, considering key performance metrics such as delay, packet delivery ratio, and throughput. The proposed DMTS protocol achieves 19.58% and 28.12% less delay in comparison with ABTS and STETS protocols. In terms of packet delivery ratio, it achieves 12.55% and 33.70% improvement when compared with ABTS and STETS protocols. Finally, there is an increase in throughput performance of proposed DMTS by 26.71% and 48.10% with its counterpart protocols. These results demonstrate the superiority of DMTS over existing protocols, making it a promising solution for real-time data exchange in VANETs, with implications for improved road safety and traffic efficiency.

Index Terms – DMTS Protocol, Time Synchronization, Clock Drift, Clock Offset, Clock Skew, Maximum Likelihood.

1. INTRODUCTION

In the last decade, the introduction of Vehicular Ad Hoc Networks (VANETs) has spurred substantial research interest. Within the VANET system, communication occurs among communicating nodes comprising both vehicles and roadside units (RSUs), primarily facilitating the exchange of crucial road traffic information [1], notably related to road safety. VANETs are provided with these communicating nodes, enabling the transmission and reception of beacon messages over wireless channels through the Medium Access Control protocol. This infrastructure is developed to enhance the reliability of communication among interconnected vehicles [2].

These beacon messages contain essential details about the transmitting vehicle, including its position, speed, and direction, thereby providing valuable insights into neighboring vehicles. However, the changing nature of the network topology in VANETs gives rise to connectivity problems and occasional communication failures, primarily due to the high relative speeds between vehicles [3-5]. In densely populated vehicular environments, vehicles often contend and interfere with each other in their competition for limited resources necessary for communication [6]. As a result, the protocol employed in VANETs must demonstrate reliability to optimize traffic efficiency.

Beacon message transmission is a fundamental aspect critical for optimizing vehicle-to-vehicle (V2V) connectivity within Vehicular Ad Hoc Networks (VANETs). VANETs represent a dynamic network where the connectivity landscape constantly changes due to vehicles entering and leaving the network, necessitating robust strategies for efficient data exchange and communication [7]. Achieving precise time synchronization is a cornerstone in the effective design of beacon message communication systems in VANETs.

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Accurate and synchronized time keeping is essential to vehicles within a VANET. It ensures that events and messages are timestamped accurately, allowing for seamless synchronization of actions and information exchange. Particularly critical for applications requiring real-time data sharing, such as collision avoidance and traffic management, precise time synchronization plays a vital role in the overall functionality and performance of VANETs [8-10].

To improve clock timing synchronization between interconnected vehicles in VANETs, a bidirectional message exchange mechanism has been widely used. This approach involves vehicles exchanging timing messages in both directions, allowing for better synchronization of their clocks. By periodically adjusting the clocks of connected vehicles, synchronization errors are minimized, leading to improved accuracy in beacon message timing and more efficient communication within the network [11].

Sophisticated methods, such as Maximum Likelihood (ML) estimation based on Gaussian delay models, have been explored to estimate clock skew. By employing ML estimation, clock skew estimation becomes more precise and reliable. This enhances the accuracy of beacon message facilitate efficient communication and coordination among timing synchronization, which is crucial for effective data exchange and coordination among vehicles in VANETs [12].

This paper introduces an innovative approach called a novel Dynamic Message Time Synchronization (DMTS) protocol, aimed at improving timing synchronization among interconnected vehicles within distributed Vehicular Ad Hoc Networks (VANETs). The DMTS algorithm employs a straightforward deterministic approach with very low estimation complexity. The DMTS algorithm utilizes the Time Division Multiple Access method to transmit beacon messages efficiently from the Cluster Heads (CHs) of vehicles to other members [13-15]. Every vehicle, upon receiving a beacon message, performs comparison with its timestamp with the information received from beacon message before forwarding it to neighboring vehicles. The DMTS algorithm stands as a potential game-changer in the realm of VANETs, promising enhanced communication, coordination, and system performance. The main objective of this research is to design a reliable DMTS protocol for real time data exchange to establish an efficient communication among the vehicles in Vehicular Ad hoc Networks as shown in Figure 1.

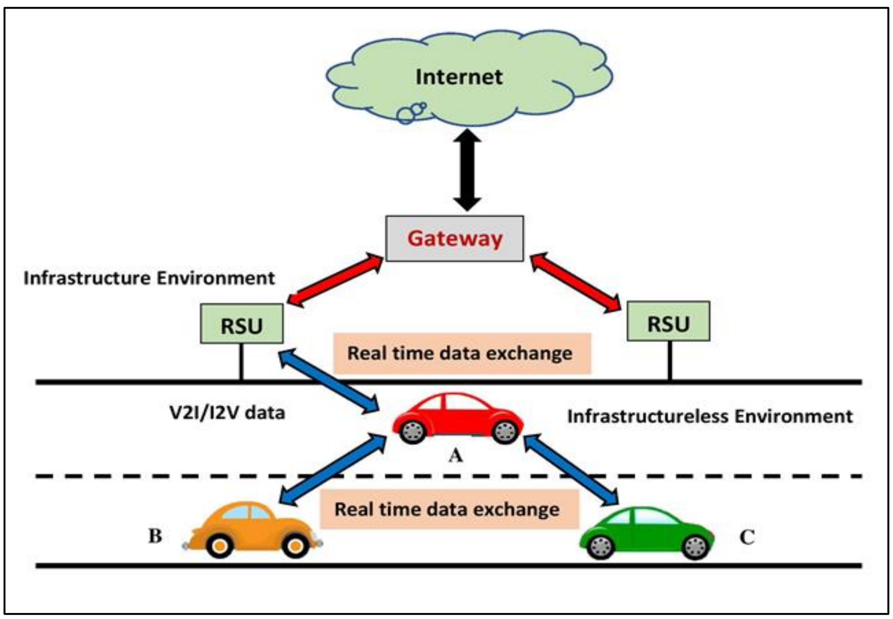

Figure 1 Real Time Data Exchange in VANETs

1.1. Problem Statement

To Design Routing Protocol with an Objective to Maximize Reliability for Real time Data Exchange using Time Synchronization in Vehicular Ad hoc Networks.

1.2. Contributions

The paper's key contributions can be outlined as follows:

1) An innovative DMTS algorithm is introduced to ensure dependable synchronization of timing messages within expansive, distributed VANETs.

2) The maximum likelihood (ML) is calculated for clock offset, utilizing a bidirectional timing message synchronization exchange model.

3) Lastly, the proposed technique is validated and a comparative analysis of the results is conducted against existing time synchronization protocols.

1.3. Organization

The next sections of this paper are structured as follows, outlining the subsequent sections and their respective content:

Section 2 contains the comprehensive study of the relevant literature pertaining to time based synchronization in Vehicular Ad Hoc Networks (VANETs). This review sets the stage for understanding the existing challenges, methodologies, and protocols in this domain. Section 3 elaborates on the proposed novel Dynamic Message Time Synchronization (DMTS) protocol. It provides an in-depth explanation of the protocol, including its design, algorithms, and mechanisms, highlighting how it addresses the identified challenges and enhances synchronization accuracy. Section 4 consists of simulated scenarios for the DMTS protocol. The outcomes of these simulations are thoroughly evaluated and discussed, considering delay, packet delivery ratio and throughput. This evaluation provides insights into the protocol's effectiveness under different conditions. Section 5 involves a comparative analysis about the DMTS protocol with existing and related time synchronization protocols. The comparison includes key aspects like delay, packet delivery ratio and throughput, offering a clear perspective on the advantages of DMTS. The final section, Section 6, serves as the conclusion of the paper. It summarizes the key contributions, discusses the implications of the findings, and outlines potential future research directions in the domain of time synchronization for real-time data exchange in VANETs.

2. RELATED WORK

Time synchronization is a basic requirement in Vehicular Ad Hoc Networks (VANETs) to enable precise and coordinated communication among vehicles, ensuring the efficient exchange of real-time data. This literature review focuses on exploring existing research related to time synchronization protocols in VANETs and sets the context for the proposed novel dynamic message time synchronization protocol.

H. Zhang et al. have introduced an effective cooperation mechanism that operates in a non-deterministic manner, aiming to minimize the associated cooperation costs [1]. In this mechanism, the cooperating nodes exchanges the data to establish communication. The advantage of this approach is that this mechanism ensures more than 78% efficient broadcast performance by selecting the most suitable collaborators but the at same time it is more challenging to precisely control and manage the cooperative broadcasting process.

