J Supercomput (2010) 53: 196–211
DOI 10.1007/s11227-010-0408-0

A new probabilistic broadcasting scheme for mobile ad hoc on-demand distance vector (AODV) routed networks

Muneer Bani Yassein · Mustafa Bani Khalaf · Ahmed Y. Al-Dubai

Published online: 17 March 2010

Abstract Broadcast is a fundamental operation used in Mobile Ad hoc NETworks (MANETs) for many services, such as route discovery and sending information messages. The direct method to perform broadcast is a simple flooding, which can decrease the performance of MANET. Recently, a probabilistic approach to flooding has been proposed as one of most important suggested solutions to solve the broadcast storm problem, which leads to the collision, contention and duplicated messages. This paper presents the Smart Probabilistic Broadcasting (SPB) as a new probabilistic method to improve the performance of existing on-demand routing protocols by reducing the RREQ overhead during the rout discovery operation. The simulation results show that the combination of AODV and a suitable probabilistic rout discovery can reduce the average end-to-end delay as well as overhead, while achieving low normalized routing load, compared to AODV that uses fixed probability and blind flooding. Simulation experiments have been conducted to examine our proposed scheme. The results show that SPB outperforms its counterparts and opens up a promising framework towards optimal probabilistic broadcasting.

Keywords MANET · Routing overhead · Flooding · Simulation · AODV

M. Bani Yassein · M. Bani Khalaf
Dept. Computer Science, Jordan University of Science and Technology, Irbid 22110, Jordan

M. Bani Yassein
e-mail: masadeh@just.edu.jo

M. Bani Khalaf
e-mail: makhalaf06@cit.just.edu.jo

A.Y. Al-Dubai (✉)
School of Computing, Edinburgh Napier University, Edinburgh EH10 5DT, UK
e-mail: a.al-dubai@napier.ac.uk

1 Introduction

Broadcast communication, in which a source node sends the same message to the remaining nodes in the network, is one of the most useful collective communication operations. Due to its extensive use, efficient broadcasting is critical to the overall performance of distributed systems. For instance, broadcasting is frequently used by many important applications such as search, discovering unicast routes between a source and a destination, data movement, and graph algorithms. Furthermore, broadcasting is fundamental to the implementation of higher-level communication operations such as gossip, gather, and barrier synchronization that utilize broadcasting as a building block, providing important control and route establishment functionality. Ensuring a scalable implementation of a wide variety of distributed applications necessitates efficient implementation of broadcast communication. Thus, any improvements to the broadcast communication can be immediately realized by higher-level MANET functionality and applications [1].

The Mobile Ad hoc NETwork (MANET) is a collection of wireless mobile devices, where transferring data between them is done by intermediate devices independently from any base station. MANETs are self-organizing/configuring mobile wireless networks that do not rely on a pre-existing infrastructure to communicate. The mobile nodes are connected by wireless links with arbitrary movements, thus leading to unpredictable topologies. In MANETs, nodes have limited transmission range, and packets may need to traverse multiple other nodes before reaching their destination. Research on MANETs was initiated three decades ago by DARPA for packet radio projects [2]. Nowadays, research in this field regained popularity due to the widespread availability of different portable wireless devices such as cell phones, PDAs and WiFi/Bluetooth enabled laptops [3].

Broadcasting scheme is a basic procedure used to send out information messages between mobile devices in MANET, and it is also the basic method for many protocols like Dynamic Source Router (DSR) [4] and AODV [5]. Although the broadcasting scheme is presumable to distribute messages between all nodes, it has several problems that decrease efficiency and performance in MANETs, such as duplicate transmission, collisions and contention; these problems are called *broadcast storm problem* [6]. In many conventional on-demand routing protocols like AODV [5], a mobile host floods Route REQuest control packets (RREQ) to its surrounding neighbors in order to discover a route to explicit destination, then each neighbor rebroadcasts the RREQ control packets until the path between source and required destination is established. Broadcasting has been a fundamental communication pattern in many networked and distributed systems. Specifically, due to the ever-changing topology, broadcast communication is essential to MANETs. The common approach for broadcasting is performed through flooding, which is well suited for MANETs as there is no need for topological knowledge. Despite the fact that flooding can be performed straightforward in MANETs, flooding is still a problematic issue and far from optimality as it generates high member of redundant messages, collisions, contentions and wasting valuable limited resources such as bandwidth and energy supplies [2].

Existing solutions to broadcast communication can be, in general, classified into two main schemes, namely *deterministic* and *probabilistic* approaches. Deterministic approach requires complete topology information to achieve optimal results. However, in MANETs, the availability of complete topology information that lasts for reasonable periods is unrealistic. Consequently, the probabilistic approach where a mobile host will rebroadcast a broadcast message that was received for the first time with a probability p and takes no action with probability $1 - p$, has been an efficient scheme for handling broadcasting in MAMETs. Studies [6] have shown that probabilistic broadcasts incur significantly lower overhead compared to blind flooding while maintaining a high degree of propagation for the broadcast messages.

