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A new connectionless routing algorithm using cross-layer design approach in MANETs

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Original scientific paper

Routing is a key issue in wireless ad-hoc networks. The goal of an efficient routing strategy is to improve packet delivery ratio (PDR) and end-to-end delay in MANETs. Limited ability of layered architecture leads to the cross-layer design usage for routing operation in wireless environment. In this paper, a cross-layer connectionless routing is proposed based on Dynamic Virtual Router (DVR). In this algorithm, virtual route discovery process is controlled by restricting the request packets' broadcast to the relatively slow speed, and low loaded nodes located in suitably crowded areas. Each destination decides to choose or discard the found route based on several cross-layer metrics. Using NS-2 simulator, the proposed algorithm is compared with standard DVR and it shows higher packet delivery ratio and lower end-to-end delay compared to DVR.

Key words: Cross-layer design, Mobility, Connectionless routing, DVR, Mobile ad hoc networks

Novi algoritam preusmjeravanja bez spajanja zasnovan na korištenju različitih slojeva unutar MANET komunikacije. Preusmjeravanje je ključni problem u bežičnim ad-hoc mrežama. Cilj je efikasne strategije preusmjeravanja unaprijediti omjer isporučenih paketa (PDR) i smanjiti ukupno kašnjenje u MANET komunikaciji. Ograničena mogućnost višeslojne arhitekture dovodi do korištenja različitih slojeva za operacije preusmjeravanja u bežičnom okruženju. U radu se predlaže preusmjeravanje bez spajanja zasnovano na dinamičkom virtualnom ruteru (DVR). U predloženom algoritmu, postupak otkrivanja virtualnih puteva upravljan je ograničenjem odašiljanja traženih paketa na relativno sporu brzinu i slabo opterećene čvorove locirane u odgovarajuće prometnim područjima. Svako odredište odlučuje o odabiru ili zanemarivanju pronađenog puta komunikacije, a zasnovano je na temelju nekoliko metrika za različite slojeve. Korištenjem NS-2 simulatora, predloženi algoritam uspoređen je sa standardnim DVR-om te pokazuje veći omjer isporučenih paketa i manje ukupno kašnjenje.

Ključne riječi: Dizajn zasnovan na različitim slojevima, mobilnost, preusmjeravanje bez spajanja, DVR, mobilne ad hoc mreže

1 INTRODUCTION

Mobile ad hoc network (MANET) is a self-configuring network of mobile nodes connected by wireless links without any infrastructure. Each node in a MANET is free to move independently in any direction, and will therefore change its links to other nodes frequently. The network topology may change rapidly and unpredictably over time. Each node must also be a router and take part in traffic forwarding process [1, 2].

Absence of fixed infrastructure in a MANET poses several types of challenges and routing is the most important one. Routing is the process of selecting paths in a network, along which the traffic is sent. It can affect the network performance metrics, such as throughput, reliability and congestion [3]. An ideal routing algorithm is the one which is able to deliver the packets to their destination with minimum amount of delay.

Due to the nodes' mobility, the shortest path algorithms are not good choices and considering mobility in the route selection phase can lead to better results. Therefore, one of the big challenges is how to measure and quantify the mobility degree and how to make this information available. On the other hand, cross-layer mechanisms can be employed to make the mobility information available in all layers [4]. Cross-layer architecture is a complementary scheme for the layered protocol stack. By weakening the strict functional separation of protocols, networking performance can improve. Network dynamics' information which can be detected at a certain layer can be identified through the network stack and every protocol can react to topological changes in the network [4].

This paper proposes a multi-criteria cross-layer routing mechanism based on DVR which uses the MAC, network and physical layers' parameters all together to improve the network performance.

The rest of the paper is organized as follows: Section 2 discusses the related works. In Section 3, DVR algorithm is described. Our proposed algorithm is described in Section 4 and its performance evaluation is presented in Section 5. Finally, Section 6 concludes the paper.

2 RELATED WORKS

An ad hoc routing protocol controls the route through which the packets traverse the network. Routing protocols are divided into two categories, based on their connectivity scheme [5]:

- Connection-Oriented Protocols
- Connectionless Protocols

Connection-oriented and connection-less protocols are two distinct communication techniques in data networks.

In connection-oriented protocols, a logical connection is established before data packet transmission. This is generally accomplished by specifying how a connection should be set up, maintained and sometimes repaired. Usually source begins this process by sending a request packet to create a connection, and the other nodes should reply to the request. Control information is exchanged to determine how the connection should be set up and maintained. If this process is going right, data packets will be sent through the determined route.

In this method, data packets will arrive in the same order as they are sent and all of them traverse the same route. Various connection-oriented routing protocols have been proposed, such as DSDV (Destination-Sequenced Distance Vector Routing), GSR (Global State Routing), AODV (Ad hoc On-demand Distance Vector) and ZRP (Zone Routing Protocol) [5, 6].

In connectionless protocols, no connection is required to be established between the nodes. Data packets are simply forwarded to the next hops without any initially established connection. In these schemes, nodes that happen to be toward the destination help to forward the data packets.

