A MODEL FOR PERFORMANCE ANALISYSIS OF MULTICAST ROUTING PROTOCOLS

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Abstract: *We study mobile communication of the ad hoc networks. Ad hoc networks are complex distributed systems that consist of wireless mobile or static nodes that can freely and dynamically self-organize [Namicheishvili et al, 2011].*

The main finding is the performance of Multicast Routing protocol with Dynamic Core (MRDC) multicast tree in a variety of mobility and communication scenarios. We focused on control plan of MRDC. Because of this, in this paper the performance means the efficiency and robustness of multicast tree. Mode selection of forwarding plan is disabled and multicast routers broadcast multicast packets. The aim of the simulation is to evaluate the robustness and efficiency of multicast tree.

The performance analysis contains of two goals: to select MRDC key parameters (e.g. period of multicast tree refresh and threshold for average queue length) and to analyze performance in different traffic loads and mobility pattern. The performance analysis is further divided into two parts: multicast tree analysis and protocol comparison.

Keywords: *Ad Hoc Networks, protocols, Routing protocols, packet, source node, Relay routing, finite memory, MRDC Multicast Tree Analysis, Simulation Metrics*

ACM Keywords: *C.2.2 Network Protocols; C.2.3 Network Operations*

Introduction

We consider the Routing protocols in Ad Hoc Networks. The network consists of three types of nodes, source, destination, and relay nodes. The main finding is the performance of MRDC multicast tree in a variety of mobility and communication scenarios. Because we focused on control plan of MRDC, in this paper, the performance means the efficiency and robustness of multicast tree. Mode selection of forwarding plan is disabled and multicast routers broadcast multicast packets [Aslanishvili, 2012].

The performance such as routing over-head and forwarding overhead of Multicast Routing Protocol with Dynamic Core (MRDC) is briefly analyzed. In this paper, we evaluate the performance of MRDC through detailed packet level simulation under a network simulator. The performance analysis contains two goals: to select MRDC key parameters (e.g. period of multicast tree refresh and threshold for average queue length) and to analyze performance in different traffic loads and mobility pattern. The performance analysis is further divided into two parts: multicast tree analysis and protocol comparison.

Model of MRDC Architecture

Contrarily to most multicast routing protocols which combine multicast packet for-warding with delivery structure construction and maintenance, Multicast routing protocol with dynamic core (MRDC) is divided into a control plan and a forwarding plan, as it is shown in Figure 1.

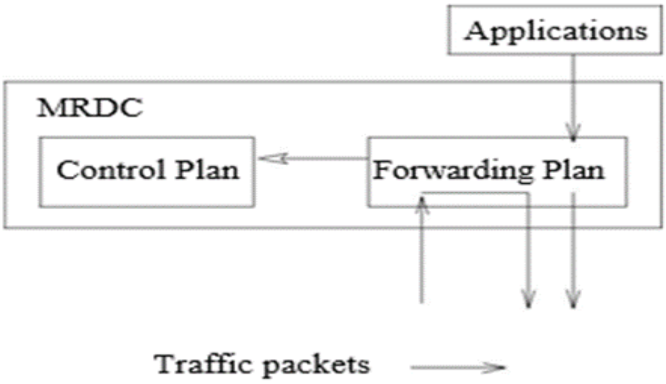


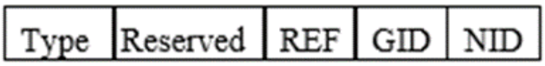
Figure 1. Multicast routing protocol with dynamic core (MRDC)

The control plan deals with the construction and maintenance of multicast delivery structures, while the forwarding plan copes with how to forward multicast packets generated by the node itself or by other nodes. This architecture allows us to concentrate on studying an optimal routing strategy to reduce global bandwidth consumption while adapting to network topology changes, and then design an adaptive multicast transmission policy regarding net-work situation and application requirements. The control plan works in a passive fashion and is driven by the forwarding plan. In fact, the forwarding plan triggers the control plan to collect and update multicast routing information. The control plan is somewhat lower layer independent in the sense that physical layer and MAC layer have little influence on the result of delivery structure. Conversely, the question of how to forward multicast packets hop by hop to their receivers is closely relative to the MAC layer in use.