Recently, a number of probabilistic approaches to flooding have been proposed to solve the broadcast storm problem [6–9]. In the conventional probabilistic scheme, the mobile host will rebroadcast a broadcast message which is received for the first time with probability p. In this scheme, the rebroadcast decision is made without any information about the network topology and the surrounding node neighbors. This paper proposes new route discovery algorithms, namely Smart Probabilistic Broadcasting (SPB) that enhances probabilistic broadcast methods to propagate the RREQ packets. To evaluate the SPB method we have used the AODV routing algorithm. Our results show that the idea of implementing AODV with SPB helps to reduce the overall routing overhead with improved end-to-end delay when compared against the traditional AODV.

The rest of the paper is organized as follows. Section 2 presents related work on some route discovery techniques. Section 3 presents the effect of using different random waypoint models on the number of neighbors. Section 4 presents Smart Probabilistic Broadcast mechanism (SPB). Section 5 shows the performance evaluation. Finally, Section 6 concludes this study and outlines some directions for future research work.

2 Related work

The direct method which uses broadcasting is flooding, where every mobile host receives a broadcast message and retransmits it to all nodes in network if it is received for the first time. In [4], the authors have studied different methods proposed to solve the broadcast storm problem, for example, blind flooding, probability-based, distance-based, counter-based, and location-based and neighbor knowledge schemes.

In [10] Q. Zhang and Agrawal implemented dynamic probabilistic broadcasting which combines the advantages of both counter-based and probabilistic methods. This algorithm adjusts the value of p based on the value of the packet counter, but it has drawbacks where the decision to rebroadcast is done after a random delay time and the probability decreases or increases according to small constant d which is not explicitly specified.

M. Bani Yassein et al. [8, 11] proposed a probabilistic flooding scheme by using multiple p, high, medium, and low. These values set according to the local neighbors' information. This improving applied over the pure broadcasting, in terms of *reachability* and *saved rebroadcast*.

Qi Zhang and Dharma implemented an approach that uses the concept of gossip and Construct minimal Dominating Set (CDS). In CDS, they classify mobile hosts into four groups according to their neighborhood information. For each group, there is a specified value of probability, so the nodes with more neighbors are given higher probability while the nodes with fewer neighbors are given lower probability [12].

Cartigny and Simplot [13] proposed an algorithm which combines the advantages of both probabilistic and distance methods to privilege the retransmission by nodes that are located at the radio border of the sender. The value of probability p is determined by the information collected from the node neighbors and the constant value K, which is an efficiency parameter, set to achieve high reachability.

In [14], the authors proposed an adaptive counter-based scheme in which each node dynamically adjusts its threshold value C based on local neighbors' information. The fixed threshold C is computed based on a function $C(n)$, where n is the number of neighbors of the node. In this approach, the value of n can be achieved through periodic exchange of 'HELLO' packets among mobile nodes.

In [15], the authors presented efficient broadcasting schemes that combine the advantages of pure probabilistic and counter-based schemes. The rebroadcast decision depends on both fixed counter threshold and forwarding probability values. The value of probability is set according to packet counter that not exactly indicates the number of node neighbors.

Zone Routing Protocol (ZRP) [14] is another technique that was proposed to reduce RREQ control packets, which uses a combination of two protocols, namely *proactive* and *reactive*; it takes the advantages of both protocols in order to solve the flooding of RREQ control packets. In case of *proactive*, route information is available when it is needed; as a result, a node can immediately send a data packet to a required destination in minor delay before data transmission. On the other hand, in case of *reactive*, since route formation is not available, a significant delay is produced in order to determine a route. The route discovery procedure in ZRP is established as follows. If the destination is the one inside the zone of the source that is called *Interzone Routing*, the source already knows the route to the destination, since the Interzone Routing uses proactive protocols. Otherwise, the source node will be broadcasting RREQ control packets to its peripheral nodes instead of flooding it, since the path between nodes in different zones use reactive protocol.

In [16], the authors introduced a technique to reduce the RREQ overhead during route discovery operation, using the previous path. The authors suggest, when the path between source and destination is changed, that the new path between them will not be extremely different from the previous one. In such a case, the flooding operation for RREQ control packets will be performed only by the new nodes in the new path at maximum k hops. The k hops is a threshold calculated by the dissimilarities between nodes from old and new paths. However, this technique has disadvantages when applied over a highly dynamic network.

3 The effect of using different system parameters on the number of neighbors

In MANETs there are different important system parameters that affect network performance, such as node mobility, node density and traffic load; these are considered in the performance analysis [8]. Because the nodes in MANETs spread randomly and the topology changes frequently, the density of nodes will be different from low to high levels accordingly. In this paper the forwarding probability p will consider this variety of density since the probability p will set for different values in dense area (high density indicates that p will be low), and also set for different values in sparse one (this means p will be high). The node's neighbor information is the simple approach to decide if a current node is in dense area or not; the information is collected by broadcasting "Hello" packet every second for only one hop. This packet will guarantee for every node to have an updated neighbor list. By using the number of neighbors for each node, the rebroadcast probability will be dynamically adjusted in order to provide a new insight into the trade-off between the values of p and the node's surrounding environment.

By extensive simulation study, three values of average numbers of neighbors are determined: the minimum average number of neighbors ($\text{avg}_{\min}$), the average number of neighbors (avg) and the maximum average number of neighbors ($\text{avg}_{\max}$).

