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Alireza Shams Shafigh, Beatriz Lorenzo, Savo Glisic

Fuzzy Logic Based Rate Control Scheme for ODMRP in Mobile Ad hoc Networks

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Original scientific paper

On Demand Multicast Routing Protocol (ODMRP) is a popular solution designed for ad hoc networks with mobile hosts. Its efficiency, simplicity, and robustness to mobility render it one of the most widely used multicast routing protocols in Mobile Ad hoc NETworks (MANET). In ODMRP, there is no input rate control for upper layer traffic. So, it's possible that high dense traffic flow causes congestion in networks. In this work, an enhancement to ODMRP is proposed referred to as fuzzy logic based Rate Control ODMRP (FRC-ODMRP). FRC-ODMRP attempts to adapt the arrival rate from upper layers to the state in the network by using feedback information from receivers of the multicast group. Accordingly, source comes up with a decision whether to increase or decrease its transmission rate based on information collected from the receivers. In this research, delay and packet delivery ratio reconsidered as indicators of congestion in addition to number of received packets. Simulation results demonstrate that FRC-ODMRP achieves significant performance improvements in comparison to conventional ODMRP and QoS-ODMRP. Indeed, it efficiently handles simultaneous traffic flows such that no one could dominate available bandwidth of networks.

Key words: Fuzzy logic, Ad hoc networks, ODMRP, Join query, Congestion

Na neizrazitoj logici zasnovano upravljanje frekvencijom za ODMRP u mobilnim *ad hoc* mrežama. *On Demand Multicast Routing Protocol (ODMRP)* popularno je rješenje namijenjeno *ad hoc* mrežama s mobilnim domaćinima. Efikasnost, jednostavnost i robusnost u smislu mobilnosti učini su ovu metodu jednom od najraširenijih *multicast* protokola u *ad hoc* mobilnim mrežam (eng. MANET). Kod ODMRP-a nema upravljanja ulaznom frekvencijom za promet višeg sloja. Zbog toga je moguće da gusti promet uzrokuje zagušenje u mrežama. U ovome je radu predstavljeno poboljšanje ODMRP-a nazvano ODMRP zasnovan na fuzzy logici (FRC-ODRMP). FRC-ODRMP pokušava prilagoditi dolazne signale iz viših slojeva stanju u mreži koristeći povratnu informaciju od primatelja iz *multicast* grupe. Prilikom istraživanja dodatno je uzet omjer kašnjenja i dostavljenih paketa kao pokazatelj zagušenosti mreže uz broj dostavljenih paketa. Simulacijski rezultati pokazuju kako FRC-ODMRP značajno poboljšava performanse u odnosu na konvencionalni ODMRP i Qos-ODMRP. Dodatno, simultani promet efikasno je upravljan tako da nitko ne može dominirati dostupnom propusnošću mreže.

Ključne riječi: neizrazita logika, *ad hoc* mreže, ODMRP, upit, zagušenje

1 INTRODUCTION

Motivated by increasing usage of laptop computers and communication over wireless devices, wireless communications between mobile users are becoming increasingly on-demand and as such they are going to be an integral part of the future generation of mobile services. People can deploy and set up their own on fly MANETs. A MANET is an infrastructure-less, dynamically reconfigurable wireless network, wherein mobility of nodes results in rapid and unpredictable changes in the network topology. Ad hoc networks have been conventionally considered for numerous practical applications such as military applications, emergency operations, and rapid construction of temporal wireless networks [1].

The rapidly growing technology and popularity of Internet results in many new and challenging applications such as videoconferencing, interactive gaming, and distributed database applications. Thus, MANETs are employed to support collaboration among a team of users. Multicasting support is critical and desirable feature of ad hoc networks. The advantage of multicast communication is in efficient utilization of bandwidth and network resources due to transmission of data packet with a single transmission to a group of receivers. Therefore, multicasting plays a crucial role in ad hoc networks. Several multicast routing protocols, designed for static networks, such as Multicast Open Shortest Path First (MOSPF) [2], Protocol Independent Multicast (PIM) [3] and Core Based Trees (CBT) [4], do not perform well in ad hoc networks. Frequent topology changes along with fragile structures maintained in ad hoc networks results in reconstruction of multicast tress as connectivity and mobility changes. Moreover, such protocols mostly rely on routing like link state or distance vector [5] routing, which are time-varying in mobile ad hoc networks and result in excessive overhead and unreliable routes. Therefore, more attention needs to be paid to the multicast routing in ad hoc.