Each packet is forwarded independent of others. So data packets might arrive out of order at the destination. But, there is no need to maintain any connection, and nodes do not need to keep information about their neighboring nodes. Various connectionless routing protocols have been proposed such as CBF (Contention-Based Forwarding) and DVR (Dynamic Virtual Router).

Advantages and disadvantages of connection-oriented and connectionless approaches are provided in Table 1. According to Table 1, connection-oriented routing algorithms suffer from link breaks in high mobility environments. But connectionless routing algorithms can inherently handle the high mobility.

3 DVR ROUTING ALGORITHM

To reduce the number of nodes needed in data forwarding and to handle a high mobility environment, the concept of virtual router is introduced. In this approach, communication link breaks are prevented instead of recreating the broken routes.

A virtual router is defined as a logical router that is associated with a particular geographic area and is composed of some mobile nodes [7, 8]. Mobile nodes which are situated within the virtual router's geographical area can take part in data packets forwarding. In this environment, data packets are transmitted over a chain of virtual routers. Since these virtual routers do not move, the communication connection is much less susceptible to the nodes' mobility. When a source wants to communicate with a destination, it broadcasts the route request packet to its neighbors. When a node receives the unseen RREQ packet, the packet ID is cached in its packet ID cache and route request packet forwarding is delayed for a random time interval. In this random interval, it senses the channel to hear the same delayed packet forwarding. In such cases, the packet is not forwarded. Otherwise, at the end of the delayed period, the node attaches its own ID to the packet and broadcasts it. When the destination receives the route request packet, a route reply packet will be sent to the source node via the traversed relay nodes in the RREQ, through which the communication path will be set. Route reply packet will traverse the shortest path until it arrives at the source node. Route reply packet contains a route ID and the distance of the route to the destination (DTD). Destination node ID and a local particular number together determine the route ID. Each node that receives the route reply keeps the packet's route ID in its route ID cache and becomes a part of the communication route. Relay nodes and the overhearing nodes will be assisted to forward the data packets from the source to the destination.

The key advantages of DVR approach are as follows [7]:

1. When a node moves away, a nearby node can take over the data forwarding task with no delay. This ensures low packet loss and excellent end-to-end delay
2. Virtual routers are dynamically created for each communication session, when they are needed
3. Mobile nodes do not need to have a GPS
4. Mobile nodes do not need to know the position of virtual routers.

Meanwhile, DVR algorithm has better functionality, due to the use of dynamic virtual router. However, the number of hops is the only metric for the route selection, which

Table 1. Advantage and disadvantage of two categories

Approaches	Advantages	Disadvantages
Connection-Oriented Approach	Resource reservation ability Sequencing guarantee Short headers More reliability	No alternate routing around congestion Vulnerability to router failures along the path Memory requirement at the nodes Connection set up process delay Higher overhead and bandwidth usage for connection setup process
Connectionless Approach	Robustness to router failures More potential for congestion adaptation No need to connection setup	No sequencing Longer headers

does not always lead to the optimal route. Therefore, the proposed algorithm uses a combined criterion, based on cross-layer design to improve the selected route in DVR.

4 MOBILITY ADAPTIVE CROSS-LAYER DESIGN

Our main work is not to propose a new routing algorithm. We argue that the current designs are not flexible enough to achieve the optimal performance. For example, in DVR, the shortest path is always selected for packet forwarding whereas the shortest path is not always the optimal one.

Furthermore, mobility is an important challenge in MANETs, and majority of the routing protocols including DVR have failed to face a network with high mobility. Also, mobility status of the nodes is not considered in the route establishment procedure of DVR.

As the last point, since TCP/IP architecture is designed for wired networks, wireless transmission poses challenges to this well-defined protocol stack. Layers of TCP/IP model are too strict to provide all the services which are required in these domains and cross-layer design, where the traditional boundaries among layers are violated, is used in different ways to achieve better performance [9].

In the original OSI networking model, strict boundaries are enforced between the layers, where information is kept strictly within its original layer [10]. Cross-layer design removes such strict boundaries to allow communication between the layers by permitting one layer to access another layer information [11].

Our proposed algorithm is a cross-layer designed one which considers MANET nodes' mobility [12, 13] in its route setup process as well. Number of hops as the network layer metric, node load as the MAC layer one and number of neighbor nodes as the physical layer one are considered in our cross-layer design.

In the next subsections, mobility consideration and cross-layer metrics are explained in detail.

4.1 Definition of the node's relative mobility

Node's mobility degree is quantified periodically based on its neighborhood information. It is worth noting that two nodes are assumed neighbors, if they are located within each other's transmission range. The calculated mobility degree is used to determine the best reliable virtual route between the source and destination during the route setup and data forwarding phase. Therefore, frequent link breaks associated with unstable paths and containing highly mobile nodes are avoided.

