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ORIGINAL ARTICLE

Mobility and Load aware Routing protocol for ad hoc networks

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Abstract Mobile ad hoc networks (MANETs) are very promising wireless technology and they offer wide range of possibilities for the future in terms of applications and coverage. Due to the complex nature of MANETS, their development processes face several challenges such as routing. Many routing algorithms have been proposed for MANETs. Reactive routing protocols are favored and popular in MANETs because they are more scalable and generate fewer overhead on the network. But, these protocols suffer from the broadcast storm problem due to the flooding strategy that is used in the route discovery process which causes redundancy, contention and collision problems. In order to reduce the effects of the broadcast problem, a Mobility and Load aware Routing scheme (MLR) is proposed in this paper. MLR controls the flooding process by restricting the rebroadcast messages on the slow speed and low loaded nodes. Each node decides whether to forward or drop the received request message based on several factors (such as speed and routing load) using Markovian Decision Process tool. Simulation results show that MLR scheme outperforms the original AODV protocol in terms of normalized routing load and average end-to-end delay.

1. Introduction

Mobile ad hoc network (MANET) is an infrastructure-free network usually constructed without a priori knowledge of the environment (Internet Engineering Task Force, in preparation). It consists of a number of nodes distributed over a geographical area that dynamically changes their positions and able to join, move or leave the network freely. Because of limited radio propagation range of the nodes, routes are mostly multihop. Therefore, each node has a responsibility to be a route to forward packets for other nodes. The network topology changes frequently in MANET because of nodes mobility and power limitations. Thus, routing protocols in such networks play a significant rule.

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The routing process is one of the most challenging aspects in MANETs because of its limited resources, dynamic features and instable wireless links. The famous classification type of ad hoc the routing protocols divides them into proactive and reactive classes based on the way the route information is determined, maintained and stored. In the proactive routing protocol, every node keeps up-to-date information about all nodes in the network by periodically exchanging routing information so each node has a complete view of the network topology. It has the advantage of shortest response time to determine up-to-date routes but wastes the network resources by control packets and routes that may not be used at all. The Destination-Sequenced Distance Vector (DSDV) protocol (Perkins and Bhagwat, 1994) is an example of this type.

In the reactive routing protocol, the routes are created only when a node wants to send data to another node in the network (i.e., on demand). There are no predefined routes. Its main advantage is the reduced overhead on the network because there is no need to exchange information about the network topology. On the other hand, it increases the time to find the route, and the source must reinitiate a new route request when the old has failed. Also, it has to rebroadcast a large number of requests during the route discovery process which causes the broadcast storm problem. Ad hoc On-demand Distance Vector (AODV) is an example of this type (Perkins and Royer, 1999).

Reactive protocols are favored than proactive protocols because they are more scalable and generate less traffic as they discover routes only when needed (Royer and Tog, 1999). The main goal of reactive protocols is to find the shortest path from the source to the destination when the communication takes place. The route discovery process in these protocols floods the network with route request packets and causes the broadcast storm problem (Ni et al., 1999), which leads to degradation in the performance of the network. In addition, the percentage of link breakage is high, especially when the mobility of nodes is high because any movement can make the route unusable and it may be lost. Solving the problem by preventing high-speed nodes from participating of the route discovery process can lead to finding a more stable route, and reduces the routing overhead. But, this may lead to network congestion and concentrate the routing load on certain nodes while others remain idle.

In this paper, we focus on building a more stable route and balancing the load among various routes in a high mobility and high traffic load environment. We propose a new scheme called Mobility and Load aware Routing scheme (MLR), which utilizes the speed and traffic load of the intermediate nodes, to determine the best reliable route during the route discovery process and to prolong the life time of the whole network. Each node decides whether to rebroadcast or drop the arrived request using the Markovian Decision Process (MDP) tool. The main goal of the new scheme is to maximize the throughput of the network and minimize the average delay and the routing overhead.

The rest of this paper is organized as follows. Section 2 presents some of the related works. Section 3 gives an overview of the Markovian Decision Process (MDP). In Section 4, we discuss the main idea and the operation details of the MLR scheme. Section 5 presents the simulation environment and experimental results. The paper is concluded in Section 6.

2. Related works

Many schemes have been proposed to solve the broadcast storm problem in the reactive protocols by using different mechanisms to control the broadcast process. The main solution theme is based on the idea of just allowing a deterministic group of neighbors to do the rebroadcast process. This group is chosen based on different criteria. Some schemes like location-based scheme, counter-based scheme, distance-based scheme and probabilistic scheme (Ni et al., 1999) differentiate the time of rebroadcast and let the node decides to whether rebroadcast or not, using some fixed thresholds. These schemes decrease the delay time and reduce the number of Route Request (RREQ) packets. On the other hand, they have some disadvantages as the need of some special devices (e.g. GPS), using fixed thresholds and miss the destination problem (low reachability).

Other schemes have been also proposed that use other factors like mobility and traffic load of the nodes to improve the network performance. When the mobility of the nodes is taken into account, choosing the nodes with low mobility leads to discover a more stable route and can eliminate many redundant broadcast packets.

