ADAPTIVE ROUTING UPDATE APPROACH FOR VANET USING LOCAL NEIGHBOURHOOD CHANGE INFORMATION

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ABSTRACT

The recent advancements in the field of wireless communication have enabled some wireless networks to become of highly dynamic in nature, like Vehicular Ad hoc Networks (VANETs). This emergence of specialised networks involves high relative node velocity and high active node density. Such complexities demand more efficient and intelligent routing techniques. An efficient routing algorithm finds the best possible route with minimum overhead, updates it on availability of a better one and then maintains route in case of link breakages. Many routing protocols focus on finding and maintaining efficient routes, whereas very less emphasis is put on route update. We have evaluated some existing route updating techniques, which are based on periodic, event triggered or flow based routing information sharing schemes. The evaluation shows that current routing metric sharing schemes do not perform well under varying network scenarios. Subsequently, a model is proposed for adaptive route update of dynamic networks. From theoretical analysis and simulation, the results show that the proposed adaptive route update approach is applicable to a number of routing strategies. The proposed adaptive strategy for routing information sharing is not restricted to any specific routing approach and can enhance the efficiency of routing protocols in varying network conditions.

Keywords: Routing Update and Maintenance, Vehicular Ad-hoc Networks (VANET), Adaptive Decision Making, Mobile Ad-hoc Networks (MANET), Cross Layer Architecture

1.0 INTRODUCTION

Wireless networks prevalence is highly growing. The desire for data connectivity at any place and time has changed the dynamics of wireless data networks. Scalability under increased network size becomes difficult due to high mobility. Combined effect of large network size and mobility causes peculiar problems of disconnected topologies, sudden change in active node densities, broadcast storms and requirement of data dissemination in irregular regions and for longer durations [1]. Common cases of the highly dynamic wireless networks are Vehicular Ad hoc Networks (VANETs), convoys and fleet movements, etc. [2].

Highly dynamic networks pose many challenges to current routing strategies. These complex networks require more flexible, generic and adaptive route update and maintenance strategies [3, 4]. The goal of any routing protocol is to provide best possible path from source to destination. However, the efficiency of any routing protocol can be enhanced by adapting the following:

- Reducing control overhead,
- Updating the new route as quickly as possible, on availability of a better one, and;
- Immediately finding an alternate path in case of route failure.

To achieve these goals, three basic questions need to be answered:-

- What is the metric used in route calculation?
- How is the selected metric disseminated in the network?
- How the available routes are determined using metric information?

Researchers provide many different options for the selection of metrics [5]. There exists a large number of routing and comparative protocols exist using a combination of some of these metrics and others, to target a variety of network-scenarios and other functions [3, 5–15].

Most protocols consider two basic (or their derivatives) approaches for sharing of routing metrics. The approaches used either in isolation or in combination are:-

- Establishment of route prior to their need. Generally, information beacons are shared amongst nodes after fixed intervals. This approach is also called periodic or proactive routing information sharing.
- Information beacons shared among nodes after occurrence of some predefined event. This approach is also called event triggered or reactive routing information sharing.

Generally, the decision to share routing metric (i.e., proactive, reactive or a derivative thereof) is not based on run-time network conditions. Instead, the protocols usually consider off-time configurations for route optimisation. By and large, current routing strategies consider predefined & fixed route update policy [4].

The goal of updating a route on availability of a better one requires updated information of network conditions, either through dedicated control messages, or through behaviour / performance analysis. The selection of routing metric, routing metric sharing approach and routing strategy is based upon different factors, such as type of wireless networks, node distributions, mobility patterns, QoS support and applications [16-18]. Due to the peculiar nature, wireless networks involve multi-facet problems. Any single metric sharing scheme cannot fulfil the requirements of all of the factors. Resultantly, no static scheme can support all scenarios and network conditions [16].

Most of the routing research is based upon network situations, rather than generic mathematical modelling. A VANET node moving on highways can have zero relative velocity with reference to a node moving at same speed and towards same direction. However, a neighbour moving at same speed, can have a relative velocity double of its own velocity, if both nodes are moving in opposite direction. Similarly, nodes at road blockades and road crossings may face dense node conditions as compared to nodes moving on highways. Such complications emphasise the use of adaptive route update and maintenance approaches, rather than conventional routing metric sharing approaches.

Authors in [19] described maintenance of routes as the most critical problem related to VANETs. This survey classified VANET routing protocols based upon flooding, mobility, infrastructure, location and probability models.

Authors in [20] considered vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communication paradigms and environmental constraints as the major design factors. The paper grouped VANET routing protocols into four categories as MANET routing protocols adapted in VANET, position based, delay tolerant and QoS aware routing protocols.

Most routing protocols either target dense networks or sparse ones [21]. Efficient VANET routing protocol must offer low overheads, minimum time cost and adaptability for both dense and sparse networks [21]. The paper categorised VANET routing protocols as carry and forward, multi-hop forwarding and delay bounded routing.

In general, researchers agree on the following conclusions for VANET:-

- No single approach offers efficiency under varying network conditions.
- Different routing protocols can be merged for increased efficiency under varying conditions.
- Most routing protocols do not consider current traffic state while determining their routes.
- Most routing protocols do not support efficient Internet connectivity.
- V2V based routing protocols do not support delay tolerant networks, whereas, delay tolerant routing protocols do not offer optimum route and QoS support.
- Routing protocols based on greedy forwarding do not offer QoS support.

Researchers have observed that topology routing may not perform well under sudden topological changes [9]. On the other hand, geographical routing may not perform well without an accurate and updated location information. Moreover, geographical routing can form routing loops or a packet can travel a longer route due to disconnected network topologies [22]. Though these protocols address scalability and delay in route determination issues, lack of updated and exact location of all the nodes can degrade the routing performance [9]. Network partitioning and mapping of geographical regions on road layout is another major limitation of geographical routing.

For ease of understanding, routing in ad-hoc networks can be grouped into 11 different categories considering the use of different metrics, metric sharing as well as routing approaches [5]. Many researchers proposed adaptation in routing through different approaches [23-25].

The study in [16] shows that both periodic or event triggered route maintenance cannot work efficiently for highly dynamic networks. Considering design limitations of non-sharing of runtime control information, adaptive route update is technically not possible in reactive routing. In contrary to it, periodic approach causes significant overhead for large networks, especially with high node density. The movement from dense urban areas to sparse highways may involve change in node density and large variations in relative node velocity, etc. Hence, single or static metric sharing approach cannot perform efficiently under all VANET topologies.

To overcome the problems of static metric sharing approach, we propose an adaptive route update scheme. The proposed adaptation will augment on to the concept of proactive routing. The finding and update of the routewill be based on the use of logical conditions. This scheme is independent of any baseline routing algorithm, e.g., minimum hop count or shortest distance, etc.

We suggest that instead of updating the route on fixed conditions, each node should observe changes around it before opting for route update. Changing values of different metrics, e.g., throughput, list or count of neighbour nodes, SINR, etc., can provide significant information regarding changes in network topology around a node. By determining such changes, nodes can predict possibility of link breakage with next hop neighbour or link establishment with the 2^{nd} hop neighbour.

The proposed adaptive strategy for route update is based upon run-time network conditions and it is independent of time factor. Hence, it will significantly reduce routing overhead, as compared to proactive routing metrics sharing at fixed intervals. Accordingly, any protocol can be significantly improved through adaptive route update, regardless of its baseline route finding approach.

After the developmeht of the proposed mathematical model for adaptive route optimisation, the simulative analysis of the proposed approach is performed against state of the art routing protocols. There can be other factors as well, which affect adaptive route update strategy, e.g., channel fading, deployment pattern or randomness in traffic pattern, etc. However, the detailed evaluation of all of the factors is beyond the scope of this paper.

The rest of this paper is organised as follows. Section II explains the model for adaptive route update. Section III deals with adaptive route update strategy, followed by the evaluation of the proposed strategy. Section IV concludes the paper.

2.0 MODEL FOR ADAPTIVE ROUTE UPDATE

Before the establishment of an adaptive route update strategy, the behaviour of VANET nodes under changing conditions needs to be understood. For this purpose, we developed a theoretical model for VANET nodes under changing network topologies. Efforts were put in to make a generic model, applicable to most VANET scenarios.

2.1. Evaluation Of Route Update Strategy Requirement

The availability of updated information of network topology or routing control information is the pre-requisite for adaptive route update. By design, such information is not available under reactive routing protocols. To observe the theoretical behaviour of a proactive routing approach, we evaluated control packets of OLSRv2 and a state of the art proactive routing protocol. Although the use of topology based protocols for dynamic networks is argued in literature, behaviour of all proactive metric sharing protocols remains the same under dense conditions. OLSRv2 uses multi-point relay (MPR), as a cluster head concept [26]. From the OLSRv2 header, each node within one hop region adds 128 bits in its MPR discovery packet, for each neighbouring node.