4.1.1 Nodes' mobility degree calculation

Node's mobility degree is a parameter that is determined locally and periodically and is dependent on the node's local situation. Change of neighboring nodes within time is used to calculate the mobility degree of a node [13-15]. Therefore, node's mobility degree at t represents the changes in its neighboring nodes compared to $t - \Delta t$ and nodes joining or leaving the transmission range will affect this parameter.

To better understand, consider the following scenario [15].

Node A has 11 neighbors as shown in Fig. 1a and during the interval of Δt, its neighborhood changes as shown in (Fig. 1b): E and F leave and B, C and D join A's transmission range. As a result, five changes are made in A's neighborhood information during Δt (Fig. 1c). At the end of each time interval, the node calculates its mobility degree according (1). Mobility degree of Node A is equal to 5/14 in the given example.

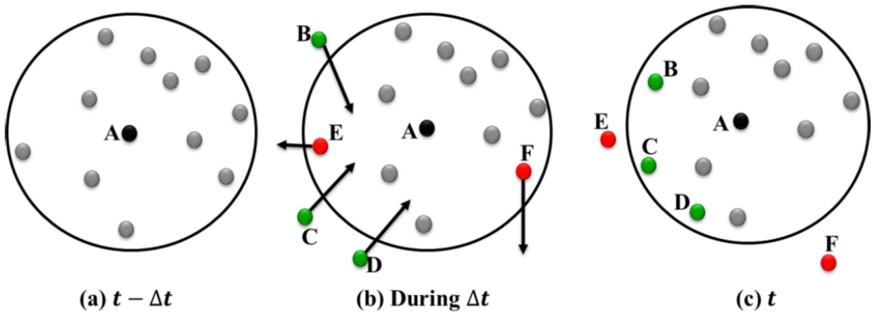

Fig. 1. Nodes' mobility [13]

$$\text{Mobility}\,(A,t)=\begin{cases}\frac{N^{\text{in}}_{\text{nodes}}(t)+N^{\text{out}}_{\text{nodes}}(t)}{N^{\text{in}}_{\text{nodes}}(t)+N^{\text{out}}_{\text{nodes}}(t)+N^{\text{remain}}_{\text{nodes}}}, & \text{Neighbors}\neq 0,\\ 0, & \text{Neighbors}=0,\end{cases} \tag{1}$$

where:

- $N^{\text{in}}_{\text{nodes}}$ is the number of nodes joining A's transmission range during Δt interval.
- $N^{\text{out}}_{\text{nodes}}$ is the number of nodes leaving A's transmission range during Δt interval.
- $N^{\text{remain}}_{\text{nodes}}$ is the number of neighboring nodes that remain within A's neighborhood during Δt interval.
- $\text{Mobility}\,(A,t)$ is the mobility degree of node A.

After the mobility degree determination, it is important to note that each node's mobility is characterized by the following two parameters:

- Average mobility degree of the node and its neighboring nodes
- Variance mobility degree of the node and its neighboring nodes

Equations (2) and (3) are used to calculate these parameters. Using the average mobility cannot be sufficient by itself and only one node with high mobility degree in the neighboring area can cause unreliability. Therefore, variance is also considered to cover this issue.

$$avg_{(node)}=\frac{\sum_{i=1}^{N+1}\text{Mobility}_i}{N+1}, \tag{2}$$

$$var_{(node)}=\frac{\sum_{i=1}^{N+1}\left(\text{Mobility}_i-avg_{(node)}\right)^2}{N+1}, \tag{3}$$

where $N+1$ is the number of neighboring nodes and the corresponding node itself, and Mobility_i is the mobility degree of the i^{th} neighbor.

Each node performs mobility quantification based on its neighborhood local information periodically. Hello packets are used to collect this local data. They are broadcasted locally and include the node's IP address and mobility degree. Consequently, each node can calculate its mobility degree and accordingly mobility average and variance are updated (see (2) and (3)). These two parameters are added to their corresponding fields in both the route request and data packets and are updated by the intermediate nodes along the route to show their maximum values. These parameters are used at the destination to choose the best path for the next data packets' transmission.

4.2 Cross-layer metrics

In this subsection, cross-layer metrics used in the proposed algorithm are defined.

4.2.1 Network layer metric

Number of hops is the network layer metric that is used for the route selection process [16]. This parameter is denoted by Hop_Metric_{ij} and is normalized as shown in (4):

$$\text{Hop\_Metric}_{ij}=1-\frac{\text{Hop\_Count}_{ij}}{\text{Node\_Number}}, \tag{4}$$

where Hop_Count_{ij} is the number of hops from Source *i* to Destination *j* and Node_Number is the maximum number of nodes in the network. The hop count is also an added field to the packets that is updated and incremented by the intermediate routers as it is forwarded to the destination.

4.2.2 MAC layer metric

Load of the nodes is the MAC layer metric which is considered in this paper. The route whose maximum nodes' load is smaller would be the preferred route [17].

