Journal of Network and Computer Applications 35 (2012) 942–950

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

On-demand multicast routing protocol with efficient route discovery

Mohammad-Amin Kharraz [a,b], Hamid Sarbazi-Azad [c,b], Albert Y. Zomaya [d,*]

[a] Faculty of Science and Technology, Sharif University of Technology—International Campus, Iran
[b] School of Computer Science, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
[c] Department of Computer Engineering, Sharif University of Technology, Tehran, Iran
[d] Centre for Distributed and High Performance Computing, School of Information Technologies, The University of Sydney, Sydney, Australia

ARTICLE INFO

Article history:
Received 31 July 2010
Received in revised form
22 January 2011
Accepted 9 March 2011
Available online 16 March 2011

Keywords:
Mobile *Ad hoc* networks
Routing protocol
Multicasting
Multicast mesh

ABSTRACT

In this paper, we introduce an efficient route discovery mechanism to enhance the performance and multicast efficiency of On-Demand Multicast Routing Protocol (ODMRP). Our framework, called limited flooding ODMRP, improves multicasting mechanism by efficiently managing flooding mechanism based on delay characteristics of the contributing nodes. In our model, only the nodes that satisfy the delay requirements can flood the Join-Query messages. We model the contributing nodes as M/M/1 queuing systems. Our framework considers the significant parameters in delay analysis, including random packet arrival, service process, and random channel access in the relying nodes, and exhibits its best performance results under high traffic load. Simulation results reveal that limited flooding ODMRP drastically reduces the packet overhead under various simulation scenarios as compared to original ODMRP.

1. Introduction

Mobile *ad hoc* networks (MANETs) have been recognized as one of the most evolving research areas among the emerging wireless technologies. In MANETs, the routing functionality is solely devoted to the contributing nodes. As a consequence, the performance of routing protocols is strongly impacted by the stochastic behavior of the nodes especially in scenarios where frequent topology changes happen. Therefore, an important consideration in design of routing mechanisms can be dedicated to routing improvement especially where the same data are transmitted to multiple destination nodes. Multicasting is born out to enhance the efficiency of wireless links for group-oriented applications such as video conferencing where efficiently exploiting network resources is a critical factor. Multicast mechanism drastically reduces communication costs by minimizing bandwidth consumption, sender and router processing, and delivery delay (Paul, 1998). Different from unicasting, multicast messages are injected to the network only once and only duplicated at the branch points. Consequently, the transmission overhead within the network can be efficiently managed.

During the last few years, many multicast routing protocols have been proposed to enhance the multicast mechanism in wireless networks. *Ad-hoc* multicast routing protocol utilizing increasing numbers (AMRIS) (Wu et al., 1999), core assisted multicast protocol (CAMP) (Garcia et al., 1999), on-demand multicast routing protocol (ODMRP) (Yi et al., 2003), and multicast ad-hoc on-demand multicast routing protocol (MAODV) (Royer and Perkins, 2000) address multicasting issues by applying different routing strategies.

In this paper, we study the single hop delay characteristics, including network queuing, contention, and transmission delay to develop a strategy that uses single hop delay to perform the flooding mechanism in an efficient manner. We have implemented our model on top of ODMRP routing protocol to enhance the high cost flooding mechanism of this protocol. Our routing model, called limited flooding ODMRP, takes advantages of the mesh architecture and path redundancy while decreasing traffic congestions and overhead of original ODMRP by refining the flooding procedure during route setup and route maintenance phases.

The rest of the paper is organized as follows. In Section 2, we present an overview on other extensions of ODMRP. In Section 3, we introduce our approach based on single hop delay analysis. In Section 4, simulation results are provided. Finally, concluding remarks and future works are presented in Section 5.

2. Related work

This section provides a general overview on multicasting trends and previous frameworks introduced in research community. Several multicast routing protocols with unique features have been proposed for MANETs in the literature. We briefly point

* Corresponding author. Tel.: +61 293516442.
E-mail addresses: kharraz@ipm.ir (M.-A. Kharraz), azad@sharif.edu, azad@ipm.ir (H. Sarbazi-Azad), a.zomaya@usyd.edu.au (A.Y. Zomaya).

1084-8045/$ - see front matter Crown Copyright © 2011 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jnca.2011.03.012

out the strategies used to establish multicast routing by analyzing these multicast mechanisms.

Core assisted multicast routing protocol (CAMP), proposed in Garcia et al. (1999), is a receiver initiated shared multicast mesh routing protocol. CAMP extends the usage of core nodes to establish multicast mesh. When a node wishes to join a multicast group, it sends the join request message to multicast group. The first node that receives the join request message responds to the node by sending a join acknowledgment message and it becomes a member of the multicast group. CAMP uses as many cores as desired for a given mesh (Garcia et al., 1999). It improves the network reliability in the cases where the core of the group fails. In CAMP, instead of flooding the advertisement packets to the network, each core disseminates the mappings of multicast addresses to one or more core addresses to the network (Vaishampayan and Garcia-Luna-Aceves, 2004). Consequently, CAMP enhances the scalability of the protocol as compared to flood based routing protocols. However, CAMP is based on unicast routing protocols and it could be the Achilles' heel in routing functionality of CAMP.

Ad-hoc multicast routing utilizing increasing id-numbers (AMRIS) is another multicast routing protocol introduced by Wu et al. (1999). Unlike CAMP, AMRIS does not require unicast routing protocol to construct tree between the contributing nodes. The key idea behind AMRIS that differentiates it from other multicast protocols is that each participant in the multicast session has a specific multicast session member id (msm-id) (Santos et al., 2007). In AMRIS, the shared multicast tree is established from a special source node, called Sid, that has the smallest id number and is responsible to broadcast NEW-SESSION packets. Each node calculates its own msm-id and rebroadcast the corresponding NEW-SESSION packets with the new msm-id. In AMRIS, the nodes are required to rebroadcast beacon to the neighboring nodes. Each beacon includes a set of information such as msm-id, registered parent, membership status, child id, and partition id. If a node fails to receive beacon for a specific period of time, the node concludes that the neighboring node has failed or moved out. The drawback of AMRIS is that each node sends a periodic beacon to signal their presence to the neighboring nodes, which is very sensitive to mobility and traffic load (Lee et al., 2000). As a consequence, if the links in the tree structure break, the packets are lost until the tree is reconfigured. This shortcoming dramatically degrades the successful packet delivery where packet drop strongly affects the quality of service and brings user dissatisfactions.

