An Adaptive Packet Injection Rate Control Protocol to Support Priority-based QoS Provisioning in Ad hoc Network with Directional Antenna

Dola Saha, Siuli Roy, Somprakash Bandyopadhyay
Indian Institute of Management Calcutta
Kolkata, West Bengal, India
Tel: +91-33-2467-8300 Fax: +91-33-2467-8362
E-mail: {dola, siuli, somprakash}@iimcal.ac.in

Tetsuro Ueda, Shinsuke Tanaka
ATR Adaptive Communication Research Lab.,
Kyoto, Japan
Tel: +81-774-95-1529 Fax: +81-774-95-1509
E-mail: {teueda, shinsuke}@atr.co.jp

Abstract

The rising popularity of multimedia applications and potential commercial usage of Mobile Ad hoc network (MANET) clearly indicates that Quality of Service (QoS) support in MANETs is an unavoidable task. Essentially, Multimedia traffic should get preference over conventional data traffic during communication through some kind of priority-based mechanism to assure a timely and guaranteed delivery of multimedia data. In this paper, we have proposed a scheme for supporting QoS in MANET by classifying the traffic flows in the network into different priority classes, and giving different treatment to the packet injection rate of the flows belonging to different classes. In our suggested scheme, the MAC protocol of any intermediate node of a flow detects the presence of high priority traffic in its neighborhood (transmission/reception zone) and back-propagates this knowledge back to the source which then can adaptively control packet injection rate of the low priority flow. This will ensure the high priority flow to get desired access to the medium to maintain its flow-rate.

1. Introduction

Numerous solutions to the QoS problem in mobile ad hoc networks have been proposed in recent past [1,2]. However, as indicated in [3], limited bandwidth of the mobile radio channel prevents giving every class of traffic the same QoS except when the network is very lightly loaded. So, some means for providing each class a different QoS must be implemented by assigning priority to one class over another class in terms of allocating resources. Thus, linkage between QoS and priority is a common one in the literature. Though several solutions for wireline environment is present, they do not work well in wireless ad hoc networks because of shared communication environment and host mobility.

Two flows in ad hoc wireless network will affect each other, when the two routes belonging to these two different flows share common nodes, or, they are close enough to interfere each other, causing route coupling [4]. In this case, nodes in those two routes constantly contend for access to the medium they share. In such a situation, if the packet-injection-rate of one flow is reduced, the other flow will get more chances to access the medium they share, which eventually reduces the congestion and improves the throughput of the second flow. Thus, prioritized flow control is an effective means to provide service differentiation to different class of service.

Some researchers have introduced end-to-end rate control in transport layer to achieve service differentiation [5]. But, end-to-end rate control has many drawbacks in wireless medium. Firstly, end-to-end rate control mechanism is based on measuring congestion-driven packet losses, where as, packet loss may occur due to some non-congestion loss like poor link quality, route failure due to mobility, or simply due to random channel error. Secondly, loss of feedback while traveling from receiver back to sender can distort sender's perception about network congestion. But the most important aspect is that, these schemes cannot guarantee desired rates for high-priority traffic. Earlier work on service differentiation through rate control of a flow [5] focuses on individualized flow control. Here, flows are controlled individually with a rate vector based on end-to-end feedback, where high priority flows are throttled less aggressively than low priority flows. So, high priority flow rate may not maintain a desired level of flow. Our objective is to adaptively maximize low priority flows while maintaining high priority flows at a desired level so that full utilization of wireless medium is achieved due to adaptive rate control. To provide this desired service differentiation to high priority flows, we need a rate control algorithm, where the low priority flows, causing interference to a high priority flow, detect and measure high priority flow- rate at each node on their routes and consequently adjust their flow-rates to protect the high priority flow at its desired level. This detection and measurement should be done at MAC layer of each node participating in routing from source to destination.