Average queue length is a good metric for the nodes' load demonstration. Every node uses Exponentially

Weighted Moving Average (EWMA) [18] to estimate its average queue length, according (5) and upon packet arrival and departure. When a node's average queue length is lower than the minimum load threshold, its load metric will be set to 0 and if it exceeds the minimum threshold, the load metric will be calculated by (6). Also when the average queue length exceeds the maximum load threshold, the load metric will be equal to 1.

$$\overline{\text{Queue\_length}}_i^c = (1 - W_q) \times \overline{\text{Queue\_length}}_i^p + W_q \times \text{Queue\_length}_i, \quad (5)$$

$$\text{Node\_Load}_i = \frac{\overline{\text{Queue\_length}}_i^c - \min_{lth}}{\max_{lth} - \min_{lth}}, \quad (6)$$

where:

- $\overline{\text{Queue\_length}}_i^c$: The current average queue length of Node i
- $\overline{\text{Queue\_length}}_i^p$: The previous average queue length of Node i
- W_q: Weight parameter, $0 \leq W_q \leq 1$
- Queue_length_i: Current queue length of Node *i*
- Node_Load_i: Load metric of Node *i*
- $\min_{lth}$: Minimum queue length threshold
- $\max_{lth}$: Maximum queue length threshold.

Weight parameter is used to estimate the average queue length in EWMA relation (5). It reflects the sensitivity of the average queue length to its actual timely changes.

Each node can calculate its load according (6).This metric is added to its corresponding field in both the route request and data packets and is updated by the intermediate nodes along the route to show its maximum value. Finally, this metric is also used at the destination to choose the best path for the next packets' transmission.

4.2.3 Physical layer metric

Each node needs to compete for transmission channel in the wireless network. Therefore, increasing the number of neighboring nodes leads to longer transmission delays due to the channel acquiring time. On the other hand, when the number of neighboring nodes decreases, link breaks will be frequent. Thus, the number of node's neighbors is chosen as the useful physical layer metric in this paper.

As mentioned before, each node periodically broadcasts a hello packet. The number of hello packets received during a fixed time can be an estimate of the number of neighbor nodes. These packets are sent periodically in order to establish and maintain neighbor relationships. They contain various information including the source node's ID, mobility average and variance fields. The Average number of node's neighbors can be calculated using EWMA formula [18] (as shown in (7)) and it is normalized according (8) to form the physical layer metric called as the neighboring metric:

$$\overline{\text{Neigh\_No}}_i^c = (1 - W_q) \times \overline{\text{Neigh\_No}}_i^p + W_q \times \text{Neigh\_No}_i, \quad (7)$$

$$\begin{cases} \text{if } \left(\overline{\text{Neigh\_No}}_i^c \geq \max_{nth}\right) & \text{Node\_Neigh}_i = \frac{\max_{nth}}{\overline{\text{Neigh\_No}}_i^c} \\ \text{else} \quad \text{Node\_Neigh}_i = \frac{\overline{\text{Neigh\_No}}_i^c}{\max_{nth}} \end{cases}, \quad (8)$$

where:

- $\overline{\text{Neigh\_No}}_i^c$: The current average number of Node *i*'s neighbors
- $\overline{\text{Neigh\_No}}_i^p$: The previous average number of Node *i*'s neighbors
- Neigh_No_i: Current number of Node *i*'s neighbors
- W_q: Weight parameter, $0 \leq W_q \leq 1$
- Node_Neigh_i: Neighboring metric of Node *i*
- $\min_{nth}$: Minimum neighboring threshold
- $\max_{nth}$: Maximum neighboring threshold.

It is notable that the amount of W_q will be set differently in (7), when $\overline{\text{Neigh\_No}}_i^c$ reaches $\min_{nth}$ and $\max_{nth}$ levels. It is explained more completely in Section 5.2.

The neighboring metric of each node is calculated according (8) and is added to both the route request and data packets. This metric is updated by the intermediate nodes along the route to show its maximum value at the intermediate nodes. Finally, this metric is also used at the destination to choose the best path for the next packets' transmission.

4.2.4 Multiple criteria combination

After defining different layer metrics, they are combined to form a single rule for route selection procedure.

This mixed multidimensional criterion is expressed as (9) below:

$$\text{Mixed\_Metric} = \text{Hop\_Metric}_{ij} \times (1 - \text{Node\_Load}_{ij}) \times \text{Node\_Neigh}_{ij} \times (1 - \text{Mobility\_Metric}_{ij}), \quad (9)$$

$$\text{Mobility\_Metric}_{ij} = avr_{(node)} \times \sqrt[3]{var_{(node)}}, \quad (10)$$

where:

- Hop_Count_{ij}: The number of hops from Source *i* to Destination *j*

- $\mathrm{Node\_Load}_{ij}$: Maximum load metric of the nodes on the route from Source *i* to Destination *j*
- $\mathrm{Node\_Neigh}_{ij}$: Maximum neighboring metric of the nodes on the route from Source *i* to Destination *j*
- $\mathrm{Mobility\_Metric}_{ij}$: Mobility metric between source node *i* and destination node *j* in terms of average and variance of the mobility.

Source node initiates route discovery process by broadcasting the RREQ packet. Each intermediate node that receives the RREQ packet updates its mobility parameter fields (both mobility average and variance fields) and cross-layer metrics. They are updated to show their maximum values at the intermediate nodes, as the route request or data packet is forwarded to the destination.

