A Modified Robust Queue Management with Feedback Compensation Technique to Manage the Congestion Control in Wireless Communication Networks

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Abstract--- At present there has been a tremendous growth in the computer networks and wireless networks. Due to the enormous growth of voice, audio, video and data applications over the wireless networks, the requirement of congestion control mechanism is also developing along with the development of wireless network applications. The congestion in the network has drastically affected the Quality of Service (QoS) requirements of the applications. Active Queue Management (AQM) is the technique of signaling Transmission Control Protocol (TCP) sources from middle routers and its major purpose is to lessen the congestion and also satisfy the QoS requirements. In this paper, Modified Robust Queue Management with Feedback Compensation Technique is proposed that helps to reduce the delay and low loss service. The proposed technique is based on feedback compensation technique and the algorithm used in this Modified RQM is called Modified Proportional Integral based series compensation, and Position feedback compensation (Modified PIP). The performance of Modified RQM with Feedback (MFPIP) is evaluated against the existing RQM in terms of packet loss, queue size, unloaded buffer size, End-to-End delay, bandwidth utilization and jitter value. It is revealed from the results that the Modified RQM with Feedback (MFPIP) is more effective in handling the congestion control in Wireless Communication Networks.

Keywords--- Active Queue Management (AQM), Robust Queue Management (RQM), Modified Proportional Integral based series compensation and Position feedback compensation (Modified PIP)

1. Introduction

Wireless sensor network (WSN) distributes sensor nodes, without any outside control, spontaneously and in spatial. This enables user to cooperatively monitor physical or environmental conditions, namely, temperature, sound, vibration, pressure, motion or pollutants. In essence, each sensor node comprises sensing, processing, transmission, mobilizer, position finding system, and power units. These nodes collect and transmit the information that they sense, process and mobilize. Under light load the data movement in the network is under control. When an event has been detected, the load becomes heavy and the data movement also increases. This might lead to clogging and overcrowding.

Among the various processes that happen in the WSN the most perplexing, difficult to solve situations happen with a regards to issues that relate to Congestion and it has vast theoretical study in wide area networks, such as the Internet.

Congestion is a basic operation in networking and has a rich history of algorithm development and it has two components:

1. The temporary, random fluctuations in the packet arrival process, called “transient”
2. The continuous oversubscription of a link’s bandwidth, called “sustained”

The many sources for congestion are buffer overflow, concurrent transmission, packet collision and many to one nature.

1.1 Active Queue Management (AQM)

AQM is one of the solutions to the aforementioned congestion and overcrowding of data movement. Depending on the queue measurement technique, the AQM schemes are classified into two categories called Instantaneous Queue Measurement and Queue Averaging Algorithm. When the queue crosses certain limit of data movement [11], packets are dropped from the buffer at the tail, randomly or at the front. This notifies to sources via TCP about the beginning of clogging of sensor nodes as no acknowledgements (ACK) are received at its incipient stage. AQM helps with the reaction to this congestion notification, the source reduces its window size before the window collapses as the congestion arise. This results in under-utilization of the routers outgoing link. AQM also is the process to equally distribute the use of output link of router, by distributing the input in such a way that every source gets the fair share of the output link of router.

1.2 Motivation for AQM Control

To design a AQM scheme, the model of the network, Transmission Control Protocol(TCP) and Queue dynamics are necessary. The various models used to capture these dynamics are Fluid-Flow model, Drop-Tail model and Random Early Detection. Random Early Detection (RED) [13],is believed to offer intelligent dropping of the packets at the router and is discussed below:

The assumptions made while designing the existing AQM schemes [12], especially for RED are that all sources are TCP sources, that Round Trip Time(RTT) delay is ignored that the outgoing link capacity of the router is fixed and also that the packet size is constant.

AQM schemes were designed assuming that the sources are TCP sources. In the event of congestion, the TCP sources will reduce the sending data rate upon receiving the congestion notification from the AQM scheme at the router, however, the data rate of UDP sources will remain unaffected.

In simplifying the linearized model of window dynamics in the AQM scheme, RTT delay is ignored. RTT defines the time by which the congestion information is conveyed towards sources. The outgoing link capacity of the router is fixed in this model however this assumption may not be true in the wireless links where the link capacity is varied with time. If the aim is to keep the queue at a desired set value, then the variations in the capacity are certainly a cause of concern.

