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Left-Right-Front Caching Strategy for Vehicular Networks in ICN-Based Internet of Things

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ABSTRACT In Vehicular Ad-hoc Networks (VANET), vehicles act like mobile nodes for fetching, sharing, and disseminating important information related to vehicle safety, warning messages, emergency events, and passenger infotainment. Due to continuous information sharing of vehicles with their surrounding nodes, Road Side Units (RSUs), and infrastructures, the existing host-centric IP-based network cannot fulfill the requirements of VANETs. Therefore, Information Centric Networking (ICN) architectures are the introduced to comprehensively address the problems of Internet of Things (IoT)-based VANETs, known as VANET-IoT. This paper introduces a new ICN-based proactive left-right-front (LRF) caching strategy for VANETs, which maximizes the performance of VANETs by placing content proactively at the right nodes. The proposed strategy also provides a mechanism for the timely dissemination of safety-related messages. LRF is compared with other caching strategies in the NS-3 simulator, which outperforms those schemes in terms of cache utilization, hop ratios, and resolved interest ratios with respect to 100 MB, 500 MB, and 1 GB cache sizes.

INDEX TERMS IP-based network, VANETs, information centric network, VANET security, Internet of Things.

I. INTRODUCTION

A Serious concentration has been made in the vehicular ad hoc network (VANET) technology [1], [2] since 1990s, and especially in the last decade, many advancements have been seen. Internet of Things (IoT) has been deployed (and being deployed) in various domains, such as agriculture [3], [4], healthcare [5]–[8], cloud computing [9], [10], edge computing [11], smart cities [12]–[14], smart homes [15], etc [16], [17]. However, VANETs in combination with IoT is a familiar research topic and has attracted attention from the research community at large [18]. VANETs drive networks on wheels and assist drivers and passengers by implementing the latest technologies in vehicles [19], [20]. In a secure VANET-IoT, each vehicle acts as a network node containing On-Board Units (OBU) [21]–[24] that exchange and transfer information to nearby vehicles and access points on the road, named Road Side Unit (RSU) [25]–[27]. All RSUs are placed on the side of roads for information exchange. In secure VANET-IoT, vehicles are also equipped with Vehicular Network sensors (VNS) that sense and process information from surrounding conditions, i.e., warning signs on roads, movement of other vehicles, sudden breaks sensing, accident conditions, etc., [28], [29]. VANETs applications are primarily divided into three categories [30], i.e., Road Safety [31], Infotainment Related, and Traffic Management [32], [33]. In VANETs, vehicles or nodes use intelligent transportation systems (ITS) [34] providing convenience to drivers by enhancing road safety and traffic efficiency [35]. VANETs use wireless communication [36] for message transferring among vehicles in a decentralized manner [37].

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In a secure VANET-based Internet of Things (IoT), i.e., VANET-IoT, connections are created among different network participants, i.e., Vehicle-to-Vehicle (V2V) [38], Vehicle-to-Infrastructure (V2I) [39], and Vehicle-to-everything (V2X) [40]. Mainly, VANETs use three types of communications for information retrieval and sharing [41]. First is the V2V communications that occur among vehicles for direct information sharing and transferring. V2V communications, which is also called communications of vehicles, mostly use two types of broadcasting techniques, i.e., Naive broadcast [42] and Intelligent broadcast [43]. Naive broadcast sends messages to all vehicles in the front direction and ignores messages coming from the back. Intelligent broadcast sends a limited number of messages for an event and stops broadcasting when a vehicle receives a message in a controlled manner [44]. Second is the V2I communications, which permit vehicles to communicate with RSUs [45], [46]. In V2X communications where *X* is any third party (pedestrians, road signals, other vehicles, infrastructure, etc.) that are involved in the communication. V2X communication is also called Hybrid communication [47].

VANETs mostly use two basic mechanisms for data dissemination, i.e., push-based [48] and pull-based [49] schemes. A push-based mechanism broadcasts messages proactively to other vehicles without sending any request. This mechanism is used to push necessary information in approaching vehicles, such as road safety and warning messages. The pull-based mechanism first sends a message for the content/data it needs, and the response contains the data packet. This mechanism is mostly used for infotainment-related services or where communications start with the request of consumer/requester [50]. VANET nodes mostly use wireless communications for information transferring. For this purpose, radio waves, Dedicated Short Range Communication (DSRC) [51], and IEEE 802.11p [52] are used.

VANET nodes are highly mobile due to which the connection time for information sharing is very short that leads to the problem of connectivity [53]. Many strategies that use IP-based ad-hoc networking are proposed in the literature [54] for routing and forwarding. The currently used host-centric network cannot fulfill the requirements of highly mobile VANET nodes. Direct V2V communications are not secure with the TCP/IP implementation because of network topology, a large number of nodes/vehicles, and ad-hoc network connectivity. There are also some technical limitations when we try to run or implement an IP-based system over the IEEE 802.11p [55]. To deal with this problem, researches have been trying for the last decade to embed a newly emerging technology in VANETs, named Information-Centric Networking (ICN) [56]. To support V2V communications, named-data networking (NDN), and Content Centric Networking (CCN) [57], which are instances of the ICN, best fit in the future Internet [56]. ICN architectures work well in searching, sharing, and retrieving information in highly mobile nodes of VANETs. The main problem in the existing techniques is at the access points or RSUs when a vehicle moves away from the RSU. Due to frequent changes in the RSUs and movement of the vehicles, connectivity and delivery problems arise. Hence, a proactive caching strategy, named Left-Right-Front (LRF) is proposed in this study to improve the performance of VANETs. In addition, this strategy also well addresses the issues of intermittent connectivity. The LRF caching mechanism is especially designed for the ICN-based VANET whereby vehicles move from one location to another with frequent mobility and content caching becomes difficult. The proposed strategy is suitable for improving cache utilization, hop ratios, and resolved interest ratios.

The LRF caching strategy is a novel approach presented to cope with the problems of the dynamic nature of network and mobility due to IoT-based VANET nodes in the ICN environment. The proposed cache strategy fully utilizes ICN architectures with little modification in the NDN stack. Furthermore, the LRF caching approach is compared with PeRCeIVE [58] and Q-Learning [59] with respect to various metrics.

The remaining sections of the paper are as follows: Related studies are discussed in Section II, in Section III, the LRF caching strategy is presented with detailed description; in Section IV, the scenario is built and the results are compared with that of the PeRCeIVE strategy; in Section VI, the probable limitations are provided; whereas, Section VII concludes the paper with some future research directions.

II. RELATED WORK

Preference-aware Fast Interest Forwarding (PaFF) [60] provides an interest forwarding strategy for ICN based VANETs. Firstly, PaFF selects nodes that have the same mobility and preference of video called 'associate' nodes. The associate nodes can be selected by estimating similarity in mobility patterns, video performance agreements, and by discovering associate nodes away from one hop neighborhood. Secondly, the associate nodes cache status is stored and maintained in the High Preferred Content Table (HPTC). HPTC has the name of contents cached by associate nodes and has information of the associate nodes for unicast routing. Further, PaFF provides a performance-aware selection mechanism for interest forwarding. PaFF is efficient in content searching and finding data in terms of delay as compare to other solutions but still needs improvement in the sharing of video streaming in terms of performance.

Utility Gradient cache (UG-Cache) [61] is a technique that provides cache insertion policy on the basis of request frequency and distance of cache from the content provider in ICN-VANETs. The UG-Cache increases the probability of content caching and decreases content average hop distance so that the request should be cached within the network. UG-Cache proposes a utility gradient function that informs nodes about the intermediate caching on the basis of increased cache hit rate. UG-Cache also proposes a variant named as Minimum Gradient Cache (MGCache) that works with the lowest frequency of requested content for evaluation of cache insertion. MG-Cache works with replacement policy like Least Frequently Used (LFU) for deployment. UG-Cache proposes an efficient implicit coordination scheme that reduces the cost of additional coordination in IC-VANETs. UC-Cache also lighted the future work for the improvement of cache replacement algorithms.