Note that when the first route request packet is received at the destination, it has no other choice but to select this path (regardless of its metrics) to send RREP back to the source. The metrics (mobility, hop, neighboring and load metrics) are maintained at the destination to be compared with the corresponding future values of the other available paths.

However, the decision to continue using this path depends on the metrics values of the next available paths. The mixed metric of the next received request packet and the previous one are compared. And the one with the less corresponding mixed metric is selected for the packet transmission. Therefore, a route reply packet will be sent back to the source node on the selected path.

Destination sends route update packets to the source periodically to replace the broken links with the new ones similar to DVR protocol mentioned in Section 3. Therefore, when data packet is received by an intermediate node, its whole metrics are updated to show their maximum values as it is forwarded to the destination. When data packets are received at the destination, decision is made according to the values of the computed mixed metrics and update packet will be sent on the new route if it includes the lower mixed metric. Upon receiving the route update packet at the source node, data packets will be forwarded on the new virtual route toward the destination.

Thus, the best path will be chosen according (9). This mechanism leads to more stable and reliable routes and increases the overall routing performance.

5 SIMULATION

DVR algorithm has already been compared with AODV [19, 20] and Static Virtual Router (SVR) algorithms [5]. The simulation results have indicated that both DVR and SVR techniques can handle high mobility and achieve better performance compared to AODV. On the other hand, DVR outperforms SVR using dynamic on demand virtual routers. Therefore, the proposed algorithm will be just compared to DVR in this paper.

In this performance evaluation, the impact of number of node's neighbors, nodes' speed of mobility and number of communication sessions will be investigated on the network performance. Also, Network Simulator 2 (NS2) is used as the simulation tool.

5.1 Performance Metrics

The following performance metrics will be evaluated through the simulation:

- **Packet Delivery Ratio**: the ratio of the data packets received at the destinations to the data packets generated by the sources
- **End-to-end delay (Second)**: the time it takes for the data packets to be sent from the sources to the destinations
- **Overhead**: the ratio of the total routing information transmitted or forwarded by the nodes to the total information transmitted in the network
- **Packet duplication**: the average number of duplicate packets received at the destinations for each distinct data packet.

5.2 Simulation Parameters

Parameter settings for the simulation are summarized in Table 2. All nodes are mobile. Sessions are randomly started through each simulation run. Multiple simulations runs (10 runs) with different seed numbers are conducted for each scenario and the collected data over these runs are averaged to be shown as the simulation results. 95% confidence intervals are shown in the Graphs as well.

The value of Δt in (1) is dependent on the nodes' speed and topology changes. In this paper, it is set as 1 second to achieve a better adaptation to the network changes. This value is also chosen after a simulation study that investigated the effect of the different values of Δt. Equation (10) is selected experimentally after testing various equations containing the mobility average and variance.

The minimum and maximum thresholds of queue length are set as 40% and 70% of the buffer capacity in (7) (see Fig. 2). This high minimum threshold can guarantee higher network throughput and link utilization. For the average queue size to respond quickly to the timely changes of the queue length, the value of 0.003 is assigned to the weight parameter when the minimum threshold is not met. In the area between minimum and maximum threshold,

Table 2. List of parameter settings for the simulation

Parameters	**Values**
Simulation time	1000 seconds
Simulation area	700m × 700m
Number of nodes	60, 80, 100, 140
Mobility model	Random way-point Mobility **[21]**
Pause time	Zero
Mobility velocity	10, 15, 20, 25 m/s
CBR rate	Random, 1-3 packets/s
Data packet size	512-byte
Communication sessions	3, 5, 10, 20
Duration of each session	180 seconds
Each session begins	Randomly, between 50 to 400 seconds of simulation start up
Channel capacity	2Mbps
Transmission Range	150 meters
Radio propagation model	Two-Ray Ground

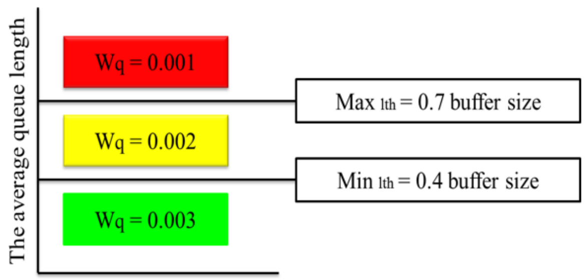

Fig. 2. Parameter configuration for node's load calculation [18]

there is no need to have high values for the weight parameter. Hence, the value of 0.002 is assigned to it. Another reason to use a lower weight parameter in this area is to gain reasonable time before hitting the maximum threshold.

The minimum and maximum thresholds are set as 4 and 7 nodes in (10) (see Fig. 3). These values have shown better performance compared to other values, while tested in several scenarios. For the average number of nodes' neighbor to respond quickly to the timely changes of the number of node's neighbors, the value of 0.003 is assigned to the weight parameter when the minimum threshold is not met. In the area between minimum and maximum threshold, there is no need to have high values for the weight parameter and the value of 0.002 is assigned to it. Hence, as it is shown in Fig. 3b, the number of node's neighbors grows with different rates in different areas.