Our mechanism is different from existing MAC-layer solutions for service differentiation [6-8]. Several efforts have been made to support QoS in MANET by changing Inter Frame Spaces (IFS) and the size of contention window (CW) according to the priority of traffic in MAC layer and modifying *backoff algorithm* accordingly. But it does not guarantee that high priority packet will always get a contention free access to the medium for data communication [8]. Multiple high priority flows contending for the medium may not always get guaranteed fair access of the medium in these schemes. Moreover, multiple low priority traffic in absence of high priority traffic may choose a large contention window leading to poor utilization of the medium. Another important aspect of QoS in MAC layer, which has not been addressed by the researchers, is the packet delivery ratio. Low priority packets in MAC layer of intermediate nodes may often found to choose increased backoff counter, which remains unknown to the source node, which may be injecting packets at a very high rate. As a consequence, the packets arriving at a very high rate at intermediate node, handling low priority flow, are not served quickly by the MAC layer and remain in queue, which may overflow leading to packet drops.

Though absolute QoS is very hard to provide in ad-hoc environment due to lossy nature of environment and mobility of users, what we try to achieve in this paper is a desired level of service to high-priority flows when they contend with low priority flows. In our suggested scheme, the MAC protocol of any intermediate node detects the presence of traffic of different priority-level in its neighborhood and back-propagates this knowledge back to the source with the CTS packet, which then can adaptively control packet injection rate of the flow. We have proposed this protocol with a very nominal overhead using omni-directional antenna and modified the scheme to show the overall improvement in throughput using directional antenna.

2. Service differentiation with rate control

In this paper, our objective is to adaptively maximize low priority flows without affecting high priority flows so that full utilization of wireless medium is achieved due to adaptive rate control. The impact of low priority flows on high priority flows is measured by the nodes participating in routing the low priority flows and accordingly low priority flows are controlled at their source in order to keep high priority flow rates at their desired level. So, each node handling a low priority flow measures the high priority flow rates in its vicinity. If it detects high priority flows in its vicinity operating at a lower rate, it implies that these high priority flows are contending with the low priority flow. Accordingly, low priority flow is reduced to maintain high priority flow rates at their desired level. This adaptive control mechanism will be illustrated shortly.

To implement the scheme, we have used a special type of RTS and CTS packets. There is an extra field in the RTS packet, which denotes the communication-id & priority-level of the flow to which the packet belongs. This extra field in RTS is required to make the neighbors aware of the priority-level of the on-going communication. Similarly, CTS packet also has two extra fields. The first field is exactly similar to the extra-field of RTS packet, and is required to convey the priority-level of the on-going communication to its neighbors. The

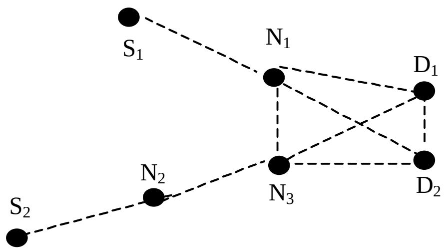

Figure 1: Using omni-directional antenna Low Priority Flow (S_2-D_2) is disturbing High Priority Flow (S_1-D_1). *Dotted Lines show omni-directional connectivity*

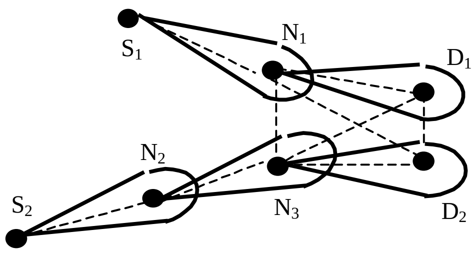

Figure 2: Using directional antenna Low Priority Flow (S_2-D_2) can coexist with High Priority Flow (S_1-D_1).

second field contains the maximum packet-arrival-interval of high priority communication in its vicinity. Even in presence of more than one high priority flow in the neighborhood of a low priority flow, back-propagation of the maximum packet arrival interval of the high priority flow is done. This indicates that the low priority flow can adaptively adjust itself repeatedly, so that the high priority flows can get maximum chance to the medium and their expected packet arrival interval is maintained. The second extra field of CTS is required to back-propagate the contention high priority flows are experiencing due to the low priority flow.

