Multi-Metric QoS-balancing Relay Selection Algorithm in V2X Communications

Aljawharah Alnasser, Hongjian Sun, *Senior Member*, *IEEE*, and Jing Jiang, *Member*, *IEEE*

***Abstract*—As the network topology frequently changes, direct communication with the infrastructure unit is not always available. Therefore, the road entity requires to choose Device-to-Device (D2D) relay node to forward its packet to the nearest infrastructure unit. In this paper, we propose a model for selecting a D2D relaying node to connect the source road entity with LTE-V2X infrastructure. The proposed Quality of Service (QoS)-balancing relay selection takes into consideration the QoS requirements when electing D2D relaying node. It is a multi-criteria scheme that applies the Analytic Hierarchy Process for making-decision. The criteria are related to channel capacity, link stability, and end-to-end delay. We conduct various experiments with various network scenarios to evaluate the performance of the proposed model. Simulation results showed that the proposed model improves Packet Dropping Rate by 78% and average delay by 45% in comparison with the existing model.**

***Index Terms*—ITS, QoS, relay selection, V2X.**

I. Introduction

In recent years, intelligent transportation systems have attracted the attention of the automotive manufacturing sector. The road entities such as vehicles, cycles, and motorcycles are being developed to be able to communicate with the surrounding entities and infrastructure units. The communication between various road entities is called as Vehicle-to-Everything (V2X) communication. V2X supports the communication between heterogeneous nodes using a unified communication protocol, which is LTE-V2X (release 14) [1].

LTE-V2X was proposed to support V2X services where the road entity can establish two types of links which are a cellular link and Device-to-Device (D2D) link. The cellular link is established between the road entity and the infrastructure units. While the D2D link is established directly between the road entities. D2D link is used in the following scenarios [2]

- In-coverage scenario: D2D communication is established when the User Equipments (UEs) are located in-network coverage as shown in Fig.1 (a). It is managed by Evolved Node B (eNB) for load balancing or content sharing.
- Relay coverage scenario: D2D communication is established between UEs, when one of them is located out of the network coverage, to relay the packets to eNB. The relaying nodes work as a range extender of the cell as shown in Fig.1 (b).
- Out-of-coverage scenario: D2D communication is established by UEs, which are located out of the network coverage as shown in Fig.1 (c). It is used for event messages, periodic messages, sharing content and in natural disaster situations which called as Public Safety Network.

In a relay coverage scenario, considering QoS while choosing the D2D relaying node is still a challenge in V2X communication [2]. Various research were proposed that applied D2D communication for load balancing or range extending. For instance, Liu *et al.* [3] proposed a D2D communication load balancing algorithm where the D2D device uses D2D relay node to deliver its messages to eNB in case of congested cells. In addition, Zhang *et al.* [4] proposed a social-based D2D relay selection model. The link reliability is assessed via users' contact histories and channel status to improve the success rate of relay selection. Also, Gao *et al.* [5] considered the dynamic peer selection with social awareness-aided spectrum-power trading between the edge users and the D2D transmitters, where the D2D transmitters assist in relaying the data of cellular users. Liu *et al.* [6] proposed a communication-based algorithm for D2D to enhance the quality of experience in LTE-A. However, they mentioned that most of the D2D communication algorithms did not consider the speed and directions in choosing the best D2D relay node. In addition, Tata and Kadoch [7] suggested a multipath routing algorithm for D2D communication in heterogeneous networks, which considers the available bandwidth while choosing the best route. Bastos *et al.* [8] suggested a network-assisted routing algorithm in 5G to choose the best link to the base station. The link evaluation is based on the number of hops and the channel quality. However, most of the proposed solutions neglect the node mobility, which has a high impact on the selection of D2D relaying nodes.

Moreover, recent research focus on developing schemes for choosing the best gateway between VANET and LTE. For instance, Chekkouri *et al.* [9] proposed a gateway selection scheme to relay the traffic toward the base station. The evaluation criteria are related to the received power and the residence of the vehicle on the RSU range. However, the main features in the vehicular network, such as velocity and direction, are not evaluated. In addition, Wu *et al.* [10] offered a two-level clustering approach. The first level uses fuzzy logic to choose the cluster heads. It considers three factors, which are velocity, leadership, and signal quality. The second level

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Manuscript received – –, 201–; revised – –, 201–.