Generally, there exist a variety of traditional approaches that have been proposed for network layer multicast such as [5–9] mainly classified as mesh-based, tree-based, hybrid, or stateless methods.

The recent literature on performance comparison of multicast routing protocols demonstrates that mesh-based schemes outperform the tree-based schemes. The significance of mesh-based scheme lies in the fact that redundant routs in their structure results in more robustness to topology changes. To be more specific, as representative of mesh-based protocols, ODMRP [9] has verified to outperform other protocols under different network scenarios [10]. ODMRP is based on network wide flooding of control packets in fixed periodic refresh intervals to refresh and rebuild the mesh structure. Such periodic control messages intend to provide robustness to ODMRP despite mobility and unreliable wireless links.

The objective of this research is to propose a scheme that can be able to prevent congestion in the multicast routing protocol like ODMRP. Although in this paper, the protocol is implemented over the ODMRP, the proposed scheme can be applied to the most of multicast routing protocols. This enhancement to ODMRP is referred to as Fuzzy logic based Rate Control ODMRP (FRC-ODMRP) since the input rate is adapted by using the information collected from receivers of the multicast group and such information is fed into the source. Through extensive simulations it was shown that, FRC-ODMRP may achieve higher packet delivery ratio compared to conventional ODMRP. The distinctive feature of FRC-ODMRP is its ability to adapt to network dynamics.

The rest of the paper is organized as follows: in Section 2, we explain the problem statement that motivated enhancement to ODMRP in this research. In Section 3, the FRC-ODMRP is presented, including the forwarding mesh construction, reply phase, and Fuzzy tuner adapted in this scheme for adjusting the input rate. Performance evaluation of the proposed scheme is presented in Section 4. This section includes the description of simulation methodology, the simulation environment, the parameter set and a comprehensive discussion of experimental results. The discussion related to this research is presented in Section 5 followed by concluding remarks and highlighting of some future research area in Section 6.

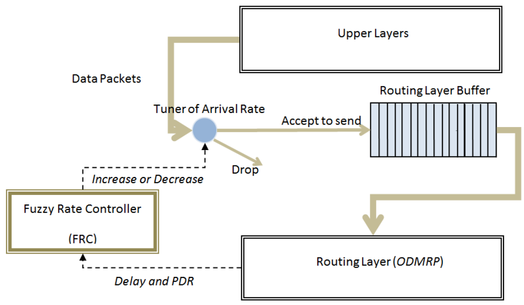

Fig. 1: Scheme of congestion controlling

2 PROBLEM STATEMENT

In spite of ODMRP's simplicity, efficiency, and robustness to mobility, it has some limitations. One of the most important defects of ODMRP is the disability of handling high dense data flows. In fact, ODMRP has no controlling mechanism for arrival traffic from upper layers. One ODMRP source node sends data packets directly after their receptions. Increasing input data rate in ODMRP leads to congestion especially in Mesh topology. To control the congestion, source nodes should be able to increase or decrease input data rate. Other issue is detection of congestion. In this paper, we use two parameters; delay and packet delivery ratio (PDR) to detect congestion. The FRC-ODMRP implements detection and control mechanism shown in Fig. 1.

In Fig. 1, Fuzzy controller uses the information on delay and PDR to increase or decrease the input data rate. So it can control congestion immediately after detection. Based on this information, the tuner of arrival rate decides about accepting or dropping packets. To implement the proposed scheme, we modify the conventional Join Query and Join Reply packets to carry the needed information.

