

# Robust Mid-range Communication in Urban VANETs

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**Abstract**—Cooperative driving and the associated need for vehicular communication motivate vehicular ad-hoc networks (VANETs). One major challenge is to provide for robust communication — in spite of highly dynamic topologies and the presence of shielding obstacles — without installing extra relay infrastructure. Traffic-density information and density estimation schemes are a valuable asset to approach this challenge. In this light we propose a novel routing protocol. Furthermore, extensive simulations are provided to support our case.

## I. INTRODUCTION

Vehicular ad-hoc networks (VANETs) commonly utilize the IEEE 802.11p protocol to provide a large spectrum of applications like traffic alert dissemination, dynamic route planning, context-aware advertisement<sup>1</sup> and file sharing [1][2][3][4]. Some of these applications are safety-critical for which robust communication is crucial. Ad-hoc communication among cars relies on multiple hops between cars. As vehicular networks are highly dynamic and obstacles frequently block communication, robustness of communication is continuously at stake [5].

In contrast to, e.g., airborne ad-hoc networks (AANETs), blocked line of sight (LOS) in city areas is the rule rather than an exception [6]. However, although VANETs have dynamically changing topologies, these topologies are geometrically more constrained<sup>2</sup> than in AANETs, [7], as road vehicles have to follow the road geometry. For predictability of VANETs, this is both which constitutes both an advantage and a disadvantage: increased predictability of the relative position of the cars allows an improvement in link selection, but the numerous LOS obstructions in VANETs significantly reduce the possibilities for path redundancy.

To provide for robust connectivity, different routing protocols have been proposed in literature. Most of them exploit geographical information to select paths based on the current road-traffic conditions. Some recently proposed routing protocols estimate road traffic conditions *in situ*, usually implying a high communication overhead as they gather non-local traffic information. In this context, this paper introduces a novel routing protocol named *traffic aware segment-based routing* (TASR), a locally informed multi-hop routing protocol for VANETs especially design to cope with the challenges in urban environments. TASR is a fully distributed protocol that does not require any roadside

infrastructure. Its mechanism is designed to improve the success probability of routing protocols by dynamically estimating the multi-hop forwarding capabilities of road segments and the network connectivity among them.

To measure TASR and compare it with other protocols a novel metric called *estimated connectivity degree* (ECD) is proposed. The ECD correlates with the connection probability, estimating the connectivity of nodes on the segments. Thus it can be employed to assess the connection quality of each candidate path between source and destination. TASR is designed for robustness by which we mean i) maximal connectivity probability, ii) minimal network delay, iii) optimal bandwidth usage and iv) low error rate.

The remainder of this paper is organized as follows: Section II discusses selected literature. The system model is described in Section III. TASR is formally introduced in Section IV and Section V presents it in full detail. Performance evaluations via simulation are provided in Section VI. Finally, Section VII concludes this paper and discusses directions for future work.

## II. STATE OF THE ART

Relevant VANET routing protocols can broadly be classified into two categories: Topology and position based. Both types exploit the node location to instantaneously select the next relay node. Topology-based protocols consider each node to have information about the entire network topology before forwarding messages. In contrast, position-based routing protocols can also work with partial location information. One early work on position-based protocols is *greedy perimeter stateless routing* (GPSR) [8]. The protocol combines greedy routing with face routing, using face routing to get out of the local minimum wherever greedy routing fails. It performs well in an open-space scenario with evenly distributed nodes — properties not regularly encountered in urban VANETs. Consequently, GPSR faces critical performance in urban environments [9]. *Geographic source routing* (GSR) [10] is also a location-based routing protocol exploiting topological information. The algorithm utilizes a street map to acquire global knowledge of the city topology. *Greedy traffic aware routing* (GyTAR) [11] is an intersection-based geographical routing capable of finding robust routes within city environments. GyTAR requires the existence of an accurate traffic information system to select routing paths. It takes into account the position of the junctions to decide the next hop for each packet. When a local optimum is discovered, the packet is carried by the vehicle until a junction is reached. The *intersection-based geographical routing* (IGRP) [12] provides an efficient selection of road intersections for the packet to pass. Road

<sup>1</sup>The MIT also provides information online, <http://cartel.csail.mit.edu>.

