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# A novel reliable low-latency multipath routing scheme for vehicular ad hoc networks

Fakhar Abbas*, Pingzhi Fan and Zahid Khan

**Abstract**

In this paper, the existing ad hoc on demand multipath distance vector (AOMDV) routing scheme for vehicular ad hoc networks (VANETs) is extended to a reliable low-latency multipath routing (RLLMR) scheme based on multipath link reliability, capable of determining the reliable routes preemptively. Here, the link reliability refers to the probability that a direct transmission link among any two vehicles remains constantly available for a specific period of time, which can be computed based on the position, route, and velocity of the vehicles to facilitate the reliable routing process in VANETs. In the proposed RLLMR scheme, the mathematical distribution of vehicles movements and link breakages is also considered to increase the reliability of the vehicular networks. The simulation results show that proposed RLLMR scheme performs better compared to existing schemes in terms of latency, reliability, throughput, and energy consumption at the cost of marginally increased routing overhead.

**Keywords:** Link reliability, Vehicular ad hoc network (VANETs), Low-latency, Routing reliability

## 1 Introduction

As an essential part of smart cities, intelligent transportation systems (ITS) and vehicular ad hoc networks (VANETs) have attracted immense attentions from academia and industries. It is considered as a unique type of mobile ad hoc networks (MANETs) [1]. In VANETs' environment, every vehicle can be connected to each other as a router, independent of the fixed infrastructure support. VANETs have different communication modes such as vehicle-to-everything (V2X), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-vehicle (V2V) [2] for many applications, which are grouped into security information and commercial applications [3], such as driver assistance, Internet access, accident notice and so on. Compared with other networks, VANETs have different characteristics [4] which include self-organization, high mobility, road design limitations, no energy constraints, and large-scale network sizes.

VANETs emerge new challenges and problems due to its dynamic environment. An effective and most reliable low-latency multipath routing scheme is vital for data dissemination to deal with the dynamic environment of VANETs. In the absence of an efficient and reliable low-latency multi-path routing schemes, vehicles may not be able to exchange information and will lose all the advantages offered by the advance VANETs technology. The routing schemes currently studied for MANETs are not appropriate for VANETs [5]. The literature on route reliability mainly deals with MANETs [6, 7]. For VANETs, Taleb et al. [8] proposed a model that considers the data about the vehicles to estimate link breakage. The vehicles are clustered based on velocity vectors. When the vehicle moved to other group, the path involved in the vehicle is discontinued. The proposed model checks and includes a most stable route from other vehicles which belong to similar groups. In [9], Feng et al. proposed a speed-based routing scheme, which depends on the relative speed among the transmitting and sending node. The area to which the packet is forwarded is predicted by estimating the future path of the receiver node depending on the position information and the speed.

A predictive based routing protocol (PRP) for VANETs is proposed in [10]. PRP is designed for mobile highway scenarios and utilizes expected movement patterns for vehicles on the roads. PRP calculates the route period and actively creates a new route from an existing fault. The reliability of the link is predicted based on the communication range, the vehicle position, and the corresponding

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speed of the vehicle. While the route contains one or many connections, the routing period is the minimum of all connections. PRP grant numerous routing requests to be processed, to see all existing paths to the target. When the source vehicle get a large number of reply messages, the route containing the maximum estimated routing period is selected. In [11], a motion predictive based routing (MOPR) scheme is proposed by Menouar et al. This scheme predicts future movement situation of the vehicles and looks for reliable routes to prevent link breakages. If there are many possible routes among the source and the target vehicle, then MOPR selects the most stable route taking into account the moving situations of the intermediate node relative to the source and ending node. This is achieved along the direction, position, and speed messages of every vehicle. It is necessary to extend the routing contents in every node to meet the conditions of scheme.

Chen et al. [12] proposed ad hoc on-demand multipath distance vector by speed metric (S-AOMDV) scheme combined with hop rate metric to make vehicle routing information available for employment and to reduce the latency of routing decisions. To get speed information for real time, authors designed an on-board diagnostic (OBD) information cluster module and results using an OBD technology to gather speed information which increase in energy consumption and routing overhead; therefore, in case of highly dynamic traffic or high load broadcast, the performance of S-AOMDV will be low due to hop and velocity metric combination to make routing selection. To evaluate the generated routes, Alghamdi [13] and Alves and Wille [14] proposed load-balancing AOMDV scheme according to the maximum node residual energy and existing number of packets. This scheme mainly utilizes the available routing information in the existing AOMDV protocol. As a result, during the computation of maximum nodal residual energy in the routing, it significantly increases the routing control overhead and end-to-end latency.

Based on the above descriptions, although considerable progress has been achieved on the reliability of VANETs, there are still many challenges that need to be addressed, such as link reliability, high mobility, and continual diversity in the vehicular network topology of urban areas which are the subject of the current study. The dense topological structure influences the performance of many existing VANETs routing schemes [15, 16]. Therefore, the reliability of multipath routing needs to be given different considerations in order to effectively organize these networks. The main objective of this paper is to propose a reliable low-latency multipath routing (RLLMR) scheme to improve the multipath routing reliability and to determine the most reliable route among the communicating vehicles in VANETs. The innovation is to design a reliable low-latency multipath routing scheme that considers the reliability of the distribution of vehicle mobile and link breakages on the highway. This work is based on a scenario in which the vehicle moves with relative speed in two directions on the highway. We have conducted comprehensive numerical and simulation experiments to demonstrate the performance of proposed scheme compared to existing schemes in terms of latency, reliability, energy consumption, and throughput at the expenses of slightly increased routing control overhead.

The rest of this paper is organized as follows. The state of the art of the paper is in Section 5. Section 2 presents the system model and multipath link reliability, Section 3 presents the proposed RLLMR scheme. Simulation results are given in Section 4, and Section 6 concludes the paper.

## 2 State of the art

To the best of our knowledge, currently, there is no earlier studies on the development of reliable routing based on low-latency multi-path routing scheme in vehicular networks on highways. The mobility model and routing reliability were studied separately.

### 2.1 AOMDV

Ad hoc on-demand multi-path distance vector routing (AOMDV) scheme is an extension based on AODV to compute multiple link disjoint and loop-free routes [17, 18]. AOMDV is mainly designed for highly dynamic traffic where route failures and link breakages appear frequently. AOMDV scheme has two essential parts: a route update method to organize and keep multiple loop-free routes at every node and a distributed scheme to find link-disjoint routes. The key objective to use AOMDV is that it permits central nodes to respond to routing request messages, whereas still choosing disjoint routes. All discovered routes are stored within routing contents, and the node selects the route according to its time stamp. The earliest established route is selected first for data transmission. In the case of maintenance, when a routing fault is detected, data can be sent to another alternative route. Figure 1 shows AOMDV complete route discovery procedure along with routing request (RREQ) and routing reply (RREP) messages.

A RREQ message is broadcasted in order to initiate path discovery process among source and destination vehicle. The neighbors, which receive the RREQ message, may be in duplicate and set the reverse routes to the source and other senders. The AODV used by the authors [19, 20] keep only one reverse path to the sender and others are discarded. If the intermediate vehicle have a path to send to the destination, it sends RREPs to the target node with reverse path and discard RREQ. In case of no path, RREQ is broadcasted. Once the destination receives the RREQ messages, different RREP messages are

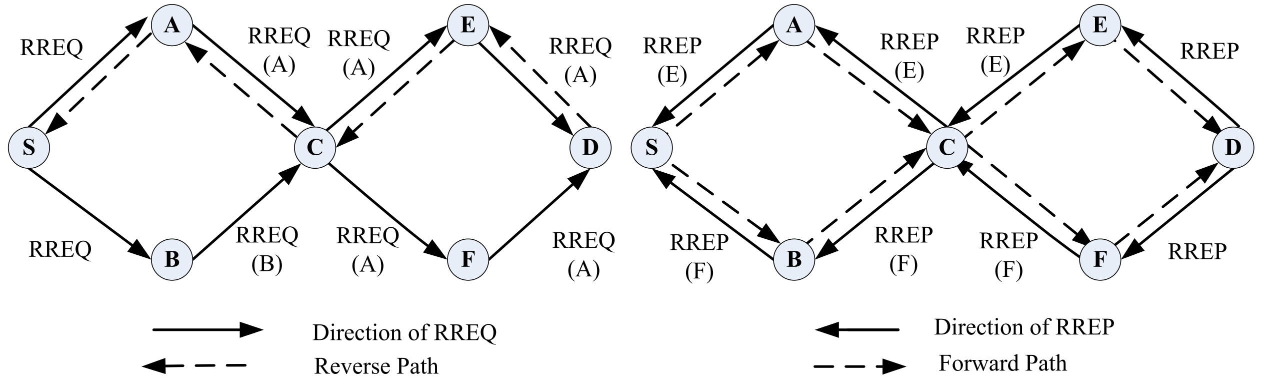


**Fig. 1** RREQ and RREP messages in AOMDV

sent to the neighbors to ensure link-disjoint. When the RREP packet is accepted by the intermediate node and the source nodes, the established link-disjoint and loop-free routes to destination nodes based on the first hop of RREP packets. For central nodes that are distributed by disjoint routes of different links, it checks to see if there are any unused reverse paths in the source. If it is, the reverse route will be selected to forward the current RREP message; otherwise, the packet will be dropped.

### 2.2 Existing schemes for comparison

In order to estimate the quality of RLLMR scheme, we have considered three existing schemes for comparison.