Join Query packets are flooded through the network in every refresh interval by the source. In FRC, these packets only carry the sent time. This field is used by receiver and source to compute RTT (Round Trip Time) time. The RTT time represents the time needed for Join Query to travel from source to receiver plus the time needed for a Join Reply packet to come back to the source. We customize Join Reply packets to carry the PDRs information to sources.

The fuzzy Tuner uses RTT and PDR to detect and control the congestion. The congestion is defined as the state of the network when all receivers are in touch (connected), RTT is high and PDR is low.

The problem gets worse when multiple sources exist in the network. In this case each source independently floods the entire network by Join Query packets regardless of other sources. Consequently, a control overhead increase, congestion occurs and data packets drop. Moreover, link breakages are more likely to occur in high mobility environment. Therefore, a balance between sending rates of sources is required. During congestion, flows use more resources and data transmission is less efficient. So it is rational to reduce input rate down to the point where the optimum rate is achieved.

In our scheme æwe feed delay and PDR information from receivers back to the sources in order to prevent flows to send more traffic to the network and avoid congestion. So, the proposed method would provide higher efficiency in controlling congestion in comparison to other methods.

3 FRC-ODMRP MECHANISM

Ad hoc networks dynamically allocate network resources on a demand basis. However, nodes in ad hoc networks are coupled with certain characteristic such as dynamically varying environment which makes it impossible to provide the QoS (Quality of Service) guarantee, generally expressed in terms of minimum bandwidth or maximum delay. An approach to deal with this problem is to control the rate at which packets are flooded through the network by employing a feedback mechanism with the aim of restricting the rate to the capacity of the connection. Currently existing routing protocols employ the feedback mechanism to achieve reliability against packet losses.

In this section, we discuss how feedback from the receivers can be used to adjust the sending rate in FRC-ODMRP, resulting in higher data delivery ratio and shorter delay.

If the source is informed about the poor data *delivery rate while RTT is high and the majority of receivers are in touch*, it takes an action to decrease the sending rate (source increase drop rate). The rationale is that scarce data delivery is mainly due to congestion, so protocol should stop the sending data packets to networks. On the other hand, high data delivery ratio identifies that the residual network capacity is available and source could send more data.

3.1 Forwarding Mesh Creation in FRC-ODMRP

In FRC-ODMRP, the multicast mesh creation and maintenance process follows the original ODMRP protocol. Similarly, the source initiates a forwarding mesh structure between source and receivers. When a node has data packets to send, it floods the entire network by a Join Query packet. In ODMRP, Join Query packets are propagated periodically in fixed refresh intervals in order to refresh the membership information and multicast routes. In FRC-ODMRP, with these packets source additionally compute RTT and PDR.

In FRC-ODMRP, the feedback information is used to implement a mechanism to control and detect the congestion of network especially within the mesh structure.

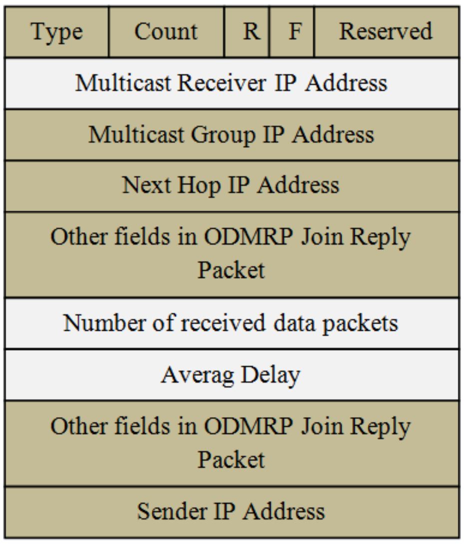

Fig. 2: Frame Format of Join Reply Packet in FRC-ODMRP

3.2 Reply Phase and Feedback Information in FRC-ODMRP

The proposed Feedback mechanism should be coupled with monitoring mechanism to watch the number of data packets successfully received at their destinations (Packet Delivery Ratio). So, in order to monitor the number of such data packets, the source needs to obtain information from each receiver indicating the delivery ratio. This can be implemented by either sending Hello packets in predefined intervals which results in saturating the network by more control packets, or using the existing control packets in original ODMRP. This does not require extra control overhead which is particularly useful in highly dynamic environments and traffic intensive scenarios.