Definition 1 Let N be the number of nodes in the network; N_i is the number of neighbors for node X:

$$\text{avg} = \frac{\sum_{i=1}^{n} N_i}{n}, \tag{1}$$

where avg refers to the average number of neighbors for all the nodes in the network. The value of avg is used as a threshold. If the node has neighbors above the avg, it is placed in a denser area where the value of rebroadcast probability p has to be low. On the other hand, if the node has neighbors below the avg, it indicates that the node is in a sparser area, so the value of rebroadcast probability p is set high. This indication helps to adjust the value of rebroadcast probability p for a given node according to its surrounding neighbors. However, this is not a fair adjustment because all nodes that have neighbors below avg—as well as all nodes that have neighbors above avg—will rebroadcast with the same probability.

Definition 2 Given two sets of nodes, $M_{\min} < \text{avg}$ and $M_{\max} > \text{avg}$, the two average numbers $\text{avg}_{\min}$ and $\text{avg}_{\max}$ of neighbors for both sets are computed as follows:

$$\text{avg}_{\min} = \frac{\sum_{i=1}^{M_{\min}} N_i}{M_{\min}}, \quad \text{where } N_i \le \text{avg}, \tag{2}$$

$$\text{avg}_{\max} = \frac{\sum_{i=1}^{M_{\max}} N_i}{M_{\max}}, \quad \text{where } N_i > \text{avg}. \tag{3}$$

Table 1 shows the summary of the $\text{avg}_{\min}$, avg and avg_2 number of neighbors at a node for different nodes' speeds. The results show that as the speed of nodes is increased, the $\text{avg}_{\min}$, avg and $\text{avg}_{\max}$ number of neighbors of the network also increases. This is because the node will visit different neighbors within a short slot of time.

Table 2 shows the summary of the $\text{avg}_{\min}$, avg and $\text{avg}_{\max}$ number of neighbors at a node for different network densities. The results show that with the number of

Table 1 The values of avg_{min}, avg and avg_{max} for different nodes' speeds

Speed of Nodes	avg_{min}	avg	avg_{max}
4	3	12	21
8	5	13	26
12	7	15	28
16	10	20	31

Table 2 The values of avg_{min}, avg and avg_{max} for different number of nodes

# of Nodes	avg_{min}	avg	avg_{max}
25	4	10	16
50	8	20	32
75	13	30	49
100	18	39	63

nodes increasing, the avg_{min}, avg and avg_{max} number of neighbors of the network also increases. This is because the larger the number of nodes for a certain network, the higher the possibility to create a dense area. As a result, the number of neighbors for a given node will increase.

4 Smart probabilistic broadcasting

In the traditional AODV [5], all RREQ packets that have been received for the first time will be flooded by the intermediate node. If the intermediate node does not have a valid route to destination, and N is the total nodes in the network, the number of possible broadcasts of an RREQ packet in AODV is $N-2$ (the source and destination will not retransmit a received RREQ that is being generated) [17].

A brief outline of the AODV-SPB is shown in Fig. 1. When hearing a broadcast RREQ packet at node X for the first time, the node compares its neighbor by avg_{min}, avg and avg_{max}: if the node has a number of neighbors n less than avg_{min}, this implies that the node is in a low sparse region. Then, the node rebroadcasts the packet according to probability p_1. However, the probability p_2 is selected if the number of neighbors n satisfies $avg_{max} \leq n < avg$: this implies that the node is in a medium sparse region. Otherwise, the value of probability p_3 is chosen if the node is in a medium density region and the number of neighbors n meets this condition: $avg \leq n < avg_{max}$. Finally, the value of probability p_4 is chosen if the number of neighbors n is $n \geq avg_{max}$: this implies that the node is in a high density region.

The conventional AODV protocol which uses blind flooding during route discovery has been modified by replacing the blind flooding with a new adjusted probabilistic scheme. AODV is already implemented in NS-2 packet level simulator [18]. The aim is to reduce the flooding of RREQ packets during the route discovery operation, and as a result reduces the broadcast storm problem. The net effect is that the overall network is improved by reducing the average end-to-end delay and also routing overhead. Since the decisions of the nodes are independent, the total number of possible

Fig. 1 Description of the SPB algorithm

The Smart Probabilistic Broadcasting ():

Get the number of neighbor n for the node X that receives RREQ.
Get the values of $avg_{\min}$, avg and $avg_{\max}$.

If packet RREQ received for the first time **then**
  If $n < avg_{\min}$ **then**
  Node X *is* located in Low sparse region: $P = p_1$;
  Else if $avg_{\min} \leq n < avg$ **then**
  Node X *is* located in medium sparse region: $P = p_2$;
  Else if $avg < n \leq avg_{\max}$ **then**
  Node X *is* located in medium dense region: $P = p_3$;
  Else if $n \geq avg_{\max}$ **then**
  Node X *is* located in high dense region: $P = p_4$;
    End_if
  End_if
  Generate a random number RN over [0, 1].
  If $RN \leq P$ **then**
    Rebroadcast the received RREQ.
  Else
    Drop it.