5.3 Simulation Results

In this simulation study, the impact of the following parameters on the new protocol's performance is investigated and DVR algorithm is compared with the new protocol.

5.4 Nodes' speed of mobility

To realize the effect of the nodes' speed on the performance metrics, the number of nodes and communication sessions are fixed at 100 and 3, respectively. Also, their speed is changed from 10 to 25 m/s. The simulation results are shown in Fig. 4. As it is shown in Fig. 4a and Fig. 4b, the proposed algorithm has higher packet delivery ratio and lower average end-to-end delay compared to DVR algorithm. DVR is robust to the nodes' mobility because the nodes on the virtual route can take part in data forwarding, but a virtual route may contain some nodes with high degree of mobility. On the other hand, DVR does not consider different metrics of lower layers in the routing process.

In the proposed algorithm, virtual routes are preferred to be constructed by the low mobility nodes. Therefore, it experiences less frequent broken links and achieves higher packet delivery ratio and lower delay in the network.

Fig. 4c shows that the proposed algorithm has higher overhead than DVR since each node sends hello messages in the network to help the nodes obtain local information about their neighbors and calculate their mobility degree. Also data packets become longer, due to the cross-layer metrics fields that are added to them.

The proposed algorithm and DVR have almost the same number of duplicate packets (see Fig. 4d) because they only forward the data packet by the nodes on the selected virtual route.

5.5 Nodes' Density

In this part it is assumed that the nodes move at the maximum speed of 15 m/s and 3 concurrent communication sessions exist in the network. The number of nodes is changed between 60 and 140 and the impact of the nodes' density is investigated. The results are illustrated in Fig. 5.

Different virtual routes can be created between the source and the destination but DVR uses the shortest path to forward the packets. However, the proposed algorithm leads to more packet delivery ratio and less average end-to-end delay (Fig. 5a and 5b).

This verifies that the shortest path is not always the best one and queuing and retransmission delays are sometimes high which will cause less desirable results in DVR.

This improvement is due to the lower nodes' load, collision and broken links in the proposed algorithm. The proposed algorithm avoids routing through high speed and

