Efficiency Assessment of Routing Protocols for Enhanced Communication in Vehicular Ad Hoc Networks

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Abstract

This paper conducts a comprehensive performance analysis of three prominent ad-hoc routing protocols: Optimized Link State Routing protocol (OLSR), Chain branch leaf (CBL), and Chain branch leaf gateway (CBL-G). The primary focus of our study revolves around evaluating these protocols with respect to network load management and throughput. Our findings highlight differences among the protocols. The comparative analysis presented in this paper offers valuable insights, aiding in the selection of ad- hoc routing protocols based on specific performance requirements within dynamic wireless networks. Emphasizing the efficacy of CBL and CBL-G in network load management and achieving elevated throughput, our research contributes to the existing knowledge base on ad-hoc routing protocols and their applicability in the context of dynamic wireless networks. The discerned results provide a nuanced understanding, guiding practitioners and researchers toward informed decisions for optimal protocol selection. Results indicates that both CBL and CBL-G effectively manage network resources CBL showing a slight increase in the number of hops compared to AODV. While CBL-G lags slightly behind CBL in performance due to increased processing demands from Roadside Units, it remains a viable protocol.

1. Introduction

Wireless ad-hoc networks have garnered considerable attention for their versatility in providing flexible and self-configuring communication in diverse scenarios, ranging from disaster response and military operations to mobile sensor networks. The dynamic nature of these networks necessitates efficient routing protocols to establish reliable and robust communication paths among nodes. Indeed, the dynamic topology of VANETs, induced by the rapid movement of vehicles, poses a fundamental challenge to routing protocols. Conventional static network routing algorithms often struggle to adapt to the dynamic nature of VANETs, where nodes continuously enter and exit the communication range. Routing protocols must address the challenge of maintaining stable and efficient communication paths amidst such constant changes in network topology.

The performance of such protocols significantly influences network throughput, delay, and load management [11, 12]. The wireless communication medium employed in VANETs introduces challenges such as signal attenuation, interference, and fading. Routing protocols must incorporate mechanisms to address these challenges, ensuring robust communication links. The ability to adapt to varying signal conditions, handle packet loss, and maintain link quality is crucial for the overall performance of the routing infrastructure. As the demand for reliable and efficient communication systems continues to escalate in today's interconnected world, researchers and industry professionals are continually exploring innovative approaches to enhance network performance and quality of service (QoS)[5-10].

This paper contributes to this ongoing exploration by conducting a detailed comparative analysis of three widely used ad-hoc routing protocols: Optimized Link State Routing protocol (OLSR), Chain branch leaf (CBL), and Chain branch leaf gateway (CBL-G). These protocols represent distinct approaches to routing in ad-hoc networks.

The CBL algorithm, as detailed in prior research [1, 6, 7], is meticulously designed to optimize network load management and achieve high throughput in ad-hoc networks. Its innovative approach employs a chain structure where nodes function as branches and leaves, facilitating efficient data transmission. The primary focus of CBL lies in minimizing network load and optimizing data routing, leading to significantly improved overall network performance.

In contrast, the CBL-G algorithm extends the functionality of CBL by incorporating Roadside Units (RSUs) as gateways [2]. This integration introduces enhanced coverage and service quality in vehicular networks. Leveraging the additional data processing capabilities of RSUs, CBL-G aims to further elevate the performance of ad-hoc communication. The integration of RSUs as gateways brings forth a novel dimension to the conventional CBL framework, presenting opportunities for advancements in communication efficiency.

The OLSR algorithm grounded in the link-state routing principle establishes and maintains a network topology by exchanging periodic link-state information among nodes [3, 9]. OLSR's distinctive features include efficient routing and multicast support, rendering it suitable for scenarios where frequent network changes occur. Its adaptability and robustness make OLSR a noteworthy contender in the landscape of ad-hoc routing protocols [11, 12].

This research contributes a comprehensive analysis of the CBL-G system, shedding light on its inherent advantages and potential for enhancing communication efficiency. Additionally, the integration of RSUs as gateways to examine its profound impact on coverage and service quality. The insights derived from this study not only advance the comprehension of decentralized communication systems but also lay a foundational framework for future deployments and improvements in network metrics, encompassing throughput, delay, and load management [4, 5].