End_algorithm

rebroadcasts of an RREQ packet N_b using the SPB algorithms is:

$$N_b = \sum_{i=1}^{4} p_i N_i \quad \text{for the SPB-AODV,} \tag{4}$$

where N_i is the number of nodes that chose p_i. If N is the total number of nodes in the network, then the total number of rebroadcasts of an RREQ packet in SPB-AODV, AODV-FP and AODV-BF is respectively related as follows [17]:

$$N_b = \sum_{i=1}^{4} p_i N_i < p \times (N-2) < N-2. \tag{5}$$

The value of the fixed probability used in AODV-FP is set at $p = 0.7$. This is because [7, 8] have shown that this probability value enables the fixed probabilistic flooding to achieve a good performance.

5 Performance analysis

Ns-2, a discrete event simulator, is used as the simulation platform designed by researchers at Berkeley University. Ns-2 provides substantial support for simulation of

Table 3 Summary of the parameters used in the simulation experiments

Parameter	Value
Transmitter range	250
Bandwidth	2 Mbit
Interface queue length	50 messages
Simulation time	900 s
Pause time	0 s
Packet size	512 bytes
Topology size	500×500 m^2
Nodes' speed	2, 4, 8, 12, 16 m/s
Number of nodes	25, 50, 75, 100 nodes
Traffic load	5, 10, 20, 30 connections
Data traffic	CBR
Mobility model	Random way-point
Number of trials	trial

TCP, routing, and multicast protocols over wired and wireless networks. The simulation scenarios consist of different mobile nodes moving in different network areas; each node has a 250-meter transmission range and a bandwidth of 2 Mbps. Each data point in the simulation results represents an average of 30 randomly generated mobility patterns in order to achieve a 95% confidence interval in the collected statistics. The MAC layer protocol is IEEE 802.11 [19]. The nodes move according to the random waypoint model. This mobility model is used to simulate 30 topologies. The speed varies from 2 to 16 m/s with the pause time of 0 s. The main parameters used in the simulations are summarized in Table 3.

The simulation scenarios consist of four different settings, each specifically designed to assess the impact of a particular network operating condition on the performance of the protocols. First, the impact of network density or size is assessed by deploying 25, 50, 75 and 100 mobile nodes over a flat space of a fixed size 500 m by 500 m. The second simulation scenario investigates the effect of an offered load on the performance of the routing protocols by varying the number of source destination pairs (flows, for short) over the range of $5, 10, \ldots, 30$ flows for each simulation scenario. The last set of simulations evaluates the performance impact of node mobility by varying the maximum node speed of 100 mobile nodes over the range of 2, 4, 8, 12, 16 m/s in a fixed area of 500 m $\times$500 m. Each flow of constant bit rate (CBR) data, which is used in many previous studies, generates data packets at the rate of 4 packets/s. The packet size is set at 512 bytes.

5.1 Effect of network density

This section presents the performance impact of network density on AODV-BF, AODV-FB, AODV-SPB, over different number of nodes. The network density has been varied by deploying 25, 50, 75 and 100 nodes over a fixed area of 500 m $\times$ 500 m. Each node in the network moves with a speed randomly chosen between 0 and 2 m/s.