Therefore, control packets sent by the original ODMRP are reused and just some bytes are added to carry the data delivery rate information to the source in addition to RTT time. This is a big advantage to memory and power constraint applications. So, in order to feedback the information to the source, we attach such information to the Join Reply packets and periodically send them back to the source. Therefore, Join Reply packet is modified in order to carry feedback information.

Figure 2 presents an extended frame format of Join Reply packet in FRC-ODMRP where three additional fields are included; the list of Multicast Receiver IP address, list of number of received data packets (packet delivery ratio) and list of average delay (RTT).They represent the number of received data packets by specific receivers and the address of the receivers which has sent such reply and average round trip time, respectively.

3.3 Probability of Increasing or Decreasing the Interval

In FRC-ODMRP, we propose to assign an array of probabilities in order to take appropriate actions for the given feedback information. These actions are defined in an array labeled as *actionProb [0]*(increase action) and *actionProb [1]* (decrease action) which are initialized by the values 0.5 and 0.5, respectively. The sending rate is varied by adjusting the *actionProbs* according to the feedback information. If *actionProb [0]* is the higher probability, the sending rate is increased. Otherwise, if *actionProb [1]* is the higher probability, the sending rate is decreased.

Upon receiving the *Join Reply* packet by the source of the group which contains the feedback information, source decides to take an action. To sum up, following actions shall be taken.

ActionProb [0] $= 0.5$ - this cell (slot) of the array stands for the probability of increasing the sending rate. When RTT is not too long and an acceptable number of transmitted packets are successfully delivered to the receivers of the multicast group, the source is notified about the satisfying success ratio of data delivery and takes an action to likely increase sending rate. At this point, an increase in sent rate may not result in loss of packets. So, the value of *actionProb [0]* is increased and if it is the higher probability in array, an increase in sent rate occurs.

ActionProb [1] $= 0.5$ - this cell of array stands for probability of decreasing the sent rate. If the source is not satisfied with the average number of received packets by the receiver, this probability is increased and if this field of array maintains the higher probability this will result in decrease in sent rate.

In FRC-ODMRP, there are two probabilities to control the sent rate in a source node. In (1), PoD is probability of Dropping and PoA is probability of accepting to send with.

$$PoD + PoA = 1. \tag{1}$$

FRC module tries to adjust PoD and PoA to balance available bandwidth between flows in the network.

3.4 FRC module description

The main contribution of this paper is proposals of a fuzzy logic controller to control congestion. This module implements a fuzzy logic based controller with three fuzzy variables: coverage percentage, RTT and PDR. These variables use membership functions presenting in Fig. 3. Co is percent of mesh coverage. It means how many receivers have received data packets. If Co is low, you could not say much about reasons of low PDR. So, if most of receivers are in touch, we are able to discuss about decrease of PDR or increase of RTT. ΔR is the difference of delivery ratios in slot time t and $t-1$. Equation (2) presents how ΔR is computed. R_t is current value of PDR and r_t is the smoothed value of R_t (5).

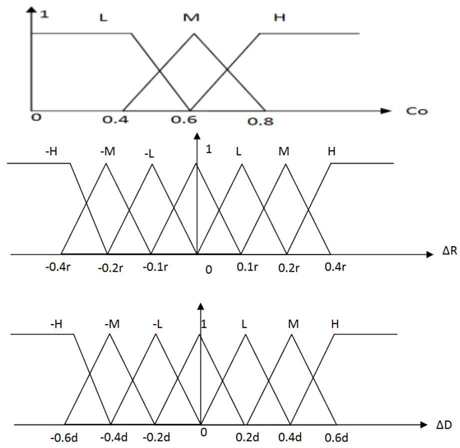

Fig. 3: Membership functions of ΔD,ΔR and Co

ΔD is the difference of RTT value in slot time t and $t-1$. Equation (3) shows how ΔD is computed. In equation (4), D_t is current RTT and d_t is the smoothed value of D_t. α and β are constants with value between 0 and 1.

$$\Delta D = D_t - d_{t-1}, \tag{2}$$

$$\Delta R = R_t - r_{t-1}, \tag{3}$$

$$d_t = (1-\alpha)D_t + \alpha d_{t-1}, \tag{4}$$

$$r_t = (1-\beta)R_t + \beta r_{t-1}. \tag{5}$$

Figure 4. represents fuzzy controller used for controlling congestion of the network. The proposed fuzzy controller has three main stages: Fuzzification, inference by rules and Defuzzification.