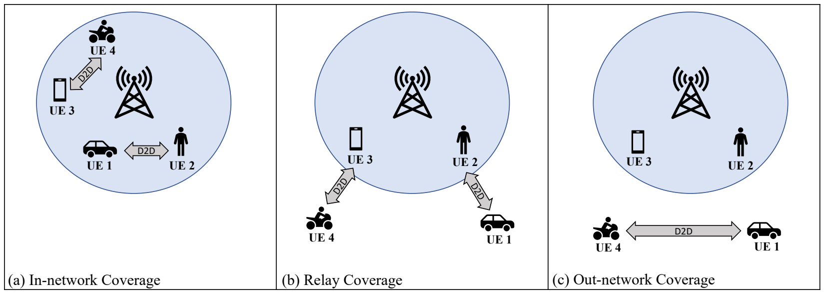

Fig. 1: D2D communication scenarios

applied Q-learning algorithm for choosing which cluster heads are responsible for providing a gateway function between V2V and LTE. They mentioned that their model causes some congestion because of few numbers of gateways. Also, Zhioua *et al.* [11] suggested an algorithm for selecting the gateway based on fuzzy logic. However, all of the previous solutions were proposed to support the communications between two different networks. However, the packet transmission delay is not considered, which is a critical feature in the vehicular network.

To overcome these limitations, this paper proposes a QoS-balancing relay selection algorithm for V2X communication. We evaluate the performance of the proposed algorithm by comparing it with the existing model [10]. This paper makes two main contributions to the field of the vehicular network:

1) We propose a novel QoS-balancing relay selection model for V2X communications where the channel model for LTE-A (release 14) is applied for a first time. Also, the link evaluation combines three main factors in vehicular networks, which are link stability, channel capacity, and end-to-end delay.
2) Based on the simulation results, Analytic Hierarchy Process (AHP) improves the decision making regarding the D2D relay node. The proposed model improves the PDR by 78% and the average delay by 45%.

The paper is organised as follows: in section II we describe the proposed system model, including the considered scenarios and path-loss model. In section III we present a detailed description of the proposed trust model. In section IV we offer the simulation set-up parameters and conduct various experiments to measure the model performance. In section V we evaluate the proposed model by comparing it with the existing model. Finally, Section VI concludes the overall work.

II. System Model

The considered network is a V2X network with a various number of road entities, which are vehicles, motorcycles, cycles and pedestrians, and M RSUs. The actual channel state is affected by obstacles such as buildings, trucks, and pedestrians. In addition, the vehicle's movement has a high impact on the transmission environment. Therefore, we have to consider these factors in the channel model. Based on LTE-V2X (Release 14) channel model in [12], we study the communication in a rural area for the line of sight scenario. Also, we consider the messages that they should be delivered to eNB such as Internet services for updating maps, downloading a video, or doing a transaction. The road entity may need to use a multi-hop route to deliver its packets to the nearest eNB in some cases such as:

- The road entity/UE has a connection with eNB, but the signal could become weaker because of the long distance between UE and eNB or the existence of obstacles. Then, the road entity decides to establish a D2D link with one of its neighbouring entities to relay the packets to eNB.
- The road entity/UE does not have a connection with eNB. Thus, the road entity establishes a D2D link with a suitable neighbouring entity to relay the packets to eNB.
- The road entity/UE could be in the network coverage, but it uses a multi-hop route to reduce the cell load.

Relay selection algorithms were used to find the optimal relaying node in the network. The vehicular network is a challenging environment; thus, finding the optimal relaying node is an open issue. The node movement and the obstacles are the main constraints to find a high-quality relaying link. Also, the high-speed entities result in short connection time. Therefore, finding a stable connection with the neighboring nodes is critical to improving network performance. Based on the used channel model, which belongs to LTE-A (release 14), the proposed model is the first paper which applies that model to measure and evaluate the communication link. In addition, the decision-making algorithm is considered while designing the model because using a sophisticated algorithm will cause a delay in choosing the suitable link; thus, the decision becomes useless when the surrounding nodes are changed. Therefore, we apply AHP algorithm, which is a computational efficiency algorithm which reduces the decision time.