The Community Similarity and Population-based Cache Policy (CSPC) [62] is a technique for caching content in IC-VANETs for the V2V scenario. CSPC first determines the dynamic privacy rating of vehicles by evaluating the contribution of vehicles according to their participation in caching the content. To find privacy ratings, vehicles are grouped to form two categories: the set of public vehicles and private vehicles. The CSPC also determines the community similarity that is subdivided into content similarity and moving similarity. Moving similarity defines the stability of the link between vehicles, as the higher moving similarity between vehicles indicates they have a more stable link. Content similarity indicates drivers with similar hobbies means there is a higher probability of vehicles to cache the same content. The CSPC decrease the average time delay, increase cache hit, and decrease cache hit distance in V2V scenario.

The Efficient Content Routing Model Based on Link Expiration Time (ECRMLET) [63] uses a strategy of ICN architecture in VANETs to decrease useless traffic and to make sure the successful return of data packets. ECRMLET calculation is based on some predefined requirements like highway environment where vehicles are moved in a parallel direction, and the transmission range is 500 meters. The ECRMLET also modifies PIT by adding two more domains receive time and tolerance time. The ECRMLET provides transmission efficiency, and the highest cache hit ratio with less response time. ECRLMET also uses full network cache and selects stable paths for routing.

Trajectory forwarding scheme (TFS) [64] is a routing protocol proposed to solve the problem of interest flooding, disconnecting link, and mobility in VANETs. TFS embeds the CCN in VANETs to tackle the forwarding problems instead of host-centric-network. TFS selects the best forwarder within the architecture of NDN. TFS selects the best forwarder within the transmission range on the basis of two metrics vehicle trajectory and vehicle velocity. Each vehicle shares its trajectory and velocity; based on these metrics, and the best forwarder vehicle is selected. TFS strategy works in two steps; in the first step, each vehicle shares its neighbor table (NT) values to neighbor vehicles by sending beacon messages. TFS through this information, select the best forwarder in the communication range, and establish a path. In TFS, when the provider receives the interest packet, it generates a data packet in response that contains requested data, hop-count, and ID of content and sends back to the consumer through the best forwarder. TFS, in this way, archives the best communication by selected forwarding and reduces delay.

PeRCeIVE [58] is a proactive caching technique that places data in the network at the right time without altering the architecture of NDN. A hierarchical namespace is used by PeRCeIVE to request data chunks in the network. In the PeRCeIVE strategy, the vehicle makes a request for the interest of data from the network through RSU with the initial request. PeRCeIVE data store requires some additional information for placing of data chunks at RSU that must be provided with initial interest requests. The information contains the position of the vehicle that determines the current location and used for caching subsection of data in a network, Velocity that predicts the position of the vehicle in future, and interest frequency used to determine the number of different requests in the network. PeRCeIVE, by using these parameters, calculates the output number of chunks and determines a way to distribute these chunks along RSUs. This strategy ensures the availability of interest requested by a vehicle when passing an RSU. Hence, it shows better results in terms of one-hop and interest ratios while keeping a minimal number of copies in the network.

In [59], a heuristic Q-learning strategy is proposed that jointly considers the problems of vehicles' mobility and caching content. In this strategy, the Q-learning algorithm takes into consideration the movement of vehicles on the basis of long short-term memory. The proposed heuristic strategy can minimize the content retrieval latency because of the derived greedy training procedures. The obtained results show that Q-learning can perform better with several reference points under various precision.

Some other strategies have been proposed in the literature are Green Information-centric Multimedia Streaming (GrIMS) [65] designed for multimedia streaming in VANETs keeping into account energy efficiency and quality of experience (QoE); Efficient Content Routing Model based on Link Expiration Time (ECRMLET) [63] used to decrease useless traffic and make sure the successful return of data packets; Information-Centric Approach for Data Dissemination (ICADD) [66] organizes information into three categories for proper data dissemination in VANETs; V-ICE architecture [67] timely spreads information related to vehicles' safety when a black ice event occurs. Black ice is an ice layer on a road surface that may cause road accidents or vehicles may lose control during traveling as it is not easily detectable; Opportunistic Interest Forwarding Protocol (OIFP) [68] proposed for Interest forwarding that defines priorities for interest transmission among neighbor nodes on the basis of distance between two nodes; Utility Gradient cache (UG-Cache) [61] provides cache insertion policy on the basis of request frequency and distance of cache from the content provider in ICN-VANETs; Density-aware Delay-tolerant (DADT) strategy [69] is used for interest forwarding, which is utilized to overcome the problems of broadcast storm, transmission overhead, and data delivery ratios; Community Similarity and Population-based Cache Policy (CSPC) [62] is designed for V2V scenarios to determine the dynamic privacy rating of vehicles by evaluating their contributions in content caching; Source Selection Dynamically Network Coding-based Information Centric Network (SSDNC) [70]

TABLE 1. ICN-based VANET strategies with their contributions and limitations.

Technique	Contributions	Limitations
PaFF [60]	Improves start-up delay and cache hit ratios.	Lacks in decreasing overhead and decreasing performance during video sharing
GrIMS [65]	Improves performance by maintaining playback continuity and provides energy efficiency.	Does not improve overhead and QoS w.r.t video sharing.
ECRMLET [63]	Reduces network traffic and provides stable routing.	Time-consuming in finding link stability and lacks energy efficiency.
ICADD [66]	Increases scalability and decreases distributing complexity of information.	Needs to broadcast information related to notifications.
V-ICE [67]	Reduces network traffic and gives good performance in timeliness and relevance.	Does not provide forwarding and caching mechanism.
OIFP [68]	Improves rates of content delivery and reduces transmission of interest packets.	Does not perform well when the number of content producers increase.
UG-Cache [61]	Increases content delivery rate and reduces average hope numbers.	Needs to improve cache replacement algorithm and cache insertion decision.
DADT [69]	Attains a satisfactory ratio in minimizing overhead while reducing response delay.	Produces a burden in the utilization of resources through transmission.
CSPC [62]	Reduces cache redundancy and overhead of cache replacement.	Bases on probability for caching affected when the community does not allow to cache content.
SSDNC [70]	Achieves the best performance and has an average delay.	Does not evaluate the scalability and may consume time in computations.
TFS [64]	Overcomes flooding and disconnecting link problem, delay, and network load.	Uses a huge computation power for searching a better forwarder.
INDBFS [71]	Improves overhead caused by flooding of messages.	Needs more simulations for further evaluation of scenarios.
PeRCeIVE [58]	Improves network performance by direct data placement and minimizes replicas away from the requester.	Does not provide details about in-network caching and the number of hops.
Q-Learning [59]	Minimizes the content retrieval latency.	Maximizes processing overhead in content searching.

is used to exploit various features for selection from multiple data sources; Improved Named Data-based Forwarding Strategy (INDBFS) [71] is used to calculate the concerned degree of nodes about a particular named content and then request interest in the direction of high concern.

Besides, several other strategies have been proposed for IoT-based VANETs caching in the ICN environment, which can be studied in the literature [72]–[82]. The comparison of the surveyed schemes along with their contributions and limitations is presented in Table 1.

III. LEFT-RIGHT-FRONT CACHE STRATEGY

The paper provides a mechanism for proactive caching and introduces Left-Right-Front (LRF) cache strategy for VANETs. The LRF cache mechanism proactively places the requested data at upcoming nodes/RSUs for vehicles. In VANETS, vehicles continuously change their positions while travelling and move with the changing RSUs. This strategy works with a predefined ICN architecture without making a change in the existing data structures. In addition, LRF just adds another data structure, named Address Table (AT), for storing the addresses of left, right, and front RSUs. The addresses of these RSUs are embedded within the design of ICN at the time of installation of RSUs.