The concept of reliability is an emerging solution to deal with the randomized nature of VANETs. Eiza et al. [20] and Kaur and Kad [16] proposed probabilistic link reliability for VANETs routing reliability and calculated link reliability by using location, velocity, and direction of vehicles along the road. They extend the link reliability to the existing AODV as the ideal route selection and improve its reliability by employing R-AODV (reliable-ad hoc on demand distance vector). R-AODV determines a single, optimum path to the target node, which improves performance compared to AODV. There are some limitations of this approach. First, the AODV chooses a route among the source and destination of the data transfer, so the performance of R-AODV will degrade due to frequent link breakage and data loss in highly dynamic VANETs or high load transmissions. In response to frequent link breakage, AODV has iteratively discovered routes that increase energy consumption and latency. Secondly, because of single direct selection, R-AODV does not have a load-balancing scheme, so data loss will increase as network density or number of vehicles increases.

The QoS-based dynamic source routing scheme (Q-DSR) is proposed in [21] by extending dynamic source routing protocol. The proposed scheme select a reliable route based on the maximum quality of service (QoS), in which the QoS value based on the connectivity level, the accessible bandwidth and mobility parameters such as speed and distance. Q-DSR is a hop-by-hop routing scheme which depends on every node through the routing messages of all neighbor nodes' information and update the data transmission. The are some limitations of this approach. First, due to payload transmission or high mobility, the performance of Q-DSR will be low, due to frequent link disconnection and data loss because it has no load-balancing scheme. Second, in order to deal with frequent link interruption, Q-DSR recursively find routes that lead to energy consumption and packet losses.

In [22], the authors introduced a trust-based ad hoc on-demand multi-path distance vector (T-AOMDV) protocol via extending the AOMDV scheme. In their considered solution, nodes compute reliable values according to multiple situations by taking into account the exchange context factors, historical connections and the behavior of neighboring nodes. There are some limitations of this approach. First, it chooses trusted routes based on neighboring node performance and recommends trusted values to compute information packets that increase latency and energy consumption. Second, T-AOMDV integrates the node's trust value into the response route during the route discovery process, increasing network load and routing overhead.

### 2.3 Contributions

On the basis of the abovementioned motivations, a reliable low-latency multipath distance vector routing (RLLMR) scheme with following features is proposed.

- The link reliability model is employed to improve the overall multipath routing performance which is considered as a metric for best route selection.
- Based on the AOMDV and link reliability, a novel reliable low-latency multipath routing (RLLMR) scheme is proposed to establish a reliable route among sender and receiver vehicles.

- For highway scenario, the link reliability and mobility model is derived by considering the mathematical distribution of vehicles' movements and their relative velocities.
- It is shown that the proposed scheme can reduce end-to-end (E2E) latency with relative speed by reducing the number of route request messages and also reduce route failure by adding reliable parallel routes to destination that increases its throughput even in case of heavy packets. Furthermore, the energy consumption is also reduced at the expenses of slightly increased routing overhead.

## 3 System model and multipath link reliability

On highways, where vehicles move at different velocities, it is a challenging case to apply reliable low-latency multipath routing (RLLMR) scheme in VANETs because it is affected by several aspects. Examples of factors affecting the reliable routing process are vehicle mobility model and vehicles traffic distribution [5, 23–27]. In order to more specifically discover the reliability of network, it is essential to judge the mobility model and vehicle traffic features. Understanding the traffic flow features of vehicles facilitate to conclude the time period of reliable communication among vehicles. The main notations used throughout this paper are summarized in the "Abbreviations".

### 3.1 Highway mobility model

To enhance the reliability of a network, we consider two-way scenario with multi-lane having $N$ total number of vehicles moving with relative speed $v$ on a highway with a normal distribution $N\left(\mu, \sigma^2\right)$. As shown in Fig. 2, the source vehicle $V_i$ requests to communicate with destination vehicle $V_j$ or neighboring vehicles. The first step is for the source vehicle $V_i$ to broadcast routing request messages (RREQ) to all neighboring vehicles in its communication range by adding its position information, route, and speed requirements. After the neighboring vehicles have received the RREQ messages, the link reliability is computed based on the Eq. (15) for the source vehicle to create a communication route that depends on the computed reliability values. If the source vehicle $V_i$ gets multiple routing replies similar to the RREQ messages, then the route having the maximum reliability value in all received routing reply messages (RREPs) will be selected. The model aims at finding the reliable route in high mobility scenarios.

We consider a macroscopic approach that defines the movement of each vehicle and models' movements such as speed and path evaluation of every vehicle as an acknowledgment to adjacent traffic. It is identified that the macroscopic approach is feasible in defining the general traffic flow position and particular vehicle [28]. Hence, the macroscopic traffic movement model is employed to define the vehicles' traffic movements and use the relative speed to examine the mathematical dissemination of vehicle movements on the vehicular network. The speed is the primary feature that influence the network topology dynamics. According to the macroscopic approach, the mobility of every vehicle $V_i$ is determined by following parameters: current location at time $t$ : $x_j(t)$ and $y_j(t)$, current speed $v_j(t)$, acceleration $a_j(t)$, and direction of mobility $\alpha_j(t)$. In VANETs environment, we assume that speed is the main feature used in determining the expected transmission time among two vehicles and vehicle speed has normal distribution. The following relationship describes the use of the urban mobility model for the highway movement model [29].

$$v_j(t+\Delta t) = v_j(t) + a_j(t) \times \Delta t \tag{1}$$

$$\Delta y_{l,m} = \sum_{z=l+1}^{m} v_{jz} \times \Delta t \times \cos \alpha_{jz} \tag{2}$$

$$\Delta x_{l,m} = \sum_{z=l+1}^{m} v_{jz} \times \Delta t \times \sin \alpha_{jz} \tag{3}$$

where $\Delta x_{l,m}$ and $\Delta y_{l,m}$ are the moving intervals of the $x$ and $y$ routes over the time $\Delta t = (t_m - t_l)$, $\Delta t$ is the time sampling interval among $t_l$ and $t_m$, $v_{jz}$ is the speed of vehicle $V_i$ at the time period $m$, and $\alpha_{jz}$ is the direction of vehicle $V_i$ movement at time period $z$. The acceleration or deceleration values are evenly uniformly distributed where $v_j(t+\Delta t)$ value does not follow the normal distribution. A feasible solution is to use the Box-Muller transform method [30] or the Ziggurat algorithm [31] to change the steady distribution of the acceleration or deceleration values to a normal distribution. However, the solution is approximately expensive and expands the complexity of the routing algorithm. A simple solution is proposed to allow the vehicles to move further or slow down or maintain the same speed by selecting a new normally distributed speed value. Suppose $V_s = \{kv_1, kv_2, ..., kv_x\}$ is the combination of normally distributed speed values with origins at $t+\Delta t$. Let $kv_x$ and $kv_o \in V_S$, where $kv_x \geq v_j(t)$ and $kv_o \leq v_j(t)$. If the vehicle selects $kv_x$, it means it is accelerating, else it is decelerating by selecting $kv_o$. The driver attitude parameter (DAP) is introduced in RLLMR scheme to identify among drivers who consider to accelerating on the average speed and the drivers who are considered to be decelerating. Equation (1) can therefore be written as follows:

$$v_j(t+\Delta t) = \begin{cases} kv_x, & \text{if } U_1 < 3\text{DAP}/4 \\ kv_o, & \text{Otherwise} \end{cases} \tag{4}$$

where $U_1$ is a random variable among 0 and 1. The DAP value on the basis of highway studies, which indicates that around 75% of the active drivers move to support

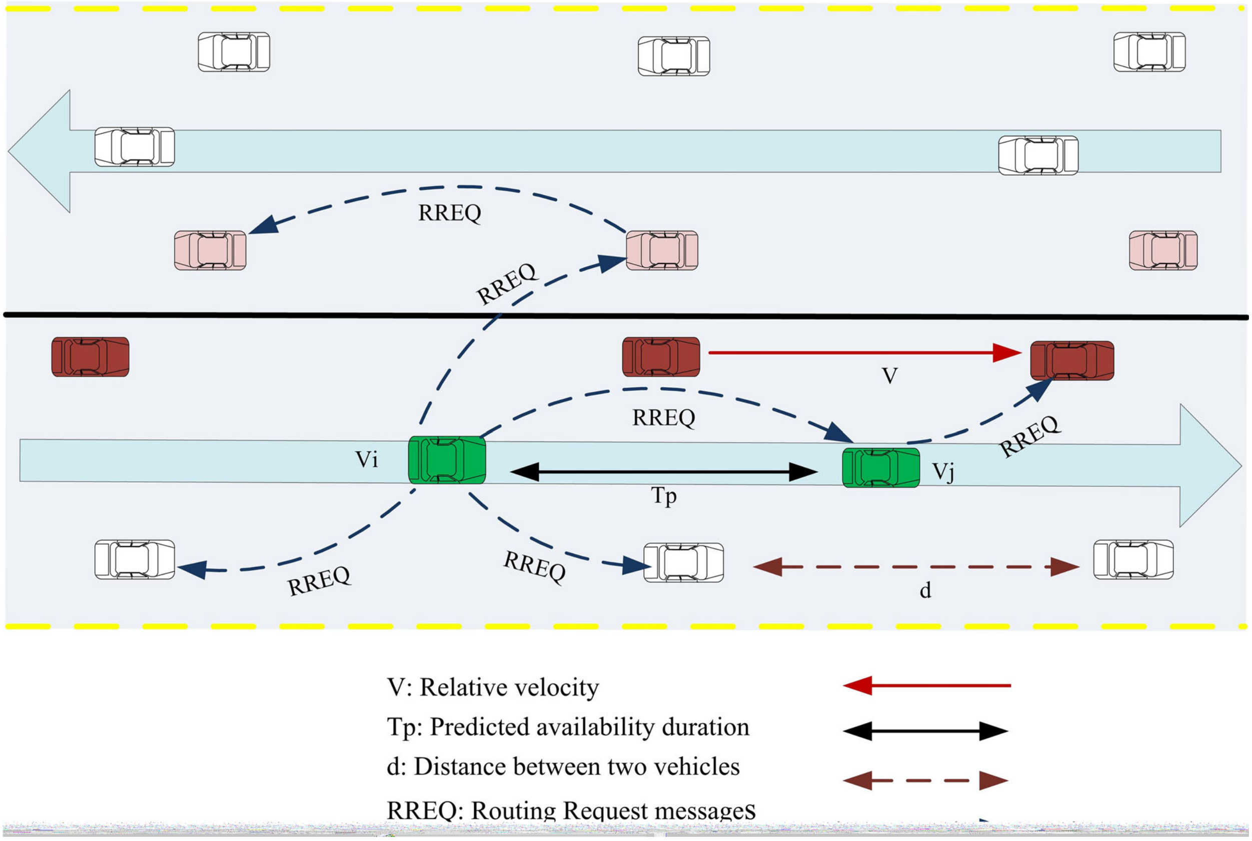


**Fig. 2** Vehicular system model

acceleration over mean speed which is used in (4) to assign the values of $v_j(t+\Delta t)$ [10, 32]. Based on the classical vehicle traffic principles, it is assumed that the vehicle have Poisson distribution arrivals [33]. Therefore, the time gap $\tau$ among vehicles is based on the following probability density function (pdf) distribution [34].