MAODV (Royer and Perkins, 2000) is another well known multicast routing protocol. MAODV is the extension of AODV routing protocol where multicast groups are identified by a unique address and group sequence number. When a node wants to join a group that is not established yet, it becomes the leader of that multicast group and is responsible for maintaining the multicast group (Vasiliou and Economides, 2005). MAODV may achieve good performance results in scenarios where mobility of nodes is negligible and network does not face frequent link breakage. This is due to the fact that reconstruction of tree in MAODV needs repetitive computational process on nodes within the network.

Vaishampayan and Garcia-Luna-Aceves (2004) propose a shared mesh multicast routing protocol called protocol for unified multicasting through announcements (PUMA). PUMA is a receiver initiative approach where receivers join the multicast group using the address of a special core node without the need for flooding of control packets from the source of the group (Ahmad, 2005). When a node wants to join a multicast group, it checks whether or not it is the first multicast receiver by checking the multicast announcement message. Multicast announcement message contains general information of the nodes such as core address, message sequence number, number of hops to the core of the group, group ID, and the address of the node from which the multicast announcement is received. If the receiver node detects the core of the group, it broadcasts the multicast announcement message and advertises the core in the group. Otherwise, it considers itself as the core of the group and starts transmitting multicast announcements periodically to its neighbors (Ahmad, 2005). The mesh constructed by PUMA restricts redundancy to the region containing receivers, thus reducing unnecessary transmissions of multicast data packets (Vasiliou and Economides, 2005). However, because the only node that can flood the network is the core of the group, it can be a point of failure. Core election is a time consuming process. In the cases where the core of the group fails, packet drop rate may drastically increase before the new core is elected.

ODMRP has been developed by Wireless Adaptive Mobility (WAM) Laboratory (Yi et al., 2003) at UCLA. ODMRP employs a mesh structure to forward multicast data packets. The mesh-based connectivity between the nodes in ODMRP results in the formation of multiple forwarding routes that result in finding the most appropriate routes. When a source node desires to send multicast data, it floods the network with Join-Query message. The Join-Query message is periodically broadcasted as long as the source node has data to send. The periodical Join-Query message refreshes multicast membership information and route updates. When an intermediate node receives a Join-Query message, it registers the source ID and the sequence number of the message in its cache to discover potential duplicates.

Join-Query messages are forwarded by relaying nodes through the network until they are delivered by the destination node. The destination node sends a Join-Table message carried by forwarding nodes all the way towards the source node. The Join-Table message reinforces the route established by the Join-Query message (Oh et al., 2008). As a consequence, the intermediate nodes become forwarding nodes for data transmission. The source node can easily terminate a multicast session by not sending the Join-Query message. Likewise, a multicast receiver can unsubscribe from a multicast group by simply stopping to send back the Join-Table message. Viswanath et al. (2006) analyzed the behavior of ODMRP under a wide range of scenarios. Simulation analysis reveals that ODMRP performs considerably better in terms of packet delivery ratio as a function of node mobility and multicast traffic load. Furthermore, ODMRP exhibits high robustness on account of its mesh structure (Viswanath et al., 2006). However, despite the remarkable features of ODMRP, it suffers from a vast variety of limitations. Technically, the mesh-based structure of ODMRP may offer a better delivery ratio but path redundancy may lead to suboptimal performance results due to high packet overhead. In these cases, costs of redundant paths incurred by mesh structures are often referred to as wasting the vital resources of multi-hop networks. Therefore, the main drawback of mesh-based routing structures may be wasting of the network resources and high packet overhead, which affects the efficiency of routing protocol, especially in QoS sensitive applications. The problem gets more complicated as the network size grows and more nodes are involved in establishing the forwarding mesh. Furthermore, the flooding mechanism of Join-Query messages improves the forwarding path setup at the expense of wasting network bandwidth, channel capacity, and packet collisions. The broadcast characteristic of flooding technique causes redundant packet overhead, which drastically reduces the efficiency of routing mechanism, especially in scenarios where a large number of nodes are distributed within the network. To complicate things further, forwarding the broadcast Join-Query message by intermediate nodes has a delay cost associated with it. This is due to the fact that packets are queued at the forwarding nodes and are relayed towards the destination nodes in a multi-hop fashion.

In order to enhance the performance of ODMRP several extensions of ODMRP are introduced in the literature, each of which tries to enhance the performance of ODMRP in terms of delivery ratio, packet overhead, and delivery delay. Enhanced-ODMRP, proposed by Oh et al. (2008), suggests a mechanism that dynamically adopts the route refresh time to the environment. This mechanism dramatically reduces packet overhead while keeping packet delivery ratio high. R-ODMRP , introduced by Pathrina and Kwon (2007), is a subset of nodes that are not on forwarding paths, stores and retransmits the received packets to the nodes located in their minimal hop count to overcome the perceived node failures. Adding data storage and retransmission mechanisms in these nodes increases the packet delivery ratio. R-ODMRP enhances network reliability at the cost of higher delivery latency and packet overhead.

Patch-ODMRP (Lee and Kim, 2001) is another derivative of ODMRP. The mesh creation in Patch-ODMRP is similar to the original ODMRP. Path-ODMRP aims at low cost link recovery breakage when mesh destruction happens within the network. Patch-ODMRP uses local flooding approach to repair mesh connectivity when mesh destruction is detected. When a node detects mesh destruction, it uses local flooding to patch itself. This mechanism avoids frequent mesh reconstruction, which results in lower computational overhead. However, detecting the symptom of mesh destruction is based on periodical signaling that introduces a higher packet overhead as compared to the original ODMRP.

ODMRP with multi-point relay (ODMRP-MPR), proposed by Ruiz and Gomez-Skarmeta (2004), reduces the packet overhead using multi-point relay nodes. The multi-point relay nodes minimize the broadcast overhead by reducing duplicated packet forwarding (Oh et al., 2008). This technique brings high scalability and effectively solves the unidirectional link problem of wireless communication (Saiful Azad et al., 2009). Performance-enhanced OMDRP (PEODMRP) (So et al., 2004) reduces the packet overhead by limiting the transmission area of Join-Query flooding. PEODMRP shows the best results in scenarios where multicast group includes multiple source nodes.

Quality of service support for ODMRP, proposed in Xue and Ganz (2003), enhances the performance of ODMRP using admission control. The admission control determines whether an incoming request is accepted or rejected based on available and consumed bandwidth. When the intermediate nodes receive the Join-Query message, they compare the value of available bandwidth with a threshold value. If the nodes can provide the required bandwidth, they change their states to registered mode and rebroadcast the Join-Reply message. This mechanism reduces transmission traffic because the contributing nodes are on the route to the source node and also have enough bandwidth, but periodic messages to acquire bandwidth information of neighboring nodes reduce the available bandwidth of the nodes.