For example, in Figure 1, let there was a continuous low-priority flow S_2-N_2-N_3-D_2. When operating alone, its flow-rate is fixed at a predefined value. Now, a high-priority flow S_1-N_1-D_1 starts. Let us assume that we want to fix and maintain this high priority flow-rate at a predefined level. However, since these two routes (figure 1) are close enough to cause route coupling, they will interfere each other, which will reduce the flow rate of high-priority flow at the interfering nodes N_1 and D_1. Our objective is to detect this reduced flow rate of high priority flow at nodes belonging to low-priority flow and back-propagate this knowledge back to the low priority source, which then can adaptively reduce its flow rate to maintain the high priority flow rate at its predefined value. To implement this, from the RTS transmitted by N_1 and CTS transmitted by D_1, both N_3 and D_2 detects the high-priority flow S_1-D_1. This remains unknown to the source S_2, which is far away from the high priority flow. So, with the help of CTS packet, D_2 transmits the knowledge to N_3. When N_3 has to send a CTS packet to N_2, it combines its own detection of high-priority traffic with the received knowledge from D_2 and cumulatively considers the contention in the flow and transmits it with the CTS packet. N_2 lastly sends this information back to S_2 with a CTS packet. The source node, S_2, then considers the contention in the medium of the flow and adaptively takes a decision of reducing packet injection rate. Hence, with no extra packet, the information of contention in the medium of a high priority flow is transmitted to the low priority source node, which adaptively reduces the packet injection rate. So, when there is no contention in the medium, even a low-priority flow can operate at its predefined flow rate.

So far we considered omni-directional neighbors using omni-directional antenna. But, to modify the scheme using directional antenna, we have to consider a directional MAC and its directional neighbors. We have implemented in [9] receiver-oriented rotational-sector based directional MAC protocol, which is capable of tracking location of its neighbors. Thus, each node is aware of its directional neighbors and this information is recorded in its Angle-Signal Table (AST). RTS and CTS packets are omni-directional, whereas Data and Acknowledgement packets are directional. Use of directional antenna in the context of ad hoc wireless networks can largely reduce radio interference, thereby improving the utilization of wireless medium. This property of directional antenna is utilized to improve the efficiency of our protocol. This can be shown by Figure 2, where simultaneous high- and low-priority traffic S_1-D_1 and S_2-D_2 can co-exist without disturbing each other, using directional antenna, which was not possible using omni-directional antenna (Figure 1). So, in presence of high-priority traffic S_1-D_1 and using directional antenna, it is not necessary for the low-priority traffic S_2-D_2 to control its packet injection rate. Using directional antenna, the detection of contention in medium is also directional in the sense that even if there are traffics of different priority-level in the vicinity, only the contention from communication in the direction of flow is considered. MAC detects the directional contention in medium consulting its AST. Since directional antenna improves SDMA (Space Division Multiple Access) efficiency, it enhances the packet injection rate of low-priority flow also with minimally disturbing other flows in the medium and hence leads to increased throughput of high- as well as low-priority traffic.

3. Protecting high priority flow rate

3.1. Detecting high priority flow rate

When a flow is initiated, packets are sent through multiple hops and at MAC layer the packet delivery at each intermediate node is ensured by RTS/CTS/DATA/ACK exchange. These RTS and CTS packets are utilized to detect and back-propagate the flow-related information on which packet injection rate control decision is taken at low priority sources. The machanism for detecting and measuring high-priority flow rate by any node n is given below:

Definition 1. $\mathbf{RRT^{Hi,\alpha,n}(t)}$ (RTS-Reception-Time) is defined as the time t when node n receives RTS at an angle α from any node currently handling the high priority Flow H_i at that instant of time.

Definition 2. $\mathbf{PAI^{Hi,\alpha,n}(t)}$ (Packet Arrival Interval) is defined as the interval between two consecutive RRT at node n for the high priority Flow H_i at an angle α with respect to node n at time t. This is used to measure the high priority flow rate by any node in its neighborhood. So,

$\mathbf{PAI^{Hi,\alpha,n}(t) = RRT^{Hi,\alpha,n}(t) - RRT^{Hi,\alpha,n}(t_{previous})}$,

where $t-\Delta t < t_{previous} < t$ and Δt is the time-band introduced to ensure the validity of consecutiveness of two RTS packets arriving at node n. For example, if node n misses an RTS due to random channel error, collision or mobility, it will wrongly calculate the flow rate. In this context, introduction of Δt is necessary. In case of high priority destination node, which will never issue an RTS, CTS Reception Time is monitored to calculate high priority flow rate at destination node of that high priority flow.