<sup>2</sup>Information in that regard is provided online, <http://www.csse.monash.edu.au/~carlo/adhoc.html>.

intersections are selected with the same four goals as TASR is designed for (maximal connectivity probability, minimal network delay, optimal bandwidth usage and low error rate). Contention-based forwarding (CBF) [13] is a geographic ad-hoc routing protocol. A sender broadcasts and the receiving neighbors will select one among them to relay the packet. The protocol is ideal for rural regions without obstacles as local maxima do not occur. Yet, CBF is not optimal in urban environments as local maxima occur with different possible paths connecting source and destination. *Topology-aware contention-based forwarding* (TOPOCBF) [14] is a routing protocol for VANETs extending CBF. In this protocol routing path selection is based on a direct estimation of their multi-hop connectivity and not only on vehicular density. To overcome some of the challenges arising with dynamic topologies, *vehicle-assisted data delivery* (VADD) [15] has been proposed which is based on *store, carry and forward*, i.e. data is submitted from source to a carrier that stores the data. Upon reaching the destination, the carrier transmits the data. There can be multiple carriers between source and destination. Each carrier is selected due to the highest predefined direction priority. Although this approach predicts the direction of vehicles movement, it does not predict any future change in the topology. *Junction-based geographic routing* (JBR) [9] is another junction-based routing protocol utilizing selective greedy forwarding to a node that is located at a junction closer to the destination. Nodes are divided into two classes, coordinators located at junctions and simple nodes placed in the middle of a road segment, i.e. the road between junctions. If there is a coordinator available, it will prioritize. The closest one to the destination is selected as the next hop instead of a random selection. The key novelty of JBR is the minimum angle method. The *multi-hop routing protocol for urban VANETs* (MURU) [16] is related to TASR. The authors introducing MURU also provide a novel metric called *expected disconnection degree* (EDD) to evaluate the probability of a candidate route to be broken. By broadcasting the route request message, the path with the smallest EDD is selected as route. MURU provides routes minimizing the hop count. MURU achieves a reasonable packet delivery ratio, but the selected end-to-end path may sometimes be invalid as mobility of vehicles can induce network partitioning.

### III. SYSTEM MODEL

This section states the six environmental conditions that we consider. 1) Vehicle communication has a range of 300m and each node<sup>3</sup> can determine its position. 2) Nodes send cooperative messages — as for instance specified in the ETSI standard [17] — enclosing their own physical location, destination when applicable, current velocity and direction information. A packet header contains information such as source ID, source location, packet generation time, expiration time and so forth. 3) Vehicles contain preloaded digital maps comprising street-level maps and traffic statistics (estimated traffic density, average vehicle speed on roads at different times of the day and traffic signal schedules at intersections). The payoff of such maps was or instance

<sup>3</sup>For convenience, we treat vehicle, car and node equivalently.

discussed by Yin et al. [18]. 4) The model region is constrained by a three-dimensional box. Vehicles are presented as mobile points and obstacles shielding communication as static square blocks. Figure 1 exemplarily shows a setting.