Figure 1 shows the LRF cache mechanism. Vehicles are moving and approaching from different sides of the roads within the ranges of their respective RSUs. These RSUs are the source of content caching and distribution. Contents are retrieved from the base station and VANET sensors. These contents are placed and forwarded according to the AT. Each vehicle can request some named content from RSUs. The RSU checks the content, if available, it responds the vehicle with the requested data. Otherwise, if the RSU does not contain the requested data, the interest is sent to the base station. A base station is a place that holds and maintains the RSUs of a certain area. Since the base station has 10 GB size in the simulated scenarios, it has enough space for caching and holding contents. Moreover, it searches the request in its CS within the network. After searching the content, the base station sends it back to the RSU that stores and provides the content to vehicles. The RSU also sends a copy of the content to the upcoming left, right, and front RSUs. These RSUs utilize this content when the vehicles move left side, right side, or may go straight to minimize the disconnection problem due to frequent changes of RSUs during vehicle movements. The LRF caching strategy works the same as that of the NDN architecture. As shown in Figure 2, vehicles initially request contents from their nearest (in range) RSUs with the help of NDN naming schemes. If the content is available at the RSU, it sends it to the vehicle as well as to addresses that are stored in the AT for proactive caching at the left, right, and front RSUs. If the content is not available at the RSU, the LRF strategy utilizes the NDN architecture. The RSU checks its PIT entries; if the same entry of the content is present in the PIT, it discards the request and makes an entry into the FIB. The entries in the FIB are sent to the base station where the base station responds to the request and provides data to the RSU. The RSU, after receiving the requested data, caches it into the CS and fulfills the request of the vehicle. The RSU also proactively caches

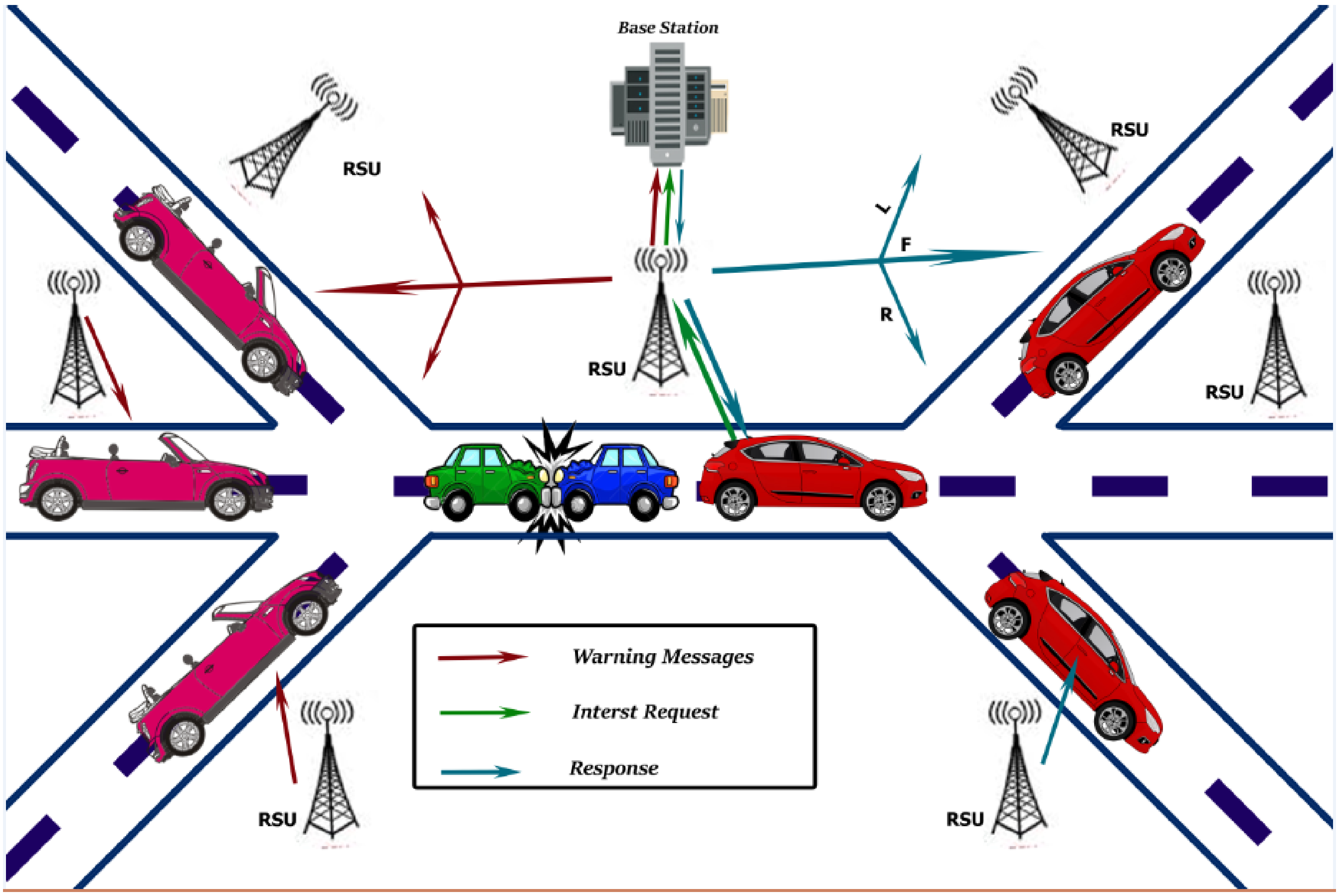

FIGURE 1. LRF caching strategy.

this information against the addresses stores in the AT. In this way, the requested data is proactively cached at the upcoming left, right, and front RSUs. The proactively placing of data at left, Right, and front RSUs is due to the fact that vehicles may either move left, right, or go straight on the road. In the LRF strategy, whether a vehicle moves at one side of the road or changes the route, it receives data/content without any delay. Data from the other two RSUs is discarded with the help of the eviction policy. The eviction policy is used to make space for newly received information from stored data on the device. In other words, when the memory of a device is full, the eviction policy is used to make space by evicting the old content. The LRF strategy uses Time-Aware Least Recently Used (TLRU) eviction policy [83] for the eviction of content from RSUs. TLRU keeps up contents in the store as per their access time. On the off chance that there is no free space and another content shows up, it deletes the least recently used one to provide space for the new content. With the help of TLRU, the old content that has no more use is evicted, and more space is provided for the newly arriving content. Therefore, using TLRU policy, the performance of the network can be increased.

A push-based mechanism is used for emergency-related messages, as shown in Figure 3. Through the push mechanism, messages are sent without interest generation from vehicles for the timely sharing of information. Sensors from the incident area, push information to the nearest RSU. These messages are specified by a special symbol. The LRF strategy uses the "#" symbol to recognize emergency messages. After this, the RSU pushes these messages to the base station for further action and providing the necessary aid. The RSU also pushes the messages to the stored addresses in the AT on the reverse path for vehicles that are approaching the incident area.