Mobility aware agent scheme (Idrees et al., 2005) uses the positions of the nodes to select the next hop of the route discovery process so the nodes with low mobility just can participate in the discovered routes. This leads to a decrease in the link breakage and the overhead of the network and an increase in the throughput of the network. The disadvantage of this scheme is the use of special devices like GPS to compute the location of each node and extra overhead due to using the HELLO packets to distribute the connectivity information.

Velocity Of Node (VON) is another mobility-based scheme that utilizes the speed of nodes to restrict the rebroadcast process to the slow speed nodes (Liu and Qu, 2008). This process makes the discovered path more stable. The disadvantage of this scheme is that the threshold speed is computed in a fixed way by using a deterministic number of slow nodes and a static view of the topology.

Reactive protocols choose the best path based on the smallest number of hops (shortest path) to reach the destination and ignore any other metrics. By doing so, the nodes which participate in the shortest path will have a high load and are always busy while other nodes are idle. Therefore, some routing protocols take into account the traffic load in the intermediate nodes during the route discovery process to balance the load in the overall network and to get a high performance.

Associativity-Based Routing (ABR) is the first protocol that considers the load as a metric in the routing process (Toh, 1997). However, it uses the load as a secondary metric and computes the load of the node as the number of routes the node participates in. The disadvantage of this protocol is that it does not account for all types of traffic loads of each data session.

Dynamic Load-Aware Routing (DLAR) uses the traffic load as the main metric in the route selection process to solve the reply storm problem (Lee and Gerla, 2001). It prevents the heavily loaded nodes from participating in the route to make it more stable. Although it reduces the end-to-end delay and increases the delivery ratio, it still has a large overhead because of the request-flooding problem in the route discovery phase.

Load aWare Routing (LWR) is another scheme based on balancing the load throughout the network (Yi et al., 2003). The main idea of LWR is to drop the redundant RREQ in the intermediate node based on some local information like node queue size and channel utilization. It reduces the effects of the broadcast storm problem but, it uses a predefined threshold to compute utilization, which cannot always give the right topology of the network. More work on AODV was conducted in Karthikeyan et al. (2010), Khelifa and Maaza (2010) and Mohseni et al. (2010). In Karthikeyan et al. (2010), the authors evaluated the performance of various routing protocol and their influence on the network performance. In Khelifa and Maaza (2010), the Energy Multi-path Ad hoc On-demand Distance Vector routing (EM-AODV) protocol was proposed. EM-AODV considers two factors, multi routes to overcome the rapid topology change problem, and residual energy to better select the routes. Mohseni et al. (2010) provides a performance evaluation comparison between various routing protocols in MANETS for different network conditions.

In this paper, we propose the MLR scheme based on the speed and the routing load of the nodes. The advantages of MLR include:

- Decrease the effects of broadcast storm problem by reducing the total rebroadcast traffic during flooding process in the route discovery process.
- Find a more stable route consisting of slow and heavily loaded nodes to decrease the overhead of the routes maintenance process and minimize the average delay.
- Save the power of the nodes by distributing the load among all nodes and decreasing the number of broadcast messages. Thus, the lifetime of the network is extended.

3. Markovian Decision Process (MDP)

MDP is a mathematical framework that has been proposed to formulate and solve decision problems with some properties (Tijms, 1984, 1994). It is used to model the situations in which the agent can exactly observe all related aspects of the environment states and make a decision to which action must be taken. A MDP represents a control problem using four objects. MDP = (S, A, T, R) where:

- S is the state space that presents all possible states of the system.
- A is the set of actions that can be taken by the agent to go to a new state.
- T is the transition function that specifies the probability that an action in a state leads to a new state.
- R is the reward function that specifies the expected value of the agent as a function of current state and action.

The transition function in MDP has the Markovian property which means that the probability of going to the next state depends only on the current state and the action to be taken. The goal of using MDP framework is to develop an optimal policy that specifies which action to perform in any state. An optimal policy is a set of actions that maximizes the expected accumulated reward over the lifetime of the agent.

Value iteration, policy iteration and modified policy iteration methods are used to solve MDP problems and based on dynamic programming (Bellman, 1957; Kaelbling et al., 1996). Value iteration method involves iterating over a value function to calculate the expected value of each state until the value differential for each state reaching to convergence point. The value function is a function of states that gives the agent an estimation of how good to perform an action in a given state depends on the expected future rewards. Eq. (1) presents the value function of a state s where γ is a discount factor between 0 and 1 and it is typically close to 1:

$$V(s) = R(s) + \gamma \sum_{s' \in S} P^a(s,s')V(s') \quad (1)$$

After computing the expected value of each state, the optimal policy (best action) π^* with a maximum expected reward can be obtained using Eq. (2). The optimal policy is a mapping from a state to the best action that should be taken. The value iteration algorithm is shown in Fig. 1:

$$\pi^*(s) = \underset{a \in A}{\mathrm{Max}} \left(R(s) + \gamma \sum_{s' \in S} P^a(s,s')V(s') \right) \quad (2)$$

4. The proposed MLR scheme

4.1. Overview and the main idea

The Mobility and Load aware Routing scheme (MLR) aims to find a stable route with a long lifetime by letting the intermediate nodes to decide whether to broadcast or drop the RREQ packets based on its speed and routing load. To make such decision, MLR uses the Markovian Decision Process (MDP) tool trying to find the best action that the node can take to maximize the overall network performance. MLR modifies the route discovery phase specifically the propagation of RREQ packets of the original reactive protocols. Route replay and maintenance is the same as the original protocol.