In Fuzzification stage, three variables are computed once a Join Reply packet is received. These variables are sent to membership functions (Fig. 3) to compute fuzzy variables.

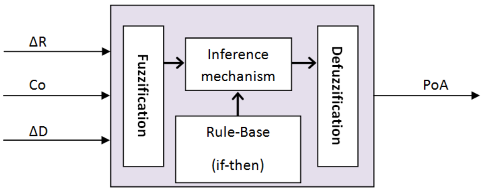

Fig. 4: Fuzzy controller

ΔR \ ΔD	-H	-M	-L	L	M	H
-H	-	-	-	-0.06	-0.18	-0.45
-M	-	-	-	-0.01	-0.12	-0.37
-L	0.15	0.12	0.04	-	-0.07	-0.31
L	0.26	0.21	0.11	0.02	-0.09	-0.26
M	0.29	0.17	0.06	0.01	-0.08	-0.29
H	0.12	0.08	0.02	-0.09	-0.18	-0.33

Fig. 5: Different values of pi if Co is high

In inference stage, fuzzy variables are used by fuzzy rules. These simple rules inspect different possible states for three parameters: Co, ΔD and ΔR. Simple rules are in format of if-then command like a following:

- If ((ΔR is high) and (ΔD is high)) then increase PoA.

Equation (6) defines Defuzzification process. It presents how probability of Accepting is computed. Parameter pi is value of the increment step (increase or decrease step) for ith rule in module of rules. Different values of pi are presented in Fig. 5.

$$PoA_t = PoA_t + \sum_{i=1}^{36} p_i. \quad (6)$$

In this paper, we only use fuzzy controller if coverage percent is acceptable (over 80%). For example in Fig. 5, when Co is over 80 percent, ΔD is high and ΔR is high; value of sent rate should be reduced by 33 percent.

To sum up the proposed scheme, main role of receiver, sender and intermediate node are presented in Fig. 6 and 7.

After Defuzzification, value of PoA is determined based on feedback information including PDR and RTT. So, source or sender node applies new sent rate and drops data packet which the current PoD.

```
Intermediates:
    If (packet type is data or Join Query)
        Forward packet
    Else if (packet type is Join Reply)
        Save new information in a Temporary List
    Else if (it's time to send Join Reply)
        Send a Join Reply including all information in Temporary List
Senders:
    If (it's time to send Join Query)
    {
        Send a common Join Query
        Initiate a timer to compute Round Trip Time
    }
    Else If (packet type is Join Reply)
    {
        Save new information in a Temporary List
        Set a timer to process information of Temporary List
    }
    Else if (it's time to process)
    {
        Sum all information in Temporary List
        ΔR=R_t-R_t-1
        ΔD=D_t-D_t-1
        PoA_t=FuzzyFunctions (ΔR, ΔD)
        PoD_t=1-PoA_t
    }
```

Fig. 6: Pseudo code of receiver nodes

```
Receivers:
    If (packet type is data)
        Increase number of received packets and sum delay for this multicast group
        Update the last active time
    Else if (packet type is Join Query)
    {
        If ((current time-last active time) <=Threshold)// the gathered statistic is
valid?
        {
            Create a new Join Reply in new format
            Insert number of received packets in Join Reply Packet
            Compute average delay= sum of delay /number of received packets
            Insert average delay in Join Reply packet
            Send a Join Reply including number of received packets
            Reset counter of received packets and sum of delay
            Update the last active time
        }
        Else
        {
            Create a new Join Reply in new format
            Set a minus value in number of received packets in Join Reply Packet
            Insert a minus value in average delay in Join Reply packet
            Send a Join Reply including number of received packets
            Reset counter of received packets and sum of delay
            Update the last active time

        }
    }
```