The assumption that the packet size is constant is enabled by the fact that TCP sources keep on adjusting the window size, keeping the packets size the same. The major disadvantages of RQM are that it is quite sensitive to parameter settings. RED [14] configurations have their own drawbacks, especially since they are valid in some particular regimes of load or traffic conditions. Furthermore, as its performance is improved, RQM becomes more and more complex to implement. Hence, proposed a system by using Modified RQM with feedback compensation is given.

I. RELATED WORKS

A substantial research work has been carried out in the congestion control, active queue management (AQM) and random early detection (RED) over the last decade. A number of efficient schemes have been proposed in the literature to address the problems and challenges of better congestion control scheme.

A significant impediment to deployment of multicast services is the daunting technical complexity of developing, testing and validating congestion control protocols fit for wide-area deployment. Gu-In Kwon et al., [1] proposed a new approach to multiple rate congestion control that leverages proven single rate congestion control methods by orchestrating an ensemble of independently controlled single rate sessions. This new scheme combines the benefits of single rate congestion control with the scalability and flexibility of multiple rates to provide a sound multiple rate multicast congestion control policy.

Active queue management (AQM) at routers can effectively control the queue length while keeping high throughput of routers. Xunhe Yin et al., [2] proposed a new AQM algorithm called Hang algorithm based on a modified Smith predictor is proposed. Theoretic analysis and extensive simulation shows that the developed control scheme is effective in dealing with transmission delay and other uncertainties. Comparison with traditional PI control and PI-Smith Predictor control is also conducted via NS2 simulation, and the results confirm the effectiveness of the proposed method in accounting for load disturbance and delay variation.

Active queue management (AQM) is an effective mechanism for congestion control problem which can achieve high quality of service (QoS) by making a better tradeoff between high throughput and low delay. A novel fuzzy AQM controller based on the relative changes of queue length and link rate is presented by Zhou Chuan et al., [3], which introduces two relative errors as congestion notifications and also as the inputs of fuzzy inference system, and then an appropriate dropping probability at router is determined by a set of fuzzy rules. Simulation results show that this proposed algorithm has better performance on queue stability and less delay, at the same time it has good robustness for nonlinearity and load variation.

Alemu et al., [4] focuses on an adaptive approach to RED, namely ARED (adaptive RED) that performs a constant tuning of RED parameters according to the traffic load. ARED requires no hypothesis on the type of traffic, which diminishes its dependency on the scenario parameters such as the bandwidth, the round-trip time and the number of active connections. Main goal is to find a simple extension to ARED in order to improve the predictability of performance measures like queuing delay and delay jitter without sacrificing the loss rate. To achieve this goal, proposed a new algorithm that sets the RED parameters and evaluate it by extensive simulations. The results show that compared to the original ARED, this algorithm can stabilize the queue size, keep it away from buffer overflow and underflow, and achieves a more predictable average queue size without substantially increasing the loss rate.

II. METHODOLOGY

The TCP end-to-end congestion control scheme is powerful in preventing congestion collapse, especially when most of the flows are responsive to packet losses in congested routers. However, unresponsive flows do not, either intentionally or unconsciously, slow down their sending rates when the network becomes congested; hence they can obtain more bandwidth. Thus, unfairness and low efficiency are inherent deficiencies of the completely distributed congestion control framework. Further, traditional end-to-end congestion control and simple drop-tail queue management at routers have limited ability to assure even minimal fairness, delay or loss guarantees. Thus, an Active Queue Management (AQM) mechanism is recommended at intermediate nodes to improve the end-to-end congestion control and provide low delay and low loss service in best-effort network by actively signaling congestion early [5].

The design goals and shortcomings of the existing RQM are discussed in the following section. Then the design of modified RQM with feedback is proposed.

3.1. Robust Queue Management (RQM)

The main intention is to design an RQM scheme that can tolerate even the large variations in capacity of outgoing link of router. The assumptions made while designing the AQM schemes, especially in RED are provided. However, in wireless scenario, there can be small or large scale fading (Fading is a deviation of the attenuation that a packet data experiences over a wireless network). In practical situations, the fading might cause large variations in link capacity. This work have assumed a link capacity of 0.5 Mbps at the router outgoing link and variations of nature 0.1 Mbps to 0.5 Mbps are considered wide variations.

The major goals of existing RQM design are as follows

(a) The priority task is to control the queue length at the router buffer at the desired set value. So in the design of a controller existing RQM have probability of drop as the control input and the queue length deviations as the controlled output.