P. Shukla et al. have introduced an approach to time synchronization [2]. The advantage of this method is efficient time synchronization which ensures a more efficient and organized time synchronization across the entire network. It provides 12% lesser delay and 15% more packet delivery ratio compared with the existing methods. The advantage of this method is efficient time synchronization which ensures a more efficient and organized time synchronization across the entire network. However, this approach heavily rely on the stability and effectiveness of the designated clusters.

H. Ateeq et al. have described a comparative study on existing time synchronization protocols for reliability [3]. The authors have demonstrated the requirement to improve the network parameters to gain reliability. This can be further compared with the newly designed routing protocols for efficiency. However, different machine learning techniques can be used further for comparison of routing mechanisms.

S. Johari et al. have proposed a strategy for channel allocation that prioritizes the selection of the most suitable Shared Control Channel (SCH) and maximizes the efficient utilization of resources [4]. Their proposed technique, employing a variable size Time Division Multiple Access (TDMA) strategy, takes into account a significant number of competing vehicles while ensuring collision-free allocation of resources. The reservation of time slot in the required SCH is 0.6 for the proposed technique and approximately 0.2 for other methods. However, implementing a variable size TDMA approach and ensuring collision-free allocation in a highly dynamic vehicular environment can introduce complexities and increase computational overhead.

J. Wu et al. have designed a TDMA based MAC protocols to provide efficient time synchronization among vehicles in VANETs [5]. This method is implemented in urban scenarios to establish an efficient communication in VANETs. It makes use of MAC protocol along with the TDMA mechanism. The advantage of this methodology is reduction among nodes in large scale VANETs but suffers with a drawback of high delay which needs to be addressed.

J. Liang et al. have proposed a time based synchronization mechanism designed for a Fog based Vehicular Ad Hoc Network (VANET) [6]. In this mechanism, a fog of clusters are used to provide direct communication within the coverage area. This mechanism focuses on achieving precise time synchronization accuracy of 81% but bidirectional message exchange and hardware-based frequency estimation can introduce complexity which needs to be addressed further.

S. Haider et al. have introduced an innovative technique called V2V Local Clock Synchronization (VLCS) based on clustering, aiming to synchronize all nodes within a VANET to a unified shared clock [7]. In this methodology, vehicle to vehicle communication can be implemented by using non time synchronization mechanism. The advantage of this method is efficient synchronization through clustering with a precision of approximately 69% but the drawback is it relies on accurate clustering which is sensitive to clustering changes.

J. A. Ansere et al. have proposed an Adaptive Beacon Time Synchronization (ABTS) algorithm aimed at improving the synchronization of timing messages [8]. ABTS achieves 10.62% less delay in comparison with STETS protocol. In terms of PDR, it achieves 18.78% improvement. Finally, there is an increase in throughput performance of ABTS by 16.87% with its counterpart protocol. The advantage of this methodology is the optimized synchronization by selecting suitable pairs thereby reducing message count but requires periodic clock adjustments which will potentially impact energy efficiency.

J. Wu et al. have presented a test bed system based on MAC protocols which relies on distributed TDMA concepts [9]. The advantage of this method is the time synchronization can be done simultaneously among multiple nodes. All the participating nodes must collaborate with each other for effective communication. However, once the set of nodes increases, this methodology becomes less efficient in terms of packet delivery ratio.

A. M. Salih et al. have proposed an innovative timing based synchronization scheme for communication systems utilizing OFDM[10]. This strategy utilizes phase shifts and power differences for timing synchronization with an accuracy of 81%. This method still cannot provide a reliable routing based on time synchronization mechanism. However, specific application in the physical layer of VANETs may limit extensive use of this approach.

G. Han et al. have proposed an effective approach for ensuring dependable transmission of beacon messages using multi-hop relays, thereby enhancing vehicle node connectivity efficiently [11]. According to the authors, This approach enhances vehicle node connectivity efficiently using multi-hop relays up to 11.25% but specific focus on beacon message transmission may limit versatility in addressing broader VANET communication challenges.

J. Adu Ansere et al. have addressed the critical challenges of reliability and energy efficiency in spectrum sensing for CR Internet of Things networks [12]. The authors have proposed a framework aimed at achieving reliable and energy-efficient spectrum sensing, contributing to the enhancement of spectrum utilization in IoT environments. However, this approach is not suitable for large scale VANETs.

I. V. Martin-Faus et al. have proposed Markov-Reward models to conduct a momentary examination of idle time within Vehicular Ad Hoc Networks (VANETs) [13]. During the simulation, it achieves an average delay of approximately 1.6 ms, PDR of 1.81 ms and throughput of 47.4 bps for 10 scenarios. The advantage of this approach is efficient time synchronization but the authors have addressed limited discussion on broader synchronization challenges.

W. Lai et al. have presented a study focused on the analysis of packet loss rate in vehicular networks[14]. According to the authors, there is decrease in the dynamics of packet loss in the context of VANETs, a critical aspect for reliable and efficient communication in vehicular environments. Through their examination of the average packet loss rate, the authors contribute valuable insights to the understanding of communication challenges in VANETs, providing essential groundwork for improving the robustness and performance of communication protocols in vehicular networks. But their methodology requires an efficient time synchronization.

J. Guo et al. have proposed a sender and receiver synchronization mechanism among interconnected vehicles [15]. The advantage of this approach is that the synchronization accuracy can be enhanced but not suitable for scalable VANETs. In the simulation, it achieves a synchronization accuracy of 79% which is considerably less for real time data exchange..

G. Han et al. have presented that time synchronization's effectiveness relies on accurate clock timing, leading to a significant reduction in communication overhead, ultimately improving the trade-off between energy consumption of 37% and synchronization accuracy of 82% [16]. The current paper delves into the utilization of beacon messages to enhance time synchronization within VANET systems.

G. Han et al. have proposed a Privacy Protection Scheme for Wireless Sensor Networks [17]. The authors have introduced an innovative approach to safeguarding location privacy, employing k-Means clustering. This scheme contributes to the evolving field of securing sensitive information in WSNs within the context of the Internet of Things but it is not reliable to attain synchronization among cluster of many vehicles. However, the k-means clustering cannot be used in case of high density nodes in VANETs.

G. Han et al. have proposed a novel Hierarchical Charging Algorithm for Wireless Sensor Networks [18]. The authors have addressed the challenge of energy replenishment in WRSNs through a hierarchical charging approach that prioritizes coverage. The paper contributes to the efficiency of WRSNs by optimizing energy replenishment strategies. However, it is not suitable for large scale VANETs.

In [19], a cross-layer approach was utilized to effectively send backup messages in VANETs. The authors explored the FTSP to reduce synchronization flaws, aiming to improve the transmission of beacon messages. This approach has a drawback of low PDR of 1.5 ms which needs to be addressed. To increase the PDR, a reliable time synchronization protocol is needed which can be design in this research work.

H. Wang et al. have contributed to the field of Wireless Sensor Networks (WSNs) with their work on ML Estimation of Clock Skew [20]. The authors have focused on WSNs with regular clock corrections. They also have presented a robust methodology for accurately estimating clock skew, addressing the challenges posed by periodic corrections and exponential delays in wireless sensor environments. However, considerable delay exists due to inaccurate time synchronization.

F. Bellili et al. have proposed a technique of time synchronization in wireless communication systems with their work on TSTC Square QAMM Transmissions [21]. The authors have presented a novel approach incorporating a code-aided Maximum Likelihood estimator and closed-form C–R Lower Bounds. This cannot be implemented in urban situations.

V. Nguyen et al. have introduced a MAC protocol based approach), aiming to eliminate extra packets present in the HER-MAC protocol [22]. This protocol significantly enhances the transmission of real-time safety up to 78% and emergency messages up to 67% across various channels but lacks a real time synchronization feature. This real time capability can be addressed in the present research work.

Y. Y. Nasrallah et al. have proposed a distributed time synchronization approach focusing on the bidirectional timing synchronization system for communication among cluster nodes [23]. The bidirectional mechanism performs well for a limited set of nodes but cannot be used for large VANETs. The advantage of this approach is increase in transmission efficiency of approximately 78.56% and at the same time encountered the issue of packet drop by 10.12%.

C. Li et al. have addressed the critical issue of connectivity probability in vehicular networks by considering the minimum safety distance [24]. The authors have investigated the connectivity analysis in VANETs. The study provides insights into the impact of minimum safety distance on the likelihood of connectivity among vehicles in VANETs. However, this method is not suitable when the distance increases.