IV. EXPERIMENTAL SETUP

The LRF caching strategy builds a simple scenario of highway, as presented in Figure 1. In this technique, vehicles move along the road, bypassing different RSUs. The RSUs act as access points and have the capability to store, search, and send different types of data as provisioned by the network. The vehicles and RSUs are connected with each other through a wireless connection, whereas RSUs and base stations have a wired connection to provide fast data access without any signal interruption. The base station is the main provider of data where RSUs and vehicles are caching locations in the network. The RSUs have overlapping ranges throughout the road/track to avoid interruptions in connectivity. In the

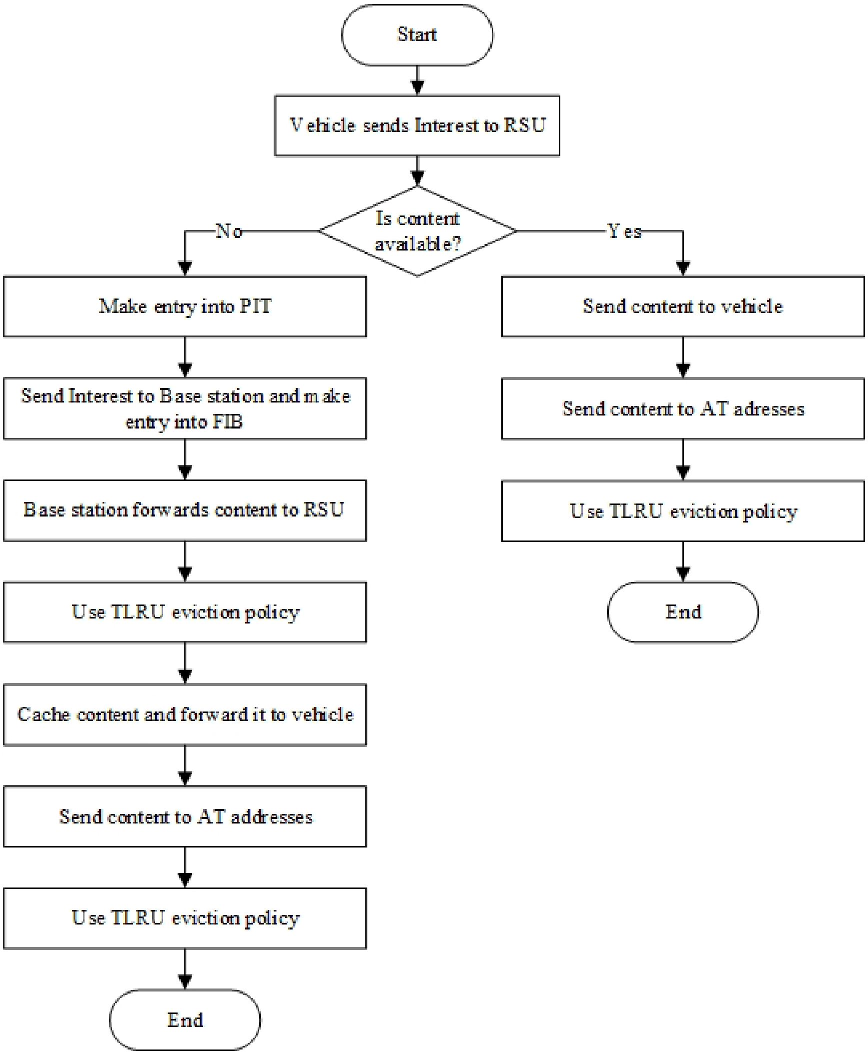

FIGURE 2. LRF working mechanism.

LRF strategy, the network has only V2I communications for complete utilization of the network. This strategy does not use V2V and other communications of VANETs. The NDN paradigm is used in the LRF cache strategy for downloading named contents. To compare the performance of LRF, PeRCeIVE, and Q-Learning caching strategies, a testbed is prepared by using the NS-3 simulator and SUMO to build ICN-based IoT-VANET. SUMO is a highly transportable, open source, continuous and microscopic traffic simulation package intended for managing huge networks. The LRF strategy is used on the highway scenario, having moving vehicles that generate different sizes and volumes of data requests. The vehicles and RSUs use IEEE 802.11 standard Wi-Fi connection for data sharing. The NS-3 simulator is used for building scenario, base station, RSUs, and vehicles. The scenario consists of 60 vehicles, 24 RSUs, and 1 interest is generated per second for a total of 1000s. The vehicles are running with a varying speed ranging from 15 to 60m/s. The RSUs are 200m away from each other so that their signal area is overlapping for improving communications performance. The RSUs are also equipped with bidirectional antennas that help make communications in all directions.

V. RESULTS AND DISCUSSION

After performing the simulations, the results of the LRF is compared with those of the PeRCeIVE and Q-Learning strategies on three defined metrics, i.e., cache utilization, one-hop ratio, and resolved interest ratio. Each metric is further tested with speed variations, i.e., low, medium, and high. In the proposed strategy, the speed of vehicles does not matter because of the proactive placement of content on all upcoming paths of vehicles, i.e., left, right, and front RSUs. In the simulation process, different numbers of tests were performed on each metric with varying speeds to produce results. Then the average of these results was taken and compared with the PeRCeIVE strategy for each metric.

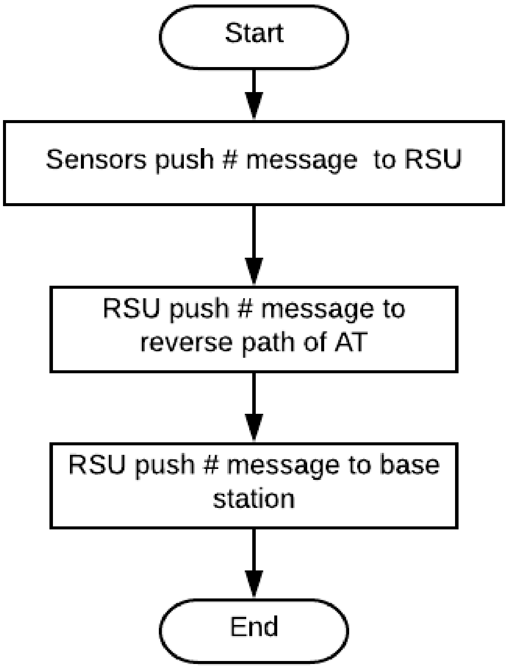

FIGURE 3. LRF working mechanism for emergency messages.

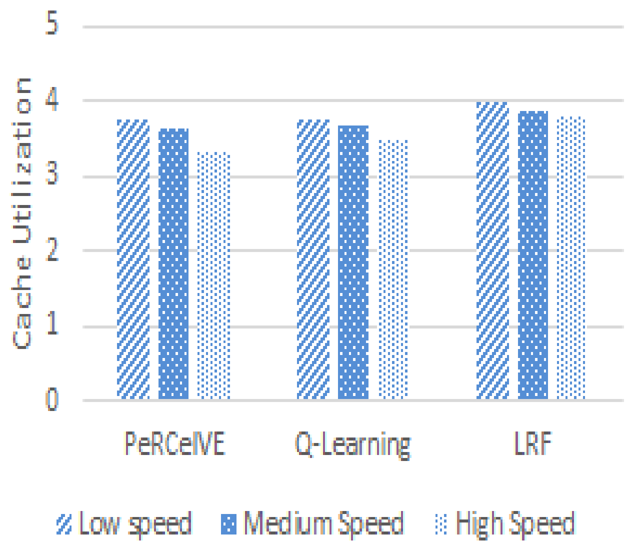

FIGURE 4. Cache utilization with different speed variations.

A. CACHE UTILIZATION

The number of copies of particular content in a network defines the cache utilization. The existing PeRCeIVE and Q-Learning schemes are affected by the popularity of content. If the popularity of content is low, PeRCeIVE and Q-Learning produce good results, but when the popularity increases, there is a decrease in the value for cache utilization. The simulation results show that for the LRF strategy, content popularity does not affect the cache utilization value. PeRCeIVE strategy produces results at an average of 3.56, Q-Learning attains 3.63 for the cache utilization value, whereas LRF strategy provides an average of 3.88 for the same metric, as presented in Figure 4. Thus, the proposed scheme produces better results than the other two strategies. The main reason behind this improvement is the use of eviction policy, i.e., TLRU, by the LRF strategy. The simulation results show that the cache utilization metric is greatly affected by the cache management policy.