Efficient routing protocols play a vital role in wireless ad-hoc networks by establishing and maintaining reliable communication paths. These protocols dictate how data is transmitted from a source node to a destination node, passing through intermediate nodes. The selection of a routing protocol significantly affects network performance design and operation. The subsequent sections of this paper delve into a more in-depth exploration of these protocols.

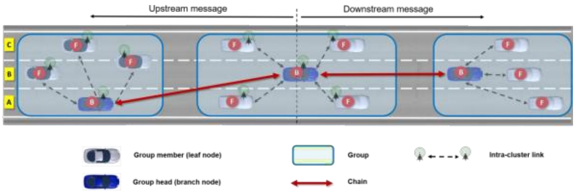

Figure 1. Representation of the functional model of CBL on a three-lane high

The paper is structured as follow Beginning with Section 2, the Background section, a detailed examination of the Chain Branch Leaf (CBL) protocol (Section 2.1) and its extension, the Chain Branch Leaf Gateway protocol (CBL-G) (Section 2.2), sets the stage for the subsequent discussions. Section 3 establishes the criteria for evaluating routing protocol efficiency. Following this, Section 4 outlines the methodology employed in the efficiency assessment. Moving into Section 5, the paper presents a thorough analysis of the results obtained from the evaluation. the Conclusion is in Section 6, summarizing the contributions and implications of the study. Finally, Section 7, Perspectives, outlines potential future directions in vehicular network research, offering insights into further advancements and applications of the proposed routing protocols.

2. Background

Wireless ad-hoc networks have emerged as a prominent solution for establishing communication in dynamic and self-configuring environments. These networks are characterized by the absence of a fixed infrastructure, making them highly suitable for scenarios such as disaster response, military operations, and mobile sensor networks. Within wireless ad-hoc networks, nodes collaborate to form a decentralized network, with each node serving as both a host and a router to facilitate communication.

One widely adopted routing protocol for ad-hoc networks is the Optimized Link State Routing protocol (OLSR) [3]. OLSR, a proactive protocol rooted in the link-state routing principle, establishes and upholds a network topology through regular exchange of link-state information among nodes. Its efficient routing and multicast capabilities render makes it suitable for scenarios characterized by frequent network alterations.

2.1. The chain branch leaf protocol (CBL)

The Chain branch leaf (CBL) algorithm [1] is another notable routing protocol garnering attention. CBL employs a chain structure in which nodes assume roles as branches and leaves. Two primary node types, "branch" and "leaf," play distinct roles in the establishment and maintenance of the communication network. Figure 1 illustrates the CBL architecture's centralized design within each cluster.

2.1.1. Branch Node. The "branch" node serves as the cluster head, elected by neighboring nodes within its one-hop vicinity. It shares the common function of sending HELLO messages like other nodes but possesses exclusive permissions to transmit Topology Control messages, transmit request messages, and actively participate in the construction of communication chains. A "branch" node functions as a central hub, relaying messages to the connected leaf nodes, upstream and downstream branches, as well as branches in other traffic directions, all based on specified requests in the streamlined data packet transmission and mitigates congestion risks.

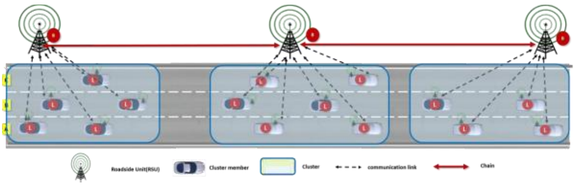

Figure 2. Representation of the functional model of CBL-G on a three-lane high with full deployment of Roadside unit message header fields

2.1.2. Leaf Node. In contrast, a "leaf" node is a standard node that connects to the nearest branch node. When no branch node is detected, the leaf node strategically selects the neighbor moving at the lowest speed and in the same direction as its branch. The primary functions of a leaf node include sending HELLO messages and handling application data traffic. Unlike branch nodes, leaves do not engage in the transmission of Topology Control messages or actively participate in chain construction.