3. On-demand multicast routing protocol with efficient route discovery

In this section, we describe our model that manages the flooding mechanism of query messages in the contributing nodes based on their delay characteristic within the network. The route discovery mechanism in ODMRP consists of two phases, referred to as query and reply phases. The query phase occurs when a source node desires to transmit multicast data. The query phase is performed by periodical broadcasting of member soliciting message (Oh et al., 2008), called Join-Query message. The reply phase reinforces the path established by the Join-Query message (Pathrina and Kwon, 2007).

When a source node has data to send, it injects the Join-Query message in the network. Each node that receives the Join-Query message rebroadcasts the message to its neighboring nodes. The Join-Query messages are forwarded by relaying nodes until they are delivered by multicast receivers. The multicast receiver sends a Join-Table message carried by forwarding nodes all the way towards the source node.

The key idea behind our work is that the Join-Query messages are flooded only by the nodes that can satisfy the single hop delay requirements. We propose a method that facilitates the estimation of single hop delay in each node. Another important implication is that it saves the network bandwidth in a sense that when an intermediate node satisfies the delay requirement, it keeps the upstream node address and floods the network with the Join-Query message, otherwise it drops the incoming Join-Query message. Our mechanism prevents the nodes with large single hop delay values to rebroadcast the query messages. Therefore, the flooding mechanism is efficiently managed by decreasing network bandwidth wastage and high packet overhead. In the following, we present the delay analysis in the contributing nodes. We decompose the single hop packet delay into contention, queuing, and transmission delay that should be considered in relaying nodes to estimate one hop delay.

3.1. Delay model

In order to meet the delay requirements for high throughput applications (e.g., voice over IP and video conferencing) the packets should be delivered by multicast receivers before the maximum threshold of 250 ms (Asif et al., 2008). Therefore, a special attention should be devoted to analyze delay characteristics in multi-hop communications for real-time applications. The delay over a single hop consists of multiple elements. The delay over the link l_{ab} from node a to b is represented as

$$d_{lab} = d^{Q}_{lab} + d^{C}_{lab} + d^{T}_{lab} \quad (1)$$

where queuing delay, defined as d^{Q}_{lab}, is the interval between the time the packet enters in the queue of node a and the time the packet reaches the head of line of the queue. The average contention delay, denoted by d^{C}_{lab}, is the time interval between the time the packet becomes the head of line packet and the time the packet is sent by the physical medium. Transmission delay, denoted by d^{T}_{lab}, is the time interval needed to transmit the packets successfully over the physical medium.

The attentions aiming at delay analysis are mainly focused on transmission delay presented in Draves et al. (2004) and Yang et al. (2005). However, the analysis in Li et al. (2009) reveals that the queuing delay of the intermediate nodes could be a large portion of the total delay over a hop and is characterized as the dominant factor that affects end-to-end delay in multi-hop communication. This is due to the fact that the nodes with greater numbers of packets in their queues need a larger proportion of time to retransmit the packet in the network. Sarr and Lassous propose delay estimation ad hoc networks (DEAN) to provide delay guarantees for QoS applications as a function of application requirements. Bisnik and Abouzeid (2009) employ open G/G/1 queuing networks to model random access multi-hop networks. They use diffusion approximation in order to evaluate closed form expressions for the average end-to-end delay. They showed that their proposed model had better performance results under heavy traffic load as compared to standard DSDV (Perkins and Bhagwat, 2001) routing protocol. In the following, we develop our delay analysis in the contributing nodes within the network.

3.2. Queuing and contention delay

In this section, we propose a queuing theoretic model for network layer queuing delay and also consider the transmission delay incurred by the MAC mechanism, which is originally designed for multicast mechanism. Our model does not include RTS/CTS or acknowledgment because these mechanisms are not used in multicast data transmission. Based on the proposed model, each node can estimate one hop delay to the neighboring nodes. The nodes that satisfy the required delay threshold are permitted to broadcast the Join-Query messages to their neighboring nodes.

We model an arbitrary node that contributes traffic forwarding, using Kendall notations based on M/M/1/K queuing system (Tijms, 2003). We assume that the contributing nodes are single servers with (FCFS) queuing policy. Packet arrival rate at node a follows an exponential distribution denoted by λ and the service rate follows an exponential distribution denoted by μ. The maximum queue size in each node is represented by K. Therefore, an arriving packet is dropped if there are already K packets in the node's queue. Suppose that the packets arrive at the relaying node by rate λ and exit by rate μ, where $\lambda \le \mu$. If the probability of having i packets in a node's queue is denoted by P_i, we can write

$$P_{i-1}\lambda = P_i\mu$$

$$P_i = \left(\frac{\lambda}{\mu}\right)P_{i-1}$$

$$\frac{\lambda}{\mu} = \rho \Rightarrow \left(\frac{\lambda}{\mu}\right)^k P_0 = \rho^K P_0$$

where ρ denotes the utilization factor. We know that

$$\sum_{i=0}^{K} P_i = 1 \Rightarrow \sum_{i=0}^{K} \rho^i P_0 = 1$$

$$P_0 = \frac{1}{\sum_{i=0}^{K}\rho^i} = \frac{\rho-1}{\rho^{K+1}-1}$$

for $\rho \neq 1$

$$P_i = \frac{\rho^i(\rho-1)}{\rho^{i+1}-1} \tag{2}$$

for $\rho = 1$

$$\sum_{i=0}^{K} \rho^i = K+1 \Rightarrow P_i = \frac{1}{K+1} \tag{3}$$

If $\rho \neq 1$ then the expected number of packets in the node's queue is given by

$$N = \sum_{i=0}^{K} nP_i = \sum_{i=0}^{K} n\rho^i P_0$$

$$\Rightarrow \frac{\rho-1}{\rho^{k+1}-1}\rho\sum_{i=0}^{K} n\rho^{n-1} N = \frac{\rho-1}{\rho^{k+1}-1}\rho\frac{\partial}{\partial\rho}\sum_{i=0}^{K}\rho^k$$

$$N = \left(\frac{(K+1)\rho^{k+1}}{\rho^k-1} + \frac{\rho}{1-\rho}\right) \tag{4}$$

and if $\rho = 1$ and $P_i = \frac{1}{K+1}$, then

$$N = \sum_{i=0}^{K}\frac{1}{K+1}i = \frac{K}{2} \tag{5}$$

and the mean waiting time from the time a packet arrives at the relaying node to the time the packet reaches the head of line of the queue in node i is