Simulation Metrics

Performance analysis aims to demonstrate the robustness and efficiency of MRDC multicast tree. The robustness is to test whether multicast tree keeps connecting and covers all reachable group members when network topology changes or con-troll message loss. On the other hand, the efficiency means whether the potential forwarding overhead and routing overhead of MRDC multicast tree scale well with different mobility and traffic scenarios. The following metrics are chosen:

- **Average number of multicast router**: This metric counts the average number of nodes on the multicast tree which transmit multicast packet during a simulation. It allows us to estimate the forwarding overhead in terms of the number of packet forwarded to deliver a multicast packet to receivers in broadcast mode and under an ideal condition (for example without trans-mission loss). Thus this metric provides the scalability and efficiency of multicast routing protocol.
- **Average number of non-member router**: It measures the means of the number of nodes which are on the multicast tree but at the same time not the group member. This metric can be used to compute routing overhead in periodical tree refresh but also the size of multicast tree. The messages used by MRDC to exchange multicast routing information among nodes have the format shown in Figure 2. Thus, we will consider them as *MRDC messages*.



Type	Reserved	REF	GID	NID

Figure 2. Structure of a MRDC message

A MRDC message contains five fields: the type of the MRDC message (Type), a reserved field (Reserved) for future use, reference number (REF), group ID number (GID) and node ID number (NID). The control overhead of MRDC comes from the periodical tree refresh and local tree repair procedures. In periodical tree refresh, CA messages are broadcast by flooding. Each node sends at least once the CA message. Then, every group member except the core sends a RAR message and should receive a corresponding RAA message. Thus, if a network consists of nodes and a multicast group contains members, the control overhead of the periodical tree refresh per seconds is formula (1.1)

$$\frac{n + 2 * (m - 1 + x)}{PERIOD\_REF} \tag{1.1}$$

where x is the number of non group member nodes on the tree.

The number of non -group member tree x node, is determined by the distribution of group members in the network. In the ideal case, where all the group members are within the coverage range of core, x reaches it minimum value, zero. On the opposite, in the worst case where group members are distributed at the bound of the network and multicast tree contains all nodes in the network, $x = n - m + 1$. Consequently, the total control message rate of MRDC per second is formula (1.2)

$$\frac{n + 2 * (m - 1 + x) + y}{PERIOD\_REF} \tag{1.2}$$

of distribution and topology change frequency.

It is not smaller than formula 1.3 for a given tree refresh period PERIOD_REF.

$$\frac{n + 2 * (m - 1)}{PERIOD\_REF} \tag{1.3}$$

Applying other two predefined parameters, number of mobile nodes and number of group members, we can calculate routing overhead of periodical tree refresh in a simulation. The number of non-member router plus the number of group members gives the total number of nodes on the tree if we do not consider network partition. That is the forwarding overhead in unicast transmission mode.

- **Number of tree repair times**: This metric counts the number of local tree repair times initiated by MRDC. MRDC's routing overhead comes from periodical tree refresh and local tree recovery. For a given simulation time, the routing overhead, generated for periodical tree refresh, can be calculated by the formula 1.3. While the routing overhead of local tree recovery varies scenario to scenario. Therefore, this metric allows us to estimates the variation of routing overhead of MRDC in different scenarios.
- **Tree broken times**: It measures the number of multicast tree broken de-texted by simulator during a simulation. Supposing that all multicast routers operate on broadcast transmission mode to deliver multicast packets simulator checks whether all group members within the same network (partition), as the core, are reachable through the multicast tree. In other words, tree broken here means the physical fragmentation of multicast tree, since simulator does not verify logical relationship among tree members.

This metric reflects the robustness of a tree-based multicast routing protocol.

To calculate these metrics, after multicast sources begins their transmission, simulator reports every half second the number of total tree nodes and interior tree nodes and whether the tree covers all reachable group members. Reachable group members are the group members who are within the same network (partition) as the core or in other words core can reach these members directly or through some other nodes. There are totally 1696 such reports during a simulation. Interior tree nodes are tree members that have downstream nodes. The number of total tree nodes minus reachable group members gives the number of non-member routers. A multicast tree covers all reachable group members if core can reach all other group members within the same network partition through the tree.