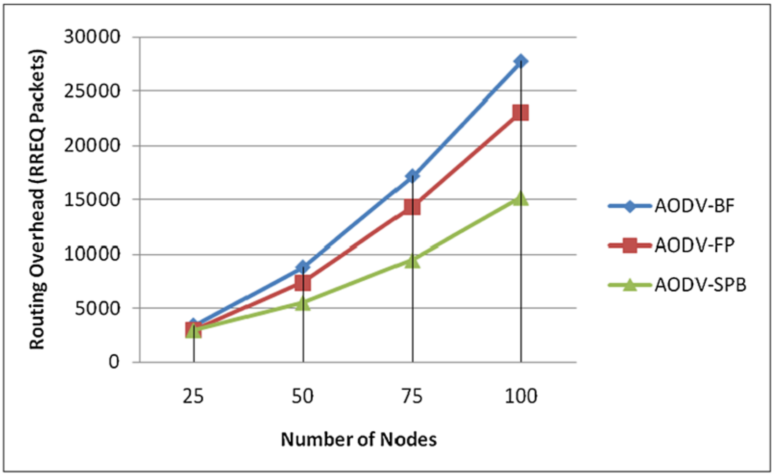

Fig. 2 Routing overhead vs. number of nodes placed over 500 m × 500 m

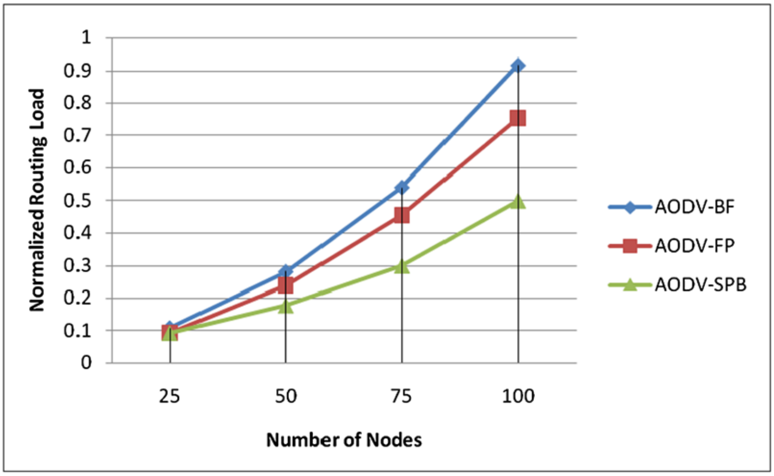

Fig. 3 Normalized routing load vs. number of nodes placed over 500 m × 500 m

Routing overhead Figure 2 shows the routing overhead incurred by AODV-BF, AODV-FB and AODV-SPB for different network densities. The routing overhead in this study represents the number of RREQ packets generated and disseminated throughout the network. The figure shows that the generated routing overhead in all the three routing protocols increases with increased number of nodes. Moreover, the figure reveals the clear advantage of AODV-SPB over AODV-BF and AODV-FB. For instance, compared with AODV-BF and AODV-FB, the generated routing overhead in AODV-SPB can be reduced by approximately 47% and 44% respectively when the number of nodes is relatively high (e.g. 100 nodes).

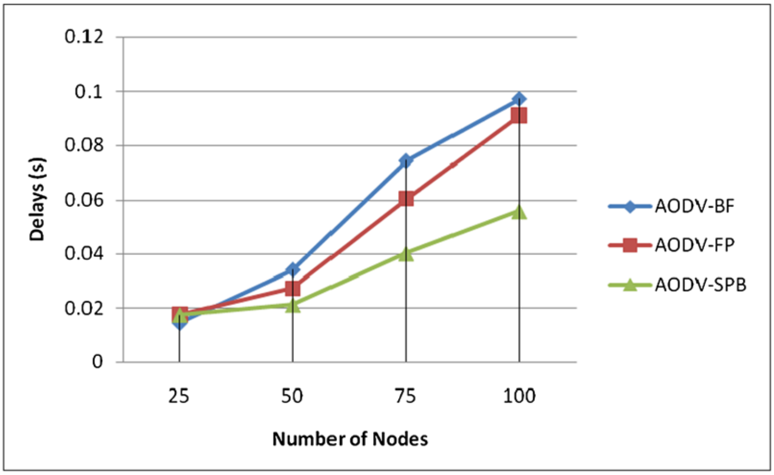

Fig. 4 Delay vs. number of nodes placed over 500 m × 500 m

Normalized routing load Normalized routing load measures the percentage of route discovery packets (that are used in finding a route) per data packet delivered to the destination. Figure 3 demonstrates the effect of network density on the performance of all three protocols in terms of normalized routing load. The AODV-SPB has superior performance over AODV-BF and AODV-FP. For more clarity, at high network density (e.g. 100 nodes) the normalized routing loads for the three protocols AODV-SPB, AODV-FB and AODV-BF are equal to 0.5, 0.7 and 0.9, respectively.

End-to-end delay The results in Fig. 4 represent the average end-to-end packet delay. In this paper, they are defined as the average time difference between when a unicast data packet was initially sent by the source node and when it was successfully received at the destination. The figure reveals the average end-to-end delays incurred by all three protocols. When network density increases, the number of duplicated RREQ packets which are generated by nodes increases as well, thus leading to the increase of a number of the dropped packets. As a result, packets experience high latencies in the interface queues.

5.2 Effect of network mobility

This section demonstrates the effect of node mobility on the performance of the three protocols. In this study, 50 nodes are placed over 500 m × 500 m with each node moving according to the random waypoint mobility model with a maximum node speed of max V. The node mobility is varied by changing the value of max V. For each simulation scenario, 10 identical randomly selected source destination connections are used.

Routing overhead Figure 5 shows the routing overhead of AODV-SPB, AODV-FP and AODV-BF with different mobility scenarios when the number of CBR is set to 10. When node mobility was increased, more RREQ packets have failed to reach

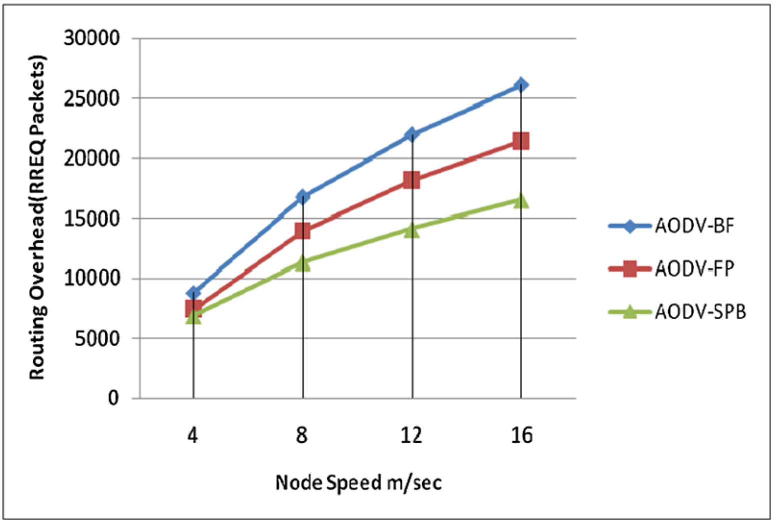

Fig. 5 Routing overhead vs. node speed for a networksize of 50 nodes and 10 connections

their destinations. In such circumstances more RREQ packets are generated and retransmitted, which leads to a higher chance of collision due to the increase of control packets. For instance, the AODV-SPB perform better than AODV-FB and AODV-BF by reducing the overhead from around 45%, when compared against AODV-FB and AODV-BF at relatively high node mobility (e.g. 16 m/s) respectively.