Fig. 7: Pseudo code of sender and intermediate nodes

4 QOS-ODMRP MECHANISM

QoS ODMRP route establishment is accomplished by on-demand routing using flooding. When a source has data to send and no route to the destinations is known, it attaches the requested bandwidth for this multicast session to Join Query packet and floods it. A function called IsQuerySentFlag is used to prevent sending Join Query for a certain time where there is not enough bandwidth. When the group is established or after timer TUnSetIsQuerySendFlag, this flag will be reset for sending new Join Query. As described in Section 3, upon receiving a Join Query packet, a bandwidth admission decision is made at each node.

When a node receives a request, if the received packet is not duplicated, the node compares channel's Bavailable and Bconsumed of that flow. If Bavailable is greater than Bconsumed and also greater than the minimum bandwidth to be reserved (Bmin or 2Bmin).This node stores new entry in its routing table and sets its status for this multicast session to "explored". In addition, it stores the last hop node information in its routing table, that is, backward route, and rebroadcasts the packet. The node will remain in explored status for period time of Texplored. In the situation that no reply packet is received by the explored node during this time, the entry in reservation table will be removed, and also late coming reply packets are denied. Since the node which propagates Join Query is not aware of downstream node in the route to the destination it uses Buplink as the estimation of Bconsumed for propagation of Join Query packet.

The destination responds back to the source with the Join Reply packet passing through the selected route. When the destination receives the Join Query packet it builds the Join Reply packet. If it has enough bandwidth for this session, it broadcasts the Join Reply to upstream node and updates its route status to the "registered" in the routing table of this session. After registration nodes are ready to accept the real data packets of the flow. Join Reply is propagated till arriving to source. The Join Reply packet marks the intermediate nodes as forwarding nodes and set their status to "registered" for this session.

In QoS-ODMRP, no explicit control packets need to be sent to join or leave the session. If a source wants to leave the session, it simply stops sending Join Query packet, since it does not have any data to send. If a destination no longer wants to receive from its source, it does not send Join Reply packet for that source. Forwarder nodes are demoted to non-forwarding if not refreshed (no Join Reply received). When a node leaves a session or is demoted to non-forwarding, it releases the requested bandwidth for that session and sends a Hello packet to its neighbor to inform them about its new self-traffic.

5 PERFORMANCE EVALUATION

5.1 Simulation Environment

The simulation code and scenario of this research was implemented within Global Mobile Simulation (GloMoSim) library [12].The GloMoSim is a scalable simulation environment for wireless network systems by using parallel discrete-event simulation capability provided by PARSEC [13]. This simulation study modeled a network of 100 mobile nodes placed randomly within an area of $1000 \times 1000\,m^2$. Radio propagation of each node was set to about 250 meters and channel capacity was 2 Mbit/sec. Each simulation is executed for 300 seconds of simulation time. The IEEE 802.11 Distributed Coordination function was used as the medium access control. The mobility model is Random-Way point where nodes randomly selected the moving direction, and when they reached the simulation terrain boundary, they bounced back and continued to move. The Constant Bit Rate (CBR) was selected as the traffic since the GloMoSim does not support Variable Bit Rate (VBR) traffic. The size of data payload was 512 bytes.

5.2 Methodology

To evaluate the multicast performance of FRC-ODMRP, in terms of network parameters, the following additional protocols are modeled and compared:

- ODMRP (On-Demand Multicast Routing Protocol)
- QOS-ODMRP (Quality of Service On-Demand Multicast Routing Protocol)

The schemes are evaluated as a function of input rate. The number of multicast groups in the studied protocols was set to 3; each multicast group size was set to 5. Multicast sessions where established with interval of 10 seconds and remained until the end of the simulation time. To evaluate the performance of the protocols, input traffic is increased from 128 Kbit/s to 1024 Kbit/s. The following metrics are collected in order to evaluate the efficiency of FRC-ODMRP:

- *End-to-End Delay*: This metric is defined as the average of end-to-end delay of packets successfully received by destination. *Packet Delivery Ratio (PDR)*: defined as the total number of data packets successfully delivered to the multicast receivers over the number of data packets originally sent.
- *Overall overhead*: defined as the total number of control and Hello packets sent and forwarded in addition to the total number of data packets transmitted in the system. That is, the total size of control overhead and data overhead.