2.1.3. Communication Chain. The resulting structure, known as Chain branch leaf (CBL), resembles a virtual spinal arrangement upheld by links between nodes. Each node within this structure is characterized by essential parameters: "BranchChoice" (indicating the address of a selected branch node), "ChainUP" (representing the address of the branch node for relaying upstream traffic), "ChainDO" (indicating the address of the branch node for relaying downstream traffic), and "Connection Time" (CT) representing the anticipated communication duration between two nodes moving at the same speed. The "BranchChoice" parameter is null for branch nodes, while "ChainUP" and "ChainDO" are empty for leaf nodes. This structured approach optimizes communication efficiency within the network by organizing nodes into cohesive chains, each under the guidance of a central branch node.Haut du formulaireBas du formulaire

The CBL protocol emphasis lies in minimizing network load and optimizing data routing, thus enhancing overall network performance. By organizing nodes in a chain structure, CBL facilitates

2.2. The chain branch leaf Gateway protocol (CBL-G)

Building upon the foundations of the CBL algorithm, the Chain branch leaf gateway (CBL-G) protocol [2, 6] extends functionality by incorporating Roadside Units (RSUs) as gateways. RSUs serve as additional access points that expand coverage and enhance service quality in vehicular networks as we can see in Figure 2. Through RSUs, CBL-G strives to further elevate ad- hoc communication performance and ensure seamless connectivity in vehicular scenarios.

The operational mechanism of CBL-G is delineated as follows and visually represented in the Figure 3. A leaf node initiates the process of establishing a connection with a nearby branch node, typically located within a single hop from its current position. This neighborhood discovery unfolds through the recurrent transmission of the "HELLO" message, a practice that persists even after the leaf node integrates into a cluster.

In scenarios of isolation, where neighboring nodes remain elusive, the leaf node designates the Roadside Unit (RSU) as its immediate branch node. The proximity of a branch node within its range triggers the identification of a potential branch in the vicinity, prompting the branch node to disengage from the RSU and establish a connection with the identified branch.

The RSU assumes a crucial role as a relay point for isolated vehicles, facilitating their connection to the infrastructure. Simultaneously, the isolated node identifies a suitable branch for affiliation, effectively preventing its continued isolation. Post-integration with the RSU, previously isolated leaf nodes continue periodic neighborhood exploration through "HELLO" message transmissions.

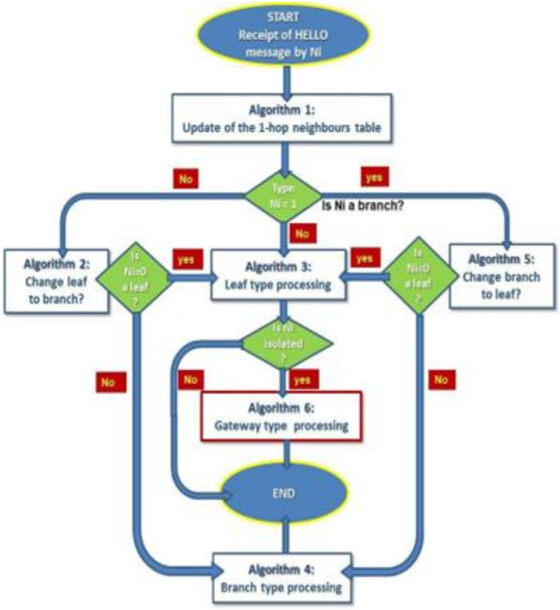

Figure 3. CBL-G algorithm processing upon reception of a Hello message

Upon detecting a neighboring node, an isolated leaf node follows a connection protocol reminiscent of the Chain Branch Leaf (CBL) approach. If the offered connection time (CT) exceeds that provided by the RSU, the leaf node designates the detected node as its connecting branch. Subsequently, the elected branch node endeavors to locate another branch for chain formation. In instances where such a branch is not found, a leaf node assumes the role of the front branch. Subsequent nodes along the route identify the presence of branches and establish connections accordingly.