R. Zhang et al. have contributed to the advancements in vehicular networks with their work on scheduling based protocol [25]. The authors have proposed a Time Division Multiple Access protocol for VANETs. The TDMA approach works well for low density nodes. This protocol is designed to enhance the efficiency of communication scheduling in dynamic vehicular environments but it is not suitable for large VANETs.

B. Hassanabadi et al. have designed a method for retransmitting safety messages within a coded network [26]. This approach enhances the reliability of message transmission, effectively addressing collision issues stemming from congestion and lossy channel in Vehicle-to-Vehicle (V2V) channels. In the simulations, it achieves a delay of 3.2 ms, PDR of 1.6 ms and throughput of 35 bps. However, it is not appropriate for scalable VANETs.

N.P Chandrasekharamenon et al. have described the connectivity in fading channels [27]. The authors have focused on measuring the connectivity aspects of VANETs within a one-dimensional framework, considering the influence of fading channels. This study contributes valuable insights into understanding the challenges and dynamics of communication link reliability in one-dimensional vehicular networks.

S. Wang et al. have conducted an evaluation of RBS methodology [28]. In this evaluation, the source node transmits a reference broadcast message multiple adjacent interconnected vehicles and manages the “local timestamps” upon receiving responses to the transmitted message. This method works well with limited set of nodes but cannot be implemented efficiently in large VANETs.

In VANET applications, DSR Communication is utilized to facilitate efficient Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) technologies. R. Ben-El-Kezadri et al. have investigated the system's performance with the utilization of communication efficiency [29]. This method integrates GPS to synchronize timestamps and improve system performance but the timestamps accuracy needs to be improved.

J. Zheng et al. have proposed their work on JTS and Localization of an Unknown Node [30]. The authors have presented an integrated approach to both synchronization of time and localization for an unknown node in WSNs. Their joint methodology addresses the challenge of accurately determining both temporal and spatial information in wireless sensor networks. Although, it suffers with the drawback of high delay and low throughput.

L. Jin et al. have proposed inter-vehicle communication systems through their work on multihop connectivity model [31]. The authors have presented an analytical model that addresses the multihop connectivity aspects of inter-vehicle communication systems. This model provides insights into the factors influencing connectivity in vehicular networks, offering a quantitative understanding of the reliability and performance of multihop communication. However, this methodology has slight overhead in synchronization setup which needs to be addressed.

In practical applications, achieving precise timing message synchronization is challenging for RBS, TPSN, and STETS protocols, especially in high-energy network topologies. The extended propagation delays and complex algorithms of these protocols result in substantial energy consumption. To address this, C. King-Yip et al. have designed a CT Synchronization

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Protocol that emphasizes scalability and robustness, particularly catering to highly dynamic traffic flow [32]. The objective of this protocol is to minimize the period of inactivity between control and service channel by optimizing synchronization efficiency. This method prioritizes scalability and robustness, catering to highly dynamic traffic flow but lacks accurate timing synchronization between messages.

Hence, a reliable time synchronization protocol is needed to provide real time data exchange in Vehicular Ad hoc Networks that can be used to establish an efficient communication mechanism among all the vehicles in real time.

The summary of the related works is shown in Table 1.

Table 1 Summary of Related Works

Author & Reference	Proposed Methodology	Advantages	Disadvantages
H. Zhang et al. [1]	Effective cooperation mechanism among nodes	Suitable in urban conditions	Not suitable in highway roads
P. Shukla et al. [2]	Organized time synchronization between sender and receiver nodes	Efficient time synchronization	Depends on the stability and effectiveness of the designated clusters
H. Ateeq et al. [3]	Comparison of time synchronization protocols	Selection of desired protocol based on network parameters	Complexity arises because of different road conditions
S. Johari et al. [4]	Channel allocation model	Efficient utilization of resources	Increased computational overhead
J. Wu et al. [5]	TDMA based time synchronization	Reduction among nodes in large VANETs	High delay in synchronization
J. Liang et al. [6]	Accurate time synchronization methodology	Precise time synchronization accuracy	Bidirectional message exchange
S. Haider et al. [7]	VLC synchronization based on clustering	Suitable for vehicle to vehicle synchronization	Sensitive to clustering changes
J. A. Ansere et al. [8]	Adaptive Beacon Time Synchronization	Suitable for small scale VANETs	Not suitable in Highway conditions
J. Wu et al. [9]	Testbed system based on MAC	Time synchronization among multiple nodes is possible	Less packet delivery rate
A. M. Salih et al. [10]	Timing synchronization scheme using OFDM	Utilizes phase shift approach	Loss of packets
G. Han et al. [11]	Transmission of beacon messages using multi-hop relays	Enhanced vehicle node connectivity	Not suitable for large VANETs
J. Adu Ansere et al. [12]	Dynamic spectrum sensing	Accurate message synchronization	Not applicable in dense VANETs
I. V. Martin-Faus et al. [13]	Momentary examination of idle time	Idle time is reduced among nodes	Less accurate in urban situations
W. Lai et al. [14]	A Multi-hop broadcast technique	Improved packet delivery ratio	Computational overhead
J. Guo et al. [15]	SRS and RRS approach for time synchronization	Suitable for small scale VANETs	Not suitable for large VANETs
G. Han et al. [16]	Accurate clock timing approach	Less communication overhead	Moderate to High delay in transmission

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G. Han et al. [17]	Location based Privacy Protection Scheme	Enhances the identification of nodes for communication	Time synchronization is not accurate
G. Han et al. [18]	CA Hierarchical Charging Algorithm	Applicable for small set of nodes	Not reliable for large set of nodes
H. Guan et al. [19]	FTSP protocol	Reduces synchronization errors	High energy consumption
H. Wang et al. [20]	ML estimation of Clock skew	Periodical clock correction	Considerable delay in synchronization
F. Bellili et al. [21]	Turbo-Coded Square QAM Modulated Transmissions	Suitable for urban VANETs	Not suitable on Highways
V. Nguyen et al. [22]	A TDMA/CSMA approach	Removes duplicate packets	Lacks a real time synchronization feature
Y. Y. Nasrallah et al. [23]	Bidirectional timing message synchronization system	Increase in transmission efficiency	High packet drop rate
C. Li et al. [24]	Connectivity probability by using safety distance	Suitable for nearby nodes	Not suitable if the distance between the nodes increases
R. Zhang et al. [25]	Scheduling Protocol based on TDMA	Suitable for small scale VANETS	Not suitable for dense VANETs
B. Hassanabadi et al. [26]	A method for retransmitting safety messages within a coded network	Enhances reliability of message transmissions	Moderate delay in transmission
N.P Chandrasekharamenon et al. [27]	One dimensional VANETs	Suitable for large number of vehicle nodes	Less accuracy in exchange of data
S. Wang et al. [28]	RBS and TPSN protocols	Works in multi-hop architecture	Not applicable for standalone nodes
R. Ben-El-Kezadri et al. [29]	Physical time stamps synchronization	Enhances utilization efficiency	Less time stamps accuracy
J. Zheng et al. [30]	Joint time synchronization model	Both time synchronization and localization are possible	High delay and low throughput is observed
L. Jin et al. [31]	Analytical Model based on Multihop Connectivity	Suitable for multi-hop network	Slight overhead in synchronization setup
C. King-Yip et al. [32]	CTSP Protocol	Reduces inactivity between control and service channel	Lacks accurate timing synchronization between messages

3. THE PROPOSED DMTS PROTOCOL

3.1. Synchronization Assumptions

This paper is based on specific assumptions to ensure a synchronized timescale for all vehicles, enhancing “time synchronization in large-scale VANETs”. The key assumptions are as follows:

- Each vehicle within the VANET acts as a node, capable of transmitting its local message and receiving beacon messages from other vehicles.
- All vehicles keep track of their local time.
- Every vehicle is assigned a distinctive symmetric localization Identifier to prevent collisions and conflicts.

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- The distribution of each vehicle is random, and each one is outfitted with Global Positioning System (GPS) or RFID technology capabilities to ascertain their current location, speed, and direction.

The Figure 2 shows the variations in clock offsets of three nodes A, B & R respectively.