$$d_{Q+C} = \frac{N}{\lambda}$$

For $\rho \neq 1$, we have

$$d_{Q+C} = \left(\frac{(K+1)\rho^{K+1}}{\rho^K-1} + \frac{\rho}{1-\rho}\right)\frac{1}{\lambda} \tag{6}$$

and for $\rho = 1$, we have

$$d_{Q+C} = \sum_{i=0}^{K}\frac{1}{K+1}i = \frac{K}{2\lambda} \tag{7}$$

Due to the fact that a node's queue size is upper bounded by a maximum queue size, say K, we can estimate the maximum queuing and contention delay. The maximum value of d_{Q+C}, denoted by $d_{upbound}$, can be calculated as

$$d_{upbound} = \lim_{\rho\to\infty} d_{Q+C}$$

$$d_{upbound} \approx \frac{K\rho^{K+1}}{\rho^K\lambda}$$

Therefore, $d_{upbound}$ is approximately defined as

$$d_{upbound} \approx \frac{K}{\mu} \tag{8}$$

This equation reveals that the maximum value for queuing and contention delay can be estimated as the ratio of maximum queue size over the service time in a node.

3.3. Transmission delay

In this section, in order to characterize transmission delay, we focus on transmission mechanism used for multicasting in random access wireless communications. Due to fundamental differences between multicast and unicast mechanism, data link layer handle multicast data in a different way. Unlike unicasting, multicast mechanism does not involve RTS/CTS exchange before data transmission. In addition, the multicast members are not required to send acknowledgment to the source node. This has a huge impact on increasing packet error rate during transmission time. Therefore, in our analysis, we assume no RTS/CTS exchange and packet acknowledgment. In order to transmit data packets using physical medium, a random access MAC model is employed. Because of shared nature of physical medium in wireless communication, the source node employs carrier sense multiple access with collision avoidance protocol (CDMA/CA) to avoid packet collision with other nodes that simultaneously occupy the wireless link resources. When a node has data to send, it senses the physical medium. If the medium is idle, the packets are injected into the network; otherwise, it waits until the medium gets idle and then it counts down a certain period of time called back-off time before sending a data packet. Duration of back-off time is exponentially distributed and is determined by a pseudo-random integer distributed in [0, W_{i-1}] range (Yang and Kravets, 2006), where W_i denotes the contention window at the ith back-off slot. When the back-off time expires, the source node listens to the transmission link. If the medium is idle, it sends the packets to the neighboring nodes. If the medium gets busy before the back-off time expires, the node timer freezes till the channel gets free. Figure 1 illustrates neighboring and interfering nodes within the network. The nodes lie within area $2A(r)$, where r is the radius of a circle centered at the source node called interference nodes. A node can successfully transmit data within the network when none of the interfering nodes concurrently transmit packet.

When the channel of the relaying node becomes free, the node starts forwarding multicast data and back-off timer of the neighboring nodes in the area $2A(r)$ gets frozen during the transmission period (Bisnik and Abouzeid, 2009). Therefore, the duration of time a wireless channel is available for data transmission for an arbitrary node with Φ interfering nodes and propagation area $4\pi r^2$ can be expressed as

$$d_{BusyChannel} = \frac{\Phi 4\pi r^2 m}{bw}$$

where m represents the packet size and bw denotes the single hop bandwidth between two nodes. Therefore, the time that the

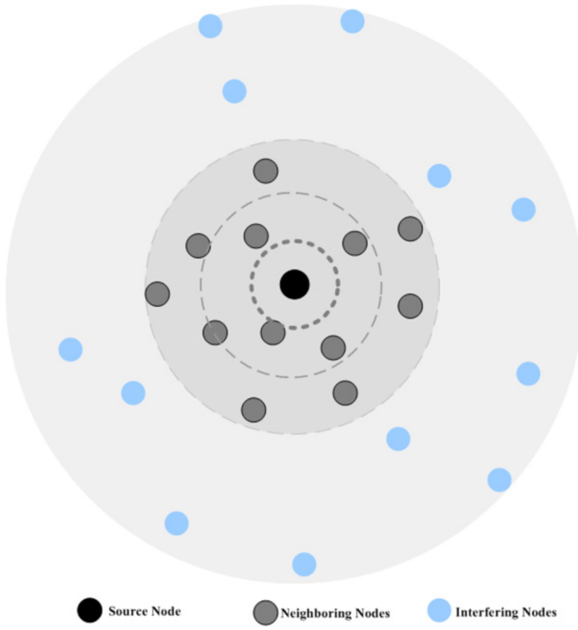

Fig. 1. Neighboring and interfering nodes of a source.

channel is available for data transmission in time unit (1 s) is

$$d_{Free\ Channel} = 1 - T_{Busy\ Channel} = 1 - \frac{\Phi 4\pi r^2 m}{bw}$$

We assume that the contributing nodes in the MAC layer use CDMA with no RTS/CTS and ACK messages. The service time can be defined as

$$T_{ServiceTime} = \varsigma + \frac{m}{bw}$$

where ς is the duration of the back-off time, and m/bw represents the transmission time, which is the time required to send the whole packet with m bits over a link with bandwidth bw. The mean transmission time required to inject a packet in the network can be defined as the time required to send the packet (service time) over the fraction of time the channel is available for data transmission. Therefore, the mean transmission delay is expressed as

$$d_T = \frac{\varsigma + \frac{m}{bw}}{1 - \frac{\Phi 4\pi r^2 m}{bw}} \tag{9}$$

Now, the single hop delay to transmit a packet from node a to its neighboring nodes can be represented as

$$d_a = d_{upbound} + d_T = \frac{K}{\mu} + \frac{\varsigma + \frac{m}{bw}}{1 - \frac{\Phi 4\pi r^2 m}{bw}} \tag{10}$$

By applying Eq. (10) in contributing nodes, each node can estimate the delay interval from the time a packet arrived at the node to the time the packet is completely injected into the network.

The delay estimation in a node can reveal a certain attributes of the node. The large single hop delay value can be resulted by a large queuing delay. The nodes that are located in a traffic congested area generally exhibit higher delay due to higher packet arrival rate at a node. Furthermore, higher delay can also reveal longer waiting time that the nodes should spend to access the channel due to neighboring interference. Thus, the nodes with high single hop delays may be located in congested areas or high interference areas where packet error rate is considerably high due to shared nature of wireless medium. When these nodes receive a Join-Query message, they check single hop delay requirement within the Join-Query message. Based on their one hop delay estimation, if the node can satisfy the delay requirement, it floods the network with Join-Query message; otherwise, it drops the incoming Join-Query message. This mechanism limits the flooding process only to the nodes that can guarantee one hop delay required. The limited flooding avoids the nodes located in congested areas or in areas where nodes are experiencing high delays.