3. Efficiency Assessment of Routing Protocols

In this paper, we undertake a comprehensive comparative analysis of these three ad-hoc routing protocols: OLSR, CBL, and CBL-G. Our goal is to assess their performance within the context of various network load scenarios and throughput dynamics. Through this evaluation, we aim to gain deeper insights into the strengths and capabilities of each protocol, thereby contributing to a more informed understanding of their applicability and effectiveness in real-world scenarios.

4. Evaluation Method

A method to quantitatively evaluate the performance of one routing protocol relative to another is through the utilization of metrics. Although some metrics used for routing protocol assessment coincide with those employed by the protocols themselves, such as end-to-end delay and hop count, others diverge in terms of bandwidth utilization. Bandwidth utilization serves a dual role: it helps assess network load when used by the routing protocol, and when used for evaluating routing protocol performance, it gauges the occupancy of routing traffic. Commonly employed metrics for the evaluation and comparison of routing protocols include:

Routing traffic throughput (M1): This metric quantifies the throughput, measured in bits per second, of routing messages transmitted across the network.

$$\text{M1}=\frac{Total\,routing\,messages\,transmitted}{total\;time}$$

End-to-end delay (M2): This refers to the delay encountered by a packet during its transmission from source to destination.

$$\text{M2}\;=\frac{Total\;End-to-End\;Delay}{total\,number\;of\;packets\;sent}$$

The retransmission rate of packet (M3): measures the ratio of retransmitted packets within the network.

$$\text{M3}\;=\frac{Number\;of\,retransmitted\,packets}{total\;tTotal\;number\;of\;packets\;sent}\;\text{x 100}$$

The Packet Delivery Ratio (PDR) (M4): the proportion of successfully delivered packets to the total number of packets sent. It provides insights into the protocol's effectiveness in ensuring reliable data transmission, complementing the existing metrics.

$$\text{M4}=\frac{Number\;of\;packets\;Successfully\;delivered}{Total\,Number\;of\;packets\;sent}\;\text{x 100}$$

5. Result analysis

The primary focus of our study is to evaluate the performance of these routing protocols in terms of network load management and throughput. Network load management denotes a protocol's ability to effectively handle increased traffic loads and maintain network stability during message transmission. In contrast, throughput represents the volume of data successfully conveyed over the network within a specified timeframe (see Figure 4).

Our objective is to establish a comparison involving the Optimized Link State Routing protocol (OLSR) [3], Chain branch leaf (CBL) [1], and the Chain branch leaf gateway (CBL-G) [2].

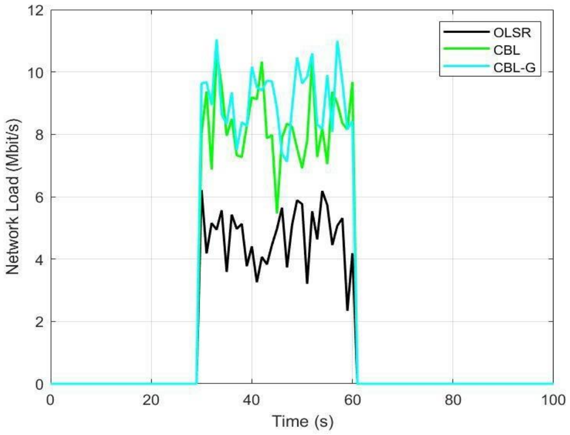

Figure 4. Network load for CBL-G protocol, OLSR, CBL, and CBL-G

The assessment centers evaluated these protocols in the context of network load management and throughput. We initiate application traffic and observe the evolution of network load, analyzing load profiles and the stability of each protocol during message transmission. Furthermore, we gauge the network throughput achieved by each protocol. Subsequent to initiating application traffic at t=30s, network load substantially increases for all routing protocols (see Figure 4). This traffic load encompasses routing and application messages within a density scenario of 2000 vehicles per hour and direction. During the transmission of application messages (between t=30s and t=60s), the OLSR protocol displays the lowest load, averaging 4.8 Mbit/s, followed by CBL with an average of 8.2 Mbit/s. For the same application traffic, the routing protocols exhibit varying network load management, ranging from one-third to triple the load.