B. ONE-HOP RATIO

It is the ratio of interests directly satisfied by the RSUs without searching within the network. In proactive approaches, the content is placed at RSUs according to the probability of interest generation prior to a request for particular content. The PeRCeIVE approach divides the content into chunks before placing it at RSUs. There is a chance for a vehicle to miss a chunk, thus, it has to request again for the same chunk. On the other hand, LRF strategy proactively places content on all paths of vehicles' movement, i.e., left, right, and front, which is also different than Q-Learning. Therefore, it increases the one-hop ratio. The simulation results show that the LRF caching strategy has 50% improvement as compared to the results of other two strategies by placing content proactively at RSUs. The results clearly show that the LRF strategy improves the performance of IoT-VANETs as compared to PeRCeIVE and Q-Learning (see Figure 5). In the simulation environment, LRF strategy achieves better value than PeRCeIVE and Q-Learning regardless of the speed.

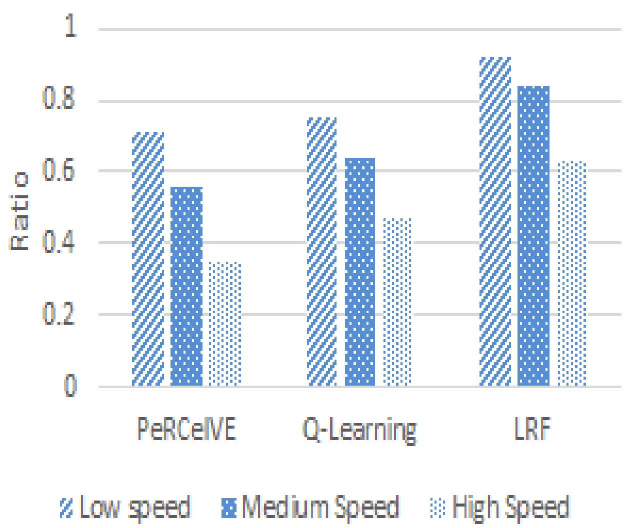

FIGURE 5. One-hop ratio with different speed variations.

C. RESOLVED INTEREST RATIO

This metric shows the ratio of interests satisfied by a vehicle as compared to the total interests sent. The ratios of interests are greatly affected by the speed and mobility of the vehicle. The vehicles requesting certain contents are also moving towards the upcoming RSUs. Therefore, there are more chances of missing contents from the requested RSU

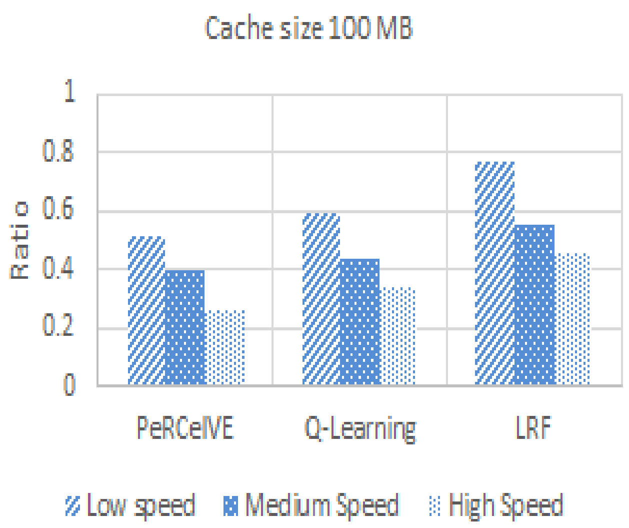

FIGURE 6. Resolved interest ratio with cache size 100 MB.

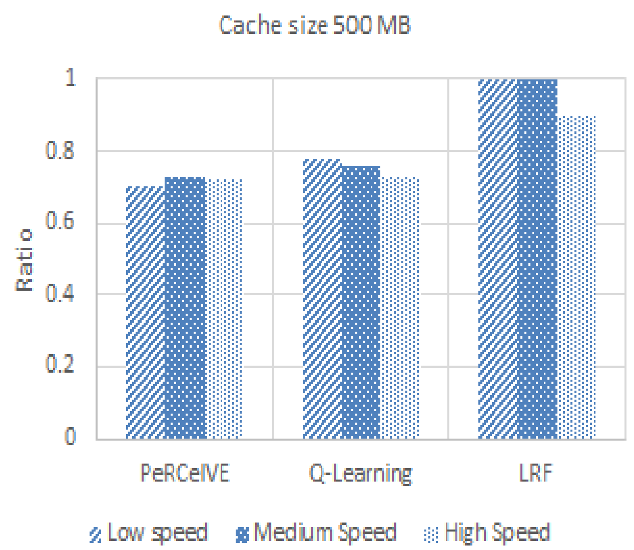

FIGURE 7. Resolved interest ratio with cache size 500 MB.

and may have to request again from another RSU. These phenomena cause the problem of mobile node delivery. Due to this problem, a vehicle has to repeat its request and therefore consumes extra bandwidth. At a very high speed, 10% of the requests may be missed to be fulfilled at the requested node/RSU. Since this parameter is mostly affected by the speed, we have evaluated it against different cache sizes, i.e., 100 MB, 500 MB, and 1 GB, respectively. The proposed strategy shows higher resolved interest ratios in all cache sizes, as presented in Figures 6 through 8. The simulation results clearly define that LRF caching strategy has better results in terms of the above-mentioned metrics. LRF strategy improves the performance of IoT-VANETs and decreases the delay time of interests by ensuring proactive data delivery at left, right, and front RSUs.

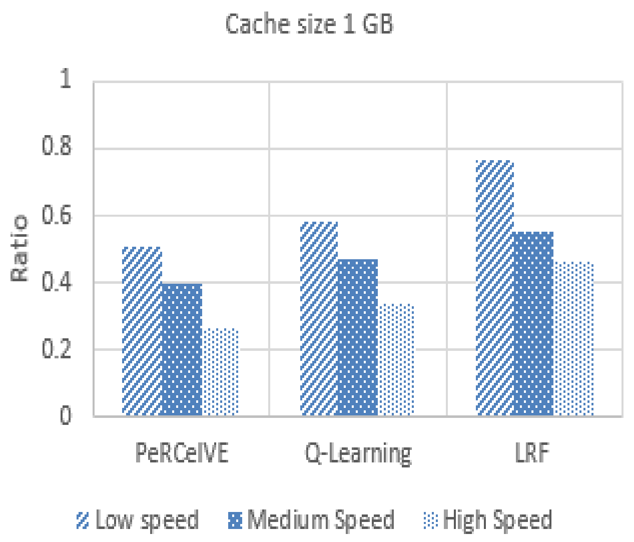

FIGURE 8. Resolved interest ratio with cache size 1 GB.

VI. LIMITATIONS OF LRF

Since LRF is simulated considering highway scenarios, which do not have frequent turns. Therefore, if LRF is deployed in case of a mountain winding road, having frequent U-turns, it would face difficulties when RSUs share content with each other. One more limitation of LRF is such that when a vehicle moves with fast speed, the RSUs may not be able to serve the user requests after asking the BS, if the content is not available in the RSU. Hence, it can be thought-out to modify LRF caching strategy to work well in such kind of challenging scenarios.

VII. CONCLUSION

This paper discusses the potentials and solutions of the ICN paradigm that provides the best results for ad-hoc networks like VANETs. This is the reason that the research community has a growing demand for ICN to be used as an alternative to the IP-based host-centric network in the IoT-VANETs.

Though several strategies have been proposed for ICN caching provided in the Related Work section, a few of them are designed to take the VANET technology into consideration joint with ICN. The proposed ICN-based LRF caching strategy is specifically designed for ICN-based VANETs, which provides better results than the existing popular strategies, i.e., PeRCeIVE and Q-Learning, by caching contents at the left, right, and front RSUs. The results show that the LRF strategy has a more significant improvement in terms of cache utilization, one-hop ratio, and resolved interest ratio. The LRF strategy also provides a mechanism for emergency-related messages to be delivered timely.