$$p_\tau(\tau) = re^{-r.\tau} \tag{5}$$

where $r$ is the traffic movement of vehicles per second and $\tau$ is the average time gap among vehicles (in seconds). According to the Eq. (5), the probability density function (pdf) for the distance $d$ of vehicles is given as follows:

$$p_d(d) = \frac{r}{v_c} e^{-r.\frac{d}{v_c}} \tag{6}$$

The pdf in (6) replaces the vehicle speed $v_c$ with constant average speed which is not entirely true in accordance with the fact that speeds are variable due to the acceleration/deceleration while driving. However, a brief description of the above pdf on vehicle distances applies to our road simulation and traffic plan design. The more general and precise distribution of distances among vehicles has been studied in [35].

### 3.2 Link reliability

Link reliability applies to the probability that a direct transmission link among any two vehicles $V_i$ and $V_j$ will be available for a specific period $t$. The link reliability $r(l)$ of link $l$ among any two vehicles at a $t$ for a specific time interval $T_p$ [20] is given as follows:

$$r_t(l) = P\left\{\text{to be continuously available until t} + T_p | \text{exist at t}\right\} \tag{7}$$

To compute the link reliability, the vehicles speed is considered as a major factor. It is noted that, the vehicles speed have a normal distribution, the calculation of $r_t(l)$ can be computed as follows, i.e., if the velocities of neighboring vehicles are changed or unchanged among $t$ and $t + T_p$, the resultant relative speed also have a normal distribution [36–39]. Let every vehicle enters a road segments with different speeds. The authors of [20] considered the steady state distribution of vehicles, where speed is modeled as Gaussian distribution with supposition that speed will be constant for a specific duration. Herein, we assumed that $h(v)$ is the probability density function (pdf) [20] of the vehicle's speed $v$

$$h(v) = \frac{1}{\sigma.\sqrt{2\pi}} e^{-\frac{(v-\mu)^2}{2\sigma^2}} \tag{8}$$

and $H(v)$ is the cumulative density function (CDF):

$$H(v < v_0) = \frac{1}{\sigma.\sqrt{2\pi}} \int_0^{v_0} e^{-\frac{(v-\mu)^2}{2\sigma^2}} dv \tag{9}$$

in which $\mu$ and $\sigma^2$ represent the mean and variance of relative speed $v$ respectively [40]. If the speeds are independent variables, hence the relative speed of two vehicles also follows normal distribution. Suppose $h(v_1) \sim N\left(\mu_1, \sigma_1^2\right)$ and $h(v_2) \sim N\left(\mu_2, \sigma_2^2\right)$ are the pdf's of two vehicles' velocities respectively. Then, pdfs of their relative velocities are $h(v_{12}) \sim N\left(\mu_{12}, \sigma_{12}^2\right)$, where $v_{12} = v_1 - v_2$, $\mu_{12} = \mu_1 - \mu_2$ and $\sigma_{12}^2 = \sigma_1^2 + \sigma_2^2$. The distribution of random variable $T$ depends on three factors.

- Relative speed $\Delta v_{ij}$ of vehicle's $V_i$ and $V_j$.
- Initial distance $d$ among vehicle's $V_i$ and $V_j$.
- Relative direction of vehicle's $V_i$ and $V_j$.

The vehicle follows a random walk mobility method, that means the vehicles can change lane with their speed. As shown in Fig. 2 $T_p$ is the prediction period for the continuous availability of a particular link. We consider $L_{V_iV_j}$ is the relative transmission range among vehicle's $V_i$ and $V_j$ which depends on the speed $v$ and direction of vehicles. The relative transmission range $L_{V_iV_j}$ in the case of same direction is as follows:

$$L_{V_iV_j} = \begin{cases} L + d, \text{if } V_j > V_i \\ L - d, \text{if } V_i > V_j \end{cases} \tag{10}$$

If vehicle's $V_i$ and $V_j$ are moving in opposite direction, then $L_{V_iV_j}$ is given as:

$$L_{V_iV_j} = \begin{cases} L - d, \text{if } V_i \text{ and } V_j \text{ are moving away} \\ L + d, \text{if } V_i \text{ and } V_j \text{ are moving to each other} \end{cases} \tag{11}$$

The distance $d$ among two vehicles $V_i$ and $V_j$ which can be computed employing the relative speed $\Delta v_{ij}$ with time period $t$ such as $d = \Delta v_{ij} \times T$ where $\Delta v_{ij} = |v_j - v_i|$. Whereas $v_i$ and $v_j$ are normally distributed random variables, $\Delta v_{ij}$ is also normally disseminated variable; hence, it can be written as $\Delta v_{ij} = \frac{d}{T}$. The $d$ can be computed as follows:

$$d = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{12}$$

Let $T_p$ be the predicted availability duration of link $l$ and $\Delta v_{ij}$ be the relative speed of vehicle's $V_i$ and $V_j$, then $T_P$ will be:

$$T_p = \frac{L_{ViV_j}}{\Delta v_{ij}} \tag{13}$$

To compute link reliability, the probability density function (pdf) of transmission period $T$ of vehicle's $V_i$ and $V_j$ is given as:

$$f(T) = \frac{L_{ViV_j}}{\sigma_{\Delta v_{ij}}.\sqrt{2\pi}} \frac{1}{T^2} e^{-\frac{\left(\frac{L_{V_iV_j}}{T} - \mu_{\Delta v_{ij}}\right)^2}{2\sigma^2_{\Delta v_{ij}}}} \tag{14}$$

where $\mu\Delta v_{ij} = |\mu v_{ij1} - \mu v_{ij2}|$ and $\sigma^2\Delta v_{ij} = \sigma^2 v_i + \sigma^2 v_j$ represents the mean and variance of the relative speed $\Delta v_{ij}$ among two vehicles, respectively. We assume that every vehicle is mobilized with GPS to classify the speed, location, and direction information.

$f(T)$ can be integrated in Eq. (14) from $t$ to $t + T_p$ to get probability that at time $t$, a transmission link will be accessible for the period $T_p$. Consequently, the link reliability $r_t(l)$ at period $t$ is computed as follows [20]:

$$r_t(l) = \begin{cases} \int_t^{t+T_p} f(T)dt \text{ if } T_p > 0 \\ 0, \text{ otherwise} \end{cases} \tag{15}$$

The integral in (15) can be solved using the Gaussian error function (Erf).

$$r_t(l) = Erf\left[\frac{\left(\frac{L_{V_iV_j}}{t} - \mu_{\Delta v_{ij}}\right)}{\sigma_{\Delta v_{ij}}\sqrt{2}}\right] - Erf\left[\frac{\left(\frac{L_{V_iV_j}}{t+T_p} - \mu_{\Delta v_{ij}}\right)}{\sigma_{\Delta v_{ij}}\sqrt{2}}\right] \quad \text{when } T_p > 0 \tag{16}$$

where the Erf is defined as follows [41].

$$Erf(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-t^2} dt - \infty < z < +\infty \tag{17}$$

### 3.3 Multipath route reliability

In VANETs, there could exist multiple routes among the sender $v_s$ and receiver vehicle $v_d$, where each route consists of a link combination among the source and the destination. Without loss of generality, for any given route, we express the number of its routes as $n : l_1 = (v_s, m_1)$, $l_2 = (m_1, m_2), ...., l_n = (m_n, v_d)$. For each link $l_n (n = 1, 2, 3, ...., n)$, we denote the value of its route reliability by the value calculated in Eq. (15). The reliable route for a route $B$, denoted by $R(B(v_s, v_d))$ [20] in the case of multiple potential routes among $v_s$ and $v_d$, is defined as.

$$R(B(v_s, v_d)) = \prod_{i=1}^{n} r_t(l_i) \text{where } l_i \epsilon R(B(v_s, v_d)) \tag{18}$$

The multipath routing reliability is the product of the reliability values of the link forming the route. Suppose there are $x$ multipath routes from source $v_s$ to the destination $v_d$. If $M(v_s, v_d) = \{P_1, P_2, P_3, \ldots.., P_x\}$ is the set of all these available routes, then the ideal route will be selected at source node based on below benchmarks:

$$\arg max_{p \epsilon M(v_s, v_d)} R(B(v_s, v_d)) \quad (19)$$

Especially, if more than one routes are available, the best reliable route is selected that meets the application's determined reliability threshold. $R(B)$ is the route reliability for a route $B$. It can be said that the route $B$ is reliable if $R(B(v_s, v_d))$ is larger than the reliability threshold required by the data traffic type. Complex data requires most stable routing compared to other common data. Therefore, the st ability threshold for complex data may be $R(B(v_s, v_d)) > 0.9$. The route could be reliable for a specific data to be transferred while it is not reliable for other types of data. In summary, the reliability of a multipath link is a relative idea and based on the type of data to be transmitted. If multiple routes meet the reliability threshold, the route with the smallest number of hops is selected.