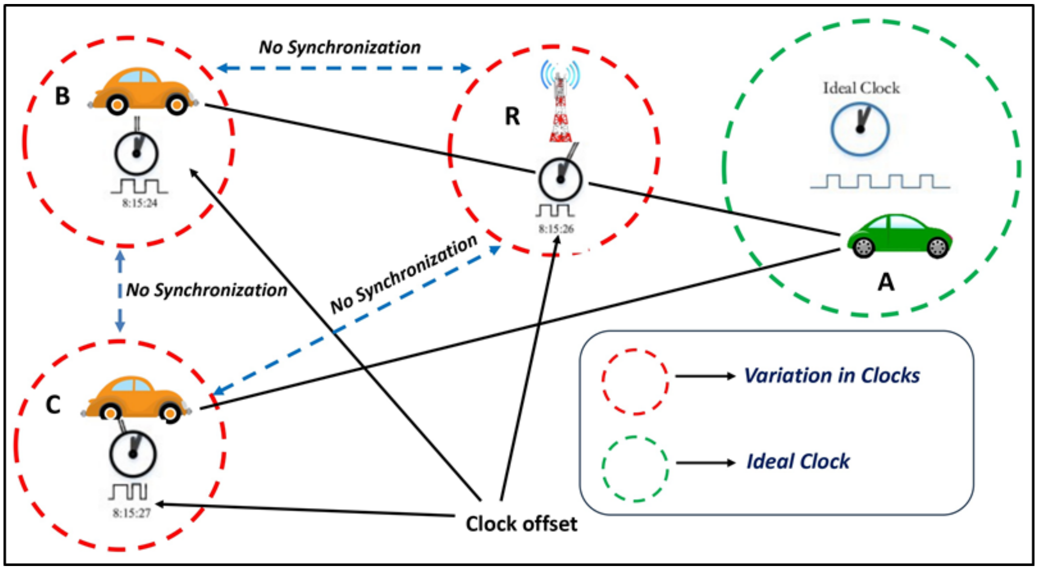

Figure 2 The Clocks of Nodes B, C and R Showing Variations in their Local Time

3.2. Clock Model

The distributed large VANET consisting of "L vehicles" is examined. Each vehicle is treated as a node equipped with its own clock, crucial for precise synchronization with other vehicles clock to enable reliable beacon message exchanges within the range across the network. Ideally, the aim is to configure the vehicle's clock (CLK) such as CLK(tr) = tr, where tr denotes the time to be referred. The clock is conceptualized as a software clock functioning as a timer to judge sequential oscillations as shown in Figure 3. In practical scenarios, achieving high precision in clocks is essential to minimize variations in clock, thereby enhancing Vehicle-to-Vehicle (V2V) communications. An ideal clock incorporates a quartz-stabilized oscillator. Considering the persistent drifting of clocks and errors associated with the clock oscillator, the clock function for the j^{th} node is represented as CLK(tr) = Ø + €tr + η, where Ø signifies "clock offset", € represents clock skew, and η denotes Gaussian noise. Consequently, the parameters of the clock are defined as follows:

1) Clock Offset (Ø): Clock offset (Ø) refers to the discrepancy or difference in time between a local clock on a device or system and a reference or standard time. In other words, it represents the difference in time between the device's clock and the ideal or true time. For a given time tr>=0, the clock offset CLKi given by a vehicle is calculated as CLKi(tr) - tr. The relative offset of clock between clocks CLKi and CLKj at tr>=0 is defined as CLKi(tr) - CLKj(tr).

2) Clock Skew (€): Clock skew (€) represents the discrepancy in frequencies of clock compared to real time. The clock skew between CLKi and CLKj can be represented as CLKi′(tr) - CLKj′(tr) at a given time tr.

3) Clock Drift: It refers to the rate of change in the clock offset over time. It indicates how much a clock's frequency deviates from the ideal or expected frequency.

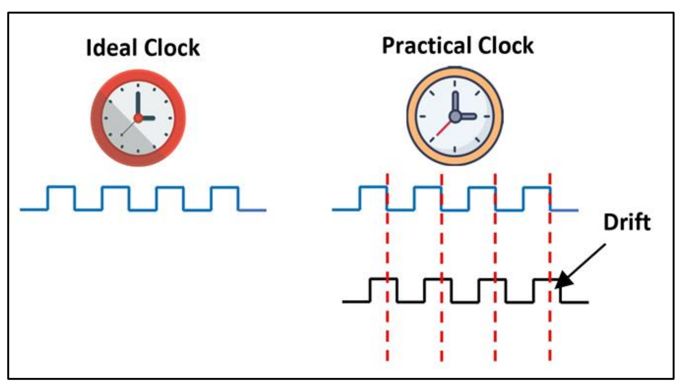

Figure 3 Difference between Ideal Clock and Practical Clock with Drift

3.3. Dynamic Message Time Synchronization

This section discusses about analysis of the bidirectional timing beacon message exchange mechanism and the derivation of the ML technique for clock offset. The ML

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approach aims to minimize computational complexity while ensuring constant beacon message transfer among interconnected vehicles, particularly under a Gaussian delay model as shown in Figure 4.