Normalized routing load Figure 6 depicts the network normalized routing load achieved by the three routing protocols against the maximum node speed. The figure shows that the network normalized routing load achieved by the protocols increased with increasing the node mobility. This is due to the fact that when the node mobility is increased, the frequency of topology changes is also increased. This can potentially trigger more new route maintenance processes, resulting from the broken routes. As a consequence, larger numbers of RREQ packets are generated and disseminated. AODV-SPB has a higher performance over AODV-FB and AODV-BF.

End-to-end delay Figure 7 depicts the end-to-end delay of data packets in the three routing protocols for different nodes' speed. The figure shows that when nodes' speed increases, the end-to-end delay of data packets also increases. This is because the paths between sources and required destinations frequently changed and established. As a result, the waiting time for data packets in interface queue is increased. However, among all maximum node speeds the AODV-SPB performs better, followed by AODV-FP and AODV-BF.

5.3 Effect of offered traffic load

In this section, the effect of offered load on the performance of the protocols has been investigated. Simulation runs have been conducted for the three protocols AODV-

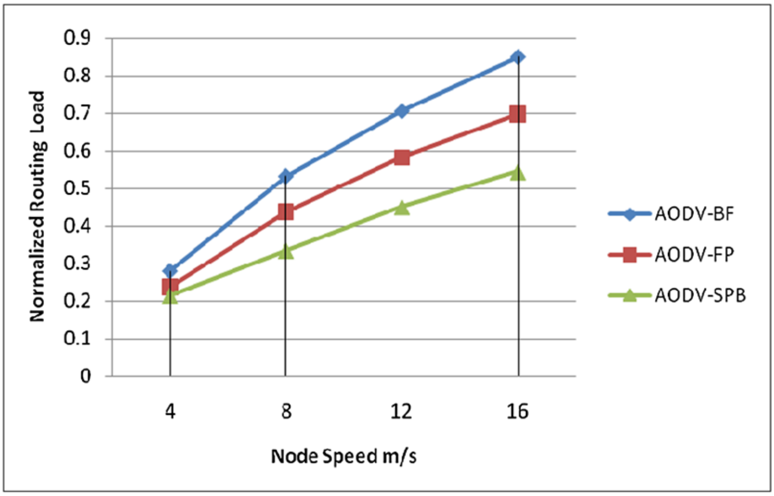

Fig. 6 Normalized routing load vs. node speed for a network size of 50 nodes and 10 connections

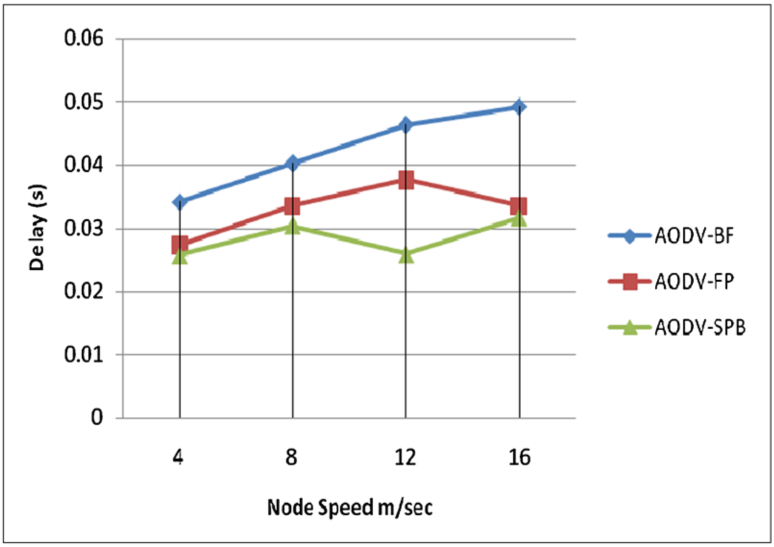

Fig. 7 Delay vs. node speed for a network size of 50 nodes and 10 connections

SPB, AODV-FB and AODV-BF, where the offered load is varied by increasing the number of source–destination pairs (flows) from 5 to 30.

The topology for each simulation scenario consists of 50 nodes placed randomly on a flat area of 500 m × 500 m, moving with the random waypoint mobility with speed between 0 and 2 m/s.