MLR aims to solve the broadcast storm problem by dealing with the dynamic topology feature of ad hoc networks and to distribute the load among all nodes in the network. This

```
Algorithm: Value Iteration
Input:   M        /* MDP to be solved */
Output: π *       /* Optimal policy */
/* First, Compute the value function of each state */
  Initialize V'(s)→0  for all s∈S
      Loop until policy good enough /* to reach the convergence*/
            Loop for s∈S
                Loop for a∈A
                      V(s): = R(s,a) + γ∑P^a(s,s')V(s')
                                        s'∈S
                End loop
            End loop
      End loop
 /* Obtaining the optimal policy from the value function */
    For all s∈S

        π*(s) = argMax (R(s,a) + γ∑P^a(s,s')V(s'))
                 a∈A          s'∈S
    End for
```

Figure 1 Value iteration algorithm.

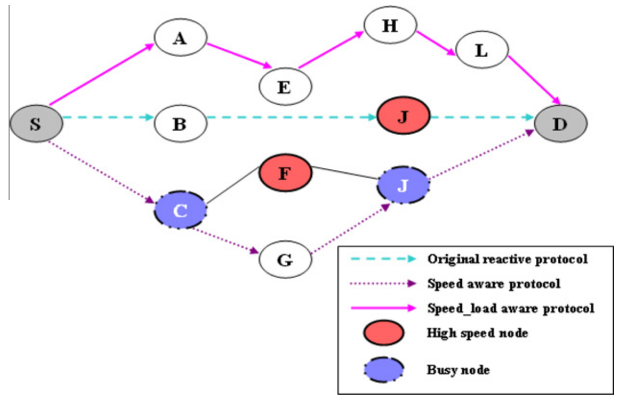

Figure 2 Route selection process using three mechanisms.

scheme takes into account the speed and the traffic load of each node. The speed of a node is considered so as to prevent a high-speed node from participating in the route discovery process. This leads to finding a more stable route, and it reduces the routing overhead. But, this may lead to network congestion and concentrate the routing load on certain nodes (high-speed nodes). To solve this problem, MLR monitors the traffic load of each node dynamically throughout the lifetime of the network. By monitoring the node load, routes that contain heavily loaded nodes can be avoided.

Fig. 2 illustrates the route selection process using the original reactive protocol, speed aware reactive protocol and MLR protocol. The original reactive protocol chooses the shortest path "S-B-J-D" with number of hops equal to 3. But, this path is not stable because it contains the high speed node J, which moves fast and changes its position, which might lead to break the discovered route and reinitiate a route discovery process for a new route. The speed aware protocol chooses the path "S-C-G-J-D" because it does not contain a high speed node and it is the first shortest path back to the source node S. But on the other hand, it contains the congested nodes C and J which increases the average end-to-end delay of the forwarding process. MLR protocol chooses the path "S-A-E-H-L-D". Although it has 5 hops to reach the destination, it is better and more stable than the other two protocols with 3 and 4 hops. Preventing the high speed nodes to be a part of the selected route and distributing the load among the nodes evenly improve the performance in terms of end-to-end delay, delivery ratio and network throughput. Moreover, it prolongs the nodes lifetime by preventing the battery power resulted from broadcasting useless control packets.

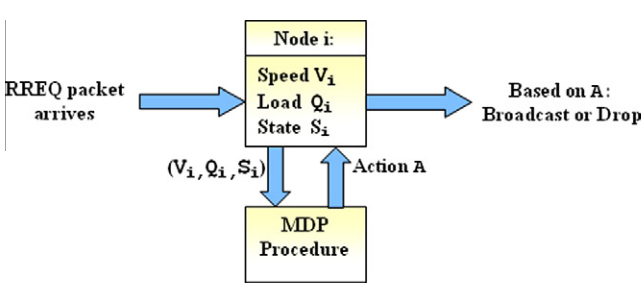

Figure 3 Decision making system model.

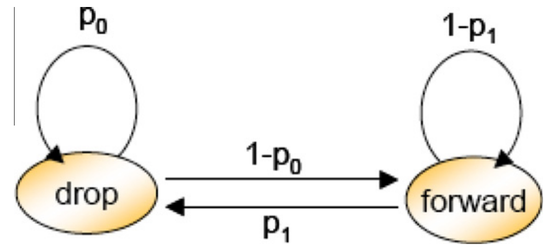

Figure 4 Transition graph.

4.2. Design of MLR

During the route discovery process, when an intermediate node i receives a RREQ packet for the first time and it is not the destination, it decides to rebroadcast or drop this packet using a decision making system as shown in Fig. 3. Node i passes three parameters to an MDP procedure to get the action A that should be taken in the current time.