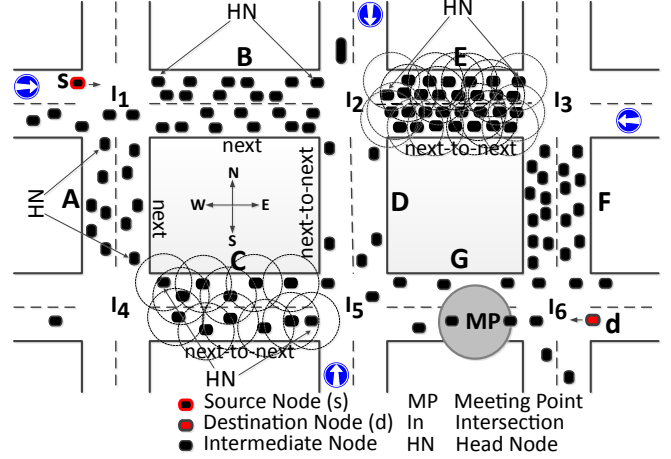


Figure 1: Trajectory model for the TASR protocol

5) A graph  $G = \{V, E\}$  represents the current communication-network topology with vertices  $V$  for vehicles and the edges  $E$  for communication channels between cars. The cars' initial positions are randomly selected with uniform distribution. Cars move with velocity  $v$ . Cars are neighbor when they are in communication range of each other. A path between two cars exist when they can reach one another via neighbors. Due to the nature of VANETs, path have continuously be re-established with dynamic routing protocols. 6) We specify the *meeting point* (MP) as estimated future position of the receiving car when it receives the packet. Consider two cars, a sender and a receiver. The sender sends a packet towards the receiver. Then, the MP is the position at the time the receiver receives the packet. More formally, let there be intermediate node  $Ni = (Ni_x, Ni_y)$  and the destination node  $Nd = (Nd_x, Nd_y)$  with its future position  $Pos_t(Ni)$  and  $Pos_t(Nd)$  respectively after some time  $t$ . Let  $\mathbb{Z}_t$  be the zone at time  $t$ , where the radio ranges of both  $Ni$  and  $Nd$  are expected to intersect and exchange the information. Thus  $\mathbb{Z}_t = Pos_t(Ni) \cap Pos_t(Nd)$ , if  $\mathbb{Z}_t = 0$ , then the radio ranges of  $Ni$  and  $Nd$  do not intersect and thus not connected, as follows;

$$Meeting\_Point_{Ni.Nd} = \begin{cases} 1 & \text{if } \mathbb{Z}_t > 0 \\ 0, & \text{otherwise} \end{cases}$$

### IV. OVERVIEW OF TASR PROTOCOL

TASR exploits heuristics to select a robust path. Consider a VANET modeled as directed connectivity graph  $G = \{V, E\}$  [19] with  $V$  cars and  $E$  communication links. A time-dependent function indicates the nodes' mobility conditions  $F(t) = f[x(i, t), y(i, t), z(i, t), v(i, t), \theta(i, t), \mathfrak{R}_i]$  with  $x(i, t), y(i, t), z(i, t)$  representing the position,  $v(i, t)$

the velocity,  $\theta(i, t)$  the movement direction and  $\mathfrak{R}_i$  is the unobstructed communication range of car  $i$  at time  $t$ .

TASR bases its routing on traffic densities in road segments to guide a packet from one junction to the next junction. Specifically, TASR looks ahead not only to the next junction, but even to the junctions after that. We call this next-to-next segment (N2N). Thus, TASR applies a look-ahead of depth two segments for routing. For the current study we select N2N as we expect i) the model to be too viscous for a smaller look-ahead and ii) traffic to be too dynamic for a larger look-ahead. Future investigations will compare trade-offs.

Consider the source node  $s$  in Figure 1 sending a data packet to destination node  $d$ . To forward the data packet,  $s$  uses the estimated real-time information about the traffic on different segments. The three possible routes are

- 1)  $sBEFGd(s \rightarrow I_1 \rightarrow I_2 \rightarrow I_3 \rightarrow I_6 \rightarrow d)$ ,
- 2)  $sBDGd(s \rightarrow I_1 \rightarrow I_2 \rightarrow I_5 \rightarrow d)$  and
- 3)  $sACGd(s \rightarrow I_1 \rightarrow I_4 \rightarrow I_5 \rightarrow d)$ .

The traffic densities on the different segments are  $A = 11$ ,  $B = 21$ ,  $C = 14$ ,  $D = 5$ ,  $E = 29$ ,  $F = 18$  and  $G = 6$  cars per segment. The segment length is considered to exceed the communication range. TASR prioritizes segments with minimal latency, i.e. few cars, with sufficient connectivity. Therefore, TASR selects  $sACGd$  deterministically.

## V. DETAILED TASR PROTOCOL

TASR is a new segment-based geographical routing protocol capable to find robust communication routes within city environments. A connected road segment is a segment between two adjacent intersections with enough vehicular traffic to ensure network connectivity. We follow recent studies in multi-hop routing in VANETs [20] which have shown that geographic routing with the help of GPS and digital maps ensures low end-to-end delay, low control overhead, and high end-to-end packet delivery ratio. Vehicles exchange packets using short-range wireless interfaces such as IEEE 802.11 and dedicated short-range communication (DSRC). All these protocols assume that an efficient location management service is available to provide the source node with the destination location for routing. Our proposed protocol adopts related techniques to provide a robust route from source to destination. The basic operation of TASR comprises two alternating phases: The first phase deals with selection of a segment, while data forwarding takes place in the second phase.