4. Performance evaluation

In this section, we compare the performance of our purposed method and the original ODMRP under various simulation scenarios and working conditions.

4.1. Simulation setup

The simulation environment used is based on NS2 (http://www.isi.edu/nsnam/ns). The simulated environment consists of 80 wireless nodes placed randomly in a $1200 \times 800\ m^2$ area with a maximum node speed of 20 m/s, unless specified, for 900 s of simulated time. The radio propagation range is 250 m and the channel capacity is 2 Mbps. The *TwoRay* propagation model is assumed. The source generates constant bit rate (CBR) traffic. Each node has a drop-tail queue, which holds a maximum of 100 packets at the constant size of 512 bytes. The packets are sent at the rate of 4 packets per second, unless specified. The single hop delay threshold is defined as 10 ms and the periodical route refresh mechanism happens at the interval of 3 s. In each scenario, 1 multicast group with 1 multicast source and 20 multicast receivers is considered. The simulation parameters are summarized in Table 1.

The following metrics are used to evaluate the performance of the protocols.

Packet delivery ratio. This metric represents the ratio of the number of packets received by multicast receivers versus the number of data packets supposed to be received. The corresponding value shows the effectiveness of the protocol in handling the traffic and delivering the data to the intended multicast receiver.

Packet overhead. This metric measures the ratio of the total number of bytes of probe packets over the total number of data bytes delivered to the receiver.

Average end-to-end delay. The average delay of a data packet delivery includes queuing, propagation, and transfer delays.

In the following, we provide the detailed evaluation of our routing protocol. We applied a wide range of scenarios to study the behavior of the limited flooding ODMRP. We study the

Table 1
Summary of simulation environment.

Parameters	Value
Network size	80 nodes over 1200 m × 800 m area
Propagation model	TwoRay
Nodes speed	1–50 m/s
Radio propagation rate	250 m
Channel capacity	2 Mbps
Default traffic rate	4 packet/s
Queue size	50 kB
Queuing policy	Drop-tail queue
Multicast group size	10–50
Number of sources	1–6
Multicast traffic flow	4–30 packet/s
Duration of experiment	900 s
Number of runs	15
Routing protocols	ODMRP, R-ODMRP, limited flooding ODMRP

performance behavior of the limited flooding ODMRP, ODMRP, and R-ODMRP in terms of multicast group size, number of source nodes, and multicast traffic load.

4.2. Effect of multicast group size

This section illustrates the behavior of the three routing protocols in terms of packet delivery ratio, packet overhead, and end-to-end delay as a function of multicast group size.

The multicast group size varies from 10 to 50 nodes. As shown in Fig. 2, the packet delivery ratio of the three routing protocols achieves similar results as the number of multicast receivers increases. Comparing the performance behavior of three routing protocols, we observe the considerable difference in delivery ratio of limited flooding ODMRP. Limited flooding ODMRP performs better at the beginning and remains constantly higher than ODMRP and R-ODMRP during the simulation time. This is due to the fact that in limited flooding ODMRP, route discovery and route refreshment are efficiently managed as long as the multicast source node has data to send. The nodes with large queuing delay may lie in congested areas where the packet drop rate is potentially high. Limited flooding ODMRP avoids the nodes with high delay value, which results in higher packet delivery ratio and lower overhead when the number of multicast receivers increases.

ODMRP exhibits the lowest delivery ratio among the three routing protocols as the number of multicast receivers increases. This can lead to a greater number of control messages as multicast group size increases. In R-ODMRP, the contribution of active non-forwarding nodes and creation of more efficient redundant links increases the probability of R-ODMRP packet delivery within the network.

Figure 3 represents the performance behavior of three routing protocols as a function of routing overhead for different values of multicast group size. Although limited flooding ODMRP exhibits similar behavior in terms of PDR as compared to ODMRP and R-ODMRP but it improves the routing overhead by approximately 40% during the simulation time. One reason is the effect of more efficient packet forwarding mechanism as multicast group size grows. This is due to the fact that when the number of multicast receivers increases, the ratio of received packets over the generated and transmitted packets increases. Another reason is that employing delay characteristics can reveal the status of a node within the network. In highly congested areas where packet arrival rate is considerably high, the delay over the corresponding nodes grows exponentially. Limited flooding ODMRP avoids using such links. Therefore, the total number of bytes of controlling packets over the total number of data bytes drastically decreases in network long run. As depicted in Fig. 3, for most of group sizes, ODMRP exhibits the highest packet overhead during the simulation time. The mesh nature of ODMRP causes greater redundancy between the nodes. Consequently, a larger number of periodical route refresh messages are flooded within the network, which increases the packet overhead. R-ODMRP also shows approximately 40% higher packet overhead as compared to limited flooding ODMRP. This is due to the fact that as the number of multicast groups increases more nodes participate as active forwarding nodes, which increases the number of query messages within the network.

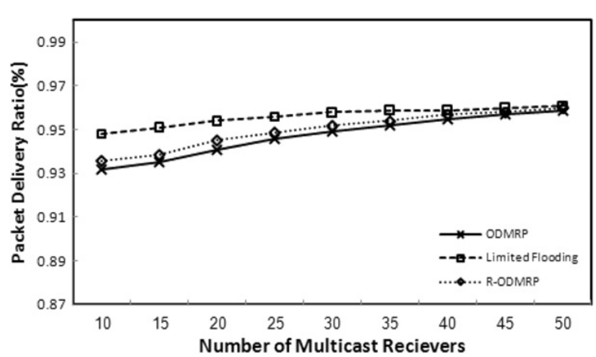

Fig. 2. Packet delivery ratio as a function of multicast group size (1 multicast group, 1 source, 0 s pause time, and 20 m/s maximum speed).

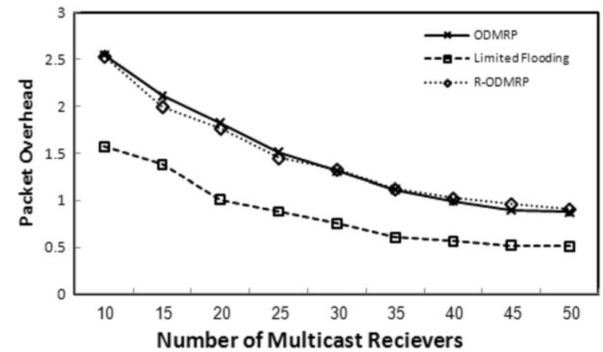

Fig. 3. Packet overhead as a function of multicast group size (1 multicast group, 1 source, 0 s pause time, and 20 m/s maximum speed).