Definition 3. $\mathbf{PAIT^{n}(t)}$ (PAI Table) is defined as the Packet Arrival Interval Table at node n at time t which stores the $\mathbf{PAI^{Hi,\alpha,n}(t)}$ for each high priority Flow H_i at each angle α, as shown in Table 1.

Table 1. PAI Table Structure at Node n at time t

Angle	**Packet Arrival Interval of Each High Priority Flow**
α_1	{…………}
α_2	{…………}
…	{…………}
α_i	{<$PAI^{Hj,\alpha i,n}(t_1)$> <$PAI^{Hk,\alpha i,n}(t_2)$>………..} where $t-\Delta t < t_p <= t$
…	{…………}
α_n	{…………}

Now, whether a low priority flow at node n is creating contention with a high priority flow is dependent on the transmission direction or transmission zone of the low priority flow and on-going high priority communication in that zone. Let us assume that a low priority flow at node n is using a transmission zone β with respect to node n. In other words, β is the direction of a low priority flow at node n at an instant of time t. Whether this low priority flow at node n is creating contention with any high priority flows in its neighborhood depends on the PAIT entry at an angle β. That is, if PAIT at an angle β contains some PAI entry for high priority flows as {<$PAI^{Hj,\beta,n}(t)$ ><$PAI^{Hk,\beta,n}(t)$>………..}, then this information needs to be back-propagated to that low-priority source for rate adjustment.

To adaptively control the flow rate of the low priority flow, only the maximum of these intervals is required to be back-propagated. If $S \rightarrow N_1 \rightarrow N_2 \rightarrow \ldots . \rightarrow N_{n-1} \rightarrow N_n \rightarrow N_{n+1} \rightarrow \ldots ..D$ be a route from source to destination of a low priority flow Li, then, $\mathbf{DMPAI(N_n)^{Li}_t}$ or Detected Maximum Packet Arrival Interval at node N_n for the low priority Flow L_i at time t is defined as the maximum Packet Arrival Interval of high priority flow in the direction of low priority flow detected at the node N_n. This is compared with $\mathbf{PPAI(N_{n+1})^{Li}_t}$ (Propagated Packet Arrival Interval) that has already been propagated to node N_n from node N_{n+1} to select the maximum packet arrival interval in the flow. So, $PPAI(N_n)^{Li}_t = Max\{DMPAI(N_n)^{Li}_t , PPAI(N_{n+1})^{Li}_t \}$. This $PPAI(N_n)^{Li}_t$ is back-propagated further with CTS packet and is updated at each intermediate node until it reaches the source node, where the adaptive flow rate control of the low priority flow is computed.

3.2 Adaptive control of low priority flow rate

The Packet Injection Rate (PIR) of the low priority flow (in packets/sec) is computed at low priority source based on the formula as follows:

$\mathbf{PIR^{L}_{new}(t)}$ (in packets/sec) **= 1/[** $\mathbf{PII^{L}_{new}(t)}$ (in seconds)**]**, where $PII^{L}_{new}(t)$ is the computed Packet Injection Interval of low priority flow L at time t.

$\mathbf{PII^{L}_{new}(t)}$ = (1 – η*[detected error in Packet Arrival Interval of high priority flow]) * $\mathbf{PII^{L}_{old}(t)}$

where, detected error in high priority Packet Arrival Interval = (Desired high priority Packet Arrival Interval - Detected high priority Packet Arrival Interval). η is the proportionality constant and is experimentally found to be 0.05. We assume that each high priority flow has a prespecified Packet Injection Rate which should correspond to the Packet Arrival Interval at any intermediate node when high priority flow does not have to face any contention. This value is known to every node in the network and this corresponds to the desired high priority Packet Arrival Interval.