III. Multi-Metric QoS-balancing Relay Selection Algorithm in V2X Communications

We propose a model for electing the D2D relay nodes that achieve a high QoS. The proposed model applies the Analytic Hierarchy Process (AHP) on the road entity level for deciding on which neighbouring node is a superior relay node as shown in Algorithm 1. AHP is a multi-metric decision-making algorithm that utilizes a hierarchical approach to assess potential

Algorithm 1 Algorithm for electing the optimal relay node

Input: $BC \leftarrow$ list of information regarding surrounding entities received from beacon messages
Output: $D_{id} \leftarrow$ the ID of chosen D2D relay node

for each time interval t **do**
  for each road entity i **do**
    if i.HasPacketToSend() **then**
      if !(i.eNBConnected()) **then**
        A in Eq.(1) is filled with BC;
        Eq.(9) is computed;
        $Y \leftarrow$ Eq.(10);
        $D_{id} \leftarrow Max(Y)$;
      end if
    end if
  end for
end for

factors [13]. It combines qualitative and quantitative factors in the analysis. The analysis can be divided into the following four steps:

A. First: build a hierarchical model

We construct the hierarchical model based on five criteria in level 1 as shown in Fig.2. Level 2 represents the potential neighbouring nodes. For evaluating these criteria, first, we require to set them up in a matrix as follow:

$$A = \begin{bmatrix} C_1^t & D_1^t & H_1^t & Acc_1^t & Q_1^t \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C_m^t & D_m^t & H_m^t & Acc_m^t & Q_m^t \end{bmatrix} \tag{1}$$

where m is the number of potential neighbouring nodes. Here, the node i is the source node which applies the algorithm to choose the optimal relay node, and node j is the potential neighbouring nodes of node i. From the information that is collected from the surrounding nodes due to periodic sending and receiving of beacon messages, the following five factors can be computed as described below.

1) Channel Capacity (C^t): As the connection time between two road entities is limited, we require a high channel capacity, which guarantees the packet delivery. We consider three parameters that affect the channel capacity, which are shadowing, multipath propagation, and signal noise. First,

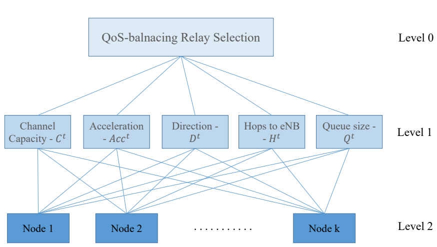

Fig. 2: Structure of AHP reliability model

we compute the received signal power with the impact of shadowing and multipath propagation using

$$RP_j(d_{i,j}) = TP_i - (PL(d_{i,j}) + X_\sigma) \tag{2}$$

where RP_j is the received signal power at neighbouring node j with distance $d_{i,j}$, TP_i is the transmission power with which node i transmits a signal. $PL(d_{i,j})$ is the average path-loss at a distance $d_{i,j}$. $X_{\sigma_{SF}} \sim N(0, \sigma_{SF}^2)$ is a random shadowing effect with a normal distribution with zero mean and σ_{SF}^2 variation. Second, we measure the Signal-to-Noise ratio (SNR_{db}) using

$$SNR_{dB} = RP_j(d_{i,j}) - P_{Noise} \tag{3}$$

where P_{Noise} is the noise signal in dbm. SNR is computed by

$$SNR = 10^{\frac{SNR_{dB}}{10}} \tag{4}$$

Finally, we compute the channel capacity with considering the noise by

$$C^t = B * \log_2(1 + SNR) \tag{5}$$

2) Link Stability: The network topology in the vehicular network is frequently changed. Thus, the communication link between two road entities does not always exist. Link stability is defined as the duration of connection lasts between two road entities. Therefore, if the link stability is high between two road entities, it could minimize the Packet Dropping Rate (PDR). It is evaluated by two main parameters as follows.

- **Acceleration (Acc^t):** is the rate of change of velocity of the road entity with respect to time t. Each road entity i computes the difference between its acceleration and the acceleration of the neighbouring entities j. It is computed by

$$Acc^t = \mid a_i^t - a_j^t \mid \tag{6}$$

  where a_i^t and a_j^t are the acceleration of node i and node j during a period of time (Δt). The relative acceleration of each node x is expressed as

$$a_x^t = \frac{v_x^t - v_x^{t-\Delta t}}{\Delta t} \tag{7}$$

  where $x \in N$ and N is the list of road entities. v_x^t and $v_x^{t-\Delta t}$ is the velocity of node x during current time t and previous time interval $t - \Delta t$.
- **Direction (D^t):** when the road entity establishes a connection with another road entity which is moving in the same direction give them higher stability than when they are moving in the opposite directions.