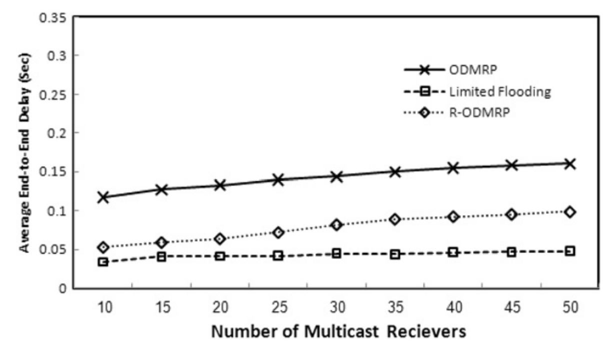

Fig. 4. Average end-to-end delay as a function of multicast group size (1 multicast group, 1 source, 0 s pause time, and 20 m/s maximum speed).

As depicted in Fig. 4, the average end-to-end delay increases as the multicast group size grows. Limited flooding ODMRP and R-ODMRP show better end-to-end delays due to their more efficient forwarding mechanism. In R-ODMRP, as the number of multicast group increases, more nodes incorporates as non-active forwarding nodes, which improves multicast traffic forwarding through redundant links from source to destinations. Limited flooding ODMRP exhibits the lowest average end-to-end delay because multicast traffic flows are conducted through the nodes that lie in non-congested areas. Our proposed mechanism avoids using the nodes with large delay values as multicast traffic forwarder, which results in lower end-to-end delay during the simulation time.

4.3. Effect of multicast traffic load

Figures 5–7 represent the effect of traffic load on network performance. The packet sending rate varies from 4 to 30 packets per second. The packet size is 512 bytes and there is one multicast source and 20 receivers in the multicast group during the simulation time. Figure 5 shows that by increasing the packet sending rate, the performance of three routing protocols partially degrades. The limited bandwidth and buffer size of the contributing nodes and also high packet sending rate cause higher congestion and packet loss in the

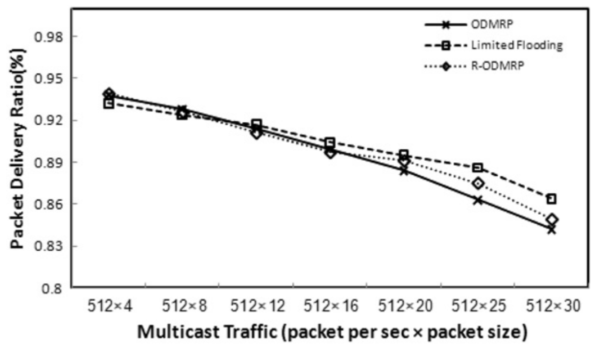

Fig. 5. Packet delivery ratio as a function of multicast traffic load (1 multicast group, 1 source, 20 receives, 0 s pause time, and 20 m/s maximum speed).

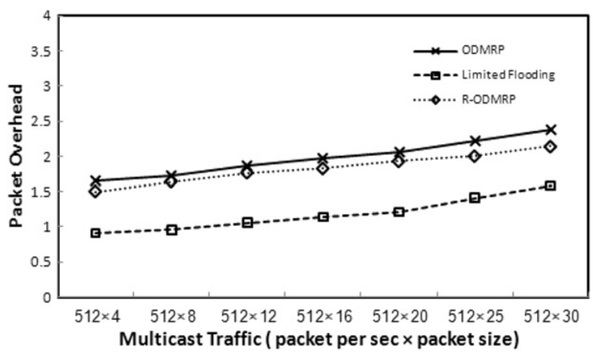

Fig. 6. Packet overhead as a function of multicast traffic load (1 multicast group, 1 source, 20 receivers, 0 s pause time, and 20 m/s maximum speed).

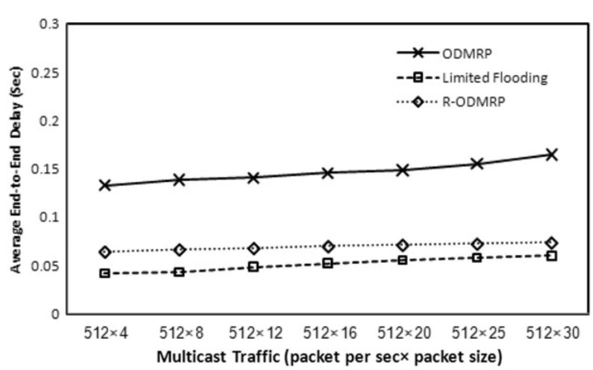

Fig. 7. Average end-to-end delay as a function of multicast traffic load (1 multicast group, 1 source, 20 receivers, 0 s pause time, and 20 m/s maximum speed).

network. Consequently, the packet delivery ratio significantly decreases while the packet overhead increases. Results achieved from simulation experiments reveal that limited flooding ODMRP outperforms the original ODMRP and R-ODMRP when the packet sending rate increases. This is because in limited flooding ODMRP, nodes avoid intensive flooding of query messages compared to ODMRP. The direct implication is that more bandwidth resources can be allocated to the nodes and also packet loss can drastically degrade within the network. Furthermore, it improves the end-to-end delay as packet sending rate increases.

As depicted in Fig. 6, packet overhead in limited flooding ODMRP remains constantly lower than that in ODMRP and R-ODMRP because it greatly reduces the cost of flooding mechanism and mesh architecture of ODMRP. Limited flooding ODMRP shows its best performance under high traffic rates. The packet overhead of limited flooding ODMRP is improved by about 40% at highest packet transmission rates.

As shown in Fig. 7, limited flooding ODMRP and R-ODMRP show similar results in terms of end-to-end delay as the multicast traffic load increases. Limited flooding ODMRP achieves the lowest values for end-to-end delay while it also induces 33% less packet overhead during the simulation time. R-ODMRP can relatively achieve better end-to-end delay compared to ODMRP but packet overhead stays as high as ODMRP for different multicast traffic loads.

ODMRP shows the highest value of end-to-end delay especially in highly congested scenarios. Extensive query messages accompanied by increasing multicast traffic load and service time delay in contributing nodes cause relatively higher end-to-end delay in ODMRP.

4.4. *Effect of the number of multicast sources*

Figure 8 illustrates the effects of the number of traffic sources in a single multicast group on packet delivery ratio. The number of multicast source nodes varies from 1 to 6 while the number of destination nodes remains 20 during the simulation time. Although the mesh structure of three routing protocols provides good delivery ratio but redundant routes in mesh architecture can be relatively an expensive factor, especially in the scenarios where multiple source nodes generate multicast traffic. One reason is that when the traffic gets intensively high, delivery ratio tends to decrease while packet overhead increases, causing extreme congestion and packet loss within the network.