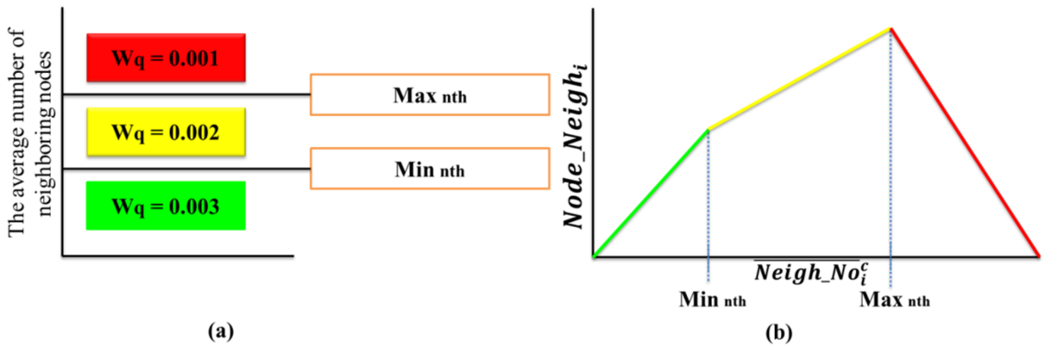

Fig. 3. Parameter configuration for the number of node's neighbors calculation

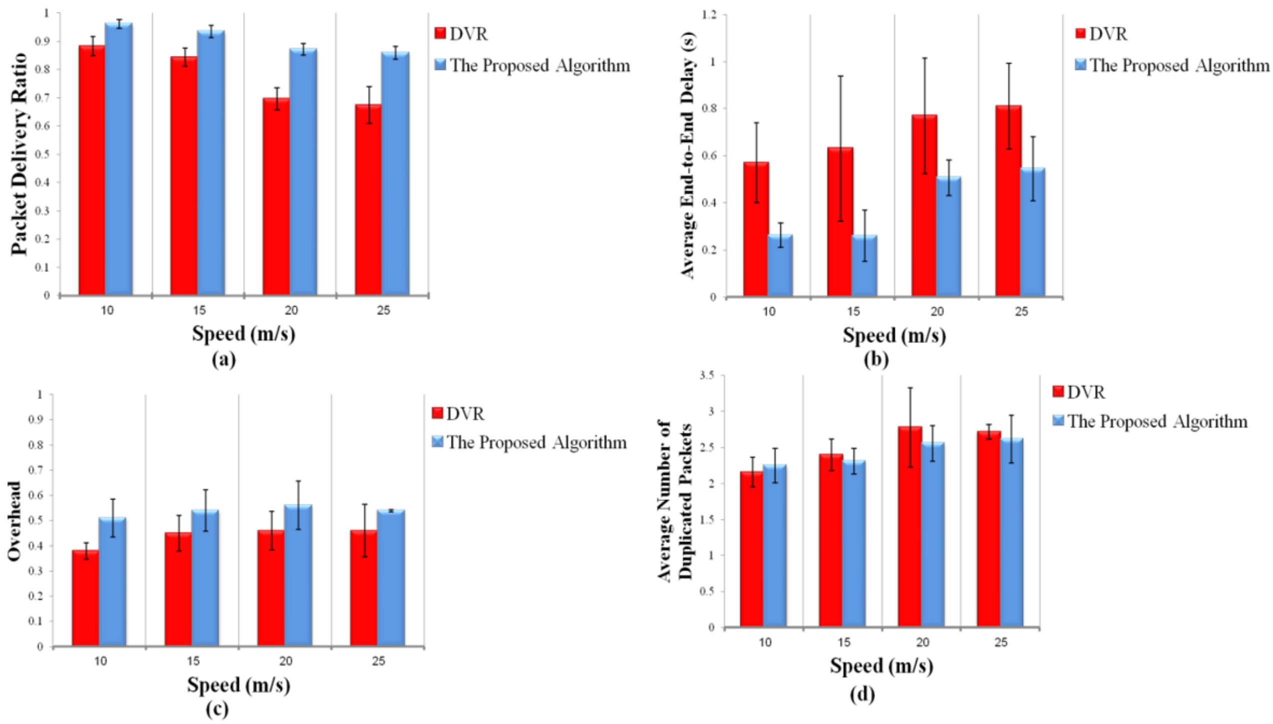

Fig. 4. (a) Data Delivery Ratio, (b) Average End-to-End Delay, (c) Overhead, and (d) Duplicated Packets versus nodes' speed of mobility

busy nodes and delivers packets with lower delays. Buffering time in the queues of the intermediate nodes is low in the proposed algorithm because the congested nodes are prevented from participating in the discovered route.

Same results as the previous section are obtained for the routing overhead and duplicate packet numbers.

5.6 Number of Communication Sessions

In this section, the simulation is run with the maximum nodes speed of 15 m/s and 100 mobile nodes. 3 to 20 communication sessions are established in the network and the effect of the number of communication sessions is studied on the proposed algorithm. The simulation results are presented in Fig. 6.

As the number of sessions increases, packet delivery ratio becomes lower due to the higher network load and congested nodes in the network. But as it is shown in Fig. 6a and Fig. 6b, the proposed algorithm outperforms DVR.

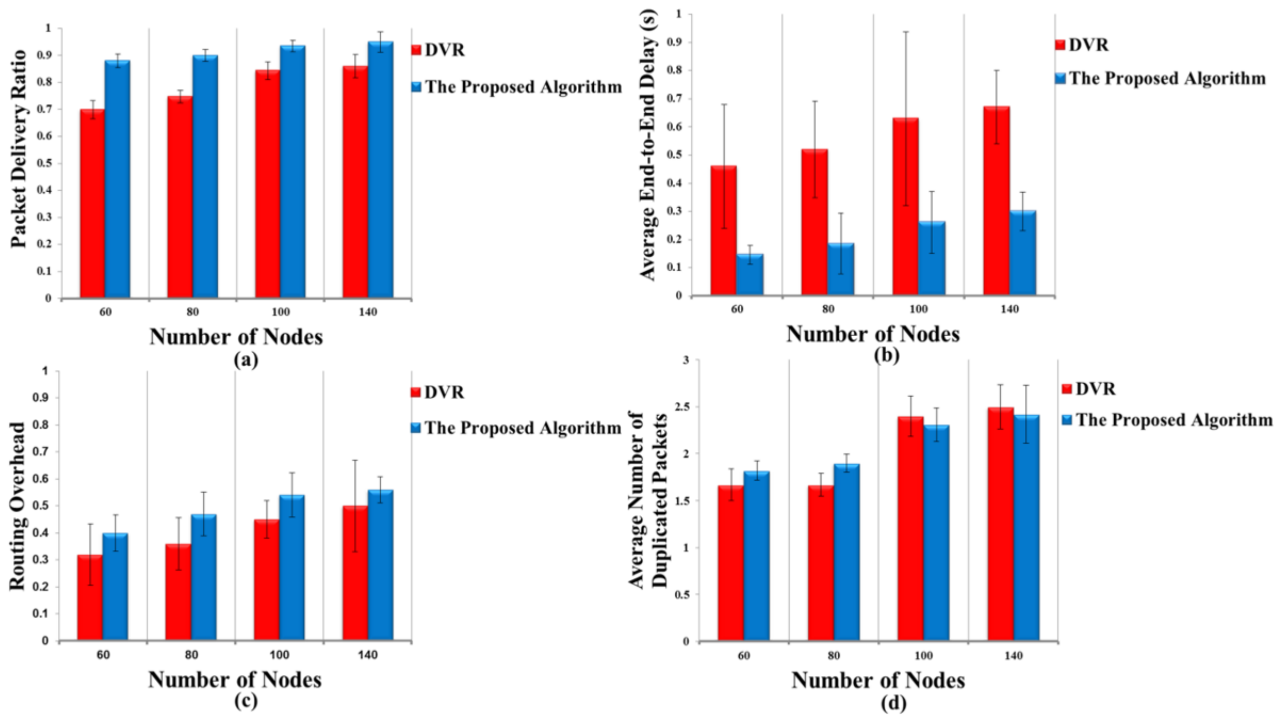

Fig. 5. (a) Data Delivery Ratio, (b) Average End-to-End Delay, (c) Routing Overhead, and (d) Duplicated Packets versus nodes' density