In the future, the work will also be extended for V2V communications. The strategy may also be modified to work for infotainment-related data for the passengers inside vehicles.

REFERENCES

[1] S. Zhong, H. Zhong, X. Huang, P. Yang, J. Shi, L. Xie, and K. Wang, ''Connecting things to things in physical-world: Security and privacy issues in vehicular ad-hoc networks,'' in *Security and Privacy for Next-Generation Wireless Networks*. Cham, Switzerland: Springer, 2019, pp. 101–134.

[2] F. M. Malik, H. A. Khattak, A. Almogren, O. Bouachir, I. U. Din, and A. Altameem, ''Performance evaluation of data dissemination protocols for connected autonomous vehicles,'' *IEEE Access*, vol. 8, pp. 126896–126906, 2020.

[3] K. A. Awan, I. Ud Din, A. Almogren, and H. Almajed, ''AgriTrust—A trust management approach for smart agriculture in cloud-based Internet of agriculture things,'' *Sensors*, vol. 20, no. 21, p. 6174, 2020.

[4] K. Haseeb, I. Ud Din, A. Almogren, and N. Islam, ''An energy efficient and secure IoT-based WSN framework: An application to smart agriculture,'' *Sensors*, vol. 20, no. 7, p. 2081, Apr. 2020.

[5] I. Ud Din, A. Almogren, M. Guizani, and M. Zuair, ''A decade of Internet of Things: Analysis in the light of healthcare applications,'' *IEEE Access*, vol. 7, pp. 89967–89979, 2019.

[6] S. U. Khan, N. Islam, Z. Jan, I. U. Din, A. Khan, and Y. Faheem, ''An e-Health care services framework for the detection and classification of breast cancer in breast cytology images as an IoMT application,'' *Future Gener. Comput. Syst.*, vol. 98, pp. 286–296, Sep. 2019.

[7] K. A. Awan, I. U. Din, A. Almogren, H. Almajed, I. Mohiuddin, and M. Guizani, ''Neurotrust -artificial neural network-based intelligent trust management mechanism for large-scale Internet of medical things,'' *IEEE Internet Things J.*, early access, Oct. 6, 2020, doi: 10.1109/JIOT.2020.3029221.

[8] A. Almogren, I. Mohiuddin, I. U. Din, H. A. Majed, and N. Guizani, ''FTM-IoMT: Fuzzy-based trust management for preventing sybil attacks in Internet of medical things,'' *IEEE Internet Things J.*, early access, Sep. 29, 2020, doi: 10.1109/JIOT.2020.3027440.

[9] K. Janjua, M. A. Shah, A. Almogren, H. A. Khattak, C. Maple, and I. U. Din, ''Proactive forensics in IoT: Privacy-aware log-preservation architecture in fog-enabled-cloud using holochain and containerization technologies,'' *Electronics*, vol. 9, no. 7, p. 1172, Jul. 2020.

[10] K. Haseeb, A. Almogren, I. Ud Din, N. Islam, and A. Altameem, ''SASC: Secure and authentication-based sensor cloud architecture for intelligent Internet of Things,'' *Sensors*, vol. 20, no. 9, p. 2468, Apr. 2020.

[11] K. Haseeb, I. U. Din, A. Almogren, Z. Jan, N. Abbas, and M. Adnan, ''DDR-ESC: A distributed and data reliability model for mobile edge-based sensor-cloud,'' *IEEE Access*, vol. 8, pp. 185752–185760, 2020.

[12] H. A. Khattak, K. Tehreem, A. Almogren, Z. Ameer, I. U. Din, and M. Adnan, ''Dynamic pricing in industrial Internet of Things: Blockchain application for energy management in smart cities,'' *J. Inf. Secur. Appl.*, vol. 55, Dec. 2020, Art. no. 102615.

[13] N. Islam, K. Haseeb, A. Almogren, I. U. Din, M. Guizani, and A. Altameem, ''A framework for topological based map building: A solution to autonomous robot navigation in smart cities,'' *Future Gener. Comput. Syst.*, vol. 111, pp. 644–653, Oct. 2020.

[14] I. U. Din, M. Guizani, J. J. P. C. Rodrigues, S. Hassan, and V. V. Korotaev, ''Machine learning in the Internet of Things: Designed techniques for smart cities,'' *Future Gener. Comput. Syst.*, vol. 100, pp. 826–843, Nov. 2019.

[15] W. Ali, I. Ud Din, A. Almogren, M. Guizani, and M. Zuair, ''A lightweight privacy-aware IoT-based metering scheme for smart industrial ecosystems,'' *IEEE Trans. Ind. Informat.*, early access, Apr. 17, 2020, doi: 10.1109/TII.2020.2984366.

[16] M. A. Khan, I. Ud Din, S. U. Jadoon, M. K. Khan, M. Guizani, and K. A. Awan, ''G-RAT | a novel graphical randomized authentication technique for consumer smart devices,'' *IEEE Trans. Consum. Electron.*, vol. 65, no. 2, pp. 215–223, May 2019.

[17] W. Ali, I. Ud Din, A. Almogren, and N. Kumar, ''ALPHA: An anonymous orthogonal code-based privacy preserving scheme for industrial cyber physical systems,'' *IEEE Trans. Ind. Informat.*, early access, Oct. 14, 2020, doi: 10.1109/TII.2020.3030961.

[18] B. Jan, H. Farman, M. Khan, M. Talha, and I. U. Din, ''Designing a smart transportation system: An Internet of Things and big data approach,'' *IEEE Wireless Commun.*, vol. 26, no. 4, pp. 73–79, Aug. 2019.

[19] C. Cooper, D. Franklin, M. Ros, F. Safaei, and M. Abolhasan, ''A comparative survey of VANET clustering techniques,'' *IEEE Commun. Surveys Tuts.*, vol. 19, no. 1, pp. 657–681, 1st Quart., 2017.

[20] K. A. Awan, I. U. Din, A. Almogren, M. Guizani, and S. Khan, ''StabTrust—A stable and centralized trust-based clustering mechanism for IoT enabled vehicular ad-hoc networks,'' *IEEE Access*, vol. 8, pp. 21159–21177, 2020.

[21] H. Tan, D. Choi, P. Kim, S. Pan, and I. Chung, ''Comments on 'dual authentication and key management techniques for secure data transmission in vehicular ad hoc networks,''' *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 7, pp. 2149–2151, Jul. 2018.

[22] T. Gazdar, A. Belghith, and A. AlMogren, ''DTCF: A distributed trust computing framework for vehicular ad hoc networks,'' *KSII Trans. Internet Inf. Syst.*, vol. 11, no. 3, pp. 1533–1556, 2017.

[23] T. Adhikary, A. K. Das, M. A. Razzaque, A. Almogren, M. Alrubaian, and M. M. Hassan, ''Quality of service aware reliable task scheduling in vehicular cloud computing,'' *Mobile Netw. Appl.*, vol. 21, no. 3, pp. 482–493, Jun. 2016.

[24] I. S. Alkhalifa and A. S. Almogren, ''NSSC: Novel segment based safety message broadcasting in cluster-based vehicular sensor network,'' *IEEE Access*, vol. 8, pp. 34299–34312, 2020.

[25] S. A. A. Shah, E. Ahmed, F. Xia, A. Karim, M. Shiraz, and R. M. Noor, ''Adaptive beaconing approaches for vehicular ad hoc networks: A survey,'' *IEEE Syst. J.*, vol. 12, no. 2, pp. 1263–1277, Jun. 2018.

[26] S. Khan, H. A. Khattak, A. Almogren, M. A. Shah, I. Ud Din, I. Alkhalifa, and M. Guizani, ''5G vehicular network resource management for improving radio access through machine learning,'' *IEEE Access*, vol. 8, pp. 6792–6800, 2020.

