Junction-Centric Data Forwarding in Urban Vehicular Communication: Future Direction and Challenges

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Abstract. All Data packet transmission is a concept in vehicular communication for achieving road safety based on Intelligent Transportation System (ITS). The packet forwarding is carried out in two scenarios including road zone and junction zone forwarding in order to address the problem of intermittent disconnection that leads to packet loss and packet error. Several studies have been conducted considering these scenarios to achieve effective communication. These studies have been revisited to provide comprehensive understanding in order to further explore the existing solutions. However, the re-visitations of these studies have not considered some of the existing junction zone packet forwarding, which is based on video data transmission. To this end, this paper suggests a qualitative review on Junction-centric Data Packet Forwarding (JDPF) focusing on vehicular communication. Precisely, a review of various junction-centric approaches with their comparative assessment is presented. Major challenges in the junction-centric data packet forwarding are identified as future directions of research. The major issues include high traffic load, incorrect metric priority selection and link disconnection at the junction area. The review would be useful to practitioners and researchers, in terms of augmenting clarity in the junction-centric data packet forwarding literature.

Keywords: Vehicular communication, Junction, Data packet, Packet forwarding, Intersection

1. Introduction

In the last few years, vehicular communication has become an emerging research domain, which attracts the interest of researchers in both academia and industries. This is due to the different application including road safety, traffic management and infotainment [1]. The safety application includes accident avoidance and cooperative driving. For traffic management, this involves toll services and road traffic information. While the infotainment includes service advertisement, internet access, entertainment and gaming [2, 3]. Vehicular Ad-hoc NETwork (VANET) is a unique type of Wireless Ad Hoc Network (WAHN), which emanate from the Mobile Ad-hoc NETwork (MANET) [4, 5]. Meanwhile, VANET has a distinctive node distribution, which is majorly based on the road path. Forwarding of a packet in the road path is based on the multi-hop concept. In general, the
features of VANET is characterized by high node mobility, constrained to road path and frequent network partition [6]. Thus, these features pose critical challenges in achieving efficient VANET communication. The constituent of the VANETs is the Road Infrastructure Unit (RIU), embedded sensors and On-Board Unit (OBU). The RIU is normally situated along the road in both urban and highway environments [7, 8]. The RIU enable communication between Vehicle-to-Vehicle (V2V) and Vehicle with Infrastructure (V2I) [9, 10]. The sensors are used for sensing the vehicle’s component and other surrounding vehicles. An example of the OBU is the Dedicate Short Range Communication (DSRC) device that provides short distance communication in V2V and V2I [11]. Therefore, in the V2V and V2I communication, different data packet forwarding strategies have been employed to attain efficient transmission. Meanwhile, different types of data packet have been considered in the previous studies including text message-based and video streaming-based data transmission [12, 13].

One of the main aspects that leads to the success of vehicular communication is the routing (packet forwarding), which are based on MANET routing protocols. These protocols include AODV Ad-hoc On-demand Distance Vector (AODV) routing [14], Dynamic Source Routing (DSR) [15], Optimized Link State Routing (OLSR) protocol [16] and so on. These protocols were adapted considering the VANET features and characteristics. Consequently, different VANETs routing protocols were proposed including Greedy Perimeter Coordinate Routing (GPCR) [17], Greedy Traffic-Aware Routing (GyTAR) [18], Static Node Assisted Adaptive Routing protocol in VANET (SADV) [19] and so on. However, not all of these protocols consider the junction-centric packet forwarding. Some re-visitations have been conducted on the existing solutions for data packet forwarding in vehicular communication. For example, in [20], a review has been conducted in vehicular communication focusing on the design considerations and challenges of vehicle to pedestrian communication system to mitigate vulnerable road users. Another review has been conducted by [23], which focused on approaches and challenges in multipath video data transmission over vehicular networks. However, the review does not consider existing solutions that explore junction-centric data forwarding strategies. In addition, a traffic-aware routing survey in vehicular networks based characteristics and challenges have been suggested in [21]. However, the review explores routing metrics measurement, recovery techniques, routing process and forwarding mechanisms of the existing solutions. However, the review does not capture some recent solutions because it was conducted in the year 2015. Therefore, considering the aforesaid limitations of the available review, there is a need to further explore recent solutions and provide a qualitative review with up to data solutions. Therefore, this paper critically reviewed the different junction-centric data packet forwarding approaches with a comparative assessment of the recent solutions. In addition, open challenges and issues in the junction-centric data packet forwarding are highlighted. The remaining parts of the paper are structured as follows. Section 2 comprises of related works, the junction-centric data forwarding strategies are presented in Section 3, and Section 4 involves the research challenges and issues, while the conclusion of the paper is provided in Section 5.