Table 1 defines the theoretical throughput of OLSRv2 routing protocol while determining MPR under different node densities. IEEE 802.11p MAC was used for the subsequent simulations in NS-2. Link throughput was computed by creating ideal conditions between two directly communicating nodes. For that, the distance between two directly communicating nodes was increased in the absence of any interfering node. From the initial distance of 1 meter, inter-node distance was increased to 1000 meters. To provide ideal conditions, data and all other overhead, including MAC contention and channel access delays were ignored. After calculating the link throughput at different distances, OLSRv2 control overhead per node per second was analytically computed. After computing link throughput, last three columns are computed mathematically. From the available link throughput, some has been utilised for routing control information (overhead per second). The remaining is available for data traffic.

Table 1 shows that channel resources may not be sufficient even for routine control traffic under high node density. By increasing the distance, the number of next hop neighbours also increases. This leads to a decrease in available throughput, in addition to an increase in contention. If all realistic overhead and delays are incorporated, theoretically, the throughput is expected to decrease significantly. In such circumstances, simple TCP sessions may be timed out adding to the control traffic. Other proactive routing protocols are expected to generate similar overheads under dense scenarios.

This simple evaluation confirms that current routing approaches with predefined and fixed route update schemes cannot perform efficiently, even for the simple high node density scenarios. Such network scenarios are common for dynamic networks, such as sports stadium, parking areas, traffic jams, etc. For these routine situations, the node density may even increase to thousands of nodes. These circumstances can cause absolute routing failure for many successful routing protocols, emphasising the need for adaptive route update with minimum overhead.

Table 1. Throughput Model of OLSRV2

Hop Range	**Link Throughput**	**Lanes**	**Nodes**	**Overhead / Second**	**Bandwidth Available for Data**
300	27 Mbps	3	180	1.56	25.44
300	27 Mbps	4	240	2.77	24.23
600	14 Mbps	3	360	6.23	7.77
600	14 Mbps	4	480	11.07	2.93
1000	6 Mbps	2	400	7.69	-1.68
1000	6 Mbps	3	600	17.29	-11.29
1000	6 Mbps	4	800	30.73	-24.73

2.2. Considerations for Adaptive Route Update Strategy

A VANET node may face repeated topological changes and approximately static behaviour during a single data session. In contrary to the behaviour of periodic and event based route update approach, we need to find the theoretical conditions for adaptive route update under varying network conditions. Each node is required to update its onward route towards destination node on two independent conditions as follows:

- When link with next hop neighbour is about to break, or;
- When a 2^{nd} hop neighbour enters in direct communication range.

With reference to changes around host node, we studied the probability of the link breakage with the next hop neighbour and link establishment with the 2^{nd} hop neighbour. The probability was studied considering the changes in neighbourhood of any host node.

To consider the varying network conditions in the model, the movement of VANET nodes was defined from a dense area to the sparse one and vice versa. Initially, the evaluation showed that any efficient VANET routing protocol should have the same behaviour as of the mathematical model. This led to the conclusion that regardless of time duration, the update of the route should only be performed considering its link status change probability, based on changes in neighbourhood of any host node. Such localised considerations by each node can improve the overall routing performance.

The involvement of minimum number of nodes is a major advantage of localised route maintenance [27]. Accordingly, in the proposed approach, all nodes are required to perform local route update in an adaptive manner, to achieve routing efficiency.

Figure 1 shows a VANET topology for two hop neighbours around a host node ***H***. Node ***H*** exists on a road segment ***XY***. The road strip is divided into multiple lanes where speed of all nodes is assumed to be the same within each lane. Lanes are numbered as per their node speed, with lane 1 is the slowest and lane 5 is the fastest lane.

There can be multiple lanes on the road, with a number of nodes moving away or towards any host node. From a VANET perspective, nodes around the host node can either be static or moving with some relative angle to each other. On a straight road, each next or 2nd hop neighbour can be static, or independently moving either parallel to ***H*** or in its opposite direction. Hence, only the next or 2nd hop neighbour will directly affect the need for adaptive route update, with all other nodes having only a secondary role. For simplicity, considering a straight road, one can assume relative angle for nodes moving in same or opposite direction as 0^0 or 180^0, respectively. Similarly, the relative angle for nodes at road crossing can be considered as 0^0, 90^0, 180^0 or 270^0. This assumption may seem restrictive. However considering the dynamics of VANET and roads layout, it can be justified. For a thorough comprehensive analysis, fine grain precision of relative angles can be considered in future.

Based on the above, in Figure 1, N(a), N(b), N(c), N(d), N(e) & N(f) denote the first hop neighbours, whereas N(g), N(h), N(j), N(k), N(l) & N(m) denote the 2nd hop neighbours of ***H***. D(1) is the destination node for data traffic, towards movement direction of ***H***. Whereas, D(2) is the destination node for data traffic against the movement direction of ***H***.

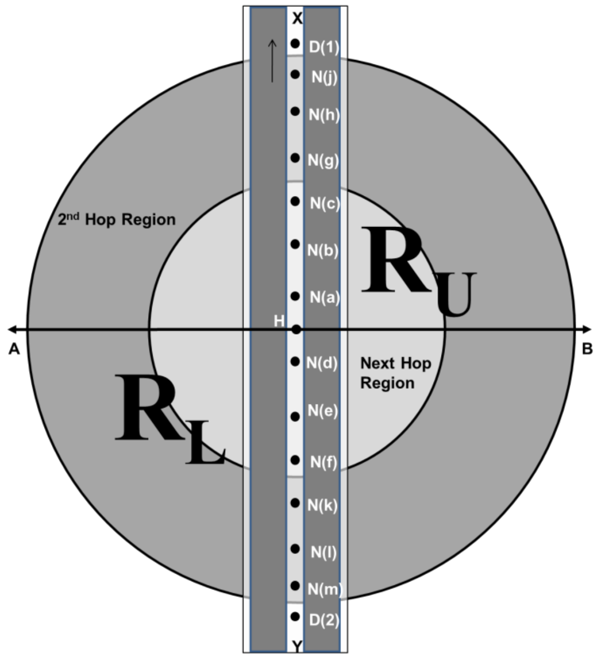


Fig 1. Communication Ranges for the Test Link Topology

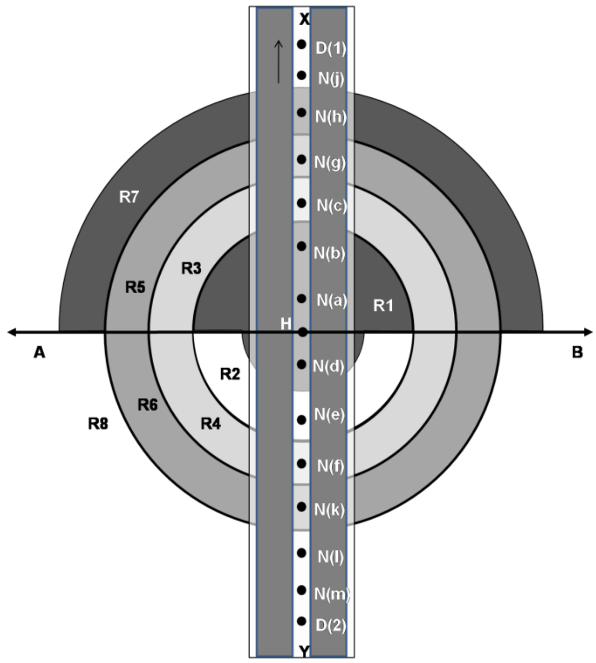


Fig 2. Logical Communication Ranges for the Test Link Topology

We need to analyse the local behaviour of the neighbours of the reference node. The direct communication between any two nodes depends on their link stability. To develop end-to-end communication, first, we need to define behaviour of two neighbours with respect to link stability. From a theoretical perspective, the link stability between two mobile nodes, i.e. the possibility of any neighbour node to affect the host node, depends upon two factors:

- The distance ($\Delta \boldsymbol{d}$) covered by next or 2nd hop neighbour, relative to the host node.
- The direction ($\Delta \boldsymbol{\theta}$) in which next or 2nd hop neighbour is moving, relative to the host node.

2.2.1. Effect of the Covered Distance ($\Delta \boldsymbol{d}$)

The link stability between any two nodes is the function of relative velocity $\Delta \boldsymbol{v}$ or maximum distance $\Delta \boldsymbol{d}$, covered by two neighbour nodes. Hence, only nodes capable of covering relative distance $\Delta \boldsymbol{d}$ during time ***t*** from the next hop region boundary, will be able to either leave the next hop region or enter in it (see Fig. 1). However, relative angle $\boldsymbol{\theta_N}$ between two neighbour nodes will affect $\Delta \boldsymbol{d}$, for nodes entering or leaving the next hop region. So, $\Delta \boldsymbol{d}$ for nodes moving in same or opposite direction on a straight road can be computed as:

$$\Delta \mathrm{d} = v_N(\cos\theta_N - v_h)\mathrm{t} \tag{1}$$

Where, $\boldsymbol{v_N}$ and $\boldsymbol{v_h}$ is the velocity of next hop neighbour and host node, respectively.