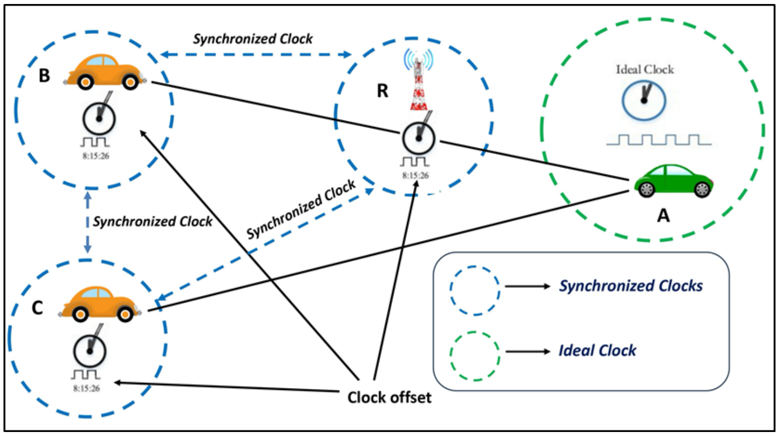

Figure 4 Architecture of Dynamic Message Time Synchronization (DMTS) Protocol

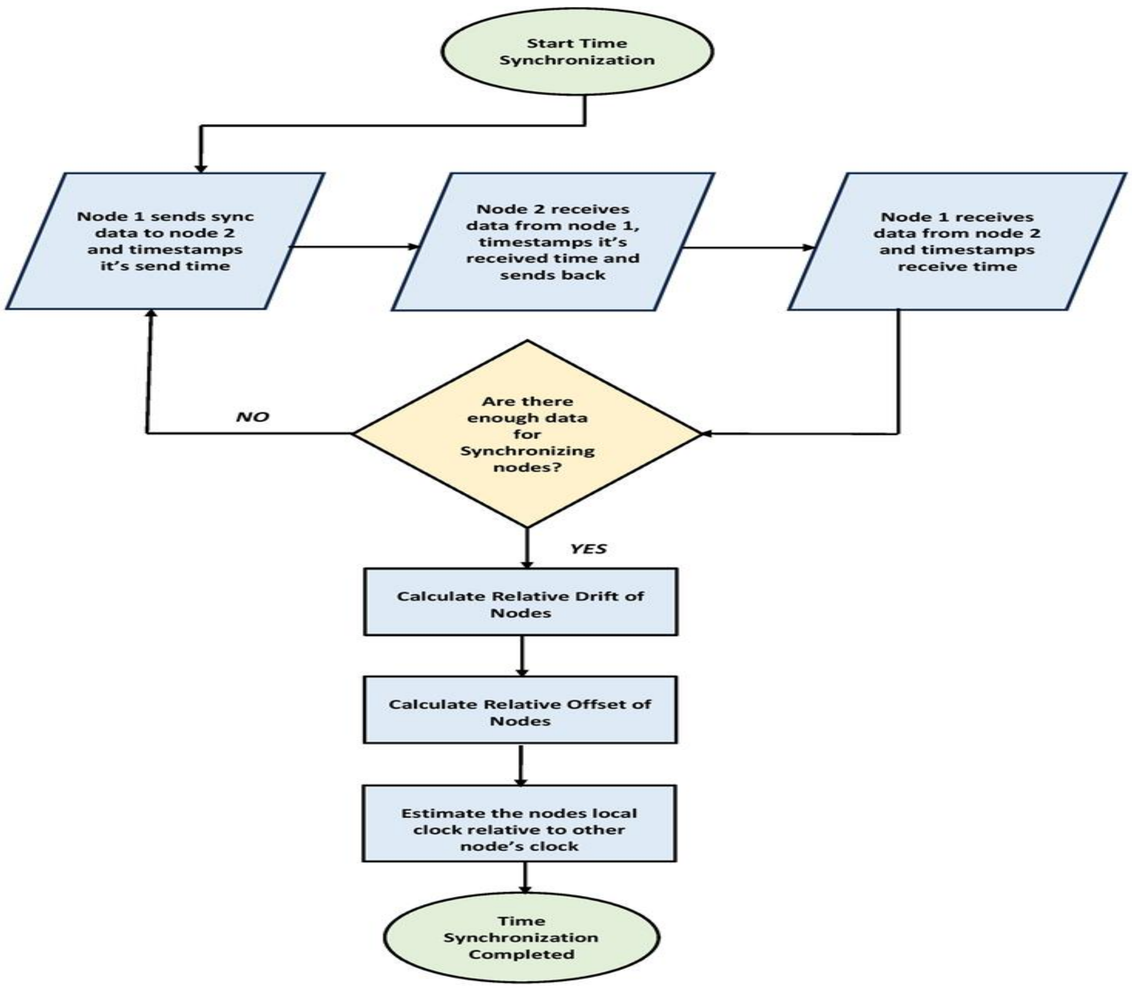

Figure 5 Flowchart for Dynamic Message Time Synchronization (DMTS) Protocol

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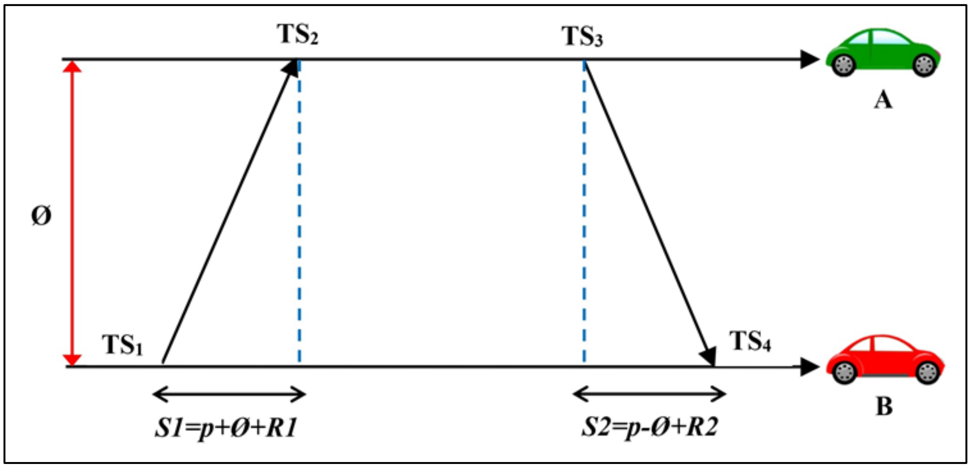

Figure 6 Working of DMTS Model

The proposed Dynamic Message Time Synchronization (DMTS) algorithm is designed to be self-configured, enabling every vehicle to capture, update, and save timestamps using its localized clock. This mechanism consists of three stages: the route discovery stage, the synchronization stage, and the network monitoring stage.

The three stages of the DMTS algorithm can be summarized as given below:

Route Discovery Stage: This phase establishes a hierarchical arrangement within the network, in relationship with the Time-Period Synchronization Protocol for Sensor Networks (TPSPSN) model.

Synchronization Stage: The DMTS algorithm performs adjustments for both the current clock offset as well as clock skew to maintain non-breakable synchronization. In contrast, TPSPSN primarily calculates the clock offset only. Consequently, DMTS requires less resynchronization in comparison with TPSPSN.

Network Monitoring Stage: In this phase, the sender node assesses the real-time network traffic situation, aiming to enhance the resynchronization phase and optimize the beacon messages quantity for pairwise synchronization.

The flowchart for the synchronization phase using DMTS protocol is shown in the Figure 5.

In the Dynamic Message Time Synchronization (DMTS) algorithm, a minimal count of timing messages are employed to periodically measure network processes. Figure 6 illustrates a bidirectional beacon timing exchange handshake between the vehicles, A and B. During the n^{th} beacon message exchange, timestamps TS_1, TS_2, TS_3, and TS_4 are established based on the localized clocks of vehicle A and B. TS_1 and TS_4 represent the localized clock time measured by vehicle A, while TS_2 and TS_3 denote the localized clock time computed by vehicle B. At first, vehicle B initiates synchronization by sending a beacon message to vehicle A with its existing timestamp TS_1. Vehicle A records and updates its timestamp to TS_2 upon message reception. At time TS_3, vehicle A then sends a synchronized message to vehicle B, incorporating TS_2 and TS_3. Finally, vehicle B receives timestamp TS_4 sent by vehicle A. Consequently, vehicle B obtains a new set of timestamps TS_1, TS_2, TS_3, and TS_4 for subsequent sessions of message exchanges.

Based on the DMTS model presented in Figure 6, the clock offset is represented through the following equation (1) and equation (2):

$$TS_2 = TS_1 + p + \text{Ø} + R1 \quad (1)$$

$$TS_4 = TS_3 + p - \text{Ø} + R2 \quad (2)$$

Here, 'Ø' represents the reference Vehicle B's clock offset relative to Vehicle A. The variable 'p' signifies the propagation delay assumed to be symmetric in both directions. R1 and R2 are random variables contributing to this propagation delay.

The presence of clock skew leads to clock offset drift in the vehicle's clock. The proposed protocol addresses this by adjusting the clock skew, ensuring reliability of beacon and efficient synchronization of time among interconnected vehicles during synchronization phase.

The clock offset (Ø) as well as propagation delay (p) can be computed as shown in equation (3) and equation (4):

$$\text{Ø} = \frac{[(TS_2 - TS_1) - (TS_4 - TS_3)]}{2} \quad (3)$$

$$p = \frac{[(TS_2 - TS_1) + (TS_4 - TS_3)]}{2} \quad (4)$$

The format of the message with synchronized clock time is shown in Figure 7. To enhance synchronization accuracy and minimize errors, it is assumed that errors adhere to a Gaussian

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probability density function. Periodic adjustments are made to the clock offsets of interconnected vehicles, maintaining reliable synchronization of clocks and timing beacon messages. The estimation of the proposed DMTS algorithm follows the approach outlined below.

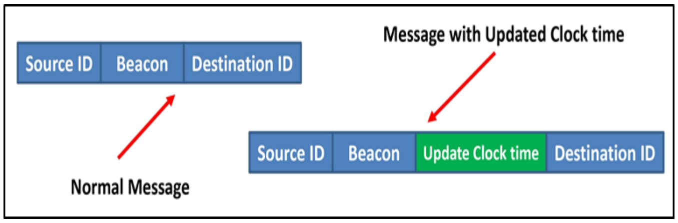


Figure 7 Format of Message with Synchronized Clock Time

3.4. Estimating DMTS Clock Offset by Using Maximum Likelihood

In the proposed DMTS algorithm, the clock skew is assumed to be absent during this period to maintain the signaling process depicted in Figure 6. Utilizing the bidirectional timing message mechanism, the clock offset is determine for Maximum Likelihood among interconnected vehicles. Considering the network's multiple propagation delays, the randomized variables R1 and R2 are regarded as independent and arbitrarily dispersed, with corresponding mean ‘μ’ and variance ‘σ²’.

Thus, the likelihood function is formulated accordingly in $U=TS_2-TS_1 = p+\emptyset+R1$ and $V = TS_4-TS_3 = p-\emptyset+R2$ observations.