### A. Segment Selection

TASR selects segments dynamically to adapt to the real-time variation in vehicle densities. Each segment has two *outmost* nodes we call *head nodes* (HN). These nodes manage the traffic into the segment or out of the segment respectively. This includes packets as well as information about traffic densities within the segment. As segment is connected when i) there is a path between the head nodes and ii) the head nodes are reachable from other segments, i.e. each head node must be close to a junction.

**Exchange Density Information:** Vehicles maintain tables of the cars within a certain distance. These tables are updated frequently. Vehicles as- and resign themselves autonomously as head node (HN).

An HNs (1) accumulates the *segment information* (SI), i.e. the data about other cars, providing it to reachable HN neighbors. (2) The HN selects the N2N segment based on retrieved information as discussed in Section V-A. An SI message comprises road ID, transmission time, transmission range and total density on the segment.

Cars might slow down or stop maximizing chances for a better selection. We utilize Krauß' formulation [21] to represent each vehicle individually by state vector information (position, velocity, direction):

$$\begin{aligned} \textbf{Velocity-update: } V_{des} &= \min[V + a, V_{safe}, V_{max}] \\ V_{safe} &= V + (d - V)/(\bar{V}/b) \\ V &= \max[0, V_{des} - a\psi R] \end{aligned}$$

$$\textbf{Motion-update: } x \leftarrow x + v$$

Here  $a$  denotes the maximum vehicle acceleration,  $b$  the maximum deceleration,  $\psi$  is the noise amplitude and  $R$  is a random number uniformly distributed in  $[0, 1]$ .  $V$  is the ego-car speed, while  $\bar{V}$  is the speed of the car ahead. This means that the drivers follow some kind of a stochastically perturbed maximum but safe velocity strategy. Moreover, if  $\bar{V}$  is the velocity of the car ahead at time  $t$  then we can further indicate with  $\bar{V} = (V + \bar{V})/2$  the average of the vehicles' velocities to determine the safe speed bound  $V_{safe}$ . Let us suppose that the frequency of hello beacons is related to the minimum contact duration. If the frequency of transmission is high, the time necessary for the information to reach the outer bounds of the geographic area is lower. For example, if the contact duration is 10 sec, the hello beacon will be transmitted every second.

**Calculating the estimated connectivity degree:** The connectivity of nodes can be computed with the *estimated connectivity degree* (ECD). It correlates with connection probability and thus characterizes the quality of each candidate path between the source and destination. The ECD is the segment-wise connectivity along a path between source and destination. Two vehicles are considered to be connected if their distance is less than the vehicle transmitting range  $R$ . A road segment is represented by a tuple of two end points as presented in [19], i.e.  $seg = (s, d^s), (s, d^d)$ , where  $(s, d^s)$  shows the street crossing on one end of the road segment and  $(s, d^d)$  is the next street crossing on the other end. So The segments in a grid are represented via the junction coordinates as  $N = \{((s_1, d_1^s), (s_1, d_1^d)) \dots ((s_n, d_n^s), (s_n, d_n^d))\}$ . For a segment, the estimated connectivity degree is computed as

$$ECD = 1 - \sum_{j=1}^k (-1)^{j-1} \binom{N_{nodes} - 1}{j} \left(1 - j \frac{\mathfrak{R}}{L_{seg}}\right),$$

where  $k = \min\{N_{nodes} - 1, \left\lceil \frac{L_{seg}}{\mathfrak{R}} \right\rceil\}$ , where  $\mathfrak{R}$  is the transmission range of each node,  $L_{seg}$  is the length of each segment and  $N_{nodes}$  is the average number of vehicles on the road segment, while  $j$  represent the segment number.

Through this formula the ECD for every N2N is computed. Based on this, TASR deterministically selects the best option under N2N segment to route to.