## 4 Proposed RLLMR scheme

### 4.1 RLLMR

To evaluate proposed reliability-based routing scheme, AOMDV routing scheme is extended to RLLMR scheme by employing reliability, where R stand for reliability. The revised tabular contents of routing replies (RREP), routing requests (RREQ), and routing tables with link reliability are presented in Fig. 3.

Routing request messages are expanded with adding new contents to its network as shown in Fig. 3a.

- *Xpos*, *Ypos* includes the coordinates of the vehicles that proceeds routing request (RREQ).
- Direction contains the vehicle motions that proceeds routing request.
- Speed contains the current vehicles relative speed that processes RREQ.
- Link_reliability contains the constraints of the link reliability between the sending and the receiving vehicle of such RREQ.

The routing reply messages are extended with including a new contents in the network, as shown in Fig. 3b.

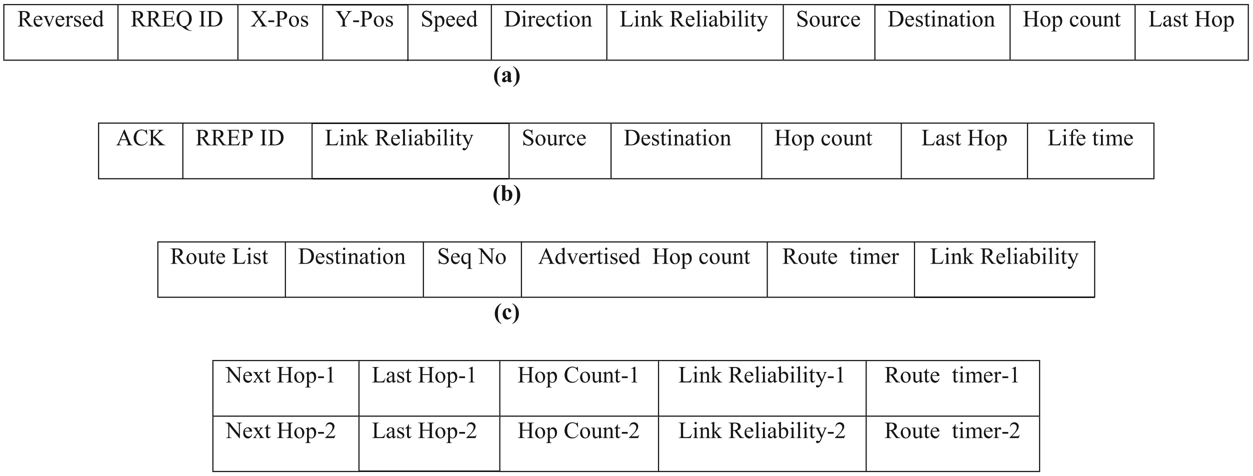
- ACK contains the response of all broadcasted messages.
- Routing reply ID contains the ID's of all RREP messages.

Routing tables are expanded by adding new data packets to its tables, as shown in Fig. 3c.

- The routing list holds records of all different paths.
- Link_reliability contains the constraints of the link reliability of that link entry. This value is kept every time with most reliable value is generated for the identical destination.

### 4.2 Routing procedure in RLLMR

Once the source vehicle $s_r$ has data for transmission, it starts with its own routing table. If it has a right route to the target $d_s$ to use, otherwise the new route discovery procedure will start. The source vehicle $s_r$ transmit RREQ information to the new neighboring vehicle and updates its position information, route and speed requirements. When the neighboring vehicle receives the RREQ, the link reliability is computed based on the Eq. (15) of the source vehicle to create a communication route that depends on the computed reliability values. Subsequently, reliability value is maintained by multiplying the computed value by the value stored in the RREQ message based on (17). The



| Reversed | RREQ ID | X-Pos | Y-Pos | Speed | Direction | Link Reliability | Source | Destination | Hop count | Last Hop |
|---|---|---|---|---|---|---|---|---|---|---|

(a)

| ACK | RREP ID | Link Reliability | Source | Destination | Hop count | Last Hop | Life time |
|---|---|---|---|---|---|---|---|

(b)

| Route List | Destination | Seq No | Advertised Hop count | Route timer | Link Reliability |
|---|---|---|---|---|---|

(c)

| | | | | |
|---|---|---|---|---|
| Next Hop-1 | Last Hop-1 | Hop Count-1 | Link Reliability-1 | Route timer-1 |
| Next Hop-2 | Last Hop-2 | Hop Count-2 | Link Reliability-2 | Route timer-2 |

**Fig. 3** Route structure of RLLMR. **a** RLLMR RREQ Contents, **b** RLLMR RREP Contents, **c** RLLMR Routing Contents

new reliability value is stored in the routing request data. Subsequently, the existing vehicle will inquire whether the RREQ was processed before or not. If it was, it means there is an opposite route to the source vehicle. If the reliability value of the reverse route is smaller as compared to the reliability value of identified one, this means that there is a new reverse route with an improved reliability values. In that process, the RREQ message will be process again. This approach permit the intermediate vehicle to process multiple RREQs' messages and send multiple RREPs to the source vehicle.

After completing the reverse route change procedure, the existing vehicle checks whether the vehicle is the target vehicle. If so, routing reply message will be transmitted back to the sender vehicle having updated reliable routing value. If this is not the target vehicle, it further examines if it has dynamic route to the receiver vehicle. If there is a route, after that the RREP message is transmitted back to the source vehicle, otherwise the RREQ is forwarded to the other vehicle. If the sender vehicle gets multiple routing replies of similar RREQ, then the route is selected having maximum reliability value among all the received RREP's. In such a way, the best reliable route is selected from source to destination.

The following, pseudocode explains the process of the RREQ messages received at the intermediate or destination node.

- Once the *RREQ* message is received, the steps below are performed:

    1. Save incoming messages in the *RREQ* _contents.
    2. Establish *RREQ_Query* message.
    3. Send the *RREQ_Query* message to check if they have received a *RREQ* message.
    4. Wait for specific period of time for *RREQ_Query_Reply* information from nearby nodes.
    5. Update the neighbor hop count based on the verification message that is received.
    6. Transmit the *RREQ* message with updated hop count value.

- When a *RREQ* information is acknowledged, perform one of the following steps:

    1. In accordance with the *RREQ*_contents, if it is a new *RREQ* message that will be saved in the *RREQ*_contents.
    2. If the same *RREQ* is received from the same node in accordance with *RREQ*_contents, the query will be ignored.
    3. If *RREQ* is the current one in the *RREQ*_contents and it has been accepted from the updated neighbor, but the similar *RREQ* has not been previously distributed, only the response is sent to the assured *RREQ_Query_Reply*

- The *RREP* message is sent once the corresponding *RREP* neighbor hops field is received.

### 4.3 Reliable route (RR) selection algorithm

The objective of route discovery process in RLLMR scheme is to determine the reliable and optimal route in all set of possible routes among the source and the destination vehicles. When the source/neighboring vehicle receives the routing request (RREQ), the reliability is computed based on the Eq. (15) of the source vehicle to create a communication route that depends on the computed reliability values. Subsequently, reliability value is maintained by multiplying the computed value by the value stored in the RREQ message based on Eq. (16). The new reliability value is stored in the RREQ data. If the source vehicle gets multiple routing replies of similar RREQ, then the route is selected having maximum reliability value among all the received routing reply (RREP's). In this way, the best reliable route is selected. When the link or route fails, the RREQ message will be processed again. The pseudocode within Algorithm 1 presents the process for the most reliable route selection.

```
Algorithm 1: Reliable route (RR) selection
Result: Return node/vehicle having maximum average reliability
Send A matrix C[x][y] represenatation of Reliable route
for $V_k \longleftarrow 1$ to N Intermediate vehicle $V_k$, among $V_j$, $V_i$ do
    for each vehicle $V_i$ do
        for each neighbor vehicle $V_j$ of $V_i$ do
            if reliability[$V_i$][$V_j$] < reliability[$V_i$][$V_k$] +reliability[$V_k$][$V_i$] based on (15) then
                reliability[$V_i$][$V_j$] $\longleftarrow$ reliability[$V_i$][$V_k$] +reliability[$V_k$][$V_j$]
            end
        end
    end
    RR $\longleftarrow$ $max_{avg}$Reliability
end
```

## 5 Experiments and result discussions

The key objective is to evaluate the efficiency of proposed RLLMR scheme under different simulation environments. In addition to that, we examine the advantages by employing proposed RLLMR scheme at different speeds and number of vehicles. All the simulation experiments are performed using Network Simulator NS3 (NS-3.25), Simulation of Urban Mobility (SUMO), and MATLAB. SUMO is an open-source microscopic highway traffic simulator licensed under General Public License (GPL), which was developed in collaboration among the Center for Applied Informatics Cologne (ZAIK) and the Institute of Transportation Systems (ITS), at the German Aerospace Center (DLR) [42]. The statistically study and implementation of probability distributions are executed using MATLAB as mentioned in system model. The performance metrics such as link reliability and reliable routes are evaluated using MATLAB. We use NS-3 to build performance evaluation and to conduct the experiments. For all simulation experiment, we execute 20 runs for every simulation experiment to get the average result. The simulation results are compared with the T-AOMDV, Q-DSR, R-AODV, and the proposed RLLMR routing scheme.