In mathematical terms, the Maximum Likelihood (ML) is computed using the following equation (5).

$$
\begin{aligned}
Z(\mu,\sigma^2;t_1) &= \sum_{j=1}^{k} f_t(t_1;\mu,\sigma^2) \\
&= \sum_{j=1}^{k} (2\pi\sigma^2)^{-1/2} \exp\left\{-\frac{1}{2}\frac{(t_j-\mu)^2}{(\sigma^2)}\right\} \\
&= (2\pi\sigma^2)^{-k/2} \exp\left\{-\frac{1}{2\sigma^2}\sum_{j=1}^{k}(t_j-\mu)^2\right\} \qquad (5)
\end{aligned}
$$

Applying equation (2) to determine ML expression as shown in equation (6)

$$
\begin{aligned}
Z(\emptyset,\mu,\sigma^2) = (2\pi\sigma^2)^K \exp\Bigg\{-\frac{1}{2\pi\sigma^2}\Bigg[\sum_{i=1}^{k}(S1_i \\
- (p+\emptyset+\mu)^2 \\
+ \sum_{i=1}^{K}(S2_i - (p+\emptyset+\mu)^2\Bigg]\Bigg\} \qquad (6)
\end{aligned}
$$

When the log-likelihood function in equation (3) is differentiated, the following result is obtained as shown in equation (7)

$$
\begin{aligned}
\hat{\emptyset} = arg\underbrace{max}_{\emptyset}[InZ(\emptyset)] &= \frac{\sum_{i=1}^{K}[S1_i - S2_i]}{2K} \\
&= \frac{\widehat{S1}-\widehat{S2}}{2} \qquad (7)
\end{aligned}
$$

Thus, the estimation of the ML for the clock offset is derived shown in equation (8) and equation (9)

$$
\begin{aligned}
\frac{\partial^2 InZ(\emptyset)}{\partial\emptyset^2} = -\frac{2K}{\sigma^2}Var(\hat{\emptyset}) &\geq -E\left[\frac{\partial^2 InZ(\emptyset)}{\partial\emptyset^2}\right]^{-1} \\
&= \frac{\sigma^2}{2K} \qquad (8)
\end{aligned}
$$

$$
\begin{aligned}
\hat{\emptyset} = arg\underbrace{max}_{\emptyset}[InZ(\emptyset)] &= \frac{\sum_{i=1}^{K}[S1_i - S2_i]}{2K} \\
&= \frac{\widehat{S1}-\widehat{S2}}{2} \qquad (9)
\end{aligned}
$$

where K represents the count of scenarios; $\widehat{S1}$ and $\widehat{S1}$ represents the “mean sampling” of scenarios S1 and S2.

In this section, the novel dynamic message time synchronization is elaborated in transmitting beacon messages across multihops. Every vehicle in VANETs is considered as a node and employ routing information to create communication pathways. To ensure the reliability and authenticity of messages, the message authentication codes are used and a shared key, KEY_{AB}, established between vehicle A and vehicle B. The “maximum propagation delay” is computed, considering a higher assumed value $p^*_X >> p^*$, where p^*_X and p^* are predicted values for multi hop and single hop respectively. In VANETs, the vehicle routes follow the sequence A-B-C-D, evenly spread within the communication range while maintaining uniform transmit energy. Vehicle A is required to communicate sequentially with vehicle C along with vehicle D, following the best shortest route, prior to establishing communication with vehicle B.

In the given Algorithm 1, TS_1 and TS_4 represent the localized clock time computed by vehicle A, while TS_2 as well as TS_3 represents the localized clock time computed by vehicle B. R_V is used to denote a random variable. Thus, the proposed novel dynamic message time synchronization (DMTS) technique is outlined in the below Algorithm 1.

1: $A(TS_1) \rightarrow C \rightarrow D \rightarrow B(TS_2)$: A, B, R_V, sync

$B(TS_3) \rightarrow D \rightarrow C \rightarrow A(TS_4)$: $B, A, R_V, TS2, TS3$, ack,

2: $KEY_{AB}[B, A, R_V, TS_2, TS_3$, ack]

3: A estimate delay $p = [(TS_2 - TS_1) + (TS_4 - TS_3)]/2$

4: If p<=p*$_X$ then Ø = [(TS_2 – TS_1) - (TS_4 – TS_3)]/2

5: A(TS_1) ->(TS_2)C

6: C(TS_{11}) -> (TS_{12})A

7: next compute the communication path way

8: pCD = [(TS_4 - TS_3) + (TS_{10} - TS_9)]/2, sync

9: pDB = [(TS_6 - TS_5) + (TS_8 - TS_7)]/2, sync

10: ØCD =[(TS_4 - TS_3) - (TS_{10} - TS_9)]/2, ack

11: compute 'p' and 'Ø' for other time stamps

12: end

Algorithm 1 DMTS Protocol

At the outset, the analysis of the proposed DMTS algorithm is conducted by studying the communicating route between two vehicles, A and B, along the pathway: A(TS_1)à (TS_2)C; C(TS_{11}) à (TS_{12})A.

Thus, these timestamps are linked together in the following manner as shown in equation (10):

$$TS_2 = TS_1 + ØAC + pAC; TS_{12} = TS_{11} - ØAC + pAC \tag{10}$$

It's important to emphasize that labels have been added to both Ø and p for clarity. Similarly, the communication pathway is determine between other vehicles (C, D) and (D, B) using the following relationships as shown in equation (11) and equation (12):

$$TS_4 = TS_3 + ØCD + pCD; TS_{10} = TS_9 - ØCD + pCD \tag{11}$$

$$TS_6 = TS_5 + ØDB + pDB; TS_8 = TS_7 - ØDB + pDB \tag{12}$$

From equation (11) and equation (12), the expressions for pCD, pDB, and ØCD are given by

pCD = [(TS_4 - TS_3) + (TS_{10} - TS_9)]/2,

pDB = [(TS_6 - TS_5) + (TS_8 - TS_7)]/2 and

ØCD =[(TS_4 - TS_3) - (TS_{10} - TS_9)]/2 respectively.

Once more, the connection is established between the propagation delay and the clock offset for the adjacent nodes' route.

(Aà C;Cà D;DàB) as pPQ = pAC + pCD + pDB and ØAB = ØAC + ØCD + ØDB.

The "DMTS algorithm" calculates the largest "estimated delay" p*$_{TS}$ to enhance all the timestamps from TS_1 to TS_{12} for neighboring vehicles.

4. SIMULATION RESULTS

In this section, simulated scenarios for the DMTS protocol are presented.

4.1. Simulation Parameters

During the simulation, the 10 repetitions of each illustration is conducted and an average is calculated from the outcomes. The proposed DMTS algorithm was implemented in two distinct pathways. Each scenario is repeated numerous times, ensuring a more number of trials, coupled with a robust time synchronization partition. This approach aimed to accelerate the coverage of vehicles swiftly in expansive, distributed VANETs. The goal was to improve the probability of message transmission and synchronization for the interconnected vehicles within VANETs. The Simulation setup is shown in Table 2.

Table 2 Simulation Parameters

Parameter	Value
Nodes Count	600
Mobile Nodes Count	1
Communication range	20 m
Beacon message speed	0-40 m/s
Node deployment area	100 x 100 m^2
Length of synchronization message	568 bits
Simulation Duration	15 Seconds
Routing Protocol	DMTS

4.2. Delay

Delay represents the time elapsed between the initiation of data transfer and its successful reception at the intended receiver.

The proposed Dynamic Message Time Synchronization (DMTS) protocol aims to minimize delay in synchronization by intelligently selecting synchronization pairs, periodically adjusting clock offsets, and optimizing the synchronization process. Lowering delay is essential for enhancing communication efficiency and enabling real-time data exchange, which is crucial for applications such as collision avoidance and traffic management.

During this simulation, the clock values at the start are initialized to zero. The Mean Square Estimators (MSEs) are plotted against the observation count to analyze beacon message synchronization. This analysis assumed a random delay, modeled using an asymmetric Gaussian distribution. As every vehicle operates at its unique "clock frequency", the "clock offsets" of adjacent nodes consistently incremented.