Simulation Scenarios

A number of movement scenarios and traffic scenarios are generated and used as inputs to the simulations. Each movement scenario file determines movements of 50 nodes. The movement model of nodes is the random waypoint model with-out pause. Each node begins the simulation by selecting a random destination in the 1000m x 1000m space and moves to that destination at a speed distributed uniformly between 0 and a maximum movement speed. Upon reaching the destination, the node selects another destination, and moves there as previously described. Nodes repeat this behavior for the duration of the simulation. Each simulation runs for 900 seconds of simulation time.

Movement patterns are generated for different maximum speed. When maximum speed equals to 0, nodes do not move during a simulation which represents stable networks. A low maximum speed results to a low relative movement speed of nodes and corresponds to low mobility cases. On the contrary, a high maximum speed means high relative movement speed among nodes and it corresponds to high mobility. Because the performance of the protocols is very sensitive to node position and movement pattern, we generated 10 movement scenarios for each value of maximum speed. Thus, each collected data in figures and tables presents an average of these 10 movement scenarios with the same max-mum speed. Network partition is tolerant in mobility scenarios while excluded in stable networks.

Traffic scenarios determine the number of groups, group members and multi-cast traffic. A number of nodes are chosen as multicast group member. To reduce side effects, membership control features are turned off. All group members join the multicast session at the beginning of the simulation and remain as members throughout the simulation. Multicast traffic is generated by constant bit rate (CBR) sources. Each source sends 4 packets per second [Aslanishvili, 2014].

The size of data payload is 512 bytes. The transmissions start at times uniformly distributed between 30 and 60 simulation seconds and continue till the end. These sources are attached to nodes which were chosen among multicast members. The number of groups is mode two of the number of sources. For example a 5-source traffic scenario defines 3 multicast groups among which 2 groups have respectively 2 sources and the third one has one source. This configuration forms not only inter-group competition but also intra-group inter-sources competition.

Implementation decisions: While implementing the MRDC in ns-2, we made following decisions. The Greatest-Range of JI message propagation is 4 hops. Upstream wait for 0.5 seconds before broadcasting another JI message. Downstream set the multicast routing entry to tree-fault state 1.5 seconds after detecting edge broken. NEIGHBOR HELLO period is set to 0.5 second and the timer of active neigh-boring entry is set to 1 second in the simulations. In order to improve bandwidth efficiency, MAC layer cooperation is used in updating active neighbor table. When a node successfully sends or receives a packet to/from a neighbor, it updates the corresponding entry in active neighbor table because MAC layer control message (RTS, CTS and ACK) is received from the neighbor.

Parameter Selection: The simulations in this step address to achieve a suitable period value for multi-cast tree refresh and optimal thresholds for transmission mode selection. These parameters will be used in the simulations of the performance analysis.

Period of multicast tree refresh: The period of multicast tree refresh is an important parameter of MRDC, which has direct impact on the performance of protocol. The longer the period is, the more slowly MRDC reacts to topology changes and the more fault might exist in multi-cast tree. That reduces the number of packets delivered to receivers. On the other hand, a shorter period means frequent network range broadcast which increases significantly routing overhead. Therefore, an ideal refresh period (PERIOD REF) should permit this protocol to deliver as many as possible multicast packets without creating significant routing overhead. For this reason, the following two metrics are employed to select period of tree refresh.

Packet delivery ratio: the ratio of the number of multicast data packets correctly delivered to the receivers versus the number of multicast data packets supposed to be received. The packets, which are sent when some receivers are unreachable for the sources because of network partition, are counted as supposed to be received by those receivers [Aslanishvili, 2014].

Number of control messages per second: The rate of MRDC control messages transmitted for multicast tree construction and maintenance. This metric is used to investigate the resource consumed by multicast routing proto-col.

Because periodical tree refresh mainly addresses topology changes, we use different movement scenarios without changing traffic scenario in this step. The maximum movement speed is varied from 0m/s (stable networks) to 20m/s (high mobility networks). A traffic scenario in which one multicast group contains 10 members and two traffic senders is chosen to simulate a group-shared case. One sender plays the role of core and the other one act as normal group member. Mode selection is disabled in the simulations. All routers broadcast multicast packets.

The simulation results are shown in Figure 3.