During time ***t***, the nodes present within distance $\boldsymbol{\Delta d}$ from the edges of communication range of ***H*** will be able to go out of its range. Accordingly, nodes closer to ***H*** may not go out of communication range. Similarly for the 2nd hop neighbours, only the nodes existing within $\boldsymbol{\Delta d}$ distance from the maximum communication range of ***H*** will have the possibility to enter within its next hop range. However, the nodes outside the area will not be able to enter one hop region in time ***t***.

In addition to $\Delta \boldsymbol{v}$, the distance $\Delta \boldsymbol{d}$ depends on time ***t***. By increasing the value of ***t***, the area $\Delta \boldsymbol{d}$ will expand and vice versa. Due to expansion of $\Delta \boldsymbol{d}$, the probability of next hop neighbour going out of range and 2nd hop neighbour coming in range of ***H***, will also increase.

In Fig. 1, the area for next and 2nd hop from which topology change may occur can be computed for the communication radius of ***r*** meters, as follows,

$$\text{Next hop area} = \pi r^2 - \pi(r - \Delta d)^2 \tag{2}$$

$$2^{nd}\text{ hop area} = \pi(r + \Delta d)^2 - \pi r^2 \tag{3}$$

$$\text{Total area of circular region (next + }2^{nd}\text{)} = 4\pi r\Delta d \tag{4}$$

$$\text{Total area road segment (next + }2^{nd}\text{)} = 4x\Delta d \tag{5}$$

Where, ***x*** is the width of the road, and the curved edges of road segment ***XY*** can be assumed as straight line according to the ratio of road width and length.

2.2.2. Effect of the Movement Direction ($\Delta \boldsymbol{\theta}$)

We considered uniformly distributed nodes moving according to Gaussian pattern on a road with two way lanes. For simple calculations, one can consider a time ***t***, during which any node can cover a maximum distance of less than half of its maximum communication range.

To consider all possibilities from the $\Delta \boldsymbol{\theta}$ perspective, we can divide next hop region around ***H*** into two equal halves (line AB in Fig. 1), according to the movement direction of ***H***.

Assuming the arrow as movement direction of ***H***, one can consider the movement relation between ***H*** and its two hop neighbours. In time ***t***, more number of nodes will be able to go out of communication region, which are present in the half opposite to the movement direction of ***H***, i.e. R_L. Similarly, more number of nodes will be able to enter the next hop region, which is present inside the half, towards the movement direction, i.e. R_U. Thus, the effect of two hop neighbours can be evaluated as:-

- A next hop neighbour present in R_U and moving with $\Delta \boldsymbol{\theta} = 0^0$ and $\Delta \boldsymbol{v} > 0$, will have the possibility of going out of range from ***H***. On the contrary, neighbour nodes with $\Delta \boldsymbol{v} \leq 0$ will not go out of communication range in time ***t***.
- A next hop neighbour present in R_U and moving with $\Delta \boldsymbol{\theta} = 180^0$ will maintain its link with ***H***.
- A next hop neighbour present in R_L and moving with $\Delta \boldsymbol{\theta} = 0^0$ and $\Delta \boldsymbol{v} < 0$, will have the possibility of going out of range from ***H***. On the contrary, neighbour nodes with $\Delta \boldsymbol{v} \geq 0$ will maintain their communication link during unit time ***t***.
- A next hop neighbour present in R_L and moving with $\Delta \boldsymbol{\theta} = 180^0$, will have $2\Delta \boldsymbol{d}$ dispersion during ***t***. Hence, it will have higher probability of moving out of communication range of ***H***.

2.3. Model for Adaptive Route Update Strategy

Considering the effect of $\Delta\boldsymbol{\theta}$ and $\Delta\boldsymbol{d}$, Fig. 2 defines the logically modified communication ranges of Fig. 1, with respect to ***H***. First four regions R1, R2, R3 & R4 show next hop coverage zone of ***H***. The regions beyond R3 & R4, i.e. R5, R6, R7 & R8, show coverage area for 2nd hop neighbours and beyond. The rest of the states remains the same.

To cater all test cases, the next or 2nd hop neighbour is considered in each region respectively. Due to limited covered distance in ***t*** duration, nodes present in 1st region, i.e. R1, will not be able to leave the next hop region. For the nodes present in 2nd region, i.e. R2, nodes moving in opposite direction of ***H***, will go out of range from ***H*** in ***t*** duration. Nodes within 3rd and 4th region, i.e. R3 & R4 will also have the possibility of link breakage as follows:

- Neighbour nodes present in R_U (R3), moving in same direction, but faster than the host node will face link breakage.
- Similarly, neighbour nodes present in R_L (R4), moving in same direction, slower than the host node, or moving in opposite direction, will go out of range from ***H*** in time ***t.***

Similar explanation exists for 2nd hop neighbour nodes in 5th and 6th region i.e. R5 & R6. These nodes will have the chance to come within next hop region. Like R2, nodes in the 7th region, i.e. R7, will be able to make direct link with ***H*** in time ***t.*** However, nodes present in R8 will not affect the next hop region.

To make a model, we can consider a sample case with all possible movement relations between host and two hop neighbour nodes. Thus, considering our assumption of maximum distance covered by any node in time ***t,*** we can draw the following conclusions for neighbour nodes with respect to the host node, present in different regions:

- From R1, no neighbour node will go out of range.
- From R2, only those neighbour nodes can face link breakages which are moving in opposite direction to the host node.
- From R3, neighbour nodes moving in same direction but faster than the host node can face link breakage.
- From R4, neighbour nodes moving in opposite direction to the host node, or moving in same direction but slower than it, can leave the next hop range.
- From R5, Similar to the behaviour of R4, neighbour nodes moving in opposite direction to the host node, or moving in same direction but slower than it, can enter the next hop range.
- From R6, Similar to the behaviour of R3, neighbour nodes moving in same direction but faster than the host node can establish a link with it.
- From R7, Similar to the behaviour of R2, only those neighbour nodes can come in range, which are moving in opposite direction to the host node.
- From R8, no neighbour node will enter the next hop range.

For an updated route calculation, the route update requirement according to expected status of next and 2nd hop neighbours is summarised in Table 2. Only regions R2 − R7 are of our interest for the adaptive route update, whereas, regions R1 and R8 do not require any route update within time ***t.***

Table 2. Route Update Requirement for Different Regions of Test Node Topology

Region	**Neighbouring Node**	**Destination Node**	**Relation with *H***	**Expected status with *H*, in *t***	**Need for route update**
R1	N(a) or N(d)	D(1) or D(2)	Next hop neighbour	Will stay in range	No
R2	N(e)	D(2)		Can go out of range	Yes
R3	N(c)	D(1)			
R4	N(f)	D(2)			
R5	N(g)	D(1)	2nd hop neighbour		
R6	N(k)	D(2)			
R7	N(h)	D(1)			
R8	N(j) or N(l)	D(1) or D(2)		Will stay out of range	No

2.4. The Probability Equation

The combined effect of $\Delta \boldsymbol{d}$ and $\Delta \boldsymbol{\theta}$ can change the behaviour of any node in a complex manner. We can consider different practical scenarios against assumptions of multiple two way lanes, nodes of uniform density and Gaussian mobility pattern. For the computation of link status of two neighbouring nodes, the determination of movement direction of neighbouring node and its current region with respect to host node is important.

The next most important factor for route update calculation is the probability of existence of next hop neighbour in R1 - R4 regions or second hop neighbour in in R5 – R8 regions. As both events are independent, their occurrence should be considered independently.

For a generic scenario of multiple lanes, a node can either move in a lane or remain stationary at road side. When moving in lane, its direction of motion can either be parallel or opposite to the reference host node. VANET architectures recommend use of all vehicles to act as communicating node, whether moving on the road, halted at signals or parked at any location. It is quite difficult to determine the exact probability of current status of any vehicle, i.e. moving, halted or parked, considering for different cities, vehicle types and traffic conditions. Hence, probability of status of host and neighbor node can be determined using weight (W_s) assignment.

The determination of neighbouring node region is another tricky task. The probability of existance of neighbouring node in some specific region i.e. $P(N_R)$, greatly depends on the routing approach. The probability of existence of any neighbour in a certain region will vary according to the considered routing metric. For example, the probability of a next hop node being closer to the edge of the next hop neighbourhood will be more, if the routing metric is minimum hop count, etc. For a generic approach, the probabilities of all of the regions were considered using probability density function of different routing approaches as follows:

- Minimum Hop Count approach: Each node selects farthest node towards the destination as a next hop neighbour to minimize the number of end-to-end hops.
- Minimum hop count with aggressive approach: It is different from the previous one as it selects the next hop neighbour as per the localized state instead of the end-to-end state.
- The Maximum Stable Link approach: It selects the next hop neighbour to have a stable link for maximum duration, considering local conditions.
- Maximal Load Distribution: This is the classical form of routing approach without inter-node distance dependency, by using metrics such as load balance or minimum cost, etc. Hence, all nodes have an equal probability to be selected as next hop neighbour when compared against inter-node distances.
- Optimised Balance Load routing approach: It is the combination of minimum hop approach with some other routing metric such as load balancing or minimum cost.
- Normalised Routing approach: It is a modified form of the Optimised Balanced Load, where the emphasis is given to load balancing and link stability, while keeping minimum hop count as a secondary metric.
- Normalised load with overlapping curve from the distance of peak value.
- Optimised balanced load with overlapping curve from the distance of peak value.