Routing overhead Figure 8 shows the performance of the three protocols in terms of routing overhead when the offered load is increased from 5 to 30 flows. As revealed

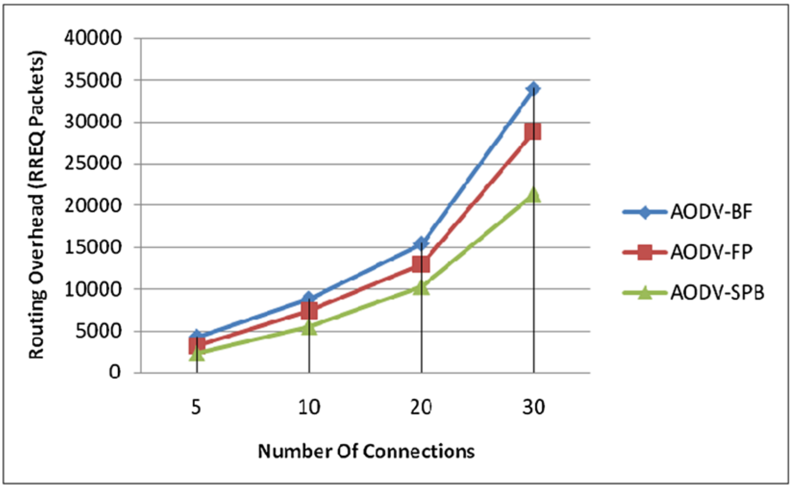

Fig. 8 Routing overhead vs. traffic for a network size of 50 nodes with node speed of 2 m/s

in the figure, the AODV-SPB incurs a lower routing overhead compared to AODV-BF and AODV-FP. For instance, at a heavy traffic load (e.g. 30 connections) the generated overhead is reduced by around 15,000 and 5000 when AODV-SP and AODV-FB are used, respectively. This performance behavior is expected since increasing the offered load leads to an increase in the number of source nodes that initiate route discovery operations.

Normalized routing load Figure 9 reports the results of the network normalized routing load versus offered load for all the three routing protocols. It can be seen in the figure that the normalized routing load achieved by the three protocols increased as the offered load increases. The figure also shows that the performance difference of the three routing protocols becomes more noticeable when the offered load is increased. This is because at high offered loads, most of the generated data packets are dropped resulting from collisions and channel contention caused by a high congestion level. For example, when the traffic load increased form 5 to 30 flows, AODV-SPB has a clear performance over AODV-FP and AODV-BF.

End-to-end delay Figure 10 demonstrates the delays incurred by all three protocols for different traffic loads. The number of total packets transmitted on the wireless channel has a significant impact on latency. If the number of packets is high, the number of collision is high, and that, in turn, leads to more retransmissions. As a result, packets experience high latencies. This is because that there is a higher number of redundant rebroadcasts of RREQ packets. This is also leading to channel contention, packet collision and, as a result, many RREQ packets fail to reach their destinations.

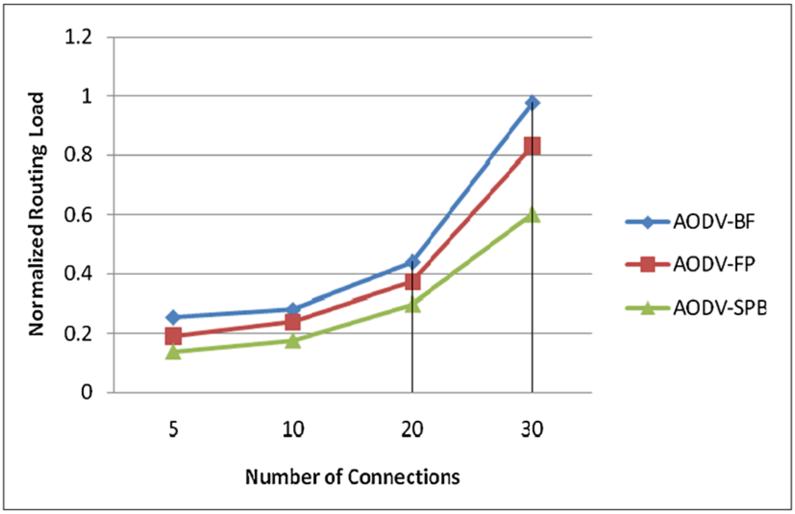

Fig. 9 Normalized routing load vs. traffic for a network size of 50 nodes with node speed of 2 m/s

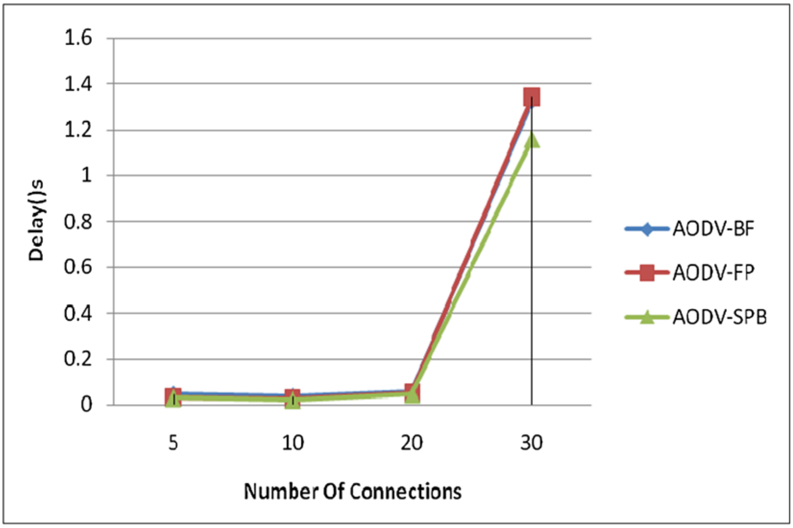

Fig. 10 Delay vs. traffic for a network size of 50 nodes with node speed of 2 m/s