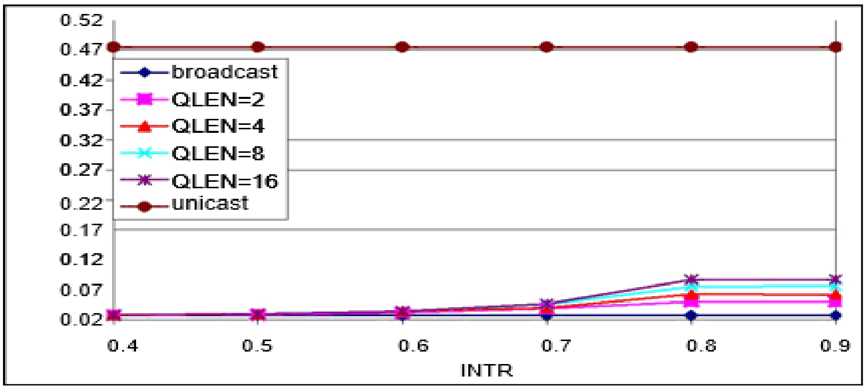


Figure 3. Original (including unicast case)

Packet delivery ratio decreases with the increase of mobility speed but in shorter periods it resists better than in longer ones, as illustrated by Figure 3. Tree structure offers the unique route to distribute data packet from sources to receivers. Once topology changes touch multicast tree, packets transferred on the broken branches will be dropped. High relative movement speed causes high degree of topology changes that in turn gives high tree break rate. A shorter tree refresh period produces more frequently recon-figuration and consequently can react more quickly to topology changes. That is why short PERIOD REF is robust against topology.

In terms of achieving a better packet delivery ratio, Figure 3 shows a con-tradition that low mobility networks favorite long period while short period is preferred in high mobility networks. After analyzing the reasons of packet delivery failure, we find the answer of this contradiction. Besides low layer transmission failure and routing protocol, packet delivery failure is also caused by the collaboration of control plan with multicast forwarding mechanism. The bad collaboration of two parts is the main reason which makes the difference of packet delivery ratio in stable and low mobility networks. Recall that, in order to remove errors and form a tree more adapt to current topology, MRDC destroys old tree and constructs a new one. These results in those multicast packets cannot be correctly delivered to all receivers during that period. More frequent tree refresh causes more delivery fail-use relative to this fact. Believing that a smart forwarding mechanism can greatly reduce this type of delivery failure, short PERIOD REF is preferred in all mobility cases. As shown in Figure 3, bigger PERIOD REF values generate smaller number of routing messages to construct and maintain multicast tree, while their con-troll overhead increases more quickly than that of smaller ones with the increase of mobility. High degree of topology changes makes MRDC generate more con-troll messages for local tree recovery. Frequent tree reconfiguration alleviates this requirement. Thus node mobility has less effect on control overhead of short PE-RIOD REF than long ones. However, in all the cases shorter PERIOD REFs gen- errata more overhead.

Short PERIOD REF makes protocol robust against topology changes. While, long PERIOD REF makes protocol efficient with low control overhead. In the rest of simulations, we use 5 seconds as PERIOD REF since in this case MRDC can deliver more than 94% data packet and create less than 5% routing overhead.

We study the impact of QLEN and INTR on the performance of adaptive multicast forwarding mechanism to obtain an optimal pair. We set node's maximum movement speed to 5 m/s and choose 6-source traffic scenario, because this is the traffic scenario in which broadcast mode begins to outperform unicast mode see Table 1. This scenario defines three multicast groups and each group has 10 members and two CBR sources. We vary the QLEN from 2 to 16 and INTR from 0.5 to 1.0. MOR is always inferior to 1.0 because it does not consider medium occupied by a node itself for sending packets. Thus, by setting INTR to 0.9, which makes the metric MOR always smaller than its threshold, we simulate the case where MAC layer counters are unavailable. For comparison reason, we also test the performance of MRDC in the cases in which all nodes operate in broadcast mode (set INTR=0 for example) or in unicast mode (QLEN=65 and INTR=1.0).

The former case is denoted as broadcast and later as unicast. In the Table 1, the maximum movement speed is varied from 0 m/s to 20 m/s to examine the robustness of the protocol against topology changes. One multicast group containing 20 members is simulated. The network load is set to very light (1 source) to exclude as much as possible the influence of traffic packets on control message transmission.