The main goal of this research is to find the conditions for route update, rather than debating on the techniques of finding a route. By definition, route update is done in the lifetime of previous route. Hence, link breakage with next hop neighbour and link establishment with 2nd hop neighbour are of prime importance.

For the detailed analysis of the behaviour of next and 2nd hop neighbour with respect to the host node, we need to evaluate each marked region independently. To start with, Table 3 defines the behaviour of two directly communicating neighbour nodes present in upper half of R3. The table presents an analysis with respect to the total number of lanes, the relative positions of both neighbours with reference to the lane and the relative angle and velocity between the neighbours. As each subregion is computed on the basis of minimum $\Delta \boldsymbol{d}$ displacement during $\boldsymbol{t}$, each node in the region will have the same affect on change in link status. Please note that as explained in section 2.2.1, the regions are not strict demarkations. The size of the region depends on $\Delta \boldsymbol{d}$ which in turn depends on $\Delta \boldsymbol{v}$ and $\boldsymbol{t}$. Accordingly, we can say that it is not important that at what location within a subregion a node lies. Rather, the important consideration is presence of a next or 2nd hop neighbour within a specific sub region, $\Delta \boldsymbol{\theta}$ and $\Delta \boldsymbol{v}$. Based on these factors, the probability that a link will break is computed.

Within time $\boldsymbol{t}$, nodes in R2 moving in opposite direction of $\boldsymbol{H}$ will remain within communication range of $\boldsymbol{H}$ with a probability of 1. However nodes with a relative movement angle of $\Delta \boldsymbol{\theta} = 0^0$, and $\Delta \boldsymbol{v} > 0$, will be of interest as they might go out of communication range resulting in link breakage. All other nodes will continue their current state during ***t***.

Observing the probability of link breakage and its relation with number of lanes, one can formulate a mathematical expression using curve fitting methodology, for the probability of link breakage of ***H*** with the neighbour node present in R3 (ref Table 3). This probability is denoted by P_{R3} and can be computed as:-

$$P_{R3} = W_S * \mathrm{P}(N_{R3}) * \left(\frac{\sum_{y=0}^{l}(\mathrm{l}-\mathrm{y})}{\mathrm{l}(\mathrm{l}+1)+(\mathrm{l}+1)^2}\right) \tag{6}$$

where $P(N_{R3})$ is the existence probability of any neighbour in R3 with weight $\boldsymbol{W_s}$, and ***l*** is the number of lanes.

Equation 2 is an analytical representation of Table 3, formulated using a curve fitting approach. Observing the possibility of link breakage with next hop neighbours or link establishment with 2[nd] hop neighbours, and its relation with number of lanes ***l***, we can draw tables for other regions, similar to Table 3. Accordingly, we can formulate mathematical expressions of probability P_R, using curve fitting methodology, for all regions, as:

For the next hop neighbour nodes going out of range

$$P_{R1} = Nil \tag{7}$$

$$P_{R2} = W_S * \mathrm{P}(N_{R2}) * \left(\frac{l^2}{\mathrm{l}(\mathrm{l}+1)+(\mathrm{l}+1)^2}\right) \tag{8}$$

$$P_{R3} = W_S * P(N_{R3}) * \left(\frac{\sum_{y=0}^{l}(l-y)}{l(l+1)+(l+1)^2}\right) \tag{9}$$

$$P_{R4} = W_S * \mathrm{P}(N_{R4}) * \left(\frac{\sum_{z=0}^{l-1}(\mathrm{l}+\mathrm{z})}{\mathrm{l}(\mathrm{l}+1)+(\mathrm{l}+1)^2}\right) \tag{10}$$

Table 3. Link Breakage Probabilities for Region 3

Lane Count	**Host Node Lane**	**Lane of Next Hop Neighbour Node**	***Δθ* (degrees)**	***Δv***	**Link Breakage Possibility**	**Link Breakage Probability**
1	0 (static)	0 (static)		0	No	1/3
		1	0	+ve	Yes	
		1	180	-ve	No	
	1	0 (static)	0	-ve	No	0
		1	0	0	No	
		1	180	-ve	No	
2	0 (static)	0 (static)		0	No	2/5
		1	0	+ve	Yes	
		1	180	-ve	No	
		2	0	+ve	Yes	
		2	180	-ve	No	
	1	0 (static)		-ve	No	1/5
		1	0	0	No	
		1	180	-ve	No	
		2	0	+ve	Yes	
		2	180	-ve	No	
	2	0 (static)		-ve	No	0
		1	0	-ve	No	
		1	180	-ve	No	
		2	0	0	No	
		2	180	-ve	No	

3	0 (static)	0 (static)		0	No	2/7
		1	0	-ve	No	
		1	180	-ve	No	
		2	0	+ve	Yes	
		2	180	-ve	No	
		3	0	+ve	Yes	
		3	180	-ve	No	
	1	0 (static)		+ve	Yes	3/7
		1	0	0	No	
		1	180	-ve	No	
		2	0	+ve	Yes	
		2	180	-ve	No	
		3	0	+ve	Yes	
		3	180	-ve	No	
	2	0 (static)		-ve	No	1/7
		1	0	-ve	No	
		1	180	-ve	No	
		2	0	0	No	
		2	180	-ve	No	
		3	0	+ve	Yes	
		3	180	-ve	No	
	3	0 (static)		-ve	No	0
		1	0	-ve	No	
		1	180	-ve	No	
		2	0	-ve	No	
		2	180	-ve	No	
		3	0	0	No	
		3	180	-ve	No	

For the 2nd hop neighbour nodes coming in range, therefore a possibility of forming a new and better link:

$$P_{R5} = W_S * \mathrm{P}(N_{R5}) * \left(\frac{\sum_{z=0}^{l-1}(\mathrm{l+z})}{\mathrm{l(l+1)+(l+1)^2}}\right) \tag{11}$$

$$P_{R6} = W_S * \mathrm{P}(N_{R6}) * \left(\frac{\sum_{y=0}^{l}(\mathrm{l-y})}{\mathrm{l(l+1)+(l+1)^2}}\right) \tag{12}$$

$$P_{R7} = W_S * \mathrm{P}(N_{R7}) * \left(\frac{l^2}{\mathrm{l(l+1)+(l+1)^2}}\right) \tag{13}$$

$$P_{R8} = Nil \tag{14}$$

where, $\mathrm{P}(N_R)$ is the existence probability of any neighbour in the specific region with weight $\boldsymbol{W_s}$, and $\boldsymbol{l}$ is the number of lanes.

Please note that the computation of the weights and existence probabilities are specific to networks and conditions, which are out of scope of this paper. To utilize this generic adaptive framework, $\boldsymbol{W_s}$ and $\boldsymbol{P_{Ri}}$ (where I = 1,2,…8) can be calculated based on the specific network, node distribution, road layout and mobility model.

Considering all regions around host node, i.e., R1 - R8, the probability of link breakage with next hop neighbour P(N1(out)), or a 2nd hop node coming in direct communication range P(N2(in)), can be formulated: As these two are independent events, the probability, denoted by P(N1(out) or N2(in)), can be computed as:

$$P\big(N1(out) or N2(in)\big) = P\big(N1(out)\big) + P\big(N2(in)\big) - \Big(P\big(N1(out)\big) \& P\big(N2(in)\big)\Big) \qquad (15)$$

Based on Eq. 7 – 14, the above expression results in:

$$P\big(N1(out) or N2(in)\big) = W_s\left(\frac{1}{2(\mathrm{l}(\mathrm{l}+1)+(\mathrm{l}+1)^2)}\right) * \Bigg(\Big(\big(\mathrm{P}(N_{R3}) + \mathrm{P}(N_{R4}) + \mathrm{P}(N_{R5}) + \mathrm{P}(N_{R6})\big) * \Big(\big(\textstyle\sum_{y=0}^{l}(\mathrm{l} - \mathrm{y}) +$$

$$z{=}0l{-}1(\mathrm{l}{+}\mathrm{z}){+}\mathrm{P}NR2{+}\mathrm{P}NR7{*}\mathrm{l}2{-}12\mathrm{ll}{+}1{+}\mathrm{l}{+}12{*}\mathrm{P}NR3{+}\mathrm{P}NR4{*}y{=}0l(\mathrm{l}{-}\mathrm{y}){+}z{=}0l{-}1(\mathrm{l}{+}\mathrm{z}){+}\mathrm{P}NR2{*}\mathrm{l}2{*}\mathrm{P}NR5{+}\mathrm{P}$$
$$NR6{*}y{=}0l(\mathrm{l}{-}\mathrm{y}){+}z{=}0l{-}1(\mathrm{l}{+}\mathrm{z}){+}\mathrm{P}NR7{*}\mathrm{l}2 \qquad (16)$$

where, $P(N_{R3})$, $P(N_{R4})$, $P(N_{R5})$, $P(N_{R6})$ and $P(N_{R7})$ are the probabilities of any node in different regions with weight $\boldsymbol{W_s}$ respectively, and $\boldsymbol{l}$ is the number of lanes.