*Why route based on ECD and N2N segment?:* Analyzing the N2N segment provides a compromise between local greedy search (e.g. selecting the best next segment) and global planning (harvest density information for all segments, then pursue global search). Using N2N does not come at a steep loss compared to global search due to the general confluence of road networks, which renders being caught in a blind route unlikely, while it at the same time is only moderately more expensive than local greedy search. Table I exemplarily shows the densities for Figure 1. In this case the preferred N segment for the source node is *A* which depends on *C* and is suitable for route selection. Yet, density is not always proportional to likelihood. For instance, *B* is less suitable in the example than *A* as it relies on *E* which is more congested than *C*.

| Segment | Position                     | Density |
|---------|------------------------------|---------|
| A       | N (next)                     | 11      |
| B       | N (next)                     | 21      |
| C       | N2N (next-to-next)           | 14      |
| D       | N2N (next-to-next)           | 5       |
| E       | N2N (next-to-next)           | 29      |
| F       | N2N2N (next-to-next-to-next) | 18      |
| G       | N2N contains 'd'             | 6       |

Table I: Segment names and positions with related density

### B. Data Forwarding

The TASR algorithm builds routes using a route request/route reply (RREQ/RREP) query cycle. After selection of the N2N segment as discussed in Section V-A, data-packets are forwarded. In a segment, packets take the shortest multi-hop path. This attribute of robustness is essential for safety critical applications. A node receiving an RREQ packet returns an RREP packet if it has a route to the destination or is the destination itself; otherwise, it will rebroadcast the RREQ. Data packets are sent to the destination after the source node receives the RREP. The routing information is updated to ensure that the best route is selected. If a link breaks while the route is active, a route error (RERR) message is sent to the source node. The source node then re-initiates a route discovery process.

## VI. PERFORMANCE EVALUATION

This section evaluates the performance of TASR and compares it with other solutions. It has been implemented in OMNeT++ 4.5 network simulator<sup>4</sup>. The Simulator for Urban MObility 0.21.0 (SUMO)<sup>5</sup> provided an environment for the real world co-simulation. The Veins 3.0<sup>6</sup> framework was employed to connect both. The test area is 2km×2km within the city of Oldenburg (Oldb), Germany, yielding the grid layout shown in Figure 2. We pessimistically consider obstacles between all segments that share no line of sight (LOS). The initial positions and destinations of all vehicles

are selected randomly. When the destination is reached, another destination is randomly selected. This procedure is repeated until the end of the simulation. The total number of nodes varies from 50 to 300 and the node velocity is 40 km/h on average. Nakagami radio propagation model is used which is general modeling of a radio channel with fading. The IEEE 802.11 DCF protocol is the MAC layer transmission protocol and the shadowing propagation model reflected the dynamic channel conditions in VANETs. We

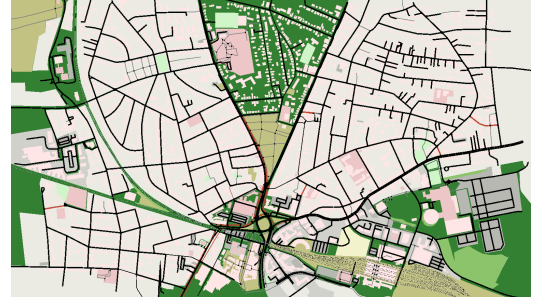


Figure 2: City of Oldenburg as a street graph in SUMO

compare the performance of different parameters of TASR with MURU [9] and JBR [16].

Figure 3a shows network performance in the terms of data delivery ratio. We set the average node speed which varies stochastically and change the number of nodes in whole network. It is observed that TASR which is based on N2N selection consistently improves over MURU and JBR concerning packet delivery ratio, often by a substantial margin of approximately 28% and 32% respectively, specially when density reach to 300. The reason behind this is the impact of congestion or contention for shared medium between nodes caused by node density is a great problem in VANETs. In this scenario TASR performs well in terms of packet delivery ratio, which shows that TASR makes better use of network density. This is because when the number of nodes increases, the estimated network connectivity probability increases too and so does the data delivery ratio. Figure 3b shows the overhead of routing protocols measured in the total number of routing packets sent. In this simulation the control packets are not included. The reason is that the proposed TASR routing protocol is essentially a location-based protocol, and it does not require any more control packets than other location based routing protocols. To keep up with VANETs mobility, data flooding may be required quite often, and the routing overhead would lead to heavy congestion in the network. Our proposed routing protocol outperforms due to the suitable segment (N2N) selection avoiding the congested segment and thus a considerable difference can be seen compared with MURU and JBR. We note that when the network density is low, like 75~100, both comparative protocols also give constant result, but when the density increases, the overhead of both routing protocols (MURU and JBR) increases dramatically compared with TASR. In these experiments we use our proposed metric ECD for TASR which is based on the selection of N2N segment and thus demonstrates that TASR by selecting N2N can dramatically improve delivery rate while minimize the

<sup>4</sup><http://www.omnetpp.org/>.