CBL and CBL-G demonstrate nearly identical network load values. Following the cessation of application message transmission, network load should equal the routing traffic sent, reverting to the state prior to t=30s. We observe this alignment for CBL and OLSR. However, this is not the case for CBL-G, suggesting that not all application traffic has been dispatched, and packets remain in queues. This implies extended transmission delays and increased packet retransmissions prior to reaching destination nodes. After t=30s, network throughput notably escalates for all routing protocols. Between t=30s and t=60s, the OLSR protocol achieves the lowest throughputs of 4.6 Mbit/s. The CBL protocol attains the highest throughput, averaging 6.3 Mbit/s.

In summation, the analysis of results indicates that the CBL protocol excels in terms of network load management and achieves the highest throughput among the assessed protocols.

The OLSR protocol demonstrates the lowest load and throughput, while CBL-G exhibits delays in stabilizing network load and registers lower throughput compared to CBL.

Regarding M2 (End-to-End Delay): The WLAN delay is minimal for our proposed CBL protocol, averaging below 0.11 s (see Figure 5). At the onset of application activation between t=30 s and t=40 s, there is an elevation in delay corresponding to increased medium access delay.

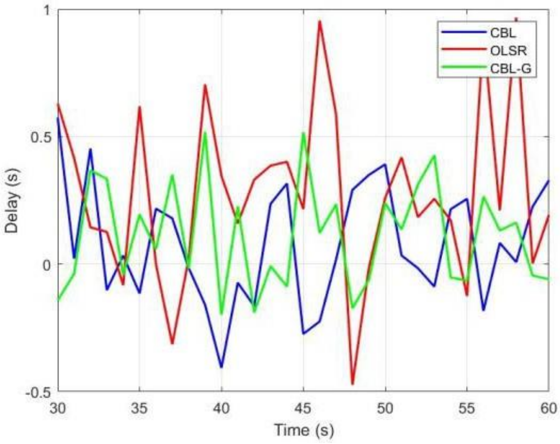

Figure 5. End to End delay (M2) for OLSR, CBL, and CBL-G

It includes Transmission Control (TC) messages for route calculation stored in routing tables (see Figure 6). At t=30 s, the routing traffic remains stable or decreases as application messages take precedence over routing messages. Post t=60 s, the routing traffic profiles of OLSR and CBL return to the levels observed before the application was activated.

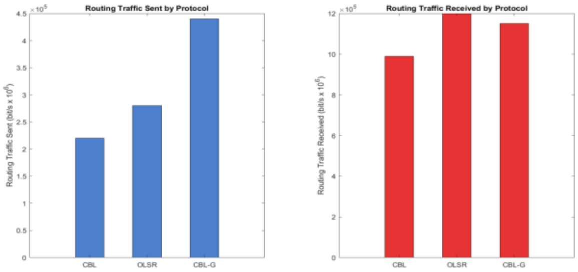

Figure 6. M4-routing traffic sent and received, by OLSR, CBL and CBL-G

This escalation arises from the CSMA/CA algorithm executed during medium access attempts of IEEE 802.11p technology nodes. At t=30 s, simultaneous activation of application traffic for all 15 source nodes leads to access conflicts, resulting in collisions.

The collision avoidance algorithm is triggered locally at each node, prompting nodes to defer transmission attempts based on randomly chosen back off delays. As initial packets are transmitted, a transmission order is established, converging toward an individual optimum among source nodes, leading to decreased medium access delay.

The OLSR protocol demonstrates an average WLAN delay of 0.27 s, while CBL-G registers 0.16 s. The CBL protocol showcases a WLAN delay below 0.16 s for 95% of the simulation time. The CBL protocol's enhancement, accounting for message reception delays and selecting MPR nodes based on this criterion, is evident in the M2 metric.