In addition to the probability curve for next hop neighbour node, the computation of probability of 2nd hop neighbour node can also be quite tricky. As for the static routing approach, same computation is performed at each node. This concept enables replication of the selected pdf curves for computation of any hop neighbour. For simplicity purposes, we computed 2nd hop neighbour probability as the replication curve of next hop neighbour for maximum distance as well as distance from peak value

Fig. 3 shows the fraction of change that is required for route update under different routing approaches computed using Equation 16. As explained earlier, the next and 2nd hop neighbours, coupled with the options possible with these nodes are prime considerations for the requirement of route update. Each lane $\boldsymbol{l}$ represents the options available to next and 2nd hop neighbour with respect to $\Delta\boldsymbol{\theta}$ and $\Delta\boldsymbol{d}$. The curves are drawn for $\boldsymbol{t = 1}$ second and $\boldsymbol{v = 33}$ m/s and a hop range of 1000 meters. The x-axis shows the number of nodes and y-axis shows the probability of change for need of link update.

For a uniform node distribution, number of lanes $\boldsymbol{l}$ is directly proportional to number of nodes $\boldsymbol{n}$. The probability of link status change is proportional directly to the change in topology, as static nodes will have no change in their status and vice versa. The monotonically increasing (and saturating) curves in Fig. 3, provide a very interesting result that the probability for route update is directly proportional to the options available to the next or 2nd hop neighbour and time $\boldsymbol{t}$ (due to involvement of $\Delta\boldsymbol{d}$). Hence, the probability of change in link status is proportional to percentage of change in topology.

It can be observed that regardless of route finding approach, higher change in network conditions (e.g. change in link topology or an increase or decrease in the node density, etc.) leads to a higher requirement of route update. Therefore, a higher change in the network conditions means higher probability of the event for route update. Such an event can be defined as the network state, where either the link with next hop node is about to break, or a 2nd hop node has come within next hop range. Same can also be stated as; the point of time when there is a higher probability that route request can lead to a better route. Hence, regardless of the route finding approach, the need to update the route increases with an increase in change in network conditions.

The determination of specific metrics and their corresponding thresholds that provide the highest probability of the event for route update requires detailed evaluation. The thresholds may vary for different routing approaches or network topologies, etc. The evaluation of a sample test case is described in the subsequent sections.

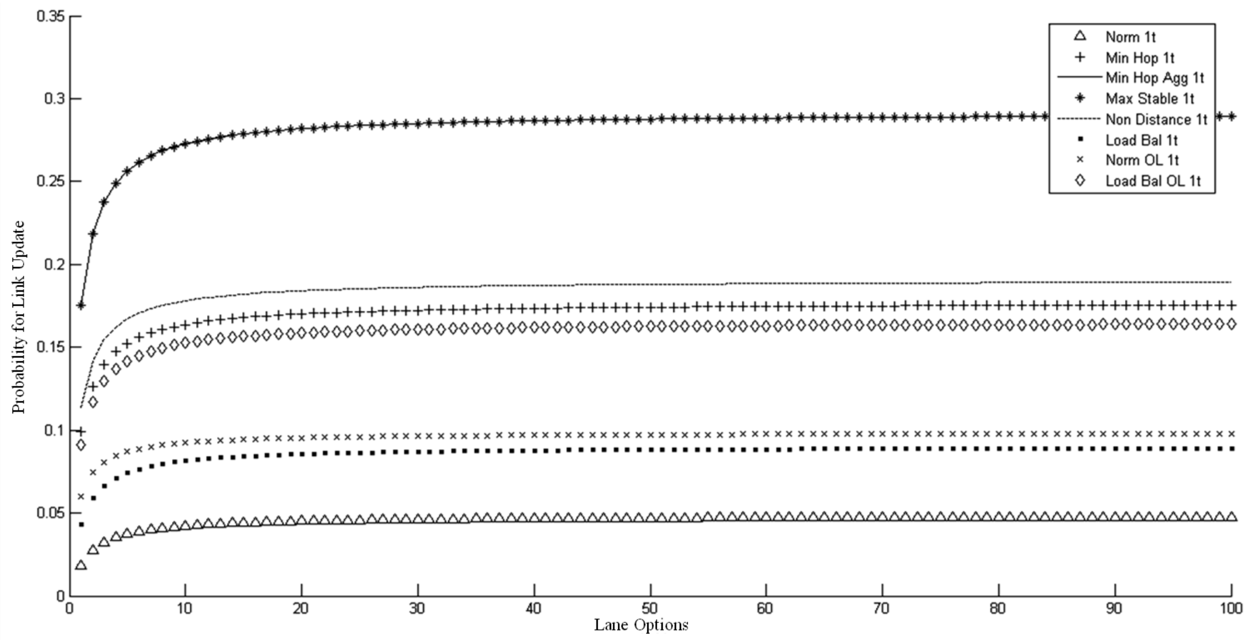


Fig. 3. Probability of Change for Need of Link Update

3.0 ADAPTIVE ROUTE UPDATE STRATEGY AND ITS EVALUATION

In the light of Equation 16, one can establish a route update strategy. Different threshold values for change of any metric or combination of metrics, computed at run-time, can develop the adaptive route update approach. Accordingly, instead of the specific value of any metric, fraction or percentage of change in the metric value can provide a solution for adaptive route update. The route update will only be requested if a change in one metric value, or a combination of more than one metrics, is above the threshold level.

As already stated, localised route repair performs better than end-to-end repair [41]. Therefore, a localised metric can show more promising results for route update, as compared to any end-to-end metric. Although the proposed approach may add complexity for processing resources, the localised metric can perform route update without adding any network overheads. Moreover, processing resources are generally not considered as a constraint in VANETs.

The salient features of the proposed approach are as under:

- Determine neighbours using standard HELLO messages.
- Determine change in selected metric value, since last route update.
- Compare change in metric value for the specific neighbourhood, against pre-computed threshold values.
- Initiate route update, if change in metric value is greater than the threshold value.

3.1. Effective Metrics for Adaptive Route Update

Analysis of networks with large topological changes shows the effectiveness of the use of the following three routing metric categories.

3.1.1. QoS Related Metrics

QoS related metrics such as throughput, delay and packet pair delays are often used in routing schemes [5]. Considering the use of local route repair, QoS metrics for next hop only, perform more efficiently than end-to-end metrics.

3.1.2. Position Related Metrics

The use of position related metrics [28], such as list of neighbours, number of neighbours and average node distance, etc. have significant importance for VANETs. These metrics are also considered for geographical addressing.

3.1.3. Physical Layer Related Metrics

The use of physical layer metrics such as SINR and received power, although requiring more complicated algorithms and design, provide more stable routes [29] [30].

3.2. Metrics used in the Simulation

For the purpose of simulation we selected metrics, one from each of the above stated three domains. The selection was based on importance of the metric and simplicity of implementation.

3.2.1. Next Hop Throughput

Although the QoS metrics, such as next-hop throughput, next hop delay and packet pair delay, have different computing techniques, they have more or less the same effect on routing strategy. For simulation, next hop throughput was computed using the amount of duly acknowledged data sent to the next hop neighbour.

3.2.2. One Hop Neighbour List

The geographical locations can be computed using GPS or non GPS techniques [44]. For highly dynamic networks, one hop neighbours' list provides a more realistic view of change in network topology, than average neighbour count or neighbour distance. During the simulation, next hop neighbour list was computed using standard HELLO messages, being broadcast periodically.

3.2.3. SINR

Being a combination of received signal strength, noise and interference, SINR provides more promising results than considering received signal strength only. Although precise computation of SINR is a complex phenomenon, simplified mathematical expression defined in [17] based on inter node distances can be used for the simulations.

3.3. Evaluation of Adaptive Route Update Strategy

To verify our research for different possible scenarios of VANET, we performed various simulations in NS-2. After comprehensive verification of the proposed scheme, we tested it against some state of the art routing protocols. As a test platform for the adaptive route update approach, we modified standard AODV routing protocol and named it as Adaptive AODV (AAODV).

AODV is one of the initial protocols that were proposed for ad hoc networks. However, its viability for VANET is generally not recommended, owing to its inherent limitations [5]. We selected AODV with the intention that if such a non-recommended protocol for VANET can be improved, it can provide strong reasons to optimise recommended VANET protocols using the proposed approach.

AODV being a reactive routing protocol, updates its route on link breakages only. However, it continuously shares HELLO messages to learn about its neighbours. AODV was modified in a manner where each node continuously measures the change in metric value. It adaptively updates its route when a change in metric value achieves a predefined threshold.