<sup>5</sup>[http://sumo.dlr.de/wiki/Main\\_Page](http://sumo.dlr.de/wiki/Main_Page).

<sup>6</sup><http://veins.car2x.org/>.

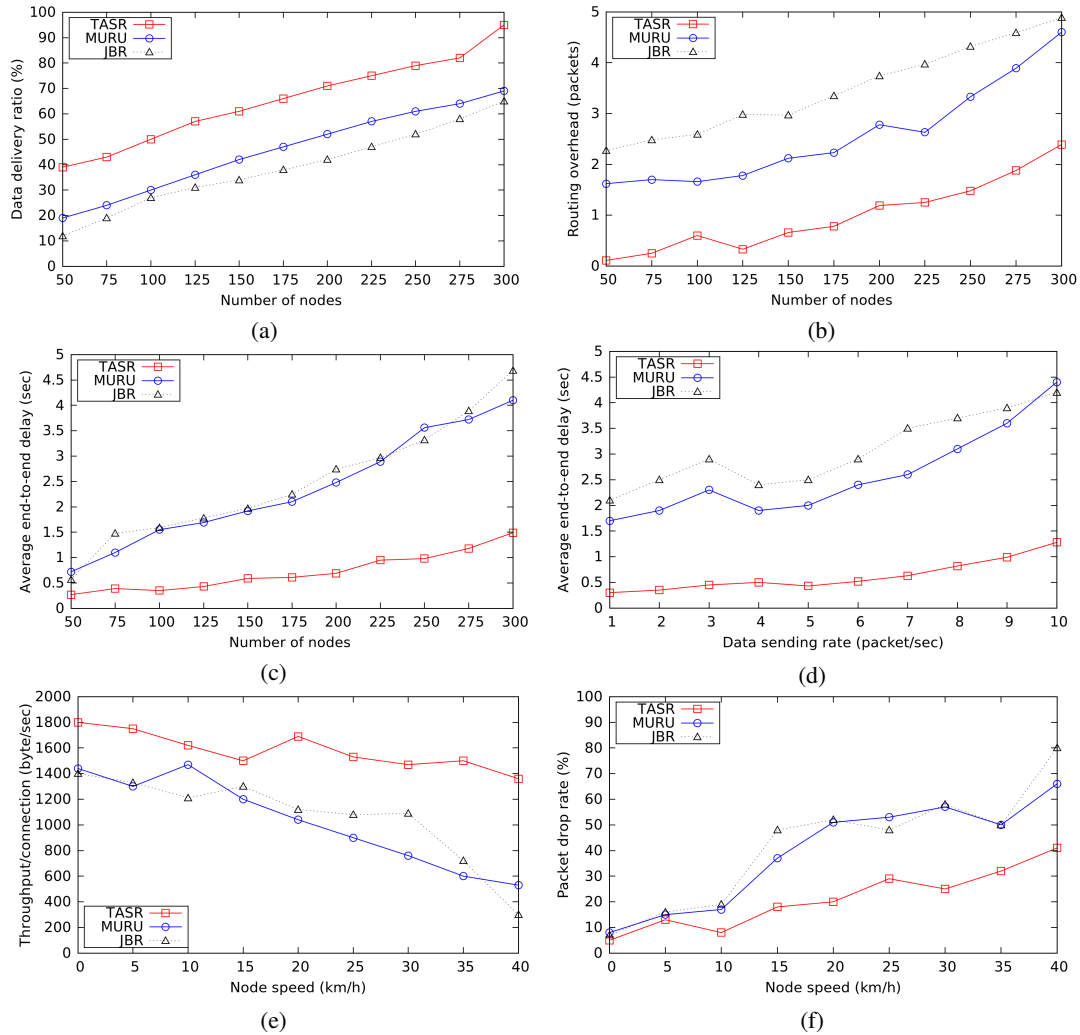


Figure 3: Impact of density in (a) Packet delivery ratio (b) Routing overhead (c) End-to-end delay, (d) End-to-end delay as a function of the data sending rate (300 nodes), Impact of node speed in (e) Throughput/connection (f) Packet drop rate.