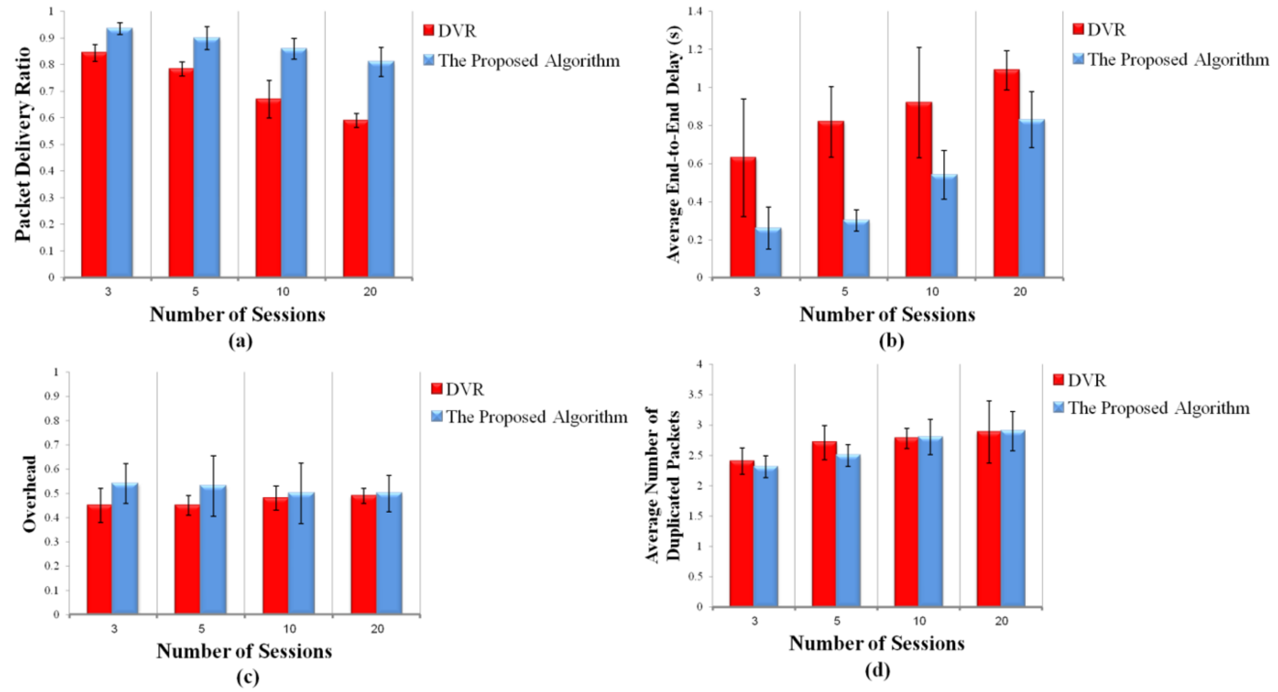

Fig. 6. (a) Data Delivery Ratio, (b) Average End-to-End Delay, (c) Overhead, and (d) Duplicated Packets versus the number of communication sessions

It can make load balancing in the entire network and better packet delivery ratio and average end-to-end delay are achieved.

Although DVR performs almost the same as the proposed algorithm in terms of routing overhead (Fig. 6c), it has a poor data delivery ratio (Fig. 6a) and also the end-to-end delay (Fig. 6b). This is due to the cross-layer design in the proposed algorithm.

6 CONCLUSION

Most MANET routing algorithms need to establish a connection before nodes can communicate with each other. This strategy is not robust to the nodes' mobility and topological changes. Connectionless approach is a routing technique for more robust communications in MANETs. However, existing connectionless routing algorithms are based on the shortest path and cross-layer metrics are not considered well. A cross-layer design is applied to DVR, as a connectionless routing algorithm, to improve its performance in this paper. Some physical, MAC and network layer metrics (number of node's neighbors, load of the nodes and number of hops) are used together in this algorithm.

The proposed algorithm avoids routing through highly mobile and congested nodes to discover more stable routes. Thus, it is resistant to link breaks and it is expected that the load will be more balanced and distributed in the network.

The simulation results showed that the proposed algorithm achieved better performance compared to DVR, in terms of average end-to-end delay and packet delivery ratio. This improvement is due to the selection of the routes with lower nodes' load, collision and broken links, which is the result of cross-layer design in the proposed algorithm.

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