The forwarding overhead in broadcast mode might remain stable since the number of interior node is nearly unchanged in dynamic networks. For the forwarding overhead of unicast mode, node mobility even decreases slightly the size of multicast tree. That can be obtained by adding the number of group members to the number of non-member routers. The result decreases from 28.23 (=20+8.23) to 26.64 (=20+6.64). One reason is that movement makes node uniformly distributed in network, and as a result, the distances, in terms of number of hops, from group members to core are reduced as shown in Table 2.

Table 2 also demonstrates the advantage of multicast comparing with unicast and broadcast in delivering a packet to multiple receivers. The distance in terms of the number of hops from core to a multicast member is exactly the forwarding overhead of sending a packet to that member.

Figure 4 shows that the packet delivery ratio of adaptive multicast for-warding mechanism as a function of INTR and QLEN. In order to show better the details of the performance curves, we enlarge the y-axis scale range from 88% to 94% and show the result in Figure 4. The simulation results show that the adaptive multicast forwarding mechanism provides the best packet delivery ratio when INTR equals to 0.7 and QLEN is 16.

Table 1. The performance of MRDC multicast tree as a function of maximum movement speed

Maximum speed (m/s)	Average nonmember routers	Average int-error node	Number of tree repair times	Number of tree broken times
0	8.24	14.81	0	8
1	7.23	12.61	51	9
2	7.05	12.51	91	19
5	7.10	12.72	205	44
10	7.10	13.06	344	74
15	6.48	12.44	466	94
20	6.64	12.84	596	122

Table 2. Multicast group in mobility simulations: distance and unreachable time

Maximum speed (m/s)	Distance (number of hops) from members to core	Times of members unreachable to core
0	63.3	0
1	49.6	0
2	49.1	0.0428
5	47.8	0.1694
10	47.0	0.1623
15	45.5	0.2077
20	45.8	0.1201

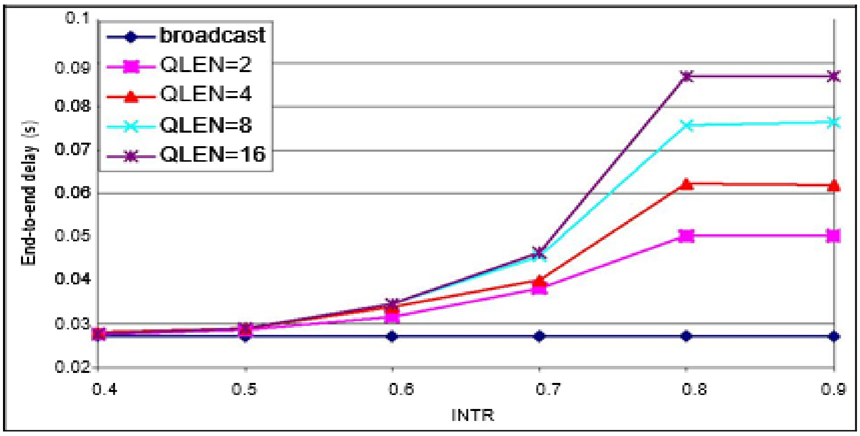


Figure 4. Enlarged (without unicast case)

Conclusion

We evaluated the performance of MRDC multicast tree in a variety of mobility and communication scenarios. Because we focused on control plan of MRDC, the performance in this paper means the efficiency and robustness of multicast tree. Mode selection of forwarding plan is disabled and multicast routers broadcast multicast packets. Although the aim of this simulation is to evaluate the robustness and efficiency of multicast tree, we introduced multicast traffic to test the “Data packets transmitted” to be the count of every individual transmission of data by each node over the entire network. This count includes transmission of packets that are eventually dropped and retransmitted by the intermediate nodes. Note that in unicast protocols, this measure is always equal to or greater than one. In multicast, since a single transmission (broadcast) can deliver data to multiple destinations, the measure may be less than one. Instead of using a measure of pure control overhead, we chose to use the ratio of control bytes transmitted to data bytes delivered to investigate how efficiently control messages are utilized in delivering data. Note that not only bytes of control messages but also bytes of data packet headers are included in the number of control bytes transmitted.

The two later metrics concerns bandwidth utilization. The number of bytes transmitted per data byte delivered can be considered as uniformed forwarding overhead and the number of bytes transmitted per data byte delivered as uniformed control overhead. The sum of these two metrics is uniformed bandwidth consumption of each protocol.

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