Regarding M3 (Packet Delivery Ratio): Packet retransmission rate remains zero before application activation. CBL displays an average retransmission rate of 0.58, while OLSR's average retransmission rate is 2.1 and 1 for CBL-G. These values indicate that CBL possesses a lower retransmission rate compared to OLSR, contributing to a reduced packet loss rate for CBL (see Figure 7).

Regarding the (M4) routing traffic sent and received, by OLSR, CBL and CBL-G, initiate routing traffic before application activation. This periodic transmission primarily involves the exchange of HELLO messages for neighborhood discovery. It indicating a swift return to the pre-activation routing dynamics.

In the context of our study involving 15 source nodes for each of the three protocols (CBL, OLSR, and AODV), a significant finding emerges regarding the behavior of routing traffic during the application exchange.

Notably, we observe a consistent and stable pattern in the routing traffic sent for all protocols throughout the application exchange process. This stability in routing traffic is particularly noteworthy given the diverse nature of the protocols under consideration. For CBL-G, CBL and OLSR protocols, the routing traffic sent maintains a steady state. Even with the dynamic nature of ad-hoc networks

The implications of this stability are significant for network performance, suggesting optimized resource utilization and reduced unnecessary overhead in routing updates. This finding contributes to a deeper understanding of the operational characteristics of the selected protocols in the context of wireless ad-hoc networks.

6. Conclusion

In summary, both CBL and CBL-G demonstrate effectiveness in efficiently managing network resources and facilitating optimal data transmission within vehicular networks. The number of hops, measuring the performance of the routing protocol in terms of the route found between source and destination nodes, reveals a slight increase with CBL compared to AODV.

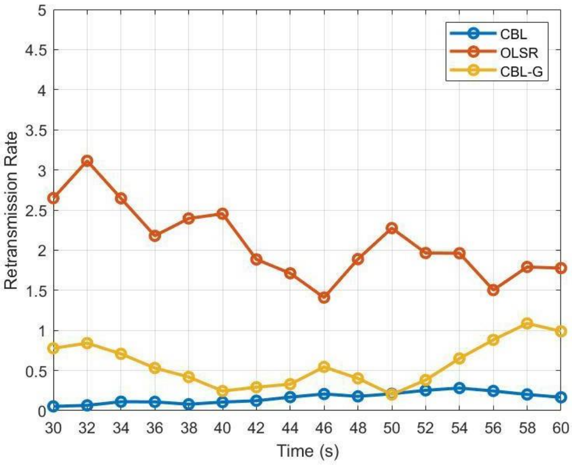

Figure 7. The retransmission rate of packet (M2) for OLSR, CBL, and CBL-G

This difference can be attributed to CBL's utilization of the branch node chain for message transmission, although it does not adversely affect packet retransmission rates.

The performance analysis, however, indicates that CBL-G consistently lags behind CBL, suggesting a minor reduction in its overall effectiveness. This performance gap is likely a result of the increased data processing demands associated with the integration of Roadside Units (RSUs) alongside the nodes in the CBL-G approach. Despite this, CBL-G remains a viable protocol, albeit with a marginal performance difference compared to CBL.

It is noteworthy that traditional protocols in the literature often optimize the number of application packet hops, leading to the selection of links between distant intermediate nodes, almost at the communication range limit. However, such links may be of suboptimal quality and result in packet losses when the established route becomes obsolete.

In conclusion, the main difference between OLSR and CBL lies in routing approaches, load management, and network structure. OLSR prioritizes efficient neighbor discovery and optimal routes, while CBL concentrates on load management, utilizing a chain structure for data routing. The choice between these two protocols depends on the specific requirements of your ad hoc network.

7. Perspectives

In future research, we aim to broaden our evaluation by introducing additional metrics to gain a more comprehensive insight into the performance of ad-hoc routing protocols in vehicular networks. These metrics include packet delivery ratio, end-to-end delay, energy efficiency, and scalability.

Assessing these parameters will provide a better understanding of the protocols' capabilities and their suitability for diverse vehicular network scenarios. This expanded evaluation will contribute to refining existing protocols and guiding the development of new ones to meet the evolving demands of vehicular networks.

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