These parameters are the speed V_i, the routing load Q_i and the current state S_i of the node i. V_i is used to prevent the high speed nodes from participating in the discovered route to make it more stable and to decrease the number of unuseful control packets propagated throughout the network. The routing load Q_i is the number of routing packets in the interface queue of the node i which includes RREQ, Rout Reply (RREP) and Rout Error (RERR) packets. It is used to save the node from occurring congestion by preventing heavily loaded nodes to be a part of a new route. S_i, which includes forward and drop states, presents the current state of node i based on the last action taken. If the S_i is forward, the chance to forward the arrived packet is decreased and visa versa.

4.3. MDP model for MLR protocol

Each node will have a corresponding set of MDP parameters S, A, P, R to pass them as input to the MDP procedure that decides the best action to be taken. MDP parameters are:

4.3.1. Set of states (S)

The possible states for each node in the network are $S = \{Forward, Drop\}$ based on the last action that the node performed.

4.3.2. Set of actions (A)

The actions set a node can perform when it receives a RREQ packet are

$$A = \{Forward\_RREQ, Drop\_RREQ\}$$

4.3.3. Transition probability function (P)

The transition function specifies the probability of reaching the next state depending only on the current state and action:

$$P^a_{ij} = \text{probability}(\text{next} = j|\text{current} = i,\ \text{action } a)$$

This probability will be constructed in MLR based on the routing load and the speed of the node. Fig. 4 shows the transition graph that presents all possible transitions of the node state. Also, Table 1 shows the corresponding transition matrix.

The probabilities are computed as follows:

- If the node in a *Drop* state

$$\rightarrow P^{D}_{11} = P_0 = \left(\left(\frac{V_i}{V_{max}}\right) * \alpha\right) * \beta + \left(\frac{Q_i}{Q_{max}}\right) * (1-\beta)$$

$$P^{F}_{12} = 1 - P_0$$

- If the node in a *Forward* state

$$\rightarrow P^{D}_{21} = P_1 = \left(\left(\left(\frac{V_i}{V_{max}}\right) * \alpha\right) * \beta + \left(\frac{Q_i}{Q_{max}}\right) * (1-\beta)\right) w$$

$$P^{F}_{22} = 1 - P_1$$

where P^{D}_{11}: probability(next = Drop | current = Drop, action *Drop_RREQ*); P^{F}_{12}: probability(next = Forward | current = Drop, action *Forward_RREQ*); P^{D}_{21}: probability(next = Drop | current = Forward, action *Drop_RREQ*); P^{F}_{22}: probability(next = Forward | current = Forward, action *Forward_RREQ*); V_i: the speed of the node *i*; V_{max}: the maximum speed that is allowed in the network; Q_i: the number of routing packets in the interface queue of the node *i*; Q_{max}: the maximum length of the interface queue that stores the routing packets for the node; α: a coefficient value specifies the percentage that is taken from the speed of the node and its adaptive based on the maximum speed V_{max}; β: a coefficient value that describes the weight of the speed in the probability function and also its adaptive based on the maximum speed V_{max}; *w*: a discount factor that gives the node in the forward state a less probability to forward again $0 < \alpha, \beta, w < 1$.

4.3.4. Reward function (R)

The reward values that the state earns when it performs a transition from the current state to the next state are shown in Table 2:

- If the action is *Drop_RREQ*, the node earns +2 points regardless of the current state.
- If the action is *Forward_RREQ* the node earns +1 points regardless of the current state.

To solve the MDP problem in MLR scheme, the value iteration method, which described in Section 3, is used.

4.4. Adaptive property of MLR

To make the MLR scheme adaptive with respect to the maximum allowable speed in the network, the values of α, β and *w* are set dynamically. The α value is used to divide the nodes into high speed and low speed groups. So, it should be chosen carefully to resolve the tradeoff between reachability and rebroadcast issues. When the speed is increased, the α value should be increased to guarantee that the request will be rebroadcasted by relatively large number of nodes to have a maximum reachability.

The coefficient value β is used to distribute the priority between speed and load factors. The speed is given a large priority when deciding to rebroadcast or not to make the discovered routes more stable and the load is considered to save the heavily loaded nodes from congestion. The β value is chosen adaptively based on the maximum speed. It is decreased when the speed is high because the congestion level is increased.

The *w* value is used to avoid the congestion in the slow speed nodes group. So, when a node is in a forward state, the chance to forward a new request is decreased. It should be chosen carefully to achieve balance between speed and congestion. The *w* value is decreased with increasing the maximum speed because the congestion level is increased.

Table 1 Transition function matrix.

State/action	*Drop_RREQ* (*D*)	*Forward_RREQ* (*F*)
Drop (*1*)	P_0	$1 - P_0$
Forward (*2*)	P_1	$1 - P_1$

Table 2 Reward matrix.

State/action	*Drop_RREQ* (*D*)	*Forward_RREQ* (*F*)
Drop (*1*)	+2	+1
Forward (*2*)	+2	+1

5. Simulation results and analysis

The simulation is conducted using GloMoSim library (Zeng et al., 1998; GloMoSim) to simulate and study the behaviors of MLR scheme. We use the well-known AODV protocol (Das et al., 2003) as a reference to improve that MLR achieves better performance against the original reactive protocols. AODV is chosen as it is a popular protocols in ad hoc networks, and it has shown better performance results relative to other protocols (Jayakumar and Gopinath, 2008; Mishra et al., 2008).