6 Conclusions and future work

Broadcast communication is an essential operation in MANETs to disseminate information to all nodes and to find unicast routes in some MANET applications. Thus, efficient broadcasting has been prioritized in many academic and industrial initiatives. The direct method to perform broadcast is a simple flooding, which can dramatically affect the performance of MANET. Recently, a probabilistic approach to flooding has been proposed as one of most important suggested solutions to solve the broadcast storm problem, which leads to the collision, contention and duplicated messages. This paper presents the Smart Probabilistic Broadcasting (SPB) as a new probabilistic method to improve the performance of existing on-demand routing protocols by reducing the RREQ overhead during the rout discovery operation. The simulation results show that a new smart probabilistic blind flooding algorithm, AODV-SPB, has superior performance over the conventional AODV-BF and AODV-FP. The AODV-SPB generates much lower routing overhead and end-to-end delay. As a consequence, the packet collisions and contention in the network are reduced. The results have also shown that although the traffic load increased, the normalized routing load is still low.

As a continuation of this research in the future, we plan firstly to combine our algorithm with different routing protocols, if a combined performance improvement is feasible. Secondly, we aim to propose a highly adjusted probabilistic flooding algorithm approach in order to facilitate the exploration of the optimal adaptation strategy. Moreover, we intend to design an analytic model for our dynamic probabilistic approach in order to facilitate the exploration of the optimal adaptation strategy.

References

1. Williams B, Camp T (2002) Comparison of broadcasting techniques for mobile ad hoc networks. In: MOBIHOC, pp 194–205
2. Sasson Y, Cavin D, Schiper A (1987) Probabilistic broadcast for flooding in wireless mobile ad hoc networks. Swiss Federal Institute of Technology (EPFL), Technical Report IC/2002/54
3. Jubin J, Tornow JD (1987) The DARPA packet radio network protocol. In: Proceedings of the IEEE, pp 21–32
4. Johnson D, Hu Y, Maltz D (2007) The dynamic source routing protocol (DSR). http://www.ietf.org/rfc/rfc4728.txt. Accessed December 2007
5. Perkins C, Belding-Royer E, Das S (2007) Ad hoc on-demand distance vector (AODV) routing. http://www.ietf.org/rfc/rfc3561.txt. Accessed October 2007
6. Ni S-Y, Tseng Y-C, Chen Y-S, Sheu J-P (2002) The broadcast storm problem in mobile ad hoc networks. In: Proceedings of the 5th annual ACM/IEEE international conference on mobile computing and networking, pp 152–162
7. Bani-Yassein M, Ould-Khaoua M, Mackenzei LM, Papanastasiou S (2006) Performance analysis of adjusted probabilistic broadcasting in mobile ad hoc networks. Int J Wireless Inf Netw 127–140
8. Sasson Y, Schiper A (2003) Probabilistic broadcast for flooding in wireless mobile ad hoc networks. In: Proceedings of IEEE wireless communications and networking conference
9. Bani Yassein M, Bani Khalaf M (2009) Performance evolution of multiple probabilities of ad hoc on demand distance vector protocol (AODV). In: Proceedings of the 4th international conference on information technology
10. Zhang Q, Agrawal DP (2005) Dynamic probabilistic broadcasting in MANETs. J Parallel Distrib Comput 220–233
11. Yassein B, Ould-Khaoua M, Papanastasiou SM (2005) On the performance of probabilistic flooding in mobile ad hoc networks. In: Proceedings of 1st int workshop on performance modelling in wired, wireless, mobile networking and computing, held in conjunction with ICPADS
12. Zhang Q, Agrawal DP (2004) Analysis of leveled probabilistic routing in mobile ad hoc networks. In: Proceedings of the IEEE international conference on communications, pp 20–24
13. Cartigny J, Simplot D (2003) Border node retransmission based probabilistic broadcast protocols in ad hoc networks. Telecommun Syst 189–204
14. Aminu M, Ould-Khaoua M, Mackenzie LM, Abdulai J (2008) Performance evaluation of an efficient counter-based scheme for mobile ad hoc networks based on realistic mobility model. In: Proceedings of the international symposium on performance evaluation of computer and telecommunication systems, Edinburgh, UK. IEEE, New York, pp 181–188
15. Tseng Y-C, Ni S-Y, Shih E-Y (2003) Adaptive approaches to relieving broadcast vol.storm in a wireless multihop mobile ad hoc network. IEEE Trans Comput 299–312

16. Castañeda R, Das SR (1999) Query localization techniques for on-demand routing protocols in ad hoc networks. In: Proceedings of the 5th annual ACM/IEEE international conference on mobile computing and networking, pp 186–194
17. Abdulai J, Ould-Khaoua M, Mackenzie LM (2008) Adjusted probabilistic route discovery in mobile ad hoc networks. J Comput Elect Eng 168–182
18. The network simulator Ns-2-the VINT pro. http://www.isi.edu/nsnam/ns/ns-build.html. Accessed December 2007
19. Colagrosso MD (2007) Intelligent broadcasting in mobile ad hoc networks: Three classes of adaptive protocols. *EURASIP*. J Wireless Commun Netw 1–16
20. Haas ZJ, Pearlman MR (2001) The performance of query control schemes for the zone routing protocol. IEEE/ACM Trans Netw 427–438