2. Related Works
In this section, the existing review papers are discussed in order to demonstrate the trend and limitation of the available review works in vehicular communication. The increasing interest in vehicular communication for enhancing safety has led to the review of existing works that consider Vehicle-to-Pedestrian (V2P) communication [20]. Therefore, a discussion on the various elements of V2P based on its characteristics with a proposed design framework have been suggested. Further, a wide review and design considerations of the available V2P proposals for attaining convenience applications and safety have been discussed. In addition, different approaches of V2P has been compared based on a case study of pre-crash scenarios and vulnerable road user groups. Lastly, discussions on some technical issues regarding the integration of V2P and vehicle to everything has been presented. However, the review only focuses on one application aspect of vehicular communication. The constituent of the VANET is the Road Infrastructure Unit (RIU), embedded sensors and On-Board Unit (OBU). The RIU is normally situated along the road in both urban and highway environments [7, 8]. The RIU enable communication between Vehicle-to-Vehicle (V2V) and Vehicle with Infrastructure (V2I) [9, 10]. The sensors are used for sensing the vehicle’s component and other surrounding vehicles. An example of the OBU is the Dedicate Short Range Communication (DSRC) device that provides short distance communication in V2V and V2I [11]. Therefore, in the V2V and V2I communication, different data packet forwarding strategies have been employed to attain efficient transmission. Meanwhile, different types of data packet have been considered in the previous studies including text message-based and video streaming-based data transmission [12, 13].

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communication but does not consider the deep issues regarding communication strategies. Hence, there is a need to further explore the existing communication strategies.

In Dua et al. [22], a review of multipath data packet transmission based on video streaming in vehicular communication has been proposed. Comparative assessments of different multipath approaches have been presented considering their packet forwarding process and routing measurement parameters. Some of the major challenges relating to the forwarding strategies are identified, which serve as the future direction of the research. Meanwhile, the review does not focus on unicast data packet forwarding and junction-centric data communication.

Similarly, considering the challenges of routing a data packet from source vehicle to destination vehicle, the existing solutions have been revisited in order to demonstrate their significance and limitation that serve as a future research direction. Therefore, the description of different routing techniques has been suggested with the goal of choosing a specific strategy depending on its use in a certain application. In addition, the routing techniques are categorized and their related advantages and disadvantages are critically discussed based on the constraints and the applications. Lastly, some parameters have been employed in the comparison and assessments of the available routing techniques in the literature [23]. However, the routing techniques considered are not focused on junction-centric data packet routing and several new solutions in routing have been proposed recently. Therefore, there is a need to investigate the recent existing solution and junction-centric routing.

In [21], a review of traffic aware protocols in vehicular communication has been proposed focusing on the network condition and traffic issues. Further, the traffic aware routing protocols are explored by investigating the capabilities and limitations of the routing strategy. They are investigated in terms of routing metrics, routing process, recovery and forwarding mechanisms. In addition, the open research problems have been discussed based on challenges and critical issues of the traffic aware routing. Although, the review also consider the junction-centric data packet forwarding, however, the studies are not recent. Thus, there is a need to explore the recent solutions that have been proposed in the junction-centric routing. Table 1 depicts the comparison of existing review’s focus that is, whether the review considers application-based, traffic-aware-based, network condition-aware-based, delay-constrained-data-based and/or junction-centric-based. Further, the range of review year is provided to show how recent the existing review work is conducted.

| Author | Review Focus | Range of Review Focus | Remark |
|--------|--------------|-----------------------|--------|
| Application-based | Traffic-aware | Network condition-aware | Delay-constrained data (video) | Junction-centric | 2010-2019 | The review only focus on application-based methods without junction-aware routing |
| [20] | ✓ | ✓ | ✓ | ✓ | 2010-2016 | This does not focus on junction-centric data routing |
| [23] | ✓ | ✓ | ✓ | ✓ | 2003-2014 | It is centred on traffic-aware routing |
| [21] | ✓ | ✓ | ✓ | | 2008-2015 | It does not review recent trends in the junction-centric routing |
| [22] | ✓ | ✓ | ✓ | ✓ | 2009-2019 | The review focus on all the characteristics including junction-centric data routing |
| Proposed | ✓ | ✓ | ✓ | ✓ | ✓ | }
2.1 Junction-Centric Data Packet Forwarding Mechanisms

In this section, the available Junction-centric Data Packet Forwarding (JDPF) mechanisms have been discussed considering their forwarding strategies. Thus, two forwarding patterns have been explored including junction-centric forwarding based on a single path and based on multipath forwarding in Subsection 3.1 and 3.2 respectively. Figure 1 depicts the taxonomy of the existing JDPF mechanisms.