5.1. Simulation setup

The simulated network consists of 100 nodes distributed randomly in a rectangular area of 2200×600 m. Each simulation ran for 500 simulated s, multiple runs were made with different random seeds to change the random simulator parameters, and the obtained data was averaged for each point. The IEEE 802.11 is used as the underlying MAC layer communication model (IEEE 802.11, 1999) with 2 Mpbs data rate and the radio range is set to 250 m. The random waypoint is used as the nodes mobility model (Camp et al., 2002) with minimum speed equal to 0 and maximum speed varied from 0 to 30 m/s with step 5. The pause time is set to 0. Constant bit rate (CBR) traffic with 512 byte data packets is used. The number of CBR connections is varying between 30 and 100. The sending packet rates used in the simulation are 4, 8, 12, 15 and 20 packets/s. Table3 summarizes the simulation parameters.

5.2. Performance metrics

The following are the metrics that are used to evaluate and assess the performance of the simulated routing protocols (Corson and Macker, 1999):

Table 3 Simulation parameters.

Parameter	Value
Simulator	GloMoSim (version 2.03)
Simulated protocols	MLR and AODV (version 13)
Simulation time	500 s
Simulation area	2200 m × 600 m
Number of nodes	100 nodes
Transmission range	250 m
Bandwidth	2 Mbps
Mobility model	Random waypoint
Minimum speed	0 m/s
Maximum speed	0–30 m/s step 5
Pause time	0 s
Traffic type	CBR
Data packet size	512 byte
Packet rate	4, 8, 12, 15 and 20 packets/s
Number of connection	30, 40, 50, 60, 80 and 100
α, β, w	Varying based on the maximum speed

1. *Packet Delivery Ratio (PDR):* the average number of data packets transmitted by the source per data packet delivered to the destination. The loosing packets are not considered.
2. *Average end-to-end delay:* the average delay from the time the packet is originated at the source to the time it reaches the destination. This delay includes delaying time of the route discovery process, buffering delay at the intermediate nodes interface queue, the transmission process at the MAC layer, packet processing, and transferring and propagation times.
3. *Normalized routing load:* the average number of routing packets that are transmitted per data packet delivered. The routing packets are computed in terms of different control packets that are used by the routing protocol algorithm. It gives a measure of the protocol overhead.
4. *Routing overhead:* the ratio of the total number of routing packets to the number of all packets that attempted to be sent to MAC layer. It addresses the ratio of the overhead of the routing packets to all packets (i.e., control and data) that transmitted by the node.

5.3. Results and analysis

To study the performance of MLR and compare it against AODV, two different types of simulation scenarios are conducted:

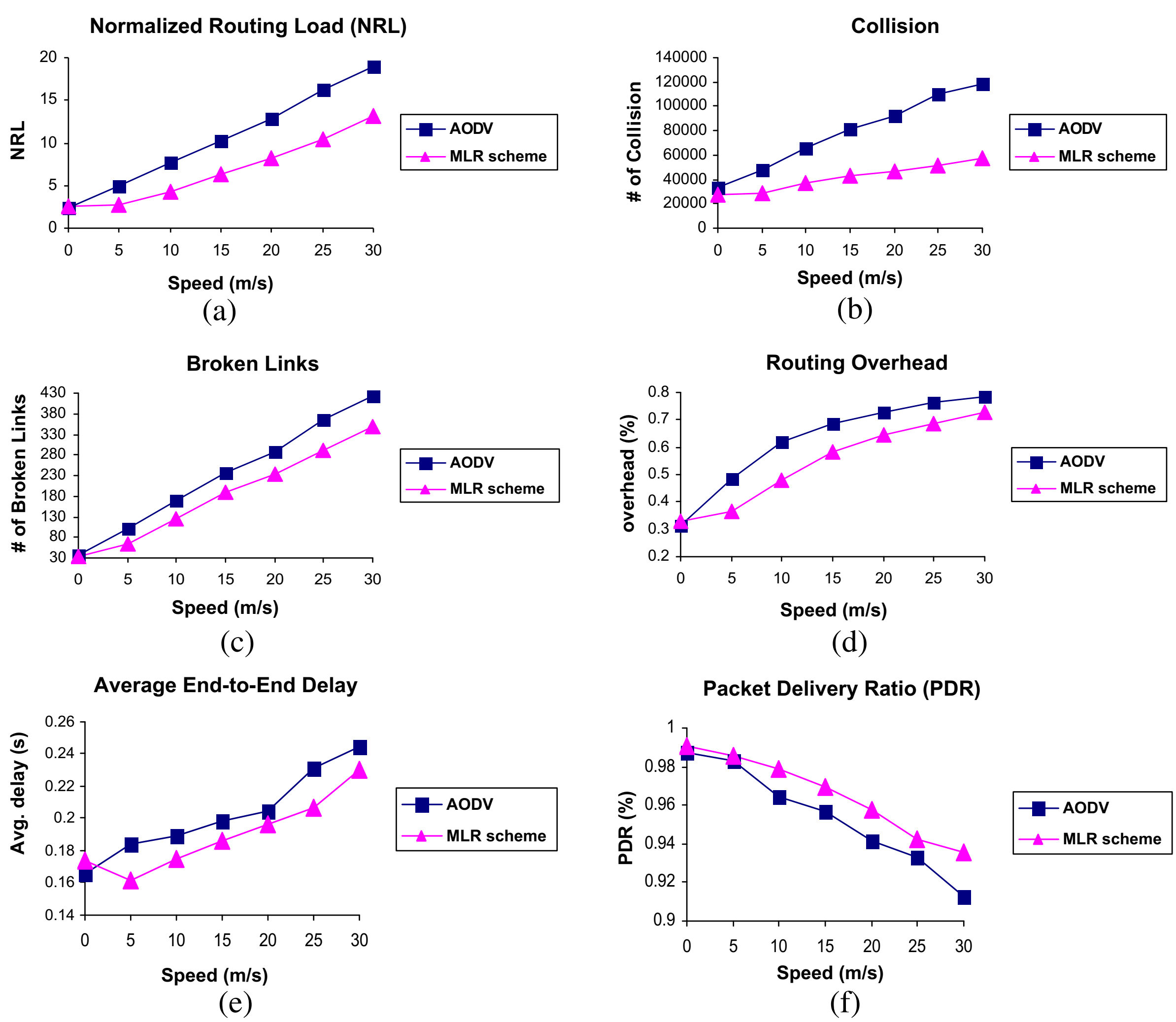

Figure 5 The performance metrics vs. speed at 4 packets/s with 30 CBR connections.

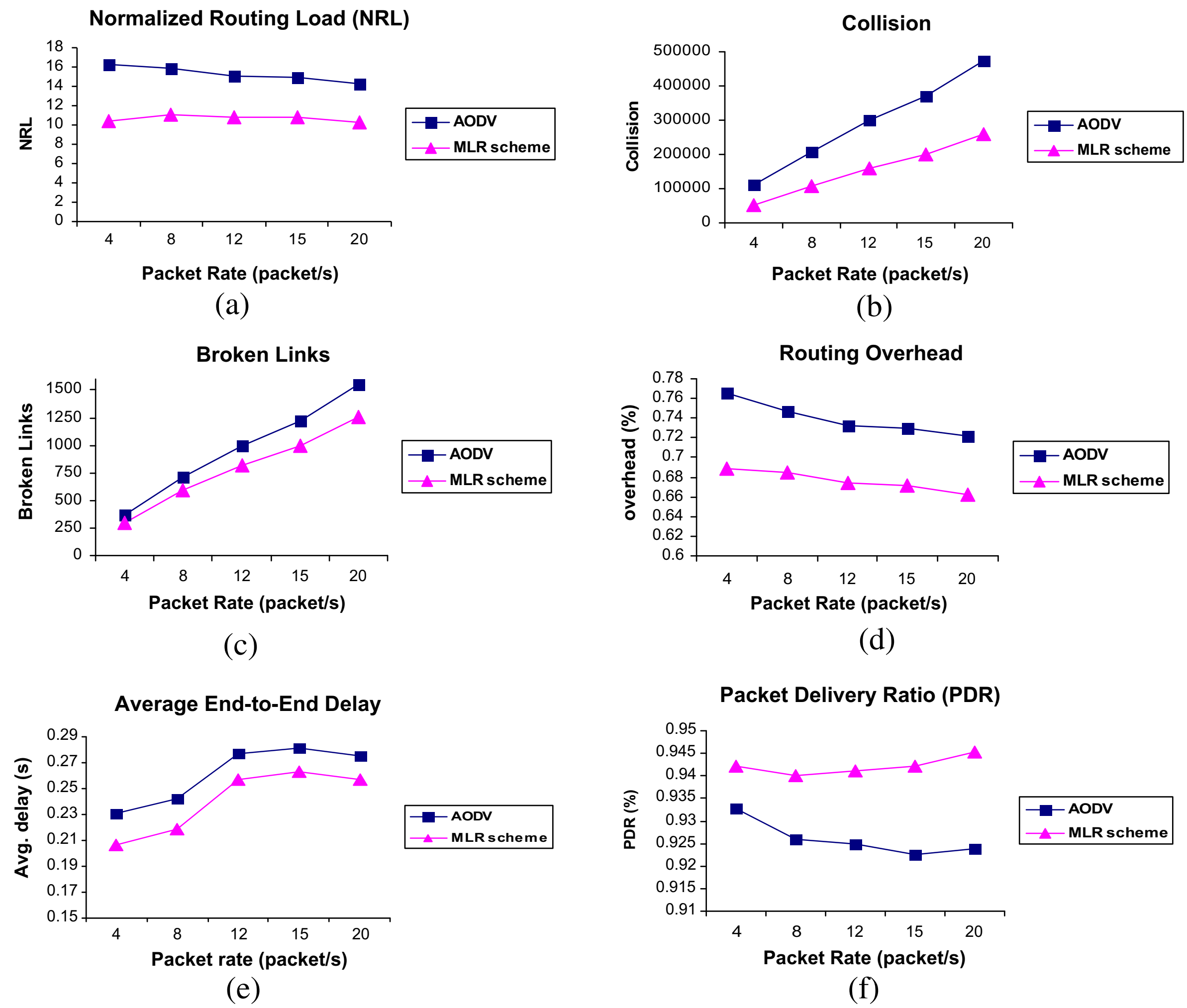

Figure 6 The performance metrics vs. packet rate at speed 25 m/s with 30 CBR connections.