### 5.1 Simulation setting

The simulation is carried over two different environments. The first environment deals with the real data traces of Inter State 5 highway Table 1. In the first scenario, we have employed real wireless open data traces [43, 44] by considering traffic scenario of Inter State 5 highway and analyzed the performance of proposed RLLMR. These real data traces are measured from the situation of several Inter State 5 highways which approximately resemble the vehicle moving scenario on the highway. The simulated data from the data set are extracted within an interval 6000 s. The vehicles travel along the highway within 40 Km at the velocity of 120 Km/h. The vehicle density is set to be 0.0016 vehicle/m. To validate the accuracy of the proposed RLLMR scheme, we simulate a real vehicular network scenario by using IEEE 802.11p technique.

The second scenario is a highway of 5 km in both directions, in which continuous arrival of vehicles is considered. The highway movement model is executed in NS-3.25 based on the Eqs. (1), (2), (3), and (4). The average relative speed of each vehicle is examined to be in the range from is 40 to 120 km/h accordingly. The speed is variable due to the unusual attitude of drivers on the highway. The simulation parameters are given in Table 2. Three different simulation experiments are performed to evaluate the significance of proposed RLLMR scheme, which are given below.

**Experiment 1:** Traffic characteristics and mobility models are core parameters for evaluating protocol performance. This experiment analyzes the relationship between the temporal positions of Inter State 5 highway traces with respect to simulation time.

**Experiment 2:** The effect of distinct vehicles on the highway from 20 to 60 vehicles to evaluate the consequence of proposed RLLMR scheme, where the relative speed of vehicle is 60 km/h.

**Experiment 3:** The effect of relative speed from 40 to 120 km/h on the performance of RLLMR. The number of vehicles on the highway is considered 50 to 100.

To evaluate the significance of RLLMR scheme, we have considered following metrics:

- Link reliability: Shows the reliability of a given route from sender to receiver vehicle. Link reliability refers to the probability that a route among any two vehicles will exist over a specific period of time.
- Average Throughput: It presents the amount of data effectively transmitted from source to destination vehicle in a specific period.
- Average end-to-end (E2E) latency: It shows the time required to send a packet from the source to target vehicle's over communication media.
- Average energy consumption: The amount of energy spent over all transmitting and receiving vehicles in the vehicular network.

### 5.2 Simulation results

In this part, we introduce and explain the performance results achieved from the simulation.

#### *5.2.1 Traffic characteristics and mobility models*

The objective of experiment 1 is to evaluate the impact of different nodes and throughput by considering relative speed of vehicles based on real data traces.

**Table 1** Simulation specification

| Inter State 5 highway California Environment | |
|---|---|
| Parameter | Value |
| Inter State 5 length L | 10 km |
| Number of lane | 4 |
| Junctions | 18 |
| Mobility traces duration | 400 s |
| Maximum number of vehicles | 1000 |
| Traffic status | Low to high density |

**Table 2** Network simulation parameters

| Parameter | Value |
|---|---|
| Road length | 1 km × 5 km |
| Mobility model | Highway |
| Connection type | UDP |
| Transmission range | 500 m |
| MAC Protocol | 802.11p |
| Simulation duration | 400 s |
| Vehicle's velocities | Normally distributed |
| Number of runs | 20 |

The real traffic scenario of Inter State 5 highway is considered with high variations in relative speeds as shown in Fig. 4. Based on the real traffic traces, it is determined that more variations in relative speed leads to more packet loss due to high density.

The real traffic scenario of Inter State 5 highway is considered with high variations in relative speeds as shown in Fig. 5. Figure 5 show the resultant cumulative density function (CDF) of vehicles relative speeds for every trace. Most vehicles in contact moves at low relative speed, but this percentage decreases for longer transmission ranges. For example, 90% of vehicles in contact move at relative speeds lower than 30 km/h at range R=200 m. From the results, it can be noticed that the distributions do not significantly change for the transmission range of 150 to 200 m, even though extended coverage ranges may include more vehicles. Consequently, we can determine that, from a certain transmission range on the additional vehicles enclosed will not substantially have such different relative velocities able to change the dissemination.

The Fig. 6 shows the performance of RLLMR with high traffic variation. Based on the real traffic traces, it is determined that more variations in relative speed leads to more packet loss as depicted in Fig. 6. In the scenario of high speed changes, where traffic is high that time there will be more packet loss due to more number of vehicles.

#### 5.2.2 *Effect of different nodes on routing performance*

The objective of experiment 2 is to evaluate the impact of different nodes on routing performance. In this case, we change number of nodes from 20 to 60 with average speed of vehicles is 60 km/h.

The Fig. 8 shows that the reliability of proposed RLLMR scheme is high in comparison to other routing schemes over different vehicles on the road. The high reliability means RLLMR provides parallel routes to destination to discover the best reliable route in the case of highly payload communication, hence the relative speed will not effect the performance, while Q-DSR and R-AODV have single route to find the reliable route to destination, so in the case of high payload communication the reliability of both schemes will be degraded because of frequent link disconnection and data loss. T-AOMDV obtains higher reliability than R-AODV and Q-DSR due to

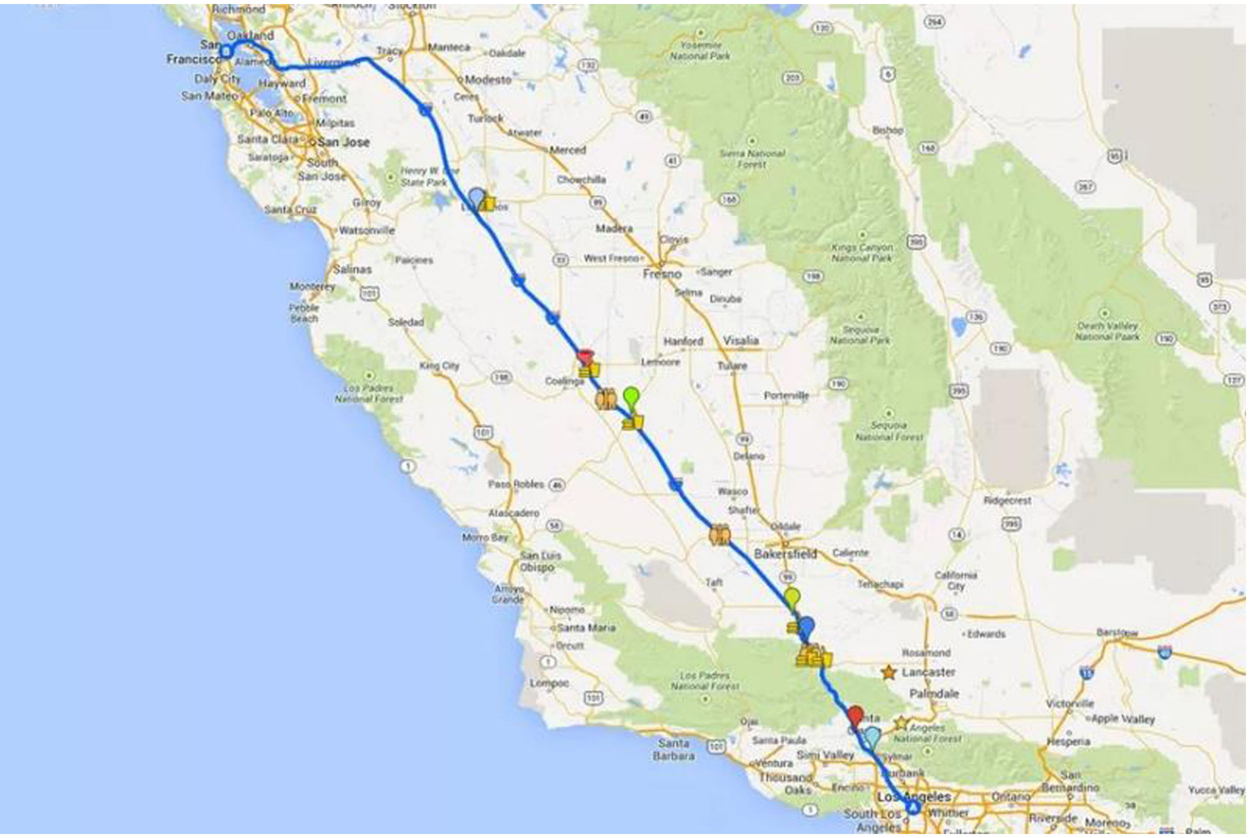


**Fig. 4** Inter State 5 highway in California

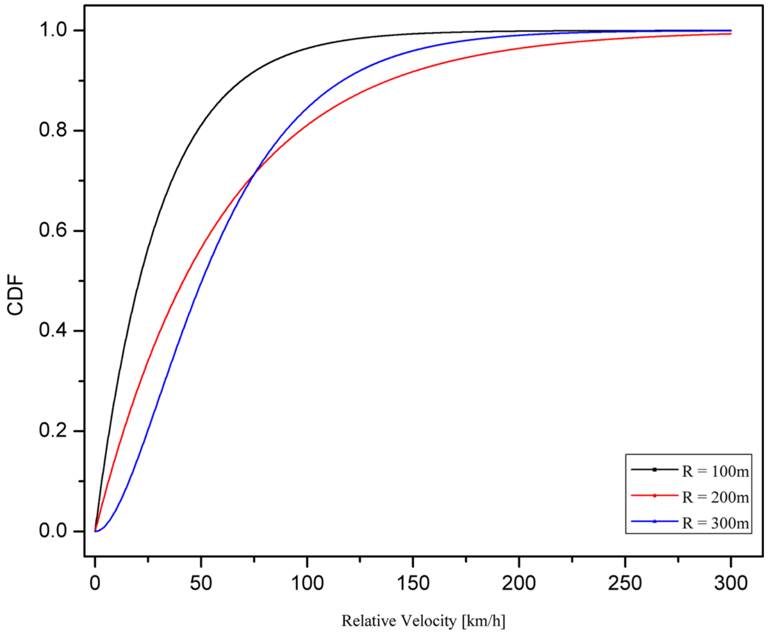


**Fig. 5** Cumulative density function (CDF) of vehicles' relative velocity

the beauty of AOMDV which provides loop free parallel routes to the destination.