![Junction-centric DPF Taxonomy](image)

**Figure 1.** Taxonomy of JDPF.

2.1.1 Single Path JDPF

The Junction-centric geographic Greedy Traffic-Aware Routing (GyTAR) mechanism has been suggested [25]. The GyTAR select intermediate junctions dynamically for a packet to traverse to reach the destination vehicle. The selection criteria consider curve-metric distance to destination and road vehicle density. Consequently, the road with the highest score is considered as the road with the largest density and shortest route to the destination. An enhanced GyTAR has been proposed for employing vehicle direction in estimating vehicle density of the road [26]. Specifically, the estimation of the vehicle density of the road only considers the vehicles that are moving towards the direction of the destination vehicle. This helps in achieving more accurate estimation for reliability in the data packet delivery because the selection of roads with high density but in the opposite direction to
the destination vehicle is avoided. Even though the forwarding overhead of iCAR is minimized in high road vehicle density, it experiences higher overhead than GyTAR.

A Vehicular Density and network Load-Aware (VDLA) data packet forwarding mechanism has been proposed. The VDLA employs real-time vehicular density and network traffic load collection estimation. Meanwhile, the routing decision is made before the packet arrives at the junction area. The junctions are dynamically choosing considering three routing metrics including network traffic load, vehicle density, and distance to destination [27]. Further, weights were assigned to adjacent roads by junction nodes in order for neighbor nodes to make a decision on selecting the most reliable road for data packet transmission. Furthermore, an enhanced VDLA mechanism has been presented, by improving on the accuracy of information in neighbor table [28]. The information table is used for the geographic greedy forwarding decision. Two problems, which are caused by the conventional hello message that has Fixed broadcast interval are outlined. First, the entries of the previous neighbor are not discarded during the period when the vehicle moved of transmission coverage. Second, neighbor vehicles information might not be updated in the neighbor information table because they are waiting for their hello message to be forwarded.

2.1.2 Multipath JDPF

The In this subsection, the JDPF mechanisms that utilize multiple paths for data transmission has been discussed. In junction-based multipath data forwarding, more than one route from source to destination are employed with logics of characteristics of the road junction in order to deliver data packet successfully. The junction is a point where vehicles are likely to change direction during data communication. This made the selection of the next forwarding vehicle to be very challenging due to direction changing. Some few research studies on multipath data forwarding have been suggested in [29-31]. Thus, in Sermpezis, et al. [29], an analytical Junction-centric Multipath Source Routing mechanism (JMSR) has been suggested. JMSR features include the junction-aware logics, the multipath route from source to destination and the source routing mechanism. The JMSR employs the geographic routing protocols, such that the location of nodes and junctions of a street are leveraged through the street’s digital maps for data forwarding purpose. In the multipath, two paths are preserved concurrently considering numerous junctions, which a routed data packet has to traverse before reaching the destination.

In addition, the JMSR embeds routing details into an individual packet, based on the source routing standard. The source routing standard is in such a way that, every individual node in the path knows the route the packet must traverse. However, in JMSR all nodes are partitioned or grouped into different routes of paths and then the cost of each path is calculated before being selected as the path for data forwarding. This approach is prone to high overhead and delay, which is a critical issue in video streaming requirements. In addition, the JMSR updates the information about the position of other nodes when the position of the destination node changes. Since it is believed that vehicles are moving very fast thus, there is a frequent change of position, hence it is important to consider the position and direction of the vehicle at the junction. The position can be employed to estimate if the vehicle has exited the junction and has taken its direction towards the destination vehicle. Thus, video packet loss can be minimized since the most optimal vehicle is considered as a forwarder at the junction area.

A data forwarding considering Priority-Based Multipath Packets transmission mechanism has been suggested (PBMP) [30]. The data-forwarding mechanism is centered on geographic routing for intersection selection. For the intersection selection, the most current traffic movement details are dynamically used for the intersection selection from source to destination node. In a normal road, suitable multiple paths are generated for delivery of data packets with a different priority. Broken paths are recovered using an intersection mechanism. The whole of the mechanism works in a way that when a data-forwarding vehicle is within two neighboring junctions, it transmits the packet to the next junction and then it performs dynamic selection of junctions/intersections. On the other hand, if the data-forwarding vehicle is positioned at the junction, then it directly
performs a dynamic selection of junctions. Afterward, the multipath transmission is triggered considering the priority of the packet, which includes low, medium, and high for packet transmission. In this mechanism, only directional and route load parameters are considered for the node selection. However, the dynamic selection at the junction area does not consider the active position of the candidate next forwarding vehicle, which is very important considering multiple road diversion at the junction area. In addition, other metrics such as SINR and bandwidth capacity are not considered when selecting the next forwarding vehicle at the junction area. Thus, the design of a junction-aware multipath transmission that considers the vehicle position and direction at the junction area is required.