[27] M. Tabassum, M. A. Razzaque, M. M. Hassan, A. Almogren, and A. Alamri, ''Interference-aware high-throughput channel allocation mechanism for CR-VANETs,'' *EURASIP J. Wireless Commun. Netw.*, vol. 2016, no. 1, p. 2, Dec. 2016.

[28] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, ''Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions,'' *IEEE Commun. Surveys Tuts.*, vol. 13, no. 4, pp. 584–616, 4th Quart., 2011.

[29] H. A. Khattak, H. Farman, B. Jan, and I. U. Din, ''Toward integrating vehicular clouds with IoT for smart city services,'' *IEEE Netw.*, vol. 33, no. 2, pp. 65–71, Mar. 2019.

[30] M. Kumar, A. K. Nigam, and T. Sivakumar, ''A survey on topology and position based routing protocols in vehicular ad hoc network (VANET),'' *Int. J. Future Revolution Comput. Sci. Commun. Eng.*, vol. 4, no. 2, pp. 432–440, 2018.

[31] R. Dilgir and A. Baez, ''Road safety study for roadway functional and preliminary designs rehabiliation of Belize's northern highway between miles 9.5-24.5: Ongoing study: Anticipated completion December 2017,'' in *Proc. 18th Int. Conf. Road Saf. Five Continents (RSC)*, Jeju Island, South Korea: Statens väg-och transportforskningsinstitut, May 2018, pp. 1–5.

[32] K. Dar, M. Bakhouya, J. Gaber, M. Wack, and P. Lorenz, ''Wireless communication technologies for ITS applications,'' *IEEE Commun. Mag.*, vol. 48, no. 5, pp. 156–162, May 2010.

[33] M. Islam, M. A. Razzaque, M. Mamun-Or-Rashid, M. M. Hassan, A. Almogren, and A. Alelaiwi, ''Dynamic traffic engineering for high-throughput data forwarding in wireless mesh networks,'' *Comput. Electr. Eng.*, vol. 56, pp. 130–144, Nov. 2016.

[34] A. Patel and P. Kaushik, ''Improving QoS of VANET using adaptive CCA range and transmission range both for intelligent transportation system,'' *Wireless Pers. Commun.*, vol. 100, no. 3, pp. 1063–1098, Jun. 2018.

[35] S. Sattar, H. K. Qureshi, M. Saleem, S. Mumtaz, and J. Rodriguez, ''Reliability and energy-efficiency analysis of safety message broadcast in VANETs,'' *Comput. Commun.*, vol. 119, pp. 118–126, Apr. 2018.

[36] V. Canas, E. Sanchez, M. Botsch, and A. Garcia, ''Wireless communication system for the validation of autonomous driving functions on full-scale vehicles,'' in *Proc. IEEE Int. Conf. Veh. Electron. Saf. (ICVES)*, Sep. 2018, pp. 1–6.

[37] M. Aguilera Leal, M. Rockl, B. Kloiber, F. de Ponte Muller, and T. Strang, ''Information-centric opportunistic data dissemination in vehicular ad hoc networks,'' in *Proc. 13th Int. IEEE Conf. Intell. Transp. Syst.*, Sep. 2010, pp. 19–22.

[38] K. Sharmila and C. Ramesh, ''Analyzing performance and QoS parameter estimation for VANET using D2D,'' in *Innovations in Electronics and Communication Engineering*. Cham, Switzerland: Springer, 2019, pp. 249–259.

[39] S. Rajab, ''Vehicle to infrastructure communications,'' in *Connected Vehicles*. Cham, Switzerland: Springer, 2019, pp. 157–179.