(b) The intention is to control these queue deviations irrespective of the capacity variations at the router outgoing link.

(c) The intention is to design a controller that is robust to the network parameters variations.

Shortcomings of the Existing RQM Scheme

In the above section summarized the algorithm of the existing RQM scheme However, this work analyzed the design steps for modified RQM. There are limitations on RQM performance and it is listed below.

(a) The existing RQM scheme assumes that the sources are TCP. In case of presence of UDP sources which work in an open loop control, RQM scheme may not work satisfactorily. In the event of congestion, AQM controller assigns penalty to TCP sources by dropping packets and TCP sources reduce their window size.

(b) The packet size of TCP should be known while designing RQM scheme. Hence, existing RQM scheme have assumed for simplicity that TCP sources send a fixed size data packets.

(c) The existing RQM scheme achieves the queue control, at the cost of almost the similar packet drop as in RED. However, to control the queue length at a very lower set point of the maximum buffer size available, incur a higher packet loss.

(d) The existing RQM scheme estimates RTT assuming that the propagation time is fixed and known in the RQM design. The actual network may have a variation from this. However, this deviation is not fed back and considered in the controller design.

(e) The existing RQM scheme is designed assuming fixed RTT. Hence, it can not be used in the networks with varying RTT.

3.2. Proposed Modified RQM Model with Feedback

Among AQM mechanisms, Random Early Detection (RED), which was originally proposed to achieve fairness among sources with different burstiness and to control queue length, is probably the best known [6].