Simulation analysis reveals that the packet overhead as a function of the number of multicast traffic sources is more noticeable in ODMRP. Periodical refresh messages for route maintenance introduce extra overhead as the number of source nodes increases. In limited flooding ODMRP, based on applying efficient

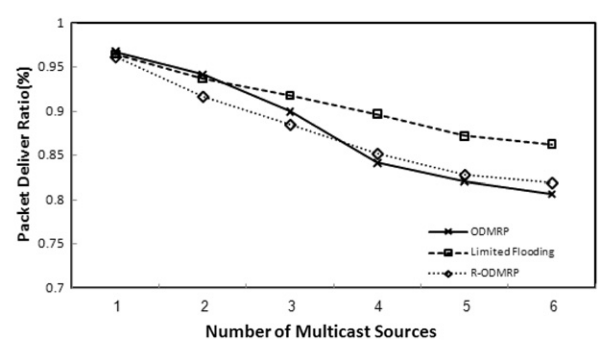

Fig. 8. Packet delivery ratio as a function of multicast sources (1 multicast group, 1–6 sources, 20 receivers, 0 s pause time, and 20 m/s maximum speed).

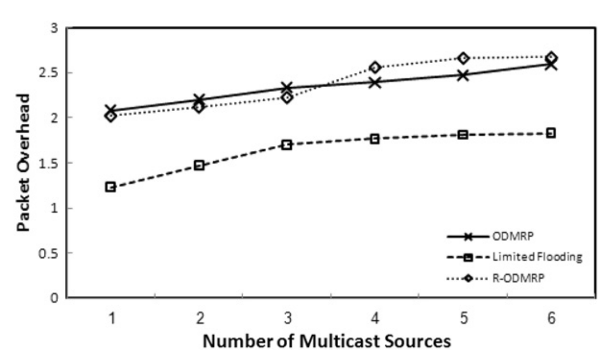

Fig. 9. Packet overhead as a function of multicast sources (1 multicast group, 1–6 sources, 20 receivers, 0 s pause time, and 20 m/s maximum speed).

flooding, the number of in-transit packets and collision occurrence probability are drastically reduced. As a consequence, results, illustrated in Fig. 9, show that our approach induces approximately 30% lower packet overhead as the number of traffic sources increases when compared to ODMRP and R-ODMRP. R-ODMRP imposes higher packet overhead under high traffic loads because in scenarios where the number of multicast sources increases, a large number of request messages are injected into the network by non-active forwarding nodes, which results in higher network congestion and packet overhead during the simulation time.

4.5. Effect of node speed

Figures 10–12 show the effect of mobility on performance of three routing protocols. The maximum node speed varies from 1 to 50 m/s for 20 multicast receivers. As depicted in Fig. 10, performance behavior of the three routing protocols as a function of delivery ratio stays similar in all cases. The mesh nature and path redundancy in these routing protocols compromise frequent link breakage. This is more sensible in scenarios where the nodes experience high mobility within the network. The fault tolerance capabilities of these mesh-based protocols keep packet delivery ratio high by forming multiple forwarding routes and preventing a high packet loss rate due to link breakage.

Figure 11 represents the imposed routing overhead as a result of mobility conditions. As depicted, the gap between limited flooding ODMRP and R-ODMRP overhead is relatively large. The non-active forwarding nodes in R-ODMRP create more resilient paths at the cost of higher packet overhead. R-ODMPR induces 42% higher packet overhead in order to achieve 95% of packet delivery ratio. The higher values for packet overhead in R-ODMRP are due to the fact that contribution of non-active forwarding nodes induces frequent message rebroadcasting, which greatly impacts its performance compared to limited flooding ODMRP.

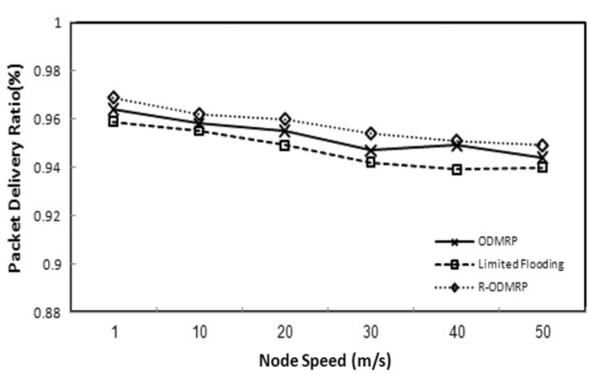

Fig. 10. Packet delivery ratio as a function of node speed (1 group, 1 source, 20 receivers, and 0 s pause time).

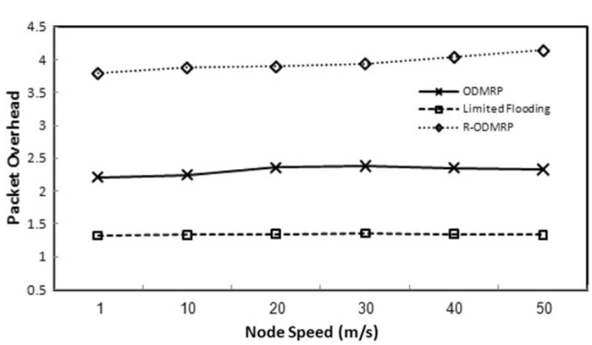

Fig. 11. Packet delivery ratio as a function of node speed (1 group, 1 source, 20 receivers, and 0 s pause time).

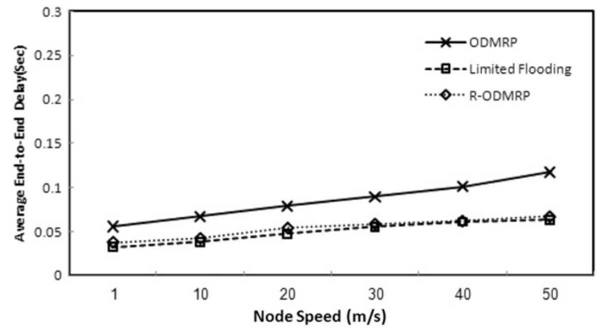

Fig. 12. Average end-to-end delay as a function of node speed (1 group, 1 source, 20 receivers, and 0 s pause time).