TABLE I: 9-points scale for PCM

Scale	Factors importance
1	Equally important
3	weakly important
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6,8	Intermediate value between adjacent scales

TABLE II: Pairwise Comparison Matrix

Criteria	C^t $(u=1)$	D^t $(u=2)$	H^t $(u=3)$	Acc^t $(u=4)$	Q^t $(u=5)$	Priority Vector
C^t $(y=1)$	1	6	2	8	4	21%
D^t $(y=2)$	1/6	1	1/4	3	1/3	4.75%
H^t $(y=3)$	1/2	4	1	6	2	13.5%
Acc^t $(y=4)$	1/8	1/3	1/6	1	1/5	1.825%
Q^t $(y=5)$	1/4	3	1/2	5	1	9.75%

As a result, when the two road entities are moving with very close speed and in the same direction that assures link stability between them.

3) End-to-End delay: To increase the QoS of V2X network, we have to achieve a minimum end-to-end delay for packet delivery. As the road entity sends packets through a multi-hop route, it is necessary to have a response in a short time. Therefore, we have to consider two main parameters while choosing D2D relay node, which are:

- **Hops to eNB (H^t):** it is the conventional node-based routing metric used to select a route with less number of hops among the available routes to eNB. Most of the routing protocols in vehicular networks use hop count as their base metric. We assume that each neighbouring road entity sends this value to the neighbouring road entities to determine the shortest route to eNB.
- **Queue size (Q^t):** we evaluate the queue size of the next hop entity to prevent buffer overflow which causes eventually to high PDR. In addition, it is essential to minimize the delay in queuing time. Therefore, the road entity prefers to choose the node with low queuing size.

B. Second: form Pairwise Comparison Matrix (PCM)

Each element in the criteria level is compared with the other elements. We applied the scale of numbers, as shown in Table I to determine the importance of one element over the different elements [13]. The values of Table II is filled in a matrix for calculations as follows

$$PCM = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ \vdots & \vdots & \vdots & p_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix} \tag{8}$$

where $p_{yy} = 1, p_{uy} = 1/a_{yu}$ and $p_{yu} \neq 0$. The number of criteria is represented by n.

C. Third: measure the weight vector of decision factors

We measure the normalized relative weight matrix (B) by dividing each element of the matrix (A) with the sum of its column.

$$B = Norm(A) \tag{9}$$

After that, we calculate Y matrix which represents the importance degree of alternatives (potential links). Then, the link with the highest importance degree is chosen as the trusted link (D_{id}). Y is computed using

$$Y = B.\overrightarrow{ePCM} \tag{10}$$

where $\overrightarrow{ePCM}$ is the eigenvector of PCM.

D. Fourth: make a consistency test for the PCM

The following equation expresses the consistency, and the measure of consistency is called the consistency index (CI)

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{11}$$

where λ_{max} is the maximum eigenvalue of PCM. The Random Inconsistency (RI) [13] is computed by

$$RI = \frac{1.987 \times (n-2)}{n} \tag{12}$$

Finally, we have Consistency Ratio (CR) as follows

$$CR = \frac{CI}{RI} \tag{13}$$

In AHP algorithm [13], if the value of CR is smaller or equal to 10%, the inconsistency is acceptable. If the CR is higher than 10%, we need to revise the PCM. In the proposed model, we compute the CR, which is equal to 2.96%.

IV. Simulation Analysis

This section describes the simulation set-up used to measure and evaluate the performance of the proposed model. Also, we study the impact of various changes in the network such as the number of road entities, number of RSUs and the node's speed on the following metrics: PDR, end-to-end delivery ratio and average delay.

A. Network specifications

In our simulations, we considered a V2X network with 100 road entities and 6 RSUs with parameters, as shown in Table III. The road entities move over an area of 800×800 m^2 with various speed ranges as shown in Table IV. The location

TABLE III: Simulation Parameters

Parameter	Value	Parameter	Value
Simulation area	800×800	Packet size	510 Bytes
Transmission time	500 μsec	Number of road entities	100
Transmission Power (dBm)	23 [14]	Transmission Range (m)	100
Average building height h	5m [12]	Antenna height for UE h_{UE}	1.5m [12]
Frequency Band	5855-5925 [12]	Noise (dBm)	-90
Bandwidth	70 MHz [12]	Queue capacity	25 packets