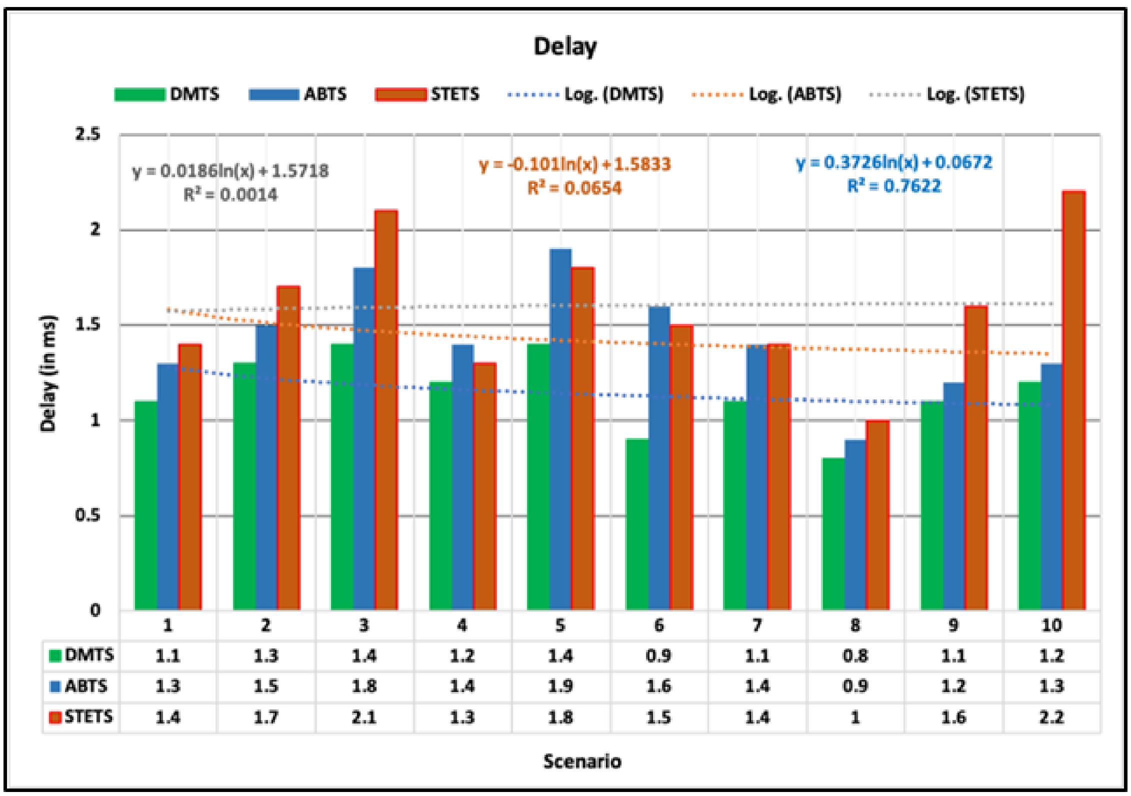
The delays in signal propagation within networks using deployed sensors are distributed independently and typically in a normal fashion. It's crucial for these delays to have equal mean and variance values to enhance synchronization accuracy and ensure reliable communication among nodes. In Figure 8, it's evident that the Dynamic Message Time Synchronization (DMTS) protocol significantly surpasses the ABTS and STETS protocols.

In scenarios where the network delay follows a Gaussian distribution, ABTS exhibits superior performance compared to STETS. However, if the delay route in the network differs from a Gaussian distribution, STETS demonstrates better performance than ABTS. Nonetheless, DMTS outperforms all these protocols as their limitations reduce with the increasing number of observations (K). Table 3. Shows the list of values for delay (in ms) in 10 scenarios for DMTS protocol in comparison with ABTS and STETS protocols.

Table 3 Performance of Delay in Different Scenarios

Scenario	DMTS	ABTS	STETS
1	1.1	1.3	1.4
2	1.3	1.5	1.7
3	1.4	1.8	2.1
4	1.2	1.4	1.3
5	1.4	1.9	1.8
6	0.9	1.6	1.5
7	1.1	1.4	1.4
8	0.8	0.9	1
9	1.1	1.2	1.6
10	1.2	1.3	2.2
Average	1.15 ms	1.43 ms	1.6 ms

Figure 8 shows decrease in delay in DMTS compare with its comparative protocols.



Scenario	1	2	3	4	5	6	7	8	9	10
DMTS	1.1	1.3	1.4	1.2	1.4	0.9	1.1	0.8	1.1	1.2
ABTS	1.3	1.5	1.8	1.4	1.9	1.6	1.4	0.9	1.2	1.3
STETS	1.4	1.7	2.1	1.3	1.8	1.5	1.4	1	1.6	2.2

Figure 8 Delay Performance of DMTS and Comparative Protocols

4.3. Packet Delivery Ratio

It is a critical performance metric used to evaluate the effectiveness and reliability of data transmission in a network.

$$PDR = \frac{No.\ of\ packets\ received}{Total\ No.\ of\ packets\ sent} \quad (13)$$

In the context of DMTS protocol, PDR (eqaution (13)) is a crucial measure of how accurately and reliably

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synchronization packets are delivered within the Vehicular Ad hoc Networks (VANETs). These synchronization packets are vital for maintaining precise time alignment among vehicles, facilitating real-time data exchange and coordination. A high PDR indicates a network's ability to successfully deliver synchronization packets to their intended recipients. Achieving a high PDR is particularly important in VANETs where timely and accurate synchronization is paramount for ensuring safe and efficient communication among vehicles. Factors such as network congestion, interference, packet collisions, and varying transmission conditions can affect PDR. The proposed Dynamic Message Time Synchronization (DMTS) protocol in this research aims to optimize time synchronization by selecting appropriate synchronization pairs and periodically adjusting clock offsets. This optimization is expected to positively impact the PDR, ensuring that synchronization packets are reliably delivered, contributing to improved communication and coordination among vehicles. In the evaluation and validation of the DMTS protocol, PDR is one of the key metrics considered. Comprehensive simulation analyses are conducted to assess the protocol's performance in terms of PDR, confirming its effectiveness in enhancing packet delivery and thereby supporting reliable real-time data exchange within VANETs. A higher PDR achieved through the DMTS protocol demonstrates its efficiency in ensuring successful synchronization and timely communication, reinforcing its potential for enhancing VANET applications and services. Table 4. Shows the list of values for packet delivery ratio (in ms) in 10 scenarios for DMTS protocol in comparison with ABTS and STETS protocols.

Table 4 Performance of PDR in Different Scenarios

Scenario	DMTS	ABTS	STETS
1	2.1	1.8	1.2
2	2.3	2.1	1.5
3	2.3	2.2	1.4
4	2.5	2.3	1.9
5	2.3	2.2	2.1
6	2.6	2.4	2.3
7	2.6	2.1	1.8
8	2.5	2	2.2
9	2.4	2	1.8
10	2.6	2.4	1.9
Average	2.42 ms	2.15 ms	1.81 ms

Figure 9 shows improvement in PDR when DMTS protocol is used in comparison with corresponding protocols.

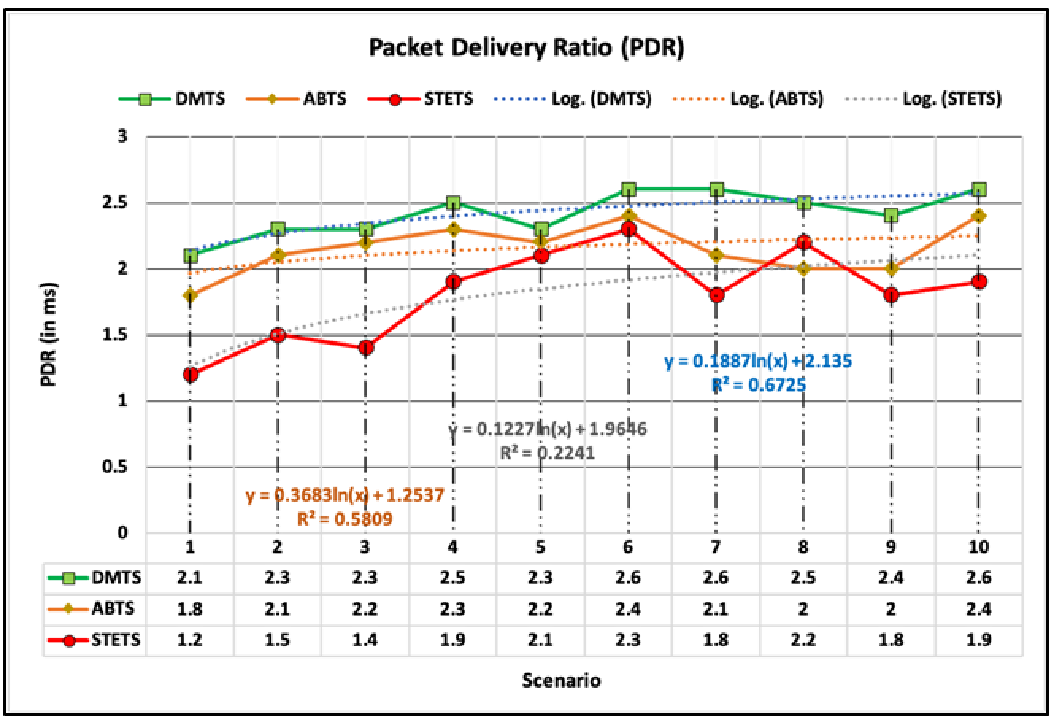

Figure 9 PDR Performance of DMTS and Comparative Protocols

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4.4. Throughput

It is a fundamental performance metric in networking that measures the rate at which data is successfully transmitted from the source to the destination in a given communication channel or network. It represents the amount of data that is effectively delivered over the network within a specific time.