overhead, especially when the number of nodes increase. With the help of ECD, packet delivery ratio is enhanced rather than choosing randomly segment selection. Figure 3c shows TASR's advantage by means of delay over different densities. The end-to-end delay is effected by delivery ratio. TASR exhibits smaller end-to-end delay than MURU and JBR at all vehicular densities. This is because of decreasing the data-sending rate as it generates many redundant packets. The smallest delay reduction with MURU is 0.7 seconds at  $N=50$  while the largest delay reduction is 4.2 seconds at  $N=300$ . Figure 3d shows that TASR has the smallest average end-to-end delay among the protocols studied. TASR perform better than MURU and JBR due to the suitable nature of the scheme. In TASR the route is already chosen by the help of ECD. We also observe that the average delay for TASR consistently remains less than 1 second while the average delay of MURU and JBR increase dramatically. The reason for this is that TASR look ahead and chose that path which have maximum connectivity and minimum number of

nodes. Figure 3e shows the appropriate simulation result that how the throughput drops as cars accelerate, yet still leaving TASR at top. In this result the average TCP throughput connection is depicted as a function of node speed. At first, we notice that the throughput of all protocols clearly stable when the node speed is low 5~15km/h. This behavior result from the network connectivity in the VANET. At lower node speed, the connectivity in the network is significantly better. Moreover, the result also may be subject to statistical fluctuation since communication partners are selected randomly. A higher node speed, the throughput of both comparative protocols clearly declines because more and more vehicles have to share a common wireless channel and the routing overhead increases. Here TASR presses home its advantages of exchanging only small routing messages. TASR was able to cope best with the fast changing network topology and the high relative speeds of the vehicles. TASR was able to provide the highest throughput (up to 1749.85byte/sec at 20km/h) of all protocols, followed by JBR. MURU's through

decrease very fast when the node speed increase (from 1511.83byte/sec vs. 10km/h to 570.64byte/sec vs. 40km/h). Finally, we can see that JBR only achieves an extremely low throughput up to 353.22byte/sec when the node speed is 40km/h. Figure 3f shows how the average packet loss at different velocities is lower for TASR than it is for its competitors. It is indicated that at low speed of less than or equal to 10 km/h, MURU and JBR have very similar drop rates of about 15%. In this case, both protocols can maintain connection for the mobile node with neighbors while traveling and losses are mainly due to packet collision. However, when the node speed increases which is also effect on the packet loss rate. In contrast, TASR outperform on low speed and high node speed as well. This indicates that our proposed protocol can reliably deliver data to intended recipients in a time-strict manner under varying traffic regimes without incurring into a high overhead in the network.

## VII. CONCLUSION

This paper introduced a novel routing protocol TASR for urban area VANETs. It exploits robust paths to achieve a high delivery ratio, low overhead and minimal packet delay. A new metric called *estimated connectivity degree* was presented for comparison. Experimental results showed TASR's superiority for selected settings. Future work will target further simulations to tune TASR to a variety of parameters. Also, a new cross-layered, hybrid protocol architecture to situationally select different routing protocols will be considered.