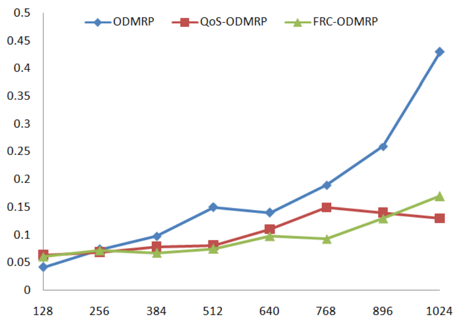

Fig. 8: End-to-End Delay as a Function of input rate (Kbit/s)

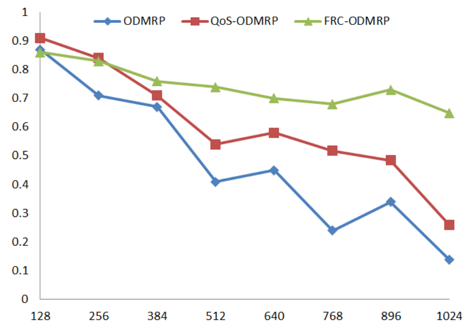

Fig. 9: Packet deliverpy ratio as a Function of input rate

6 SIMULATION RESULTS

6.1 Average End-to-End Delay

The end-to-end delay as a function of input rate is shown in Fig. 8. As expected end-to-end delay increases with increase in input rate. In QoS-ODMRP, the bandwidth reservation by admission control is performed at every node in the route discovery phase. This process increases the end-to-end delay.

In addition, bandwidth availability checking is performed two times in QoS-ODMRP, once, in route setup phase, and the second time after the route registration phase. When input rate increases, the congestion occurs in network especially in the mesh. The proposed method, FRC-ODMRP, adjusts input rate by dropping data packets in source node. Notice in QoS-ODMRP, decision is taken per flow. It allow to one flow to send data packets without any limitation but, FRC-ODMRP accept all flows to send traffic whereas adjusting their input rate. Figure 8 shows that FRC-ODMRP has lowest End to End delay due to using feedback information for avoiding congestion.

6.2 Packet Delivery Ratio

The packet delivery ratio as a function input rate is shown in Fig. 9. This figure shows that as input rate increases because of congestion the packet delivery ratio is reduced. But in case of QoS-ODMRP the data delivery ratios degrade is less than the conventional ODMRP. The reason for this is that traffic admission ratio policies are applied and only the sessions which could satisfy QoS requirements of the application are established in QoS-ODMRP. Consequently, the packet delivery ratio is significantly higher than for the ODMRP. In FRC-ODMRP, a typical flow is allowed to send data packets under threshold value. So, acceptance rate is approximately equal with packet delivery ration because FRC-ODMRP drops packets in source to balance resource consumption between multiple sessions.