Reliable routing scheme implemented with RLLMR achieves relatively high throughput in comparison to T-AOMDV, R-AODV and Q-DSR as depicted in Fig. 9. The maximum throughput means the rate at which data packet transmitted or received at the receiver vehicle effectively. RLLMR provide parallel reliable routes from the sender to receiver, hence in case of heavy traffic or high payload transmission RLLMR achieves best packet rate while T-AOMDV, Q-DSR and R-AODV have lower throughput because R-AODV and Q-DSR selects single

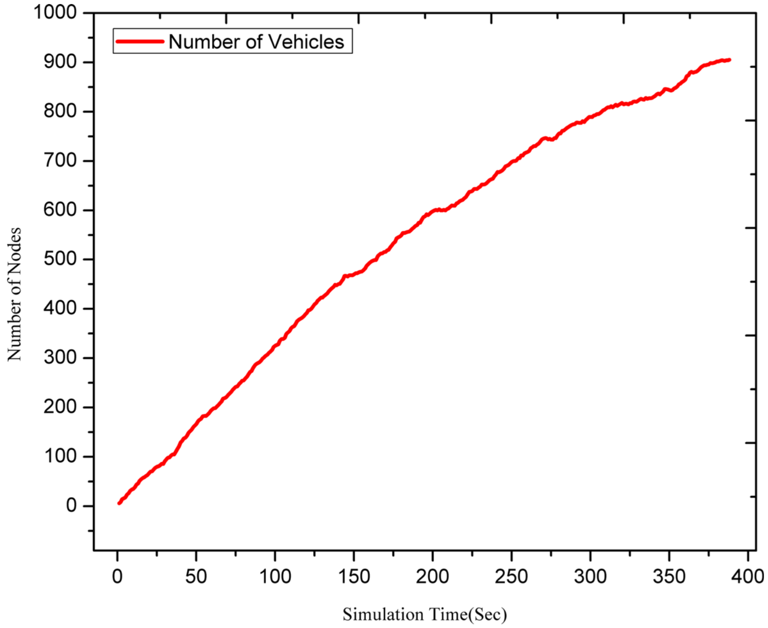


**Fig. 6** RLLMR performance on Inter State 5 highway with high traffic variation (different number of vehicles)

best route to destination. However in case of highly dynamic VANETs or high payload transmission, the average throughput of existing schemes is low because of frequently link disconnection and data loss. In order to deal with frequent link disconnections, Q-DSR and R-AODV recursively find routes, which increase routing control overhead essentially.

In Fig. 10 it is shown that, the average end-to-end latency (E2E) over different vehicles is low as compared to T-AOMDV, R-AODV and Q-DSR. The Q-DSR and R-AODV has higher end-to-end transmission latency because, Q-DSR and R-AODV check all possible routes hop-by-hop or using Dijkstra to find reliable routes to reduce link disconnection. T-AOMDV obtains lower E2E latency than R-AODV and Q-DSR because T-AOMDV keeps trust based multiple loop-free routes at every node and a assigned scheme to discover link disjoint routes.

To reduce energy consumption is an essential objective of the proposed RLLMR scheme. Figure 11 shows, the average energy consumed over different vehicles is less in comparison to T-AOMDV, Q-DSR and R-AODV. It is also shown that the energy consumption growth rate by RLLMR is less than other existing routing schemes. Less energy consumption with different number of vehicle's is, because it discovers multipath reliable routes to transmit data from the source to the destination vehicle which have less chance of link breakages. The energy consumption curve between the ranges of 40 to 50 vehicles is low because of the decline of interference among the vehicles in the vehicular network while the energy consumption increases as number of vehicle's increases due to dynamic environment. Existing schemes have higher energy consumption over speed 60 km/h due to the fact that they spend a substantial part of the network resource just to find the next reliable route. Moreover, as relative speed of vehicles increases, the average E2E latency increases due to the carry and forward strategy.

Figure 12 shows that, that, the ratio of routing overhead for RLLMR, T-AOMDV, R-DSR and R-AODV. The four schemes are influenced by the change of network topology. In RLLMR, the routing scheme uses parallel routing control messages to build the best reliable route, hence it is expected that, there will be higher routing overhead than R- AODV, T-AOMDV and R-DSR. However, the overhead of routing overhead by RLLMR is reasonably close to R-AODV. Higher routing overhead means RLLMR performs parallel route discovery process to discover the best reliable routes that generate more routing control messages.

### 5.2.3 Effect of different relative speeds on routing performance

The objective of experiment 3 is to examine the effect of different speeds on the routing performance. In this case, the speed of vehicles is changed from 40 to 120 km/h with number of nodes 50 to 100.

The Fig. 13 shows that the reliability of proposed RLLMR scheme is improved in comparison to other routing schemes. The improved reliability means RLLMR provides parallel routes to the receiver vehicle, to discover the best reliable route in case of highly payload transmission and if the speed is over 60km/h, it will not influence the reliability due to the beauty of RLLMR scheme which provides loop free parallel routes to destination. While Q-DSR and R-AODV have single route to find the reliable routes to destination, hence in the scenario of high payload communication the reliability of both schemes will be low because of frequent link disconnections and data loss.

As shown in Fig. 14 RLLMR manages higher throughput over different speeds in comparison to T-AOMDV, R-AODV and Q-DSR. The highest throughput means RLLMR provides parallel reliable routes to destination in case of substantial traffic while existing schemes have lower throughput because they selects reliable and QoS based route from source to destination hop-by-hop or using dijkstra, which improve their routing overhead in comparison to RLLMR, however the number of control messages are increased little bit in the route discovery of T-AOMDV, R-AODV and Q-DSR. Therefore in case of highly dynamic VANETs or high payload communication, the performance of existing schemes is low because of frequently link disconnections. In order to deal with frequent link breakage, existing routing schemes recursively discover trusted routes which increase energy consumption considerably.

The RLLMR scheme obtains the lowest average E2E latency over different speeds between all studied routing schemes as shown in Fig. 15. The average E2E latency of RLLMR is the lowest, which is not affected with the change of network topology. It can be seen that, the R-AODV and Q-DSR causes high end-to-end latency than T-AOMDV, when the relative speed of vehicles increases or when the traffic is highly dynamic.

The simulation result in Fig. 16 shows that the energy consumed by RLLMR is less in comparison to T-AOMDV, Q-DSR and R-AODV under different relative velocities. It also shows that the energy consumptions increase rate of RLLMR is less than that of T-AOMDV, R-AODV and Q-DSR. A slight reduction of energy consumption according to different number of vehicle in RLLMR is because RLLMR has the largest residual energy node based path load balancing scheme for the evaluation of the generated routes. The energy consumption curve between the speed ranges of 70 to 100 is low because of the reduction of interference among the vehicles in the vehicular network whereas the energy consumption increases as vehicle's

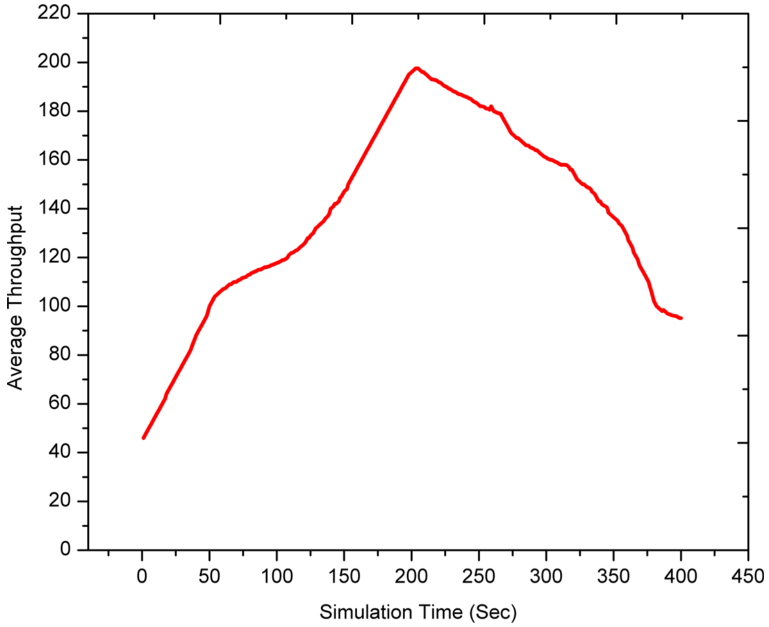


**Fig. 7** RLLMR performance on Inter State 5 highway with high traffic variation (impact of speed variation over Throughput)

speed increases. Existing schemes have higher energy consumption because of the fact that they spend a substantial part of the network resource just to discover the next reliable route.