The packet overhead of our routing mechanism remains nearly constant in all simulation points. Although in limited flooding ODMRP the delivery ratio degrades with respect to ODMRP but it achieves 94% of packet delivery ratio while incurring 40% less packet overhead in comparison to ODMRP. Interestingly, the gap between limited flooding ODMRP and R-ODMRP end-to-end delay is negligible but limited flooding ODMRP induces significantly less packet overhead compared to R-ODMRP. This is due to the fact that efficient flooding mechanism for route discovery and route maintenance cuts down the routing overhead for limited flooding ODMRP in comparison to ODMRP and R-ODMRP.

5. Conclusions

In this paper, we proposed a model for route discovery and route maintenance, called limited flooding ODMRP, to improve the flooding mechanism of the ODMRP protocol. We believe that delay characteristics of a node can exhibit the ability of the nodes for packet forwarding within the network. On the basis of applying the proposed flooding mechanism, only the nodes that exhibit good delay characteristics are permitted to flood the Join-Query messages within the network.

Simulation experiments revealed that our methodology results in approximately 40% improvement in packet overhead in highly congested scenarios. The simulation also showed that even though the performance of all three routing protocols exhibit similar behavior in terms of packet delivery ratio as a function of multicast group size, traffic load, and mobility, but limited flooding ODMRP considerably performs better in terms of packet overhead, especially under intense traffic loads.

The general conclusion from our comparative analysis is that R-ODMRP, as a new extension of ODMRP, performs well in terms of packet delivery ratio in scenarios where nodes mobility is high but has the highest routing overhead among the protocols considered. Limited flooding ODMRP provides higher performance results in terms of delivery, overhead, and end-to-end delay than ODMRP and R-ODMRP for most scenarios considered.

In our future works, we aim at running empirical analysis in real environments to study the efficiency of limited flooding ODMRP in comparison with other multicast routing protocols when high throughput applications, e.g. multimedia applications, send packets to multicast group members within the network.

References

Asif HM, Sheltami TR, Shekshouki EE. Power consumption optimization and delay minimization in MANET. In: Proceedings of the 6th international conference on advances in mobile computing and multimedia (MoMM); November 2008.

Ahmad DT. Multicasting in ad hoc networks. University of Otawa; 2005. fall.
Bisnik N, Abouzeid AA. Queuing network models for delay analysis of multi-hop wireless ad hoc networks. Elsevier Ad Hoc Networks 2009;7.
Draves R, Padhye J, Zill B. Routing in multi-radio, multi-hop wireless mesh networks. In: Proceedings of the ACM MOBICOM; 2004.
Garcia JJ, Aceves Luna, Madruga E. The core assisted mesh protocol. IEEE Journal on Selected Areas in Communications 1999;17(8). August.
〈http://www.isi.edu/nsnam/ns〉.
Lee M, Kim T. PatchODMRP: an ad hoc multicast routing protocol. In: Proceedings of the 15th international conference on information networking (ICOIN); January 2001.
Li H, Cheng Y, Zhou C, Zhuang W. Minimizing end-to-end delay: a novel routing metric for multi-radio wireless mesh networks. In: Proceedings of the IEEE INFOCOM; April 2009.
Lee SJ, Su W, Hsu J, Gerla M, Bagrodia R. A performance comparison study of ad hoc wireless multicast protocols. In: Proceedings of the 19th annual joint conference of the IEEE computer and communications societies (INFOCOM); March 2000.
Oh SY, Park JS, Gerla M. E-ODMRP: enhanced ODMRP with motion adaptive refresh. Elsevier Journal of Parallel and Distributed Computing 2008;68.
Paul S. Multicasting on the Internet and its applications. Kluwer Academic Publishers; 1998.
Pathrina D, Kwon M. RODMRP: resilient on-demand multicast routing protocol. In: Proceedings of the 21th advanced information networking and applications workshops (AINAW); May 2007.
Perkins CE, Bhagwat P. Ad hoc networks. Addision-Wesley Longman Publishing Co., Inc; 2001.
Royer E, Perkins C. Multicast ad-hoc on demand distance vector (c) routing. draftietfmanet-maodv-00.txt; 2000.
Ruiz PM, Gomez-Skarmeta AF. Reducing data-overhead of mesh-based ad-hoc multicast routing protocols by Steiner tree meshes. In: Proceedings of the first IEEE communications society conference on sensor and ad hoc communications and networks (SECON); 2004.
Saiful Azad Md, Anwar Farhat, Arafatur Rahman Md. Performance comparison of proactive and reactive multicast routing protocols over wireless mesh networks. International Journal of Computer Science and Network Security (IJCSNS) 2009;9(6) June.
So B, Jeon H, Lee J. PEODMRP: Performance enhanced on-demand multicast routing protocol. In: Proceedings of the 8th joint conference on communications & information (JCCI); July 2004.
Sarr C, IG Lassous. Estimating average end-to-end delays. In: Proceedings of the IEEE 802.11 multihop wireless networks. Available at 〈http://hal.inria.fr/inria-00166017/en/〉.
Santos RA, Edwards A, Garcia-Ruiz MA, Alvarez O, Sandoval S. Performance of topological multicast routing algorithms on wireless adhoc networks. In: Proceedings of the 6th electronics, robotics and automative mechanics conference (CERMA); September 2007.
Tijms HC. A first course in stochastic models. Chichester: Wiley; 2003.
Vasiliou A, Economides AA. Evaluation of multicasting algorithms in manets. In: Proceedings of the 3rd world Enformatika conference (WEC); April 2005.
Vaishampayan R, Garcia-Luna-Aceves JJ. Protocol for unified multicasting through announcements (PUMA). In: Proceedings of the 1st IEEE international conference on mobile ad-hoc and sensor systems (MASS); 2004.
Viswanath K, Obraczka K, Tsudik G. Exploring mesh and tree based multicast routing protocols for MANETs. IEEE Mobile Computing 2006;5(1).
Wu CW, Tay YC, Toh CK. Ad hoc multicast routing protocol utilizing increasing id-numbers (AMRIS). Functional specification. IEEE MIBCOM; 1999.
Xue Q, Ganz A. Ad hoc QOS on-demand routing (AQOR) in mobile ad hoc networks. Elsevier Journal of Parallel and Distributed Computing 2003;63(2).
Yi Y, Lee S, Su W, Gerla M. On-demand multicast routing protocol (ODMRP) for ad-hoc networks. draft-yi-manet-odmrp-00.txt; 2003.
Yang Y, Wang J, Kravets R. Designing routing metrics for mesh networks. In: Proceedings of the first IEEE workshop on wireless mesh networks (WiMesh); 2005.
Yang Y, Kravets R. Achieving delay guarantees in ad hoc networks using distributed contention window adaption. In: Proceedings of the 25th IEEE conference on computer communications (INFOCOM); April 2006.