TABLE IV: Mobility Parameters

Road Entity	Speed range
Vehicle	[54-72] km/h
Motorcycle	[54-72] km/h
Cycle	[3.6-14.4] km/h
Pedestrian	[3.6-4.32] km/h

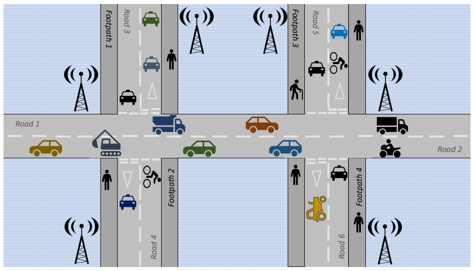

Fig. 3: Simulation area

distributions of road entities and RSUs is shown in Fig.3. The road entity sends the transaction message to the core network directly or using a multi-hop routing protocol. Also, the considered network has heterogeneous nodes where the road entity includes vehicles, pedestrians, motorcycles, and cycles.

B. Results

1) Network throughput: we evaluate the network throughput by measuring two main metrics, which are PDR and end-to-end packet delivery ratio. PDR is the rate of the packets that are generated but not delivered to the designated road entity. PDR evaluates the link between each two road entities. It is computed by

$$PDR_{i,j} = \frac{NI_{i,j}}{TI_{i,j}} \tag{14}$$

where $NI_{i,j}$ and $TI_{i,j}$ are the negative interactions and the total interactions between road entity i and road entity j respectively. On the other hand, the end-to-end packet delivery ratio represents the percentage of the arrived packets to the core network. It is measured by

$$DR = \frac{GP}{AP} \tag{15}$$

where GP is the total generated packets by all road entities, AP is the number of arrived packets to the core network.

The results that are shown in Fig.3 represent the impact of node density on PDR and end-to-end packet delivery ratio. We notice that the PDR decreases when the number of road entities increases because the number of potential relay nodes increases. Thus, the source entity has more choices to find the best one as a relay node. As much as the node density goes down, the source entity may have to send the packet to one of its neighbours even if it does not achieve a low PDR. This because it is the best link in comparison with others. On the other hand, the end-to-end packet delivery ratio goes up gradually when the number of road entities increases. The proposed model achieves a high delivery rate and very low PDR when the number of road entities is equal to 250.

In addition, the vehicular network has a dynamic topology because of the continuous movement of the nodes. As a consequence, the link stability is considered a serious challenge. Because of that, we study the impact of speed change on PDR and end-to-end packet delivery ratio, as shown in Fig.4. We set the number of road entities to be equal to 100, which is considered as low value. We notice that PDR goes up as the road entity's speed is increased because of the reduction in the connection time between two road entities. Also, the end-to-end packet delivery ratio is decreased as long as the speed increases. As much as the number of road entities is increased that will affect positively on PDR and end-to-end packet delivery ratio.

2) Average delay: is the time duration for the packet from generated until it reach to eNB. It is computed by

$$Delay = \frac{Delay\ for\ all\ delivered\ packets}{No.\ of\ generated\ packets} \tag{16}$$

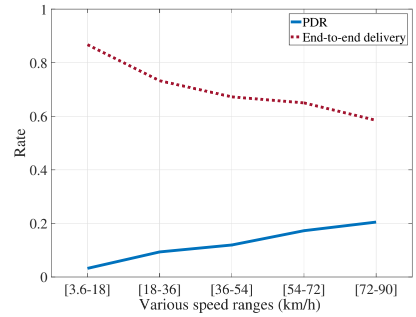

Fig. 5: The impact of speed changes on PDR and end-to-end packet delivery ratio

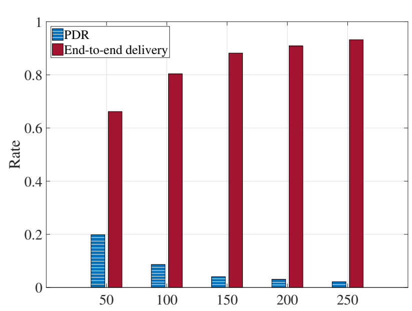

Fig. 4: The impact of various number of nodes on PDR and end-to-end packet delivery ratio