Figure 17 presents the effect of different speeds over the ratio of routing overhead. The four schemes are affected by the change of network topology. In RLLMR scheme, the routing scheme uses parallel routing messages to build the best reliable multipath route, which can be expected to have higher routing control overhead as compared to T-AOMDV, R-AODV and R-DSR. Although the overhead of routing control overhead is reasonably close to T-AOMDV and R-AODV by RLLMR. The higher routing overhead means the proposed RLLMR

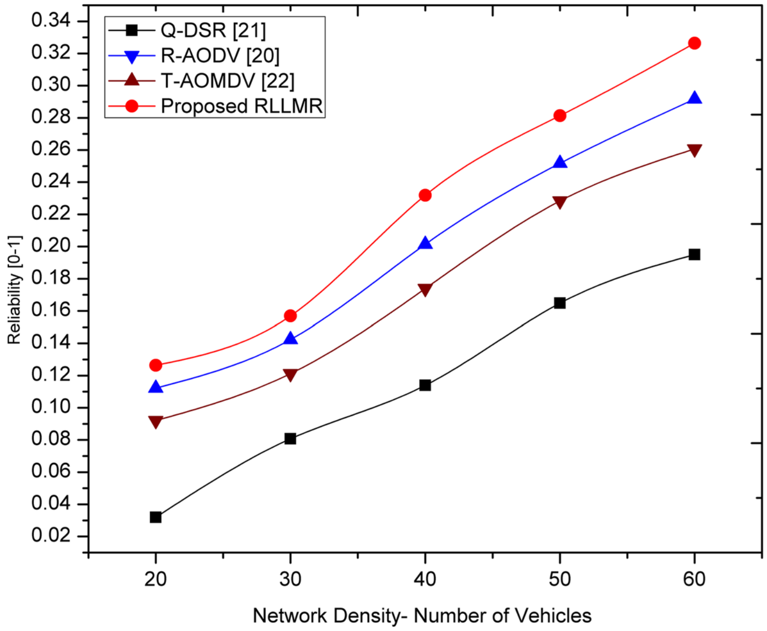


**Fig. 8** Effect of different vehicles over link reliability (average speed 60 km/h, R 1000 m, t 10 s)

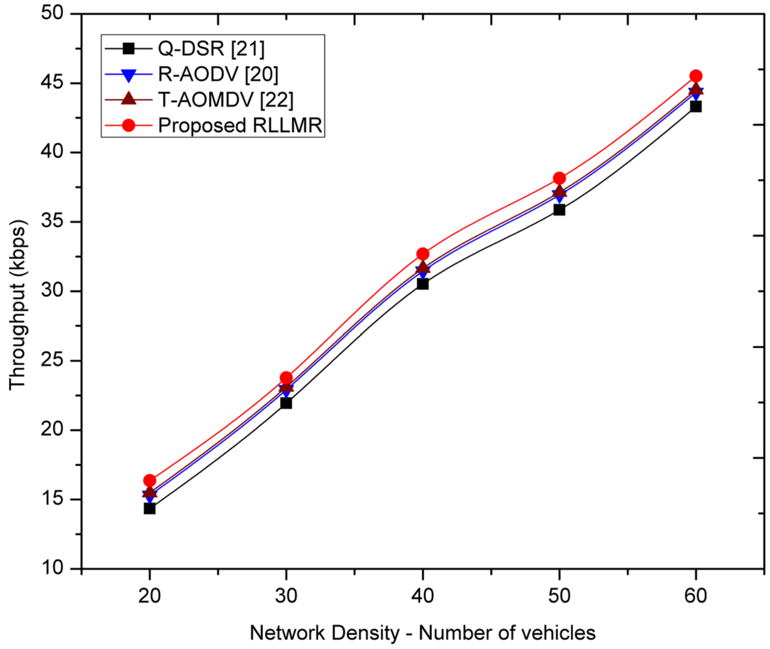


**Fig. 9** Effect of different vehicles over average throughput (Average speed 60 Km/h, R 1000m, t 10s)

scheme enables parallel route discovery process to discover the best reliable route, resulting in more routing overhead.

## 6 Conclusions

This paper presents a reliable low-latency multipath routing (RLLMR) scheme that depends on the vehicles relative speed dissemination on the highway (Figs 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17). We employed the link reliability in VANETs routing to a multipath routing scheme based on reliability and shows the benefits of employing the link reliability to enhance the performance of existing AOMDV scheme in VANETs. The routing reliability is integrated with AOMDV routing

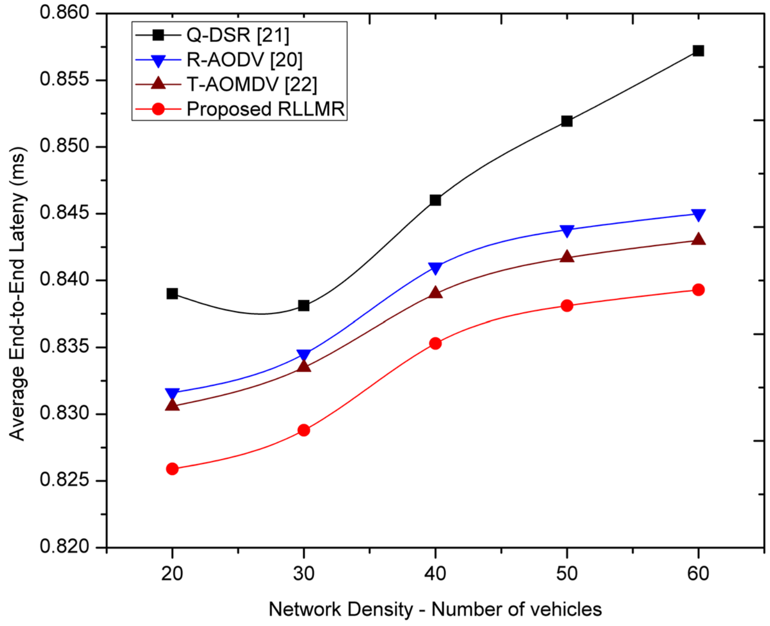


**Fig. 10** Effect of different vehicles over end-to-end latency (Average speed 60 km/h, R 1000 m, t 10 s)

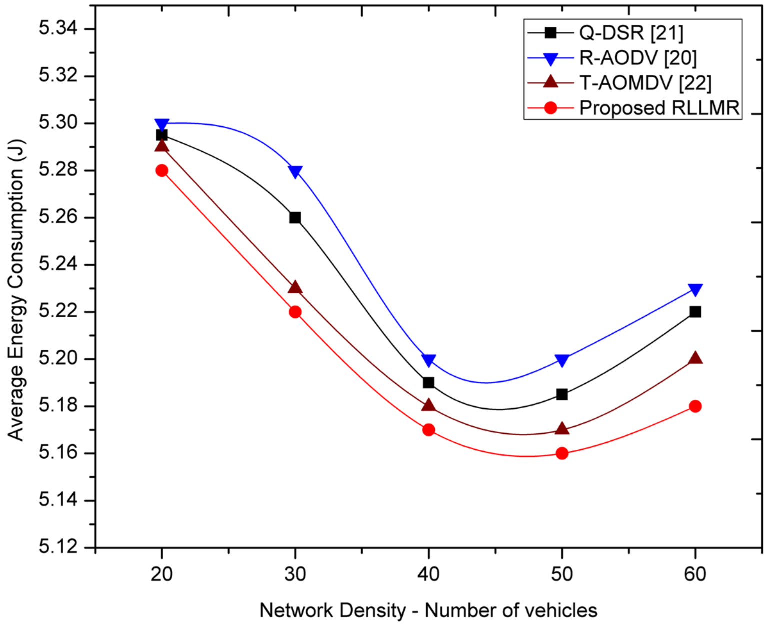


**Fig. 11** Effect of different vehicles over average energy (average speed 60 km/h, R 1000 m, t 10 s)

scheme to discover RLLMR scheme. The performance of RLLMR has been compared with T-AOMDV, R-AODV, and Q-DSR routing schemes using comprehensive simulations under different relative speeds and number of vehicles. The simulation results showed that RLLMR scheme has better average latency, reliability, and throughput compared to existing schemes. Even though RLLMR scheme has relative higher computational cost, it results in significantly less link failures and energy consumption at the cost of marginally increased routing overhead compared to the existing schemes.