[40] M. B. Diez and S. Lindenmeier, "Diversity performance of benchmark scenarios for hidden vehicle-to-X antennas underneath the roof," in *Proc. 48th Eur. Microw. Conf. (EuMC)*, Sep. 2018, pp. 308–311.
[41] M. Arif, G. Wang, and V. E. Balas, "Secure VANETs: Trusted communication scheme between vehicles and infrastructure based on fog computing," *Stud. Informat. Control*, vol. 27, no. 2, pp. 235–246, Jan. 2019.
[42] A. Mehmood, A. Khanan, A. H. H. M. Mohamed, S. Mahfooz, H. Song, and S. Abdullah, "ANTSC: An intelligent Naïve Bayesian probabilistic estimation practice for traffic flow to form stable clustering in VANET," *IEEE Access*, vol. 6, pp. 4452–4461, 2018.
[43] F. Lyu, N. Cheng, H. Zhu, H. Zhou, W. Xu, M. Li, and X. S. Shen, "Intelligent context-aware communication paradigm design for IoVs based on data analytics," *IEEE Netw.*, vol. 32, no. 6, pp. 74–82, Nov. 2018.
[44] V. Kanimozhi and S. Karthik, "A survey on multi-constrained optimal path selection schemes and authentication schemes for VANET," in *Proc. 11th Int. Conf. Intell. Syst. Control (ISCO)*, Jan. 2017, pp. 25–29.
[45] X. Jiang and D. H. C. Du, "BUS-VANET: A BUS vehicular network integrated with traffic infrastructure," *IEEE Intell. Transp. Syst. Mag.*, vol. 7, no. 2, pp. 47–57, Apr. 2015.
[46] N. Kumar, S. Zeadally, and J. J. P. C. Rodrigues, "QoS-aware hierarchical Web caching scheme for online video streaming applications in Internet-based vehicular ad hoc networks," *IEEE Trans. Ind. Electron.*, vol. 62, no. 12, pp. 7892–7900, Dec. 2015.
[47] S. Hosmani and B. Mathpati, "Survey on cluster based routing protocol in VANET," in *Proc. Int. Conf. Electr., Electron., Commun., Comput., Optim. Techn. (ICEECCOT)*, Dec. 2017, pp. 1–6.
[48] J. van der Hooft, S. Petrangeli, T. Wauters, R. Huysegems, T. Bostoen, and F. De Turck, "An HTTP/2 push-based approach for low-latency live streaming with super-short segments," *J. Netw. Syst. Manage.*, vol. 26, no. 1, pp. 51–78, Jan. 2018.
[49] H. Ismail, S. Roos, and N. Suri, "A detection mechanism for internal attacks on pull-based P2P streaming systems," in *Proc. IEEE 19th Int. Symp. World Wireless, Mobile Multimedia Netw. (WoWMoM)*, Jun. 2018, pp. 1–9.
[50] C. Chen, C. Wang, G. Zhang, Z. Ren, and J. Ma, "In-car shopping: A data dissemination scheme for vehicular networks in urban areas," in *Proc. 9th Int. Conf. Wireless Commun. Signal Process. (WCSP)*, Oct. 2017, pp. 1–6.
[51] J. B. Kenney, "Dedicated short-range communications (DSRC) standards in the united states," *Proc. IEEE*, vol. 99, no. 7, pp. 1162–1182, Jul. 2011.
[52] S. Gräfling, P. Mähönen, and J. Riihijärvi, "Performance evaluation of IEEE 1609 WAVE and IEEE 802.11 P for vehicular communications," in *Proc. 2nd Int. Conf. Ubiquitous Future Netw. (ICUFN)*, 2010, pp. 344–348.
[53] I. Din, B.-S. Kim, S. Hassan, M. Guizani, M. Atiquzzaman, and J. Rodrigues, "Information-centric network-based vehicular communications: Overview and research opportunities," *Sensors*, vol. 18, no. 11, p. 3957, Nov. 2018.
[54] J. Chennikara-Varghese, W. Chen, O. Altintas, and S. Cai, "Survey of routing protocols for inter-vehicle communications," in *Proc. 3rd Annu. Int. Conf. Mobile Ubiquitous Syst., Netw. Services*, Jul. 2006, pp. 1–5.
[55] G. Grassi, D. Pesavento, G. Pau, R. Vuyyuru, R. Wakikawa, and L. Zhang, "VANET via named data networking," in *Proc. IEEE Conf. Comput. Commun. Workshops (INFOCOM WKSHPS)*, Apr. 2014, pp. 410–415.
[56] I. U. Din, S. Hassan, M. K. Khan, M. Guizani, O. Ghazali, and A. Habbal, "Caching in information-centric networking: Strategies, challenges, and future research directions," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 2, pp. 1443–1474, 2nd Quart., 2018.
[57] L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, K. C. Claffy, P. Crowley, C. Papadopoulos, L. Wang, and B. Zhang, "Named data networking," *SIGCOMM Comput. Commun. Rev.*, vol. 44, no. 3, pp. 66–73, Jul. 2014.
[58] D. Grewe, M. Wagner, and H. Frey, "PeRCeIVE: Proactive caching in ICN-based VANETs," in *Proc. IEEE Veh. Netw. Conf. (VNC)*, Dec. 2016, pp. 1–8.
[59] L. Hou, L. Lei, K. Zheng, and X. Wang, "A *Q*-learning-based proactive caching strategy for non-safety related services in vehicular networks," *IEEE Internet Things J.*, vol. 6, no. 3, pp. 4512–4520, Jun. 2019.
[60] M. Wang, C. Xu, S. Jia, J. Guan, and L. A. Grieco, "Preference-aware fast interest forwarding for video streaming in information-centric VANETs," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2017, pp. 1–7.
[61] F. D. M. Modesto and A. Boukerche, "Utility-gradient implicit cache coordination policy for information-centric ad-hoc vehicular networks," in *Proc. IEEE 42nd Conf. Local Comput. Netw. (LCN)*, Oct. 2017, pp. 10–17.
[62] W. Zhao, Y. Qin, D. Gao, C. H. Foh, and H.-C. Chao, "An efficient cache strategy in information centric networking vehicle-to-vehicle scenario," *IEEE Access*, vol. 5, pp. 12657–12667, 2017.
[63] H. Guo, L. Rui, R. Shi, H. Huang, and X. Qiu, "A new ICN routing selecting algorithm based on link expiration time of VANET under the highway environment," in *Proc. IFIP/IEEE Symp. Integr. Netw. Service Manage. (IM)*, May 2017, pp. 640–643.
[64] H. Maryam, M. A. Shah, S. Arshad, A. Siddiqa, and A. Wahid, "TFS: A reliable routing protocol for vehicular content centric networks," in *Proc. 13th Int. Conf. Emerg. Technol. (ICET)*, Dec. 2017, pp. 1–6.
[65] C. Xu, W. Quan, H. Zhang, and L. A. Grieco, "GrIMS: Green information-centric multimedia streaming framework in vehicular ad hoc networks," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 28, no. 2, pp. 483–498, Feb. 2018.
[66] Y. Li, T. Kanter, R. Rahmani, and L. Wolf, "An information-centric approach for data dissemination in vehicular networks," in *Proc. Int. Conf. Connected Vehicles Expo (ICCVE)*, Nov. 2014, pp. 888–893.
[67] J. Chen, M. Jahanian, and K. K. Ramakrishnan, "Black ice! Using information centric networks for timely vehicular safety information dissemination," in *Proc. IEEE Int. Symp. Local Metrop. Area Netw. (LANMAN)*, Jun. 2017, pp. 1–6.
[68] X. Yu, R. W. L. Coutinho, A. Boukerche, and A. A. F. Loureiro, "A distance-based interest forwarding protocol for vehicular information-centric networks," in *Proc. IEEE 28th Annu. Int. Symp. Pers., Indoor, Mobile Radio Commun. (PIMRC)*, Oct. 2017, pp. 1–5.
[69] M. Kuai, X. Hong, and Q. Yu, "Density-aware delay-tolerant interest forwarding in vehicular named data networking," in *Proc. IEEE 84th Veh. Technol. Conf. (VTC-Fall)*, Sep. 2016, pp. 1–5.
[70] Q. Wang, D. Xie, and X. Ji, "Network codes-based content-centric transmission control in VANET," in *Proc. Int. Conf. Connected Vehicles Expo (ICCVE)*, Oct. 2015, pp. 157–162.
[71] L. Xuejie, C. Xuewei, W. Da, and X. Xin, "An improved named data based forwarding strategy in VANET," in *Proc. Int. Conf. Wireless Commun., Signal Process. Netw. (WiSPNET)*, Mar. 2017, pp. 2318–2322.
[72] Y. Meng, M. A. Naeem, R. Ali, Y. B. Zikria, and S. W. Kim, "DCS: Distributed caching strategy at the edge of vehicular sensor networks in information-centric networking," *Sensors*, vol. 19, no. 20, p. 4407, Oct. 2019.
[73] W. Huang, T. Song, Y. Yang, and Y. Zhang, "Cluster-based cooperative caching with mobility prediction in vehicular named data networking," *IEEE Access*, vol. 7, pp. 23442–23458, 2019.
[74] H. Khelifi, S. Luo, B. Nour, A. Sellami, H. Moungla, and F. Nait-Abdesselam, "An optimized proactive caching scheme based on mobility prediction for vehicular networks," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2018, pp. 1–6.
[75] I. U. Din, S. Hassan, A. Almogren, F. Ayub, and M. Guizani, "PUC: Packet update caching for energy efficient IoT-based information-centric networking," *Future Gener. Comput. Syst.*, vol. 111, pp. 634–643, Oct. 2020.
[76] H. Asmat, I. U. Din, F. Ullah, M. Talha, M. Khan, and M. Guizani, "ELC: Edge linked caching for content updating in information-centric Internet of Things," *Comput. Commun.*, vol. 156, pp. 174–182, Apr. 2020.
[77] Z. Ali, M. A. Shah, A. Almogren, I. Ud Din, C. Maple, and H. A. Khattak, "Named data networking for efficient IoT-based disaster management in a smart campus," *Sustainability*, vol. 12, no. 8, p. 3088, Apr. 2020.
[78] I. U. Din, H. Asmat, and M. Guizani, "A review of information centric network-based Internet of Things: Communication architectures, design issues, and research opportunities," *Multimedia Tools Appl.*, vol. 78, no. 21, pp. 30241–30256, Nov. 2019.
[79] A. Siddiqua, M. A. Shah, H. A. Khattak, I. Ud Din, and M. Guizani, "ICAFE: Intelligent congestion avoidance and fast emergency services," *Future Gener. Comput. Syst.*, vol. 99, pp. 365–375, Oct. 2019.
[80] O. A. Khan, M. A. Shah, I. Ud Din, B.-S. Kim, H. A. Khattak, J. J. P. C. Rodrigues, H. Farman, and B. Jan, "Leveraging named data networking for fragmented networks in smart metropolitan cities," *IEEE Access*, vol. 6, pp. 75899–75911, 2018.
[81] I. U. Din, S. Hassan, and A. Habbal, "Redundancy elimination in the future Internet," in *Proc. Int. Conf. Comput., Math. Statist. (iCMS)*. Cham, Switzerland: Springer, 2017, pp. 67–73.
[82] S. Hassan, I. U. Din, A. Habbal, and N. H. Zakaria, "A popularity based caching strategy for the future Internet," in *Proc. ITU Kaleidoscope, ICTs Sustain. World (ITU WT)*, Nov. 2016, pp. 1–8.
[83] M. Bilal and S.-G. Kang, "Time aware least recent used (TLRU) cache management policy in ICN," in *Proc. 16th Int. Conf. Adv. Commun. Technol.*, Feb. 2014, pp. 528–532.

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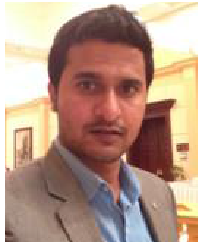

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