The positive or negative adjustment required in the PII at low priority source is a fraction of the old PII of the low priority flow, which is proportional to the error introduced in high priority Packet Arrival Interval. On high priority flow detection, if low priority PIR is decreased, its effect on the improvement of high priority Packet Arrival Interval requires some time. Hence, taking control decision on each back-propagated value of $PPAI(S)^{Li}_t$ would be incorrect and will lead to more unnecessary oscillations of both Detected high priority Packet Arrival Interval as well as PIR of low priority flow. Hence, a window is introduced at the low priority source, which effectively stores $PPAI(S)^{Li}_t$. So, the PIR or PII of low priority source L_i is controlled with the Average of $PPAI(S)^{Li}_t$, where averaging is done on the Window-Size W. Hence, Detected Packet Arrival Interval at source S for the low priority flow L_i at time t or $\mathbf{DPAI(S)^{Li}_t}$ is computed as $DPAI(S)^{L_i}_t = \left\{ \sum_{j=0}^{W-1} PPAI(S)^{L_i}_{t-j} \right\} \Big/ W$

W being the size of the window and is experimentally found to be 10. Thus the averaging automatically dampens the oscillation. Therefore, if Desired high priority Packet Arrival Interval be, say γ, then the formula for Packet Injection Interval at the source S of low priority flow L_i, can be rewritten as $PII^L_{new}(t) = (1 - \eta * [\gamma - DPAI(S)^{Li}_t]) * PII^L_{old}(t)$. Thus the low priority Packet Injection Rate is optimized gradually on repeated corrections such that it operates at a rate, which if increased, the high priority Throughput and Packet Delivery Ratio is not maintained as expected.

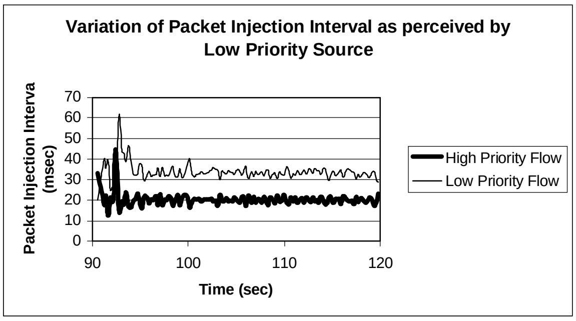

Figure 3: Variation of Packet Injection Interval of Low Priority Flow based on the perceived Packet Arrival Interval of High Priority Flow at Low Priority Source

Figure 3 shows the adaptive Packet Injection Interval control of low priority flow in response to the Packet Arrival Interval of the high priority flow as detected by the low priority source. The figure depicts how fast decision of flow rate control at low priority source is taken on the onset of a high priority flow and how fast the steady state of both high and low priority flow rate is reached with little oscillations.

4. Performance evaluation

We have evaluated the performance of our proposed protocol on QualNet simulator[10]. We have considered IEEE 802.11 MAC and 2Mbps of DS in IEEE 802.11b-DS is used as simulation parameter. We have implemented the proposed protocol with directional antenna only. We have simulated ESPAR antenna [11] in the form of a *quasi-switched beam antenna*, which is steered discretely at an angle of 30 degree, covering a span of 360 degree. We have done the necessary changes in QualNet simulator to implement the proposed protocol. For simplicity, we assume single high priority flow to prove the concept. Two other low priority flows have been introduced physically close enough beside the high priority flow to interfere with the high priority flow during data communication. We have used static routes in order to avoid the effects of routing protocols to clearly illustrate the gain obtained in our proposed protocol. Also, we have used static routes to stop all the packets generated by any routing protocol, whether it is proactive or reactive. Instead of random selection of source destination pair, we have chosen the source destination pair so that there is contention between high and low priority flows to artificially create a situation for Packet Injection Rate Control, where our proposed protocol can work. The set of parameters used are listed in Table 2.

Table 2. Parameters used in Simulation

Parameters	Value
Transmission Power	15 dBm
Receiving Threshold	-81.0 dBm
Sensing Threshold	-91.0 dBm
Data Rate	2Mbps
Packet Size	512 bytes
CBR Packet Injection Interval	20 ms
Simulation Time	5 minutes

Figure 4 and 5 shows the behavior of high priority Flow and figure 6 and 7 shows the behavior of low priority Flows respectively. The high priority flow, which if alone operates at 20ms CBR packet injection interval, yields a Throughput of nearly 200Kbps and a Packet Delivery Ratio of 1. When two other flows are introduced without any priority scheme, the performance of this high priority flow degrades to nearly one-third of that it was while operating alone as evident from Throughput and Packet Delivery Ratio shown in Figure 4 and 5 respectively. With the proposed scheme of flow rate control, both Throughput and Packet Delivery Ratio of high priority flow is maintained as it was while operating alone. So, ‘absolute service differentiation’ is achieved by the high priority flow. The Packet Delivery Ratio of high priority flow even after flow rate control of low priority flows, as seen from the third plot of Figure 5, is 0.99(<1). This is due to some initial packet losses before low priority flow rate has been controlled.