- *Mobility simulation:* is done by varying the maximum speed of the nodes to see how it affects the behaviors of the protocols in terms of some measured metrics.
- *Offered load simulation:* is done by varying the packet rate ratio to see how the protocols behave when the load is high.

5.3.1. Mobility simulation

5.3.1.1. Normalize routing load. Fig. 5(a) presents the normalized routing load vs. speed at sending rate equal to 4 packets/s with 30 CBR connections. It shows that the MLR scheme generates less routing load and reduced it to 39% comparing to AODV. MLR decreases the number of RREQ packets by letting only the nodes with low speed and low load to propagate these packets. On the other hand, AODV uses the blind flooding and allows all nodes to broadcast the RREQ packets, which lead to large routing load overhead. Also, the number of collision states in MLR is reduced to 47% as shown in Fig. 5(b) because the percentage of concurrent transmission is decreased.

The number of RERR packets is also reduced by MLR because the number of broken links is decreased due to the stable routes that are discovered. In AODV, the number of broken links is increased, especially in the high mobility scenarios as presented in Fig. 5(c) because of the nodes movement which leads to path breakages. Then it floods the network with RERR notification message which increases the routing load overhead. As a result, the overhead of the network layer at the MAC layer is decreased by 15% as shown in Fig. 5(d).

5.3.1.2. Average end-to-end delay. Although AODV uses the shortest path to forward the data, MLR generates less average delay. This verifies our earlier observation which says that the shortest path is not always the best metric to choose a path. The MLR scheme improves the average delay by nearly 8% comparing to AODV protocol as seen in Fig. 5(e). This improvement is due to the lower number of routing load, collision and broken links in MLR. MLR scheme avoids routing through high speed and busy nodes and deliver packets faster. The number of broken links is decreased due to the stable routes that being discovered by MLR which contains only low speed nodes. Also, the buffering time in the intermediate nodes queue is low because the congested nodes are prevented from participating in the discovered route. In AODV, the redundant rebroadcast causes contention and collision problems which may lead to failure in delivering of route request to the destinations. Thus, another route request is required and the delay is increased.

5.3.1.3. Packet Delivery Ratio (PDR). The goal of MLR scheme is to reduce the routing load to the maximum possible level while keeping the PDR as close as possible to AODV protocol. The obtained results show that PDR of the MLR scheme is approximately same as AODV protocol with a slight improvement of 2% as seen in Fig. 5(f). AODV broadcasts large number of routing messages during the route request process so some packets can be lost due to the contention and collision problems. When the speed is increased, the PDR is decreased because the routing traffic uses a large amount of nodes bandwidth. Therefore, the PDR is decreased for both AODV and MLR.

5.3.2. Offered load simulation by varying the sending packet rate
The offered load simulation is done by varying the sending packet rate. The maximum speed is fixed at 25 m/s while the packet rates are varied to 4, 8, 12, 15 and 20 packets/s to see the behaviors of the two protocols in the high speed and high load environment. Fig. 6(a), (e) and (f) illustrates that the MLR scheme achieves better performance in terms of normalized routing load, average end-to-end delay and Packet Delivery Ratio, respectively, and survives under heavy load. These improvements are due to the stable routes that are used in the forwarding data which only involved low loaded nodes. Therefore, the number of broken links is decreased, the number of routing packets is reduced and the collision is decreased. The average delay and packet PDR are improved as the load on the network increases because of the reduced congestion in MLR at higher loads. Also, MLR scheme avoids routing through busy nodes and deliver packets fast.

6. Conclusion

Routing is a challenging task for MANETs. Here, we propose a new Mobility and Load aware Routing (MLR) scheme that utilizes the speed and the routing load of the nodes to reduce the effects of the broadcast storm problem. MLR avoids routing through high speeds and congested nodes to discover more stable routes. The decision to whether broadcast or drop the packet's request is decided by a Markovian Decision Process. This scheme can be combined with any ad hoc reactive routing protocol to make it more efficient and scalable. The results demonstrate that our scheme achieves better performance over the original AODV protocol in terms of average end-to-end delay and Packet Delivery Ratio and reduces the normalized routing load. In the future, we propose to further investigate the effect of including other factors in the decision process such as traffic type. (Other factors such as node's density, remaining power capacity and wireless link quality can be taken into accounts to make this decision. Scalable simulation can be conducted to demonstrate the effects of changing the network size and the number of nodes on the MLR scheme. Studying the power consumption and the lifetime of the network in MLR scheme and comparing the result with the AODV protocol are also recommended).

References

Bellman, R.E., 1957. A Markov decision process. Journal of Mathematics and Mechanics 6, 679–684.