As a close to real life scenario, we simulated amalgamation of low and very high active node densities using IEEE 802.11p under NS-2. Nodes moving at different velocities (16-130 kmph) were converged from highways to a single road crossing. After staying there for a while in a static position, all nodes continued onto different roads.

All nodes were using a combination of TCP and UDP based applications. Random nodes were selected as application end nodes (source, destination or intermediate nodes) and non-end nodes (intermediate nodes only). Seven different topologies were simulated under different scenarios, by varying the number of nodes from 8 application end nodes and 18 intermediate nodes, to 128 application end nodes and 18 intermediate nodes.

Nodes were converged from sparse area (e.g. highways) to dense state (e.g. a road crossing). Node density was gradually increased by converging all nodes within one hop region of the host node. After reaching the converged region, all nodes were forced to adapt a temporary static behaviour. After staying for a while in one hop region, all nodes moved in different directions. During these simulations, quality of service parameters (throughput and latency) were measured by keeping different threshold values of all three metrics. Accordingly, threshold values were recorded under different node densities.

Connectivity state within nodes governs the topologies and scenarios within any specific environment. Accordingly, inter-node connectivity governs the routing. Fig. 4 summarizes different factors which need to be considered to study inter-node connectivity. Some of these factors are also inter-dependant to each other, e.g., halts affect node density as well as mobility among nodes. As a result, both of these factors independently affect inter-node connectivity.

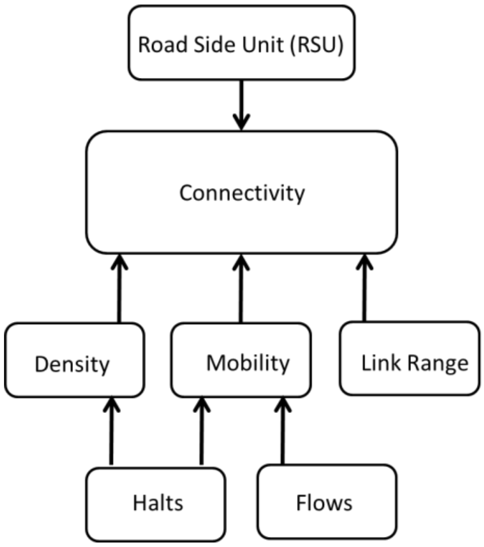


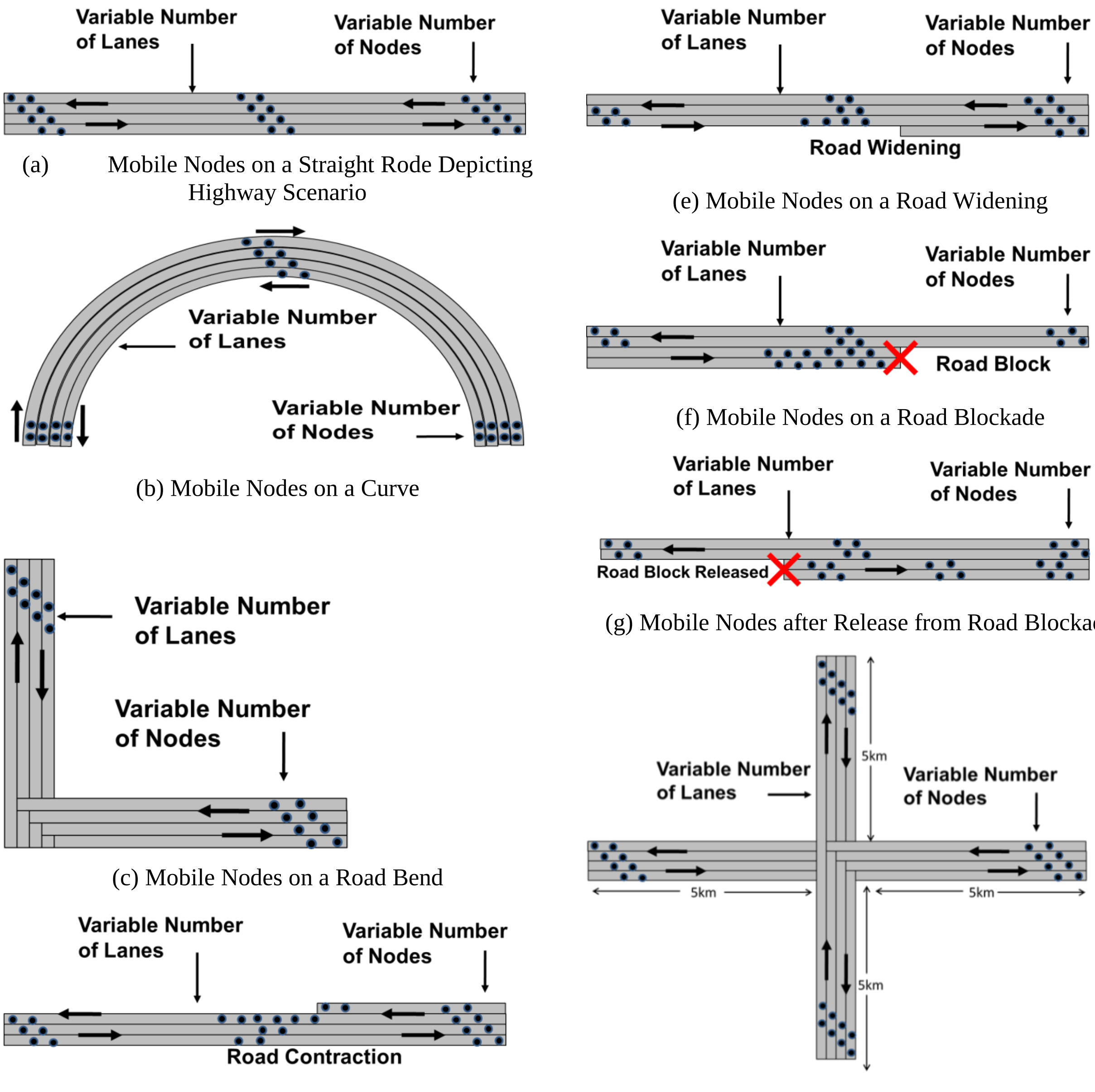
Fig. 4. Connectivity in VANET

To further analyse the proposed model of adaptive route update, we performed simulations for different possible connectivity scenarios of the VANET. These scenarios include high and variable active node density and changing node mobility, etc. There can be a number of connectivity scenarios according to type of traffic, hour of the day, physical area, etc. However, from a VANET's perspective, topologies can be grouped in two main categories, i.e., Highway scenarios and Urban or City scenarios, as follows:

3.3.1. Highway Scenario

A highway scenario generally consists of straight road with relatively low node density and fast moving nodes. Fig. 5a depicts a simple highway with multiple lanes. Node mobility is relatively simple involving just two opposite directions, i.e. $\theta=0^0$ or $\theta=180^0$. Hence, link life is significantly higher for all the nodes moving in same direction. On the other hand, if next hop node is moving in opposite direction, the nodes face frequent disconnections. There can be a few variations in the road topologies, as described below.

- Fig. 5b shows a curved road segment on a highway. Such road segments may cause minor speed variations to all nodes. However, no significant topology changes occur due to such curves.
- Fig. 5c shows a road bend on a highway. Such bends are not very common on highways in plains, however are common in mountains. As such, segments cause significant decrease in node speed, nodes face increase in node density while approaching a road bend. On the other hand, nodes face a reduction in node density while going away from road bend. Accordingly, nodes face minor but gradual topology changes.
- Fig. 5d shows a road contraction, e.g., bridges and defiles. Similar to previous case, nodes face significant increase in node density while approaching contraction point. In contrary to road bend, higher node density continues for subsequent path. Such narrowing causes temporary halt for the nodes due to reduction in space. The change in node density reduces topology changes for subsequent section. Resultantly, nodes face higher link life on the path.
- Fig. 5e shows a road widening, e.g., exit point of a bridge or defiles. The situation in this scenario is absolutely opposite to the previous case, where nodes face significant decrease in node density while leaving widening point. In contrary to the previous case, nodes face sudden acceleration, hence decrease in node density. Such widening allows nodes to move at higher speed due to availability of space. Lower node density causes sudden changes in link topology, which continues for the subsequent path. Higher topology changes cause repeated link breakages.



(a) Mobile Nodes on a Straight Rode Depicting Highway Scenario

(b) Mobile Nodes on a Curve

(c) Mobile Nodes on a Road Bend

(d) Mobile Nodes on a Road Contraction

(e) Mobile Nodes on a Road Widening

(f) Mobile Nodes on a Road Blockade

(g) Mobile Nodes after Release from Road Blockade

(h) Mobile Nodes on a Road Crossing

Fig. 5. Mobility Scenarios in VANET

3.3.2. City Scenario

In contrary to highways, an urban scenario is generally a complex case involving different situations. These situations include straight roads, road bends, road halts, crossings, etc. In contrary to highway scenarios, nodes within urban region observe rapid topology changes due to sudden acceleration and deceleration; mobility in different directions due to layout of roads and road crossings. Resultantly, link life is significantly lower as compared to highways. However, use of infrastructure nodes can help increase link life and reduce number of hops. In addition to different cases defined for the highway scenario, there can be a few variations in the road topologies, as described below.