Performance of low priority flows has been studied in two scenarios: without any priority scheme and after introducing the proposed packet injection rate control. The average Throughput of low priority flows is nearly halved after introduction of the proposed scheme. But the most important improvement is shown in average Packet Delivery Ratio, which increased from 0.82 to 0.98. This shows that with the proposed flow rate control, full utilization of the medium is done leading to negligible packet loss. This scheme maximizes the low priority flow also, and packets are injected at an optimized rate, which the network status can handle at that point of time.

5. Conclusion

We have studied the flow rate control by the detection of flows in the nodes where actual congestion is created by route coupling. Currently, we have implemented the flow control mechanism where high priority flow interacts with low priority flows. We are currently working on extending this flow rate control mechanism in cases where high priority flows contend among themselves for access to the medium. Also, by this mechanism, we are trying to improve fairness among the low priority flows when they contend among themselves for access to the medium in absence of the high priority flow.

6. Acknowledgements

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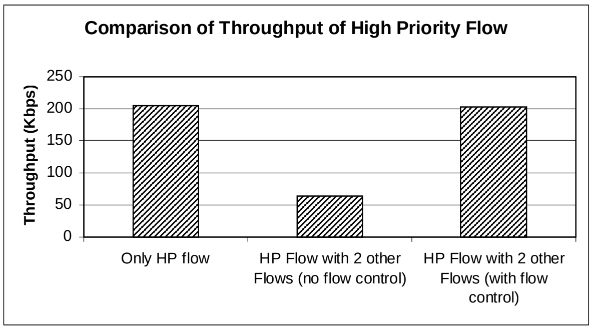

Figure 4: Comparison of Throughput of High Priority Flow

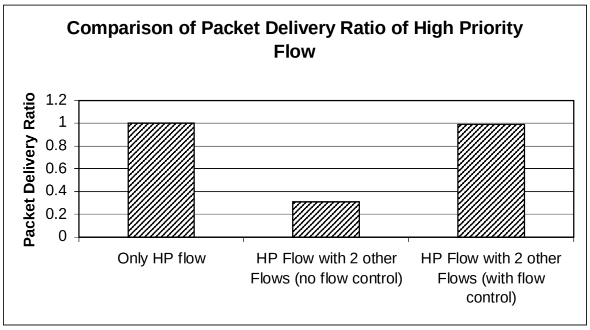

Figure 5: Comparison of Packet Delivery Ratio of High Priority Flow

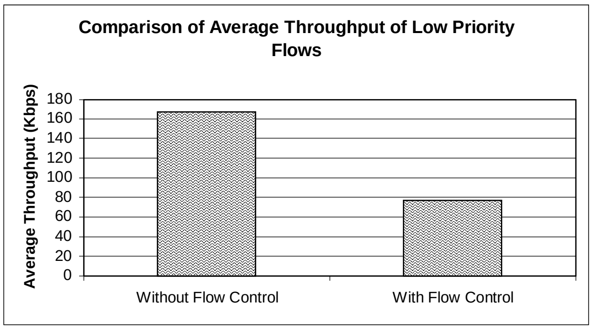

Figure 6: Comparison of Average Throughput of Low Priority Flows

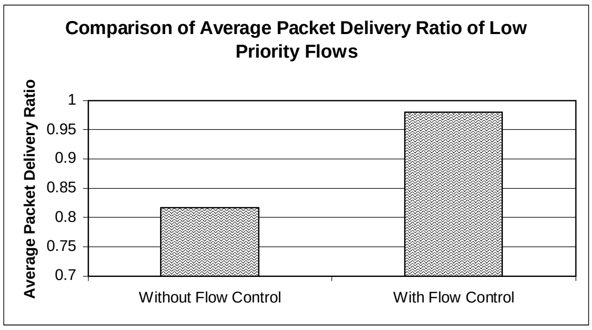

Figure 7: Comparison of Average Packet Delivery Ratio of Low Priority Flows

7. References

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