Further, Salkuyeh and Abolhassani [31] have proposed an Adaptive Multipath Video Streaming (AMVT) mechanism in order to handle the challenging problem of Video on Demand (VoD) period, which is Quality of Service (QoS). The mechanism employs the geographic routing protocol for establishing one directional VoD dissemination in a city scenario. Multiple paths are created based on the volume of the video and the total lifespan in which a path is static. A mathematical equation is derived for estimating the probability of route connectivity, it is used for choosing the best-connected routes. The best-connected route is considered based on vehicle speed, real-time traffic density, and the route length size. However, this mechanism does not consider the outage or low signal when forwarding a video packet to a junction area. It is known that at the junction area, vehicle nodes tend to change directions due to the different diversions, hence vehicle at the junction area need to be carefully selected based on their position and direction at the intersection area. In addition, regarding the use of more than 2 paths, it has been stated by Wang, et al. [32] that three or more paths might increase the intensity of route coupling effect in the multipath transmission. Hence, in this study, higher interference might be experienced which in turn affects the quality of the video streaming.

In the junction approach, most of the authors focus on how to select the best path among multiple paths based on some QoS parameters. Although, many approaches have considered solving the problem of interference, which occurs as a result of route coupling effect in the multipath transmission. However, their approaches are not sufficient for minimizing route-coupling effect most especially in the normal road setup. Because proactive measures are considered, which are not very realistic in vehicular communication considering high dynamic nature of vehicles. Further, in multiple paths, some studies have been carried out to take advantage of the junction/intersection of a road to achieve an interference-free multipath transmission. However, these approaches are all proactive based data forwarding, which generates high signaling load and overhead. In addition, due to the highly dynamic nature of vehicular communication, the proactive protocol may not be suitable because vehicles change position frequently. Therefore, a multipath video streaming solution that takes into consideration of interference between two paths, the multi-metric evaluation of vehicle in these paths and that take advantage of the road junctions with reactive geographical routing for multipath video streaming need to be developed.

3. Open Research Issues and Challenges
In this section, the open research issues and challenges are identified and discussed based on the characteristics of the vehicular network. Strict requirements for efficient vehicular communication including lower delay, proper bandwidth utilization, and packet loss/error. Considering the road topology, a junction is an area with different road segments, which lead to a change of direction of navigation. This change might lead to link disconnection. Consequently, the following open issues are highlighted.

- In urban areas, the junctions are equipped with traffic lights. These traffic lights serve as a division for the roads into various segments. The vehicles are expected to navigate when there is a green light in a segment and when the light turns to red, all vehicles in the segment
are expected to stop and wait at intersections until the light goes green. Hence, vehicles might cluster at both directions of a red light segment, which lead to a disconnected segment. Therefore, the traffic control light might lead to disconnected links in the red light segment.

- Transmission delay in roads is employed as a pointer for connectivity in the network, for example in iCAR mechanism. Nevertheless, delay in transmission can also be influenced by network load, but not only network disconnection. Thus, estimating road connectivity requires different parameters including link lifetime of the inter-vehicle.
- The traffic aware junction-based protocol employs carry and forward strategy for delivering the packet in the situation where there is a link disconnection. This strategy requires a recovery in the case if there is re-evaluation of the road to update the routing decision.
- The general concept of junction-centric traffic-aware routing relies on assigning priority to roads based on weight score for choosing the optimal road for data packet forwarding, which is based on the weighting factor. However, most of the available solution employs either fixed or variable-fixed weighting score, which might not provide a correct metric priority because the network condition changes based on the location of the vehicle.

4. Conclusions
In this paper, an extensive review of related literature on Junction-centric Data Packet Forwarding (JDPF) in vehicular communication has been presented. Different approaches based on techniques employed in the packet forwarding at the junction zone are analyzed. In addition, a comparative assessment table for the JDPF approaches is provided. Further, some research issues and future research directions of the JDPF have been discussed. In conclusion, this review work would improve the understanding of JDPF research trends and directions. Hence, this would stimulate research work in the JDPF domain by making research gap finding easier. This, in general, would lead to an improvement of the on-road safety in vehicular communication.

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