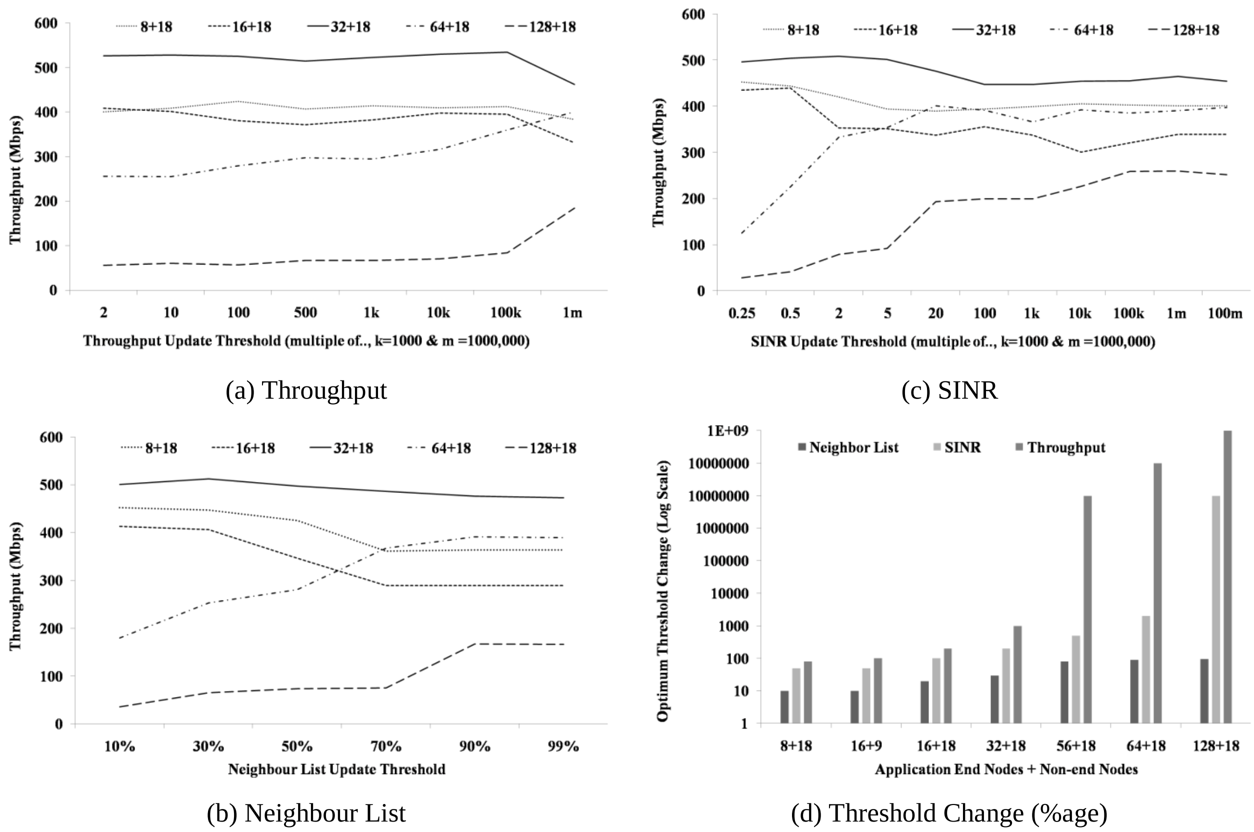
- Fig. 5f shows a road blockade scenario. These blockades are generally pre-coordinated and planned (e.g., signal halts) and sometimes are unplanned, (e.g., traffic disruption, congestion or landslides, etc.). Accordingly, these halts may prolong from few seconds to hours. These halts cause high node density within the region and nodes become almost static. Accordingly, nodes face very low topology changes while approaching and staying at halt region.

- In contrary to previous scenario, Fig. 5g shows a road clearance after a road blockade scenario. Similar to the previous scenario, these clearances are generally pre-coordinated and planned (e.g. green lights at signal halts) and sometimes are unplanned, (e.g., traffic release after disruption, congestion or landslides, etc.). At such clearing points, nodes tend to move with high acceleration causing link breakages.
- Fig. 5h shows a road crossing involving signal halts. Such crossings are very common within city scenarios. This scenario is a combination of multiple road bends, blockades and clearances. In contrary to simple road bend, road crossing coupled with signal halts creates a complex topology. Fast moving nodes from different directions will face gradual reduction in speed while approaching to signal halt. Such halts can be as long as multiple minutes. Signal halts allow node movement from one side at a time. Rest of the three road segments will face a temporary halt, hence facing very high node density. High node density scenario will continue for quite a long duration according to signal timings. After staying at signal halt with very low topology changes, nodes move in different directions on green signal. Rapid acceleration and variable movement direction cause sudden topology changes and link breakages.

3.4. Simulation Results and Analysis

Fig.s 6a, 6b & 6c show the average of total data transfer per application end node for route update at different thresholds of change in metric values. The value of SINR and throughput can vary from zero to ∞. Hence, the thresholds for change were selected as multiples of the value at last route update. However, the thresholds for change in neighbour list value were computed as %age change in metric value from the value at last route update.

Fig. 6d shows the percentage change in neighbour list, SINR and throughput, for which local route update achieved maximum throughput. It can be observed that the value of threshold for route update increases with the increase of node density for all three metrics. This result shows that threshold is dependent on total nodes involved in data transfer. In all the curves, the difference in threshold values for sparse topologies is more than dense ones.



(a) Throughput (c) SINR

(b) Neighbour List (d) Threshold Change (%age)

Fig. 6. Data Transfer Curves for Different Node Topologies (Application End Nodes + Non-end Nodes)

Consequently, the following logical conclusions can be drawn:

- Data transfer per application end node per second decreases with increase in node density.

- Threshold value for any metric starts from lower values and monotonically increases to achieve some maximum value.
- After attaining the higher threshold value for higher node densities, change in threshold values decreases significantly.
- Although the threshold curve flattens for large node densities, the monotonically increasing trend continues for all values.
- All curves match the general behaviour of mathematical model shown in Fig. 3.
- The neighbour list provided more conclusive threshold values for the test topologies and is the easiest to implement among all selected metrics.
- Adaptive route update on SINR provided best results for data transfer rate among all the test metrics.

After initial testing and loosely attaining threshold values of selected test metrics for route update, the proposed approach was compared against other protocols. For this purpose, AODVv2, OLSRv2, XORi and FROMR were compared against AAODV, for end-to-end latency and throughput.

AODVv2 and OLSRv2 routing protocols were primarily designed for Mobile Ad hoc Networks (MANET). However, their use for VANET is also suggested by researchers. For more realistic contribution under VANET environment, FROMR and XORi were selected, being designed for dynamic and scalable VANET topologies. AODVv2 and FROMR belong to reactive metric sharing family, while XORi and OLSRv2 belong to proactive metric sharing family.

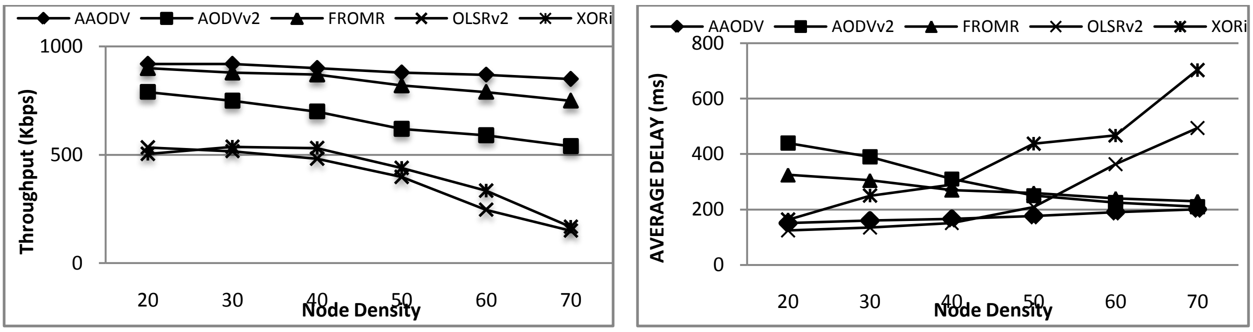
After attaining the coarse grained threshold values of selected test metrics for route update, the comparison of optimized AAODV with other standard protocols was done. All eight topologies were simulated for cross comparison of optimized AAODV.