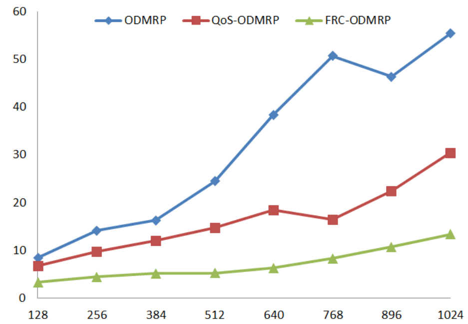

Fig. 10: Overall overhead as a Function of input rate

6.3 Overhead

Figure 10 shows overall overhead per received data packet, for three protocols versus input rate. The figure shows that overall overhead increases with increase of input data rate, because of congestion and data dropping in intermediate nodes. In case of QoS-ODMRP, Hello messages are transmitted in the network. This additional Hello control packet introduces a large amount of overhead compared to ODMRP to network. Although, QoS-ODMRP prevents propagation of Join Queries and Join Replies when there are not enough bandwidth resources for the session, still this QoS functions could not compensate the extra control packet introduced by Hello messages to the network. So, the overall overhead in QoS-ODMRP is significantly larger compared to ODMRP. Moreover, when input rate increases, PDR is decreases whereas packet dropping rate increases in intermediate node. QoS-ODMRP has no mechanism to avoid congestion because it takes decision in the beginning of the session. FRC-ODMRP always considers network condition and adjusts input rates based on it. So it simply avoids congestion by reducing sending rate.

7 CONCLUSION AND FUTURE WORK

In this paper, a new scheme to improve rate control protocols performance for multimedia applications was proposed. This technique was applied to conventional ODMRP and evaluated via several simulations with multicast scenarios. Simulation results shows that FRC-ODMRP does balance all sessions traffics considering network resource limitations and improves network performance compared with ODMRP and QoS-ODMRP by adjusting input rate.

In future researches, we are going to examine our work over real traffic sessions and evaluate its performance with different scenarios.

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Alireza Shams Shafigh received his M.Sc. degree in Computer Engineering from Iran University of Science and Technology, Iran, in 2006. He was Faculty member of Islamic Azad University, Damavand Branch in 2006-2012. He joined the Centre for Wireless Communications (CWC) at University of Oulu, Finland, where he is working on his Ph.D. His research interest is in the area of routing in computer networks, Ad hoc and sensor network and QoS provisioning in ad hoc and sensor networks.

Beatriz Lorenzo received her M.Sc. degree in Telecommunication Engineering from University of Vigo, Spain, in 2008. She was an Erasmus exchange student at University of Oulu, Finland in 2007-2008 where she was working on her M.Sc. thesis. In 2008 she joined the Centre for Wireless Communications (CWC) at University of Oulu, Finland where she completed her Ph.D. in 2012, in the area of wireless networks. She is currently a postdoctoral researcher and project manager at CWC. Her research is conducted within several academic and industry supported projects. She has published a number of papers in this field and coauthored a voluminous book entitled “Advanced Wireless Networks: 4G Cognitive Opportunistic and Cooperative Technology”, 2E, John Wiley and Sons, 2009.

Savo Glisic (M’90-SM’94) is a Professor of Telecommunications at University of Oulu, Finland, and Director of Globalcomm Institute for Telecommunications. He was Visiting Scientist at Cranfield Institute of Technology, Cranfield, U.K.(1976-1977) and University of California, San Diego (1986-1987). He has been active in the field of wireless communications for 30 years and has published a number of papers and books. The latest books Advanced Wireless Networks: 4G Cognitive Opportunistic and Cooperative Technology, 2E (John Wiley and Sons, 2009), and Advanced Wireless Communications: 4G Cognitive Broadband Technology, 2E (John Wiley and Sons, July 2007) cover the enabling technology for the definition of incoming 4G systems. He is also running an extensive doctoral program in the field of wireless networking (www.telecomlab.oulu.fi/kurssit/networks/). His research interest is in the area of network optimization theory, network topology control and graph theory, cognitive networks and game theory, radio resource management, QoS and queuing theory, networks information theory, protocol design, advanced routing and network coding, relaying, cellular, WLAN, ad hoc, sensor, active and bio inspired networks with emphasis on genetic algorithms. Dr. Glisic has served as the Technical Program Chairman of the third IEEE ISSSTA’94, the eighth IEEE PIMRC’97, and IEEE ICC’01. He was Director of IEEE ComSoc MD programs.

AUTHORS’ ADDRESSES

Alireza Shams Shafigh, M.Sc.
Beatriz Lorenzo, M.Sc.
Prof. Savo Glisic, Ph.D.
Centre for Wireless Communications,
University of Oulu, Finland,
P.O. Box 4500, FI-90014, Finland
email: alireza.shams.shafigh@gmail.com,
Lorenzo@ee.oulu.fi, glisicsavo@hotmail.com

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