Camp, T., Boleng, J., Davies, V., 2002. A survey of mobility models for ad hoc network research. Wireless Communications and Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications 2 (5), 483–502.

Corson, S., Macker, J., 1999. Mobile Ad Hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations. <http://www.ietf.org/rfc/rfc2501.txt>.

Das, S., Perkins, C., Royer, E., 2003. Ad hoc on-demand distance vector (AODV) routing. Request for Comments (RFC) 3561.

GloMoSim: Global Mobile Information Systems Simulation Library. <http://www.pcl.cs.ucla.edu/projects/glomosim/>.

Idrees, M., Yousaf, M.M., Jaffry, S.W., Pasha, M.A., Hussain, S.A., 2005. Enhancement in AODV routing using mobility aware agents. In: IEEE International Conference on Emerging Technologies, Islamabad, September 17–18, 2005, pp. 98–102.

IEEE 802.11, 1999. Wireless LAN MAC and Physical Layer Specifications. Editors of the IEEE.

Internet Engineering Task Force, in preparation. MANET Working Group Charter. <http://www.ietf.org/html.charters/MANET-charter.html>.

Jayakumar, Geetha, Gopinath, G., 2008. Performance comparison of two on-demand routing protocols for ad-hoc networks based on random way point mobility model. American Journal of Applied Sciences 5 (6), 659–664.

Kaelbling, L.P., Littman, M., Moore, A., 1996. Reinforcement learning: a survey. Journal of Artificial Intelligence Research 4, 237–285.

Karthikeyan, M. Saravana, Murali, M., Sujatha, S., 2010. Identifying performance metrics to maximize MANETs throughput. In: Proceedings of the International Conference on Advances in Computer Engineering (ACE), June 20–21, 2010, pp. 357–359.

Khelifa, S., Maaza, Z.M., 2010. An energy multi-path AODV routing protocol in ad hoc mobile networks. In: Proceedings of the Fifth International Symposium I/V Communications and Mobile Network (ISVC).

Lee, Sung-Ju, Gerla, Mario, 2001. Dynamic load-aware routing in ad hoc networks. In: Proceedings of the IEEE International Conference of Communication (ICC) 2001, vol. 10, Helinski, Finland, pp. 3206–3210.

Liu, Wang-gui, Qu, Zhao-wei, 2008. Scheme for on-demand route protocol in ad-hoc networks. The Journal of China Universities of Posts and Telecommunications 15 (Suppl.), 41–45.

Mishra, Namit, Pandey, Amit, Nahata, Naveen, Sinha, Rakesh, Tapaswi, S., 2008. Selection of ad hoc network routing protocols by performance analysis. In: Proceedings of the Second National Conference on Challenges and Opportunities in Information Technology (COIT-2008) RIMT-IET, Mandi Gobindgarh, March 29, 2008, pp. 113–116.

Mohseni, S., Hassan, R., Patel, A., Razali, R., 2010. Comparative review study of reactive and proactive routing protocols in MANETs. In: Proceedings of the Fourth IEEE International Conference on Digital Ecosystems and Technologies (DEST), p. 304.

Ni, Sze-Yao, Tseng, Yu-Chee, Chen, Yuh-Shyan, Sheu, Jang-Ping, 1999. The broadcast storm problem in a mobile ad hoc network. In: Proceedings of the Fifth International Conference on Mobile Computing and Networking (ACM MOBICOM'99), Seattle, August 1999, pp. 151–162.

Perkins, C., Bhagwat, P., 1994. Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. In: Proceedings of the ACM SIGCOMM'94 Conference on Communications Architectures, Protocols and Applications, London, UK, August 1994, pp. 234–244.

Perkins, Charles E., Royer, Elizabeth M., 1999. Ad hoc on-demand distance vector routing. In: Proceedings of the Second IEEE Workshop on Mobile Computing Systems and Applications (WMCSA'99), New Orleans, LA, February 25–26, 1999, pp. 90–100.

Royer, E.M., Tog, C.-K., 1999. A review of current routing protocols for ad hoc mobile wireless networks. IEEE Personal Communications Magazine, pp. 46–55.

Tijms, Henk C., 1984. Stochastic Modeling and Analysis: A Computational Approach, first ed. John Wiley and Sons, Chichesters/New York/Toronto/Singapore, p. 159.

Tijms, Henk C., 1994. Stochastic Models: An Algorithmic Approach, first ed. John Wiley and Sons, Chichesters/New York/Toronto/Singapore, p. 181.

Toh, C.-K., 1997. Associativity-based routing for ad-hoc mobile networks. Wireless Personal Communications Journal 4 (2), 103–139.

Yi, Yunjung, Kwon, Taek Jin, Gerla, Mario, 2003. A Load aWare Routing (LWR) based on Local Information. Telcordia Technologies, Applied Research, University of California, Los Angeles.

Zeng, Xiang, Bagrodia, Rajive, Gerla, Mario, 1998. GloMoSim: a library for parallel simulation of large-scale wireless networks. In: Proceedings of the 12th Workshop on Parallel and Distributed Simulation, Banff, Alberta, Canada, May 26–29, 1998, pp. 154–161.