3.4.1. Comparative Simulations Highway Scenario

For the simulation under a multiple lane highway scenario, we simulated Fig. 5 by keeping nodes with variable speed according to their lane position. The number of lanes and the corresponding speed varied from one scenario to another. For clarification purposes, we considered road lanes approaching at the road crossing as well as outgoing lanes. Nodes moved at the same velocity in each lane of a single road. However, lanes are classified according to their speed as Slow, Medium, Fast and Super-Fast. To simulate node overtaking scenario, nodes were allowed to switch from one lane to other. The lane speed varied from as low as 16 kmph to as fast as 130 kmph.

Fig.s 7a shows the comparison of optimized AAODV against other selected protocols for throughput in highway scenario. The x-axis of the graph shows the combination of different active + passive node densities. The y-axis of the graph shows the average throughput of other routing protocols against AAODV.

During the simulation, it was observed that nodes did not face frequent topology changes for neighbours moving in same direction as host. However, link life among neighbours moving in opposite direction was significantly low. Relatively low mobility behaviour among nodes moving in same direction caused higher link stability and link life. Such circumstances supported simple reactive protocols as compared to proactive protocols.



(a) Normalised Throughput (b) End-to-End Latency

Fig. 7. Comparison of Different Protocols against Adaptive Route Update in Highway Scenario

From the graph, we can observe that for all node densities, FROMR performed better than other protocols and remained close to Adaptive AODV. Although AODVv2 showed better results than OLSRv2 and XORi, it remained inefficient against FROMR and AAODV. Interestingly, on increasing node density, the gap between FROMR / AODVv2 and AAODV started increasing. Both FROMR and AODVv2 opt to select next hop neighbour towards destination, which can offer minimum hop count. Accordingly, both protocols tend to select next hop neighbour closest to their maximum hop range. As proved previously, probability of availability of next hop closest to maximum hop range increases with increasing node density. However, the selection of next hop neighbour closest to maximum hop range decreases the link life due to the involvement of lower Δd value. Accordingly, at a higher node density, nodes faced relatively higher rate of link breakage. Resultantly, AAODV showed more improvement at higher node densities.

OLSRv2 and XORi showed worse performance against all other protocols at all node densities. Performances of both protocols further degraded at higher node densities. Although stable links were available, both protocols continuously updated their routing tables. Such updates caused significant overhead in all node densities. The effect was more prominent at higher node densities.

Fig. 7b shows the comparison of AAODV against other selected protocols for average delay. The x-axis of the graph shows the combination of different average node densities. The y-axis of the graph shows the average delay of other routing protocols against AAODV.

Delay graph shows that OLSRv2 offered minimum delay at low node densities. As the overhead is not a significant problem at low node density, proactive protocols supported the scenario. The proactive design of OLSRv2 allowed timely update of routing information. Similarly, XORi being proactive in nature showed low delay than other reactive protocols. For low node densities, AODVv2 showed slightly higher delay as compared to XORi and OLSRv2. AODVv2 and FROMR showed higher latency being reactive in nature. As FROMR uses the concept of Adaptive Multipath Routing coupled with location update, it showed better performance than AODVv2. The simple reactive design of AODVv2 forced new route request in case of link failure, hence causing highest latency.

On increasing the node density, the increased overheads caused significant increase in end-to-end latency for both proactive protocols, i.e. XORi and OLSRv2. Although, FROMR showed better latency than XORi and OLSRv2, regular location updates caused relatively higher overhead than AODVv2. Accordingly, due to minimum overheads, AODVv2 showed best results as compared to FROMR XORi and OLSRv2. However, the delay in new route request in case of link failure caused higher average latency as compared to AAODV. In comparison to AODVv2, AAODV timely updates its route prior to link failure. Hence, for the overall comparison, AAODV showed smoother behaviour as compared to all other protocols with overall best latency values.

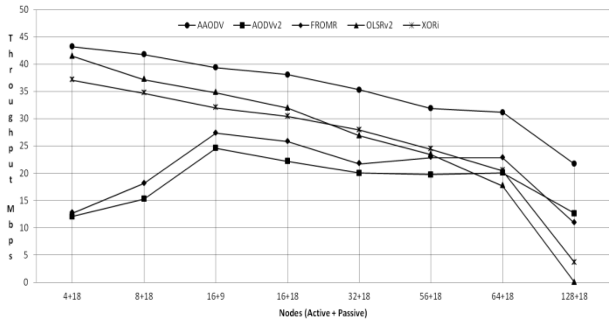
3.4.2. Comparative Simulations Urban Scenario

For the simulation of urban or city scenario, we considered the amalgamation of low active node density with very high active node density, by converging highly mobile nodes moving on different roads with variable velocity, to a single road crossing. The convergence scenario increased the road density by bringing all nodes in one hop communication zone. After staying for a while in this state like the initial simulation, all nodes continued their move on different roads indifferent directions. We considered four long roads of 5 kilometres approaching to a road crossing.

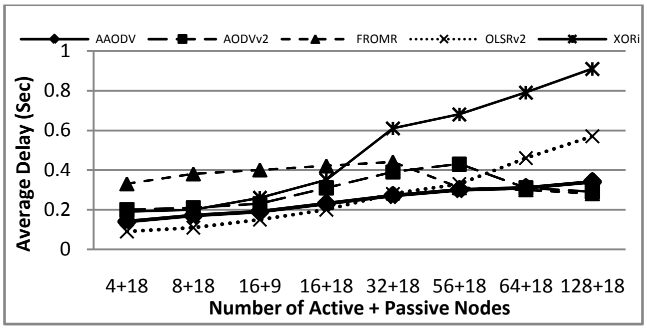
Fig. 8a shows the throughput comparison of AAODV against AODVv2 (DYMO), OLSRv2, FROMR and XORi. At low node densities, the comparison of AAODV, XORi and OLSRv2 curves shows better performance in terms of end-to-end latency and throughput due to timely route update and optimisation. Although both proactive protocols faced overhead issues, the effect of overheads was not significant at lower node densities.

On increasing the node density, performance of OLSRv2 and XORi suffered significantly due to increased overheads. For higher node densities, XORi showed better throughput than OLSRv2. However, significant increase in end-to-end latency was the major drawback observed for XORi. On the other hand, AODVv2 and FROMR did not update their route due to their reactive design, and faced performance degradation. FROMR performed slightly better than AODVv2 at lower node densities. FROMR has an edge over AODVv2 as it adaptively selects route to destination from all available routes. However, the overall performance of both protocols followed the same trend regardless of the node density. Moreover, both protocols did not update their routing tables in the presence of more and optimised routes.

At higher node density, all protocols other than AAODV faced higher contention as well as increased size of control traffic. Under high contention state, these protocols faced repeated route errors due to design limitation of maximum three retries. Both proactive protocols experienced exponential increase in control traffic and faced lack of communication resources even for control traffic only.



(a) Normalised Throughput



(b) End-to-End Latency

Fig. 8. Comparison of Different Protocols against Adaptive Route Update in Urban Scenario

On the other hand, both reactive protocols faced false or unintentional route failures due to lack of communication resources. Such false route failures forced the routing protocol to find new routes. At the same time, neighbour nodes provided divergence of routes due to the availability of more options for path to destination. Such false route updates and route divergence improved the performance of both reactive protocols. However, the unintentional updates did not cause all nodes to update their route. Furthermore, such behaviour is not a guaranteed one.

Fig. 8b shows the comparison of optimized AAODV against other selected protocols for average delay. The x-axis of the graph shows the combination of different active + passive node densities. The y-axis of the graph shows the average delay of other routing protocols against AAODV.

We can observe that for low node densities, OLSRv2 offered minimum delay owing to its simple proactive design. XORi showed more delay than OLSRv2 but better than AODV, which is proactive in nature. By increasing the node density, the increased overheads caused a significant increase in end-to-end delay for both XORi and OLSRv2. For low node densities, AODVv2 showed higher delay as compared to XORi and OLSRv2. Although FROMR computes multiple paths, in our case, the alternate path is again suboptimal. Resultantly, FROMR showed the highest latency at low node densities due to additional overheads. AODVv2 and FROMR showed better performance at higher node densities due to reduced overheads as compared to other two protocols. At higher node densities, AODVv2 showed minimum delay due to its pro-active design and false route update, as already explained. For the overall comparison, AAODV showed smooth behaviour as compared to all other protocols with overall best delay figures.

The use of adaptive route update can make any routing protocol more efficient. The optimisation of adaptive route update can be performed on different node densities and types of networks. However, the threshold level for optimised adaptive route update may vary for different networks.

4.0 CONCLUSIONS

The analysis of reactive and proactive routing protocols, and their derivatives, proves their inefficiency for highly dynamic networks. Rapid topology changes demand adaptive use of run-time intelligence for route update. The proposed adaptive route update scheme can be implemented with any baseline routing algorithm, and will allow all nodes to locally update their routes on availability of a route better than the current one. With the analysis of different route update strategies, we can conclude the following:

- Regardless of baseline routing algorithm, the adaptive route update can make any routing protocol more efficient than a routing protocol with static route update approach.
- Different metrics can be used for adaptive route update.
- The optimization of adaptive route update can be performed on different node densities and different types of networks.
- The threshold level for optimised adaptive route update may vary by changing the type of network.

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