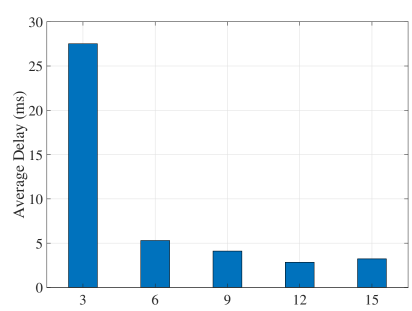

Fig. 6: The impact of various number of RSUs on the average delay

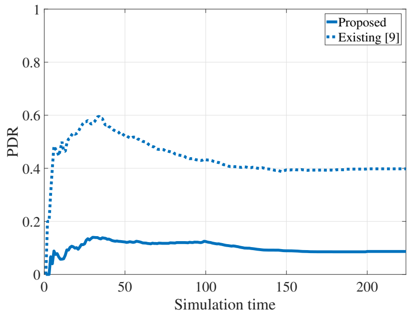

Fig. 7: Evaluation measure for PDR

Here, we study the impact of various numbers of RSUs on the average delay, as shown in Fig.5. We observe that the average delay reduces when the number of RSUs goes up. When the number of RSUs is equal to three, the chance of finding a direct link with the core network is low. Therefore, increasing the number of RSUs achieves a small average delay.

V. Performance Evaluation

We use the existing model [10] as a benchmark to evaluate the performance of the proposed model. The existing model suggested a hierarchical approach to decide if a vehicle should act as a gateway or not. In the first level of clustering, they proposed the fuzzy logic algorithm to choose cluster heads. Then, they applied the Q-learning algorithm to select some of the cluster heads as gateways between IEEE802.11p with LTE networks. Also, it considers four main parameters to choose gateways, which are velocity, direction, signal quality, and the number of hops from the base station. The main object of their proposed model to achieve a minimum number of gateways and ensure packet delivery with the shortest path. However, it causes congestions in the gateway nodes [10]; thus, it leads to a buffer overflow. Therefore, it decreases the packet delivery ratio. On the other hand, the proposed model measures the queue size, in addition to the number of hops, while evaluating the relaying nodes. Thus, PDR and delivery ratio are the main metrics that we need to measure to assess the proposed model.

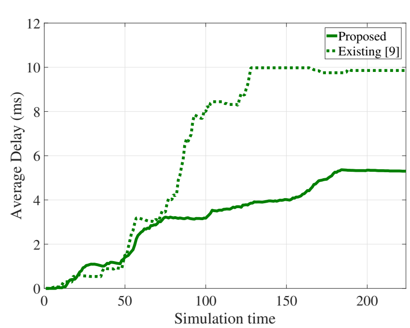

Fig. 8: Evaluation measure for average delay

A. Comparison Results

1) Evaluation measure for PDR: we conduct an experiment to study the performance of the proposed model in comparison with the existing model regarding PDR, as shown in Fig.6. We notice that the PDR starts with high values in the existing model, then it goes down gradually with time. By the end of the simulation, the PDR is equal to 40%, which quite high because the algorithm updates the gateways every one second, and they used a complex algorithm which causes a delay. By that time, the network topology may change while electing new gateways. On the other hand, the PDR in the proposed model is slightly decreased with time. In general, it has a stable curve during the simulation time. The proposed model achieves very low PDR in comparison with the existing model.

2) Evaluation measure for average delay: we study the average delay in the proposed model in comparison with the existing model in Fig.7. We notice that the delay in the existing model is lower than the proposed one until the 70^{th} time interval. After that, the delay in the existing model is increased to reach $10\ ms$. The main reason is the increase of the generated packets; thus, the queue size of gateway nodes is increased in the existing model, which causes a high delay. However, in the proposed model, the source node can choose any neighbouring node as a relay node to avoid congestion.

VI. Conclusion

In this paper, we proposed a multi-metric QoS-balancing relay selection algorithm V2X network. The link evaluation is based on three factors, which are link stability, channel capacity, and end-to-end delay. Various changes, such as the number of road entities, the number of RSUs and the node's speed are considered to study the performance of the proposed model. Simulation results showed that the proposed model improved PDR by 78% and average delay by 45% in comparison with the existing model. In future work, we will extend the decision-making algorithm to include the decision regarding the cellular links with considering of the interference challenges [15].

Acknowledgement

This work was supported by the European Commissions Horizon 2020 framework programme (H2020/2014-2020) under grant agreement no. 734325 TESTBED project (http://testbed-rise.com/).

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