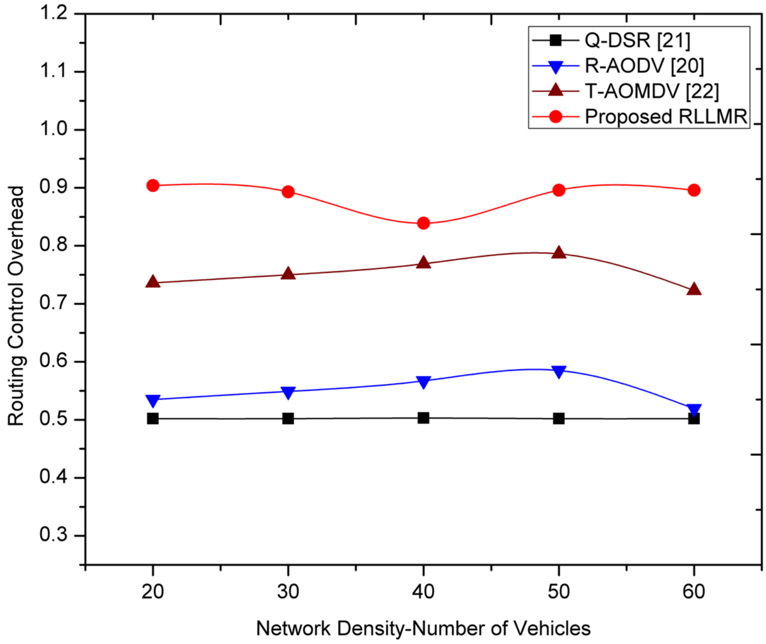


**Fig. 12** Effect of different vehicles over routing overhead (average speed 60 km/h, R 1000 m, t 10 s)

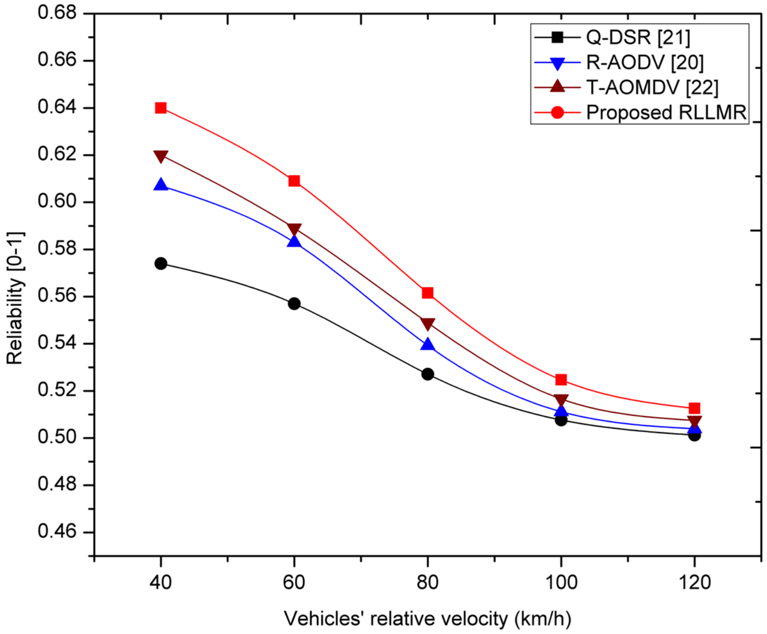


**Fig. 13** Effect of different velocities over link reliability (nodes 50, R 1000 m, sig 5 km/h, t 10 s)

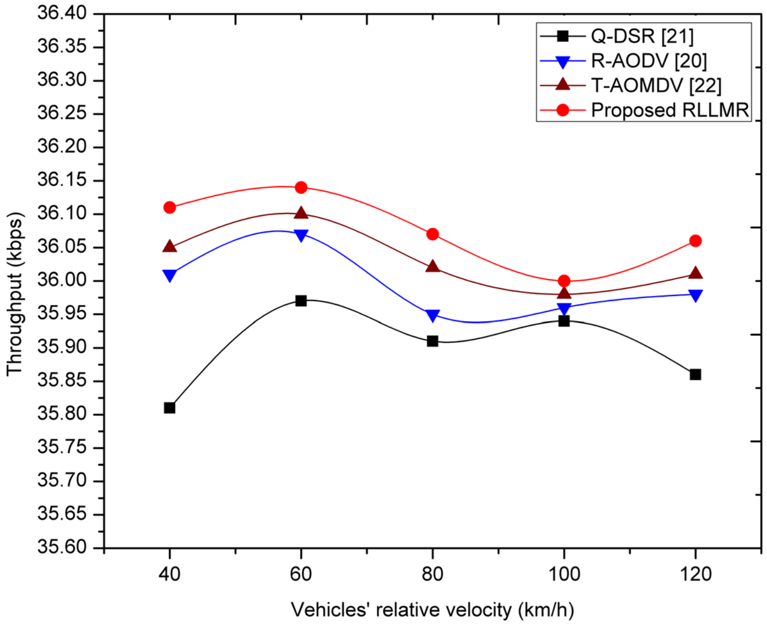


**Fig. 14** Effect of different velocities over throughput (nodes 50, R 1000 m, sig 5 km/h, t 10 s)

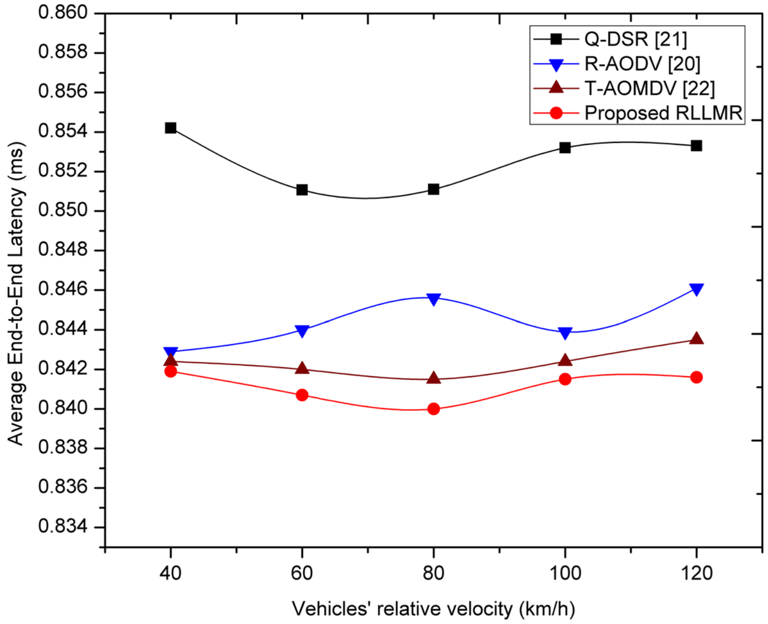


**Fig. 15** Effect of different velocities over end-to-end latency (nodes 50, R 1000 m, sig 5 km/h, t 10 s)

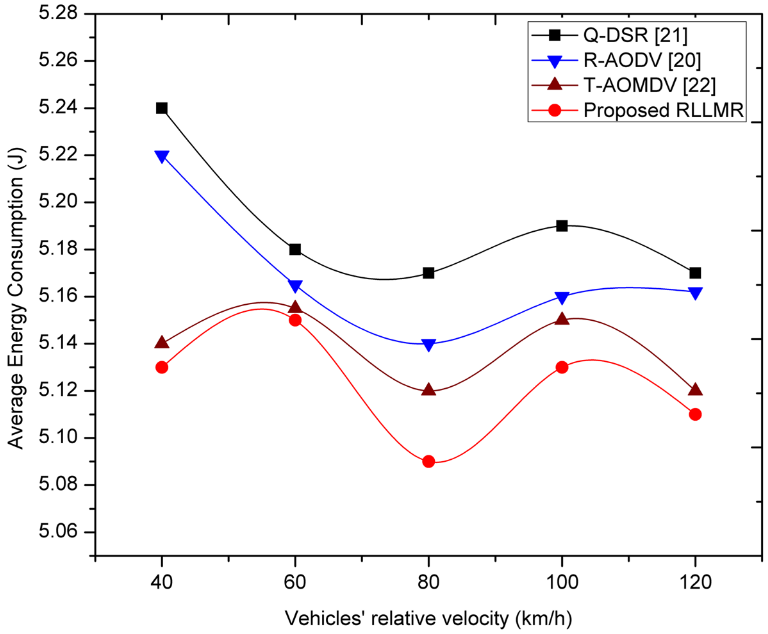


**Fig. 16** Effect of different velocities over average energy consumption (nodes 50, R 1000 m, sig 5 km/h, t 10 s)

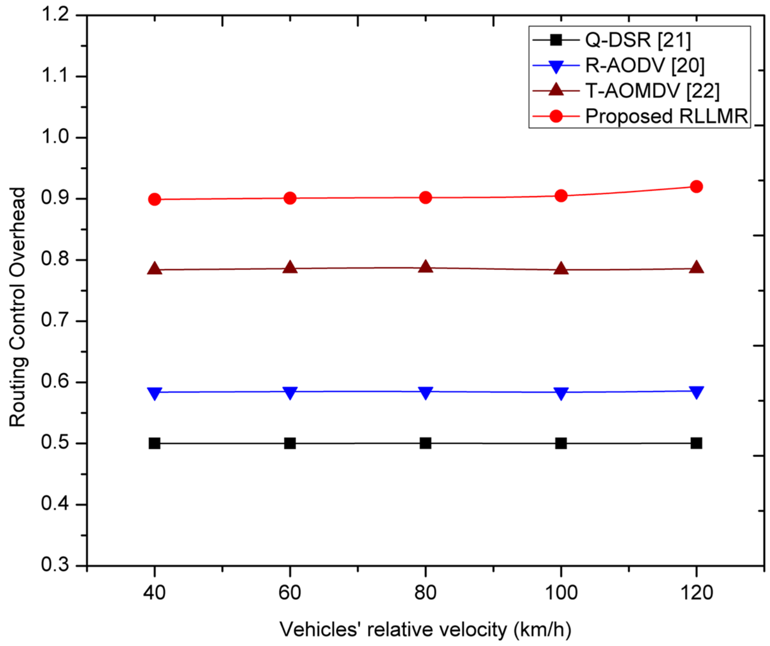


**Fig. 17** Effect of different velocities over routing overhead (nodes 50, R 1000 m, sig 5 km/h, t 10 s)

### Abbreviations

$r_t(l)$: The link reliability value; $a_j(t)$: Acceleration or Deceleration of vehicle $V_j$ at time $t$ [m/s$^2$]; $\alpha_j(t)$: The way of movement of the vehicle $V_t$ at time $t$; $\Delta t$: Time sampling interval among $t_l$ and $t_m$ [s]; $s_r$: The source node; $d_s$: The destination node; $R$: The wireless communication range [m]; $f(T)$: The probability density function for the communication time $T$; *erf*: The Gauss Error Function; $U_1$: Random variable originated among 0 and 1 used to determine the driver's behavior; $L_{v_iv_j}$: The relative transmission range; $\Delta v$: The relative speed among two vehicles [m/s]; $T_p$: The prediction period for the continuous availability of a particular link; $\mu$: The average/mean value of vehicle speed [m/s]; $\sigma^2$: The variance value of vehicle speed [m/s]

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### Availability of data and materials

Not applicable.

### Authors' contributions

All authors have equal contribution. All authors read and approved the final manuscript.

### Competing interests

The authors declare that they have no competing interests.

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