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## REFERENCES

- [1] S. Dashtinezhad, T. Nadeem, B. Dorhonceanu, C. Borcea, P. Kang, and L. Iftode. Trafficview: A driver assistant device for traffic monitoring based on car-to-car communication. In *Proceedings 59th IEEE Semi-annual Vehicular Technology Conference*, pages 2946–2950, Milan, Italy, May 2004.
- [2] P. Zhou, T. Nadeem, P. Kang, C. Borcea, and L. Iftode. Ezcab: A cab booking application using short-range wireless communication. In *Proc. 3rd IEEE International Conference on Pervasive Computing and Communications (PerCom)*, pages 27–38, HI, USA, March 2005.
- [3] A. Nandan, S. Das, G. Pau, and M. Gerla. Co-operative downloading in vehicular ad-hoc wireless networks. In *Proceedings 2nd Annual IEEE Conference on Wireless On-demand Network Systems and Services*, pages 32–41, Switzerland, January 2005.
- [4] O. Riva, T. Nadeem, C. Borcea, and L. Iftode. Context-aware migratory services in ad hoc networks. *IEEE Transactions on Mobile Computing*, 6(12):1313–1328, December 2007.
- [5] C. Sommer, D. Eckhoff, R. German, and F. Dressle. A computationally inexpensive empirical model of IEEE 802.11 p radio shadowing in urban environments. In *2011 Eighth International Conference on Wireless On-Demand Network Systems and Services*, 2011.
- [6] M. Boban, T. Vinhoza, J. Barros M. Ferreira, and O. Tonguz. Impact of vehicles as obstacles in vehicular ad hoc networks. *IEEE journal on selected areas in communication*, 29(1):15–28, January 2011.
- [7] *Airborne Ad Hoc Networks*, <http://www.csse.monash.edu.au/~carlo/ad-hoc.html>.
- [8] B. Karp and H.T. Kung. GPSR: greedy perimeter stateless routing for wireless networks. In *Proceedings of the ACM/IEEE Int. Conference on Mobile Computing and Networking*, USA, 2000.
- [9] S. Tsiachris, G. Koltsidas, and F. N. Pavlidou. Junction-based geographic routing algorithm for vehicular ad hoc networks. *Wireless Personal Communications*, 71(2):955–973, September 2012.
- [10] L. Liu, D. IL, Z. Wang, and W. Jehng. A geographic source routing protocol for traffic sensing in urban environment. In *IEEE International Conference on Automation Science and Engineering*, pages 347–352, USA, August 2008.
- [11] M. Jerbi, R. Meraihi, S. M. Senouci, and Y. G. Doudane. GyTAR: improved greedy traffic aware routing protocol for vehicular ad hoc networks in city environments. In *Proceedings of the 3rd international workshop on Vehicular ad hoc networks*, USA, 2006.
- [12] H. Saleet, K. Naik, R. Boutaba, A. Nayak, and N. Goel. Intersection-based geographical routing protocol for vanets: A proposal and analysis. *IEEE Transactions on vehicular technology*, 60(9), 2011.
- [13] H. Fussler, J. Widmer, M. Kasemann, M. Mauve, and H. Hartenstein. Contention-based forwarding for mobile ad hoc networks. *Ad Hoc Networks*, 1:351–369, 2003.
- [14] M. Rondinone and J. Gozalvez. Exploiting multi-hop connectivity for dynamic routing in vanets. In *8th International Symposium on Wireless Communication Systems*, Germany, 2011.
- [15] J. Zhao and G. Cao. VADD: Vehicle-assisted data delivery in vehicular ad hoc networks. *IEEE Transaction on vehicular technology*, 2008.
- [16] Z. Mo, H. Zhu, K. Makki, and N. Pissinou. Muru: A multi-hop routing protocol for urban vehicular ad hoc networks. In *Proceeding 3rd Annual International Conference Mobile Ubiquitous System Networking and Services*, pages 1–8, 2006.
- [17] ETSI. Intelligent Transport Systems (ITS), Vehicular Communications, Basic Set of Applications, Definitions. Technical Report 102 638, European Telecommunications Standards Institute, 650 Route des Lucioles, F-06921 Sophia Antipolis Cedex - FRANCE.
- [18] J. Yin, T. Eibatt, G. Yeung, B. Ryu, S. Habermas, H. Krishnan, and T. Talty. Performance evaluation of safety applications over dscc vehicular ad hoc networks. In *Proceeding VANET*, pages 1–9, 2004.
- [19] H. Higaki. Navigation system based dtn routing in sparse vehicular networks. In *International Conference on Communications and Information Technology*, pages 171–175, March 2011.
- [20] A. Hinds, S. Zhu M. Ngulube, and H. Aqrabi. A review of routing protocols for manets. *International Journal of Information and Education Technology*, 3(1), February 2013.
- [21] S. Krauss, P. Wagner, and C. Gawron. Metastable states in a microscopic model of traffic flow. *Physical Review of statistical, nonlinear, and soft matter physics*, 1997.