$$Throughput = \frac{\sum PR}{\sum t_{st} - \sum t_{sp}} \quad (14)$$

In the context of DMTS protocol, throughput (equation (14)) is a critical indicator of the network's efficiency in transmitting synchronization messages and facilitating real-time data exchange among vehicles within the VANETs. A higher throughput implies that the protocol is capable of efficiently utilizing the available network bandwidth to transmit synchronization packets and other data. The proposed Dynamic Message Time Synchronization (DMTS) protocol aims to optimize time synchronization and, by extension, improve throughput. By intelligently selecting synchronization pairs and readjusting clock offsets, the protocol seeks to enhance the efficiency of synchronization message transmission, consequently leading to increased throughput. Improved throughput is crucial for enabling timely and reliable communication, especially in scenarios where real-time data exchange is essential for ensuring traffic safety along with reliability. In the evaluation and validation of the DMTS protocol, throughput is one of the key performance metrics considered. Comprehensive simulation analyses are conducted to assess the protocol's throughput, demonstrating its effectiveness in enhancing data transmission rates and, ultimately, improving communication and coordination among vehicles within the VANETs. Achieving a higher throughput through the DMTS protocol signifies its potential to optimize real-time data exchange and enhance the performance of VANET applications and services. Table 5. Shows the list of values for throughput (in bps) in 10 scenarios for DMTS protocol in comparison with ABTS and STETS protocols.

Table 5 Performance of Throughput in Different Scenarios

Scenario	DMTS	ABTS	STETS
1	48	35	31
2	58	45	35
3	61	52	47
4	68	61	44
5	75	65	50
6	74	64	54
7	78	63	53
8	76	65	52
9	80	50	58
10	84	54	50
Average	70.2 bps	55.4 bps	47.4 bps

Figure 10 shows an improvement in throughput when DMTS is used.

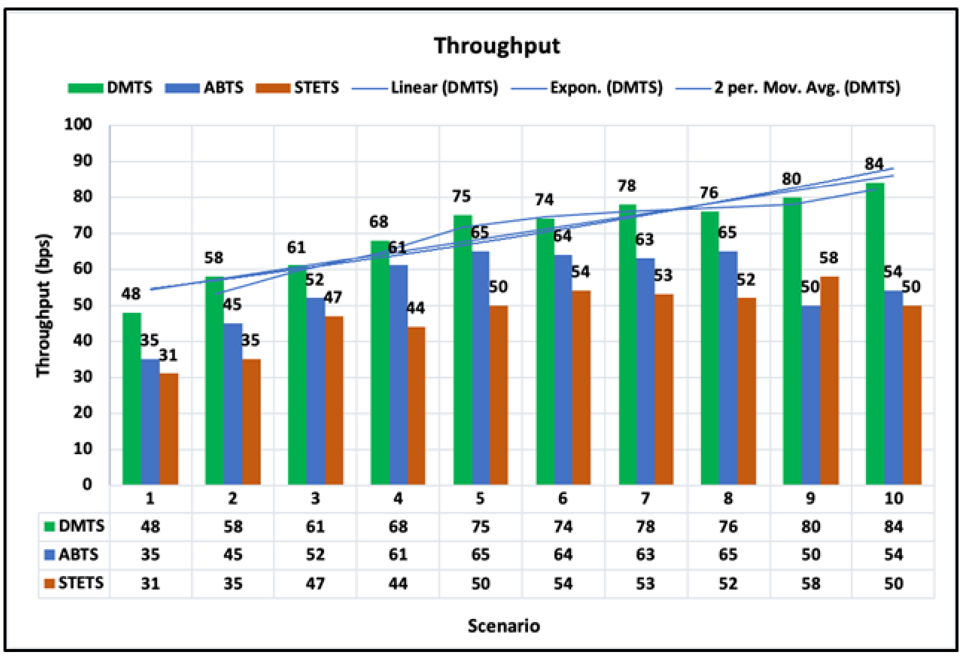

Figure 10 Analysis of Throughput of DMTS with Counterpart Protocols

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5. SYNTHESIS

The Comparison of DMTS with its counterpart protocols is shown in Table 6.

Table 6 Comparison of DMTS with its Counterpart Protocols

	DMTS	ABTS	STETS
Delay (in ms)	1.1	1.3	1.4
	1.3	1.5	1.7
	1.4	1.8	2.1
	1.2	1.4	1.3
	1.4	1.9	1.8
	0.9	1.6	1.5
	1.1	1.4	1.4
	0.8	0.9	1
	1.1	1.2	1.6
	1.2	1.3	2.2
Average	1.15 ms	1.43 ms	1.6 ms
Packet Delivery Ratio (in ms)	2.1	1.8	1.2
	2.3	2.1	1.5
	2.3	2.2	1.4
	2.5	2.3	1.9
	2.3	2.2	2.1
	2.6	2.4	2.3
	2.6	2.1	1.8
	2.5	2	2.2
	2.4	2	1.8
	2.6	2.4	1.9
Average	2.42 ms	2.15 ms	1.81 ms
Throughput (in bps)	48	35	31
	58	45	35
	61	52	47
	68	61	44
	75	65	50
	74	64	54
	78	63	53
	76	65	52
	80	50	58
	84	54	50
Average	70.2 bps	55.4 bps	47.4 bps

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Table 7 Synthesis of DMTS with its Counterpart Protocols

Protocol	Delay	Packet Delivery Ratio (PDR)	Throughput
DMTS	1.15 ms	2.42 ms	70.2 bps
	Low	High	High
ABTS	1.43 ms	2.15 ms	55.4 bps
	Medium	Medium	Medium
STETS	1.6 ms	1.81 ms	47.4 bps
	Medium	Low	Low

As described in the Figure 8, the DMTS protocol achieves less delay in comparison with its corresponding protocols which is denoted as Low in the Table 7.

The performance of PDR of DMTS as depicted in Figure 9 is much higher in comparison with its corresponding protocols and hence it is denoted as High in Table 7.

As depicted in the Figure 10, the DMTS protocol achieves significantly high throughput in comparison with its corresponding protocols which is denoted as High in the Table 7.

Hence, it can be noticed from the above comparison that the proposed DMTS protocol performs efficiently in comparison with the ABTS and STETS Protocols in terms of delay, packet delivery ratio and throughput.

6. CONCLUSION

This research focuses on improving time synchronization in large-scale VANETs through the introduction of a novel Dynamic Message Time Synchronization (DMTS) algorithm. The DMTS algorithm optimizes synchronization by intelligently selecting synchronization pairs, effectively reducing the number of transmitted timing messages and enhancing reliability. A key feature of the DMTS algorithm is the periodic readjustment of clock offsets in connected vehicles, resulting in improved synchronization accuracy. By leveraging two-way timing message synchronization and ML estimation for clock offset design, the algorithm showcases its effectiveness, as validated through extensive simulation analyses. It outperforms the ABTS and STETS protocols with a notable 19.58% and 28.12% reduction in delay, respectively. Moreover, the DMTS protocol exhibits enhanced Packet Delivery Ratio (PDR), achieving improvements of 12.55% and 33.70% when compared to ABTS and STETS protocols. The throughput performance of the DMTS protocol is also noteworthy, showing an increase of 26.71% and 48.10% when compared to its counterparts. The simulations underscore the DMTS protocol's advantages over existing counterparts, demonstrating its potential to significantly enhance time synchronization in large-scale VANETs. Ultimately, the DMTS algorithm represents a promising solution poised to advance intelligent transportation systems and optimize vehicular communication efficiency. The findings presented in this research contribute to the advancement of time synchronization techniques in large-scale VANETs, enhancing their potential to revolutionize the efficiency and safety of modern transportation systems. Future research could focus on optimizing the DMTS algorithm by integrating it with advanced machine learning techniques which could enhance the DMTS algorithm's adaptability and predictive capabilities, enabling it to anticipate and respond more effectively to dynamic network conditions.

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RESEARCH ARTICLE

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