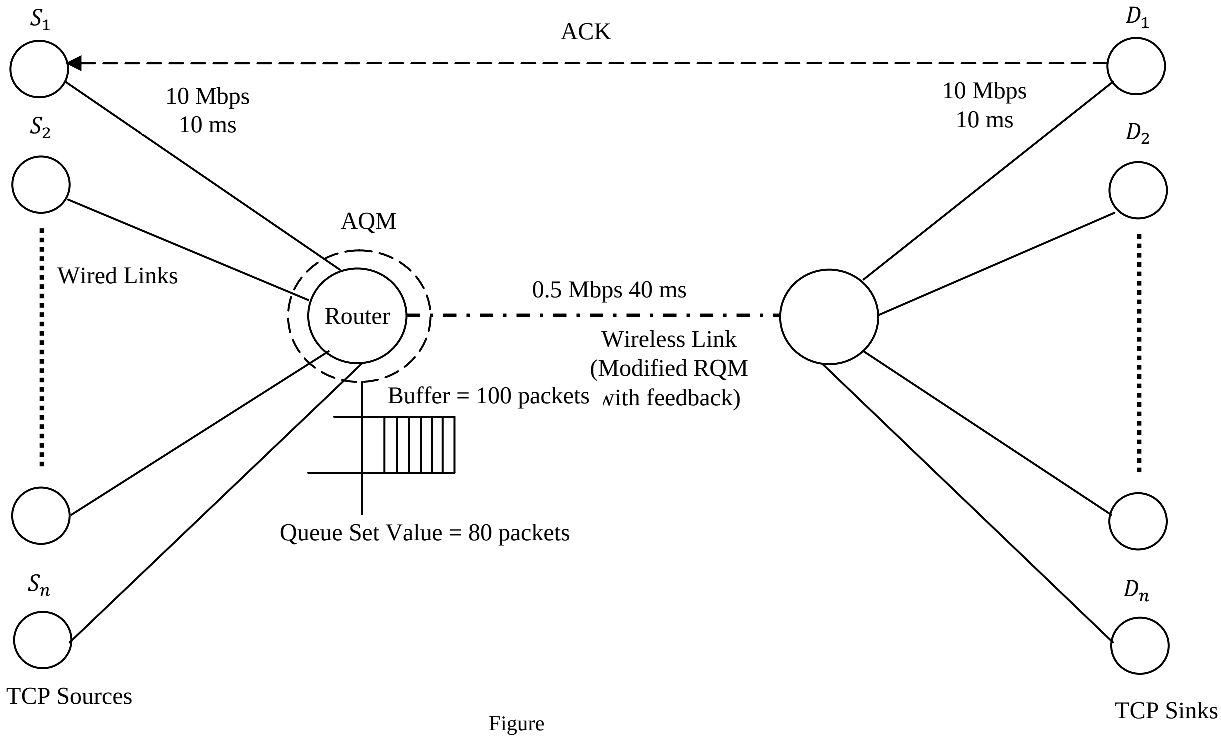

Figure 3.1: Overall Architecture of Proposed Modified RQM Model with Feedback

In this approach applied series and feedback compensation schemes simultaneously to design an RQM controller and develop the proportional integral based series compensation and position feedback compensation algorithm (PIP) to improve the responsiveness and robustness of the pi controller. By choosing appropriate feedback compensation parameters, the properties of the corrected system can be determined mainly by series and feedback compensation elements. Thus, PIP can eliminate errors due to inaccuracies in the linear system model as well as eliminate the sensitivity to changes in system parameters like load level, propagation delay, etc. Simulations and analysis indicate that PIP is more responsive and robust than PI. It can maintain the queue length at a desired level with small oscillations regardless of load levels.

3.3. Control System Model and Feedback Compensation

TCP/RQM Control System Model

Nonlinear ordinary differential equations, which describe the transient behavior of networks with RQM routers supporting TCP flows, are developed in [7]. These equations are linearized in [8] and the linear TCP/RQM system model can be depicted as in Figure 3.2, where, q_0 is the reference queue size, $G_1(s)$ is the RQM controller, and $G_2(s)$is the TCP window-control and $q(s)$ is the queue dynamics parameter.

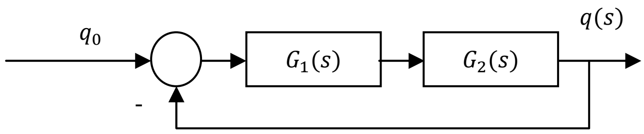

Figure 3.2: Block diagram of a linear TCP/RQM control system

The action of an RQM control law is to mark (or drop) packets with probability p as a function of the measured difference between the real queue length q and the reference queue length q_0. The transfer function of $G_2(s)$ is

$$G_2(s) = \frac{K_m}{(T_1 s + 1)(T_2 s + 1)} \qquad (1)$$

With

T_1= Time Factor of G1

T_2= Time Factor of G2

$$K_m = \frac{(RC)^3}{2N}, T_2 = R$$

With

R=Round-Trip Time (RTT)

N=active TCP sessions

C=link capacity (packets/sec)

Feedback Compensation

When the desired transient or steady state behavior of a control system is difficult to obtain, compensation elements are often introduced into the system. These compensation elements are designed so that they help achieve system performance, i.e. bandwidth, phase margin, peak overshoot and steady state error, etc, without modifying the entire system in a major way. Feedback compensation [15] is one of the widely used compensation techniques because of its specific ability to improve system performance [9]. The most significant features of feedback compensation can be summarized in four aspects.

- First, the impact of nonlinear characteristics in the system may be alleviated.
- Second, the time-constant of the element enclosed by feedback compensation can be decreased such that the system will react promptly.
- Third, feedback compensation can make the system less sensitive to parameter changes as well as robust control does.
- Finally, feedback compensation is very effective in restraining noise.

With regard to the advantages mentioned above, feedback compensation is well suited for TCP/RQM systems. Figure 3.3 exhibits the new structure when feedback compensation is introduced into the system illustrated in Figure 3.2. Here, $G_1(s)$ can be viewed as series compensation element, $G_c(s)$is the feedback compensation element and $G_2(s)$is the uncorrected system. The action of feedback compensation is similar to $G_1(s)$ in that it marks (or drops) packets with probability as a function of the queue length q.

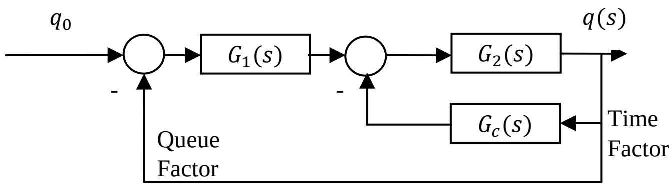

Figure 3.3: The structure of feedback compensation system

According to the block diagram the open-loop transfer function of the system is

$$G(s) = \frac{G_1(s)G_2}{1 + G_2(s)G_c(s)}$$

Consider frequency response of the inner loop.

$$|G_2(jw)G_c(jw)| \gg 1 \qquad (2)$$

where w is the TCP window size.

If the inequality is satisfied within the dominant operation frequency of the system, the open-loop transfer function is approximate to

$$G(s) \approx \frac{G_1(s)}{G_c(s)} \qquad (3)$$

3.4. MFPIP Protocol

In this section, the design of the Modified Feedback PIP protocol is discussed in detail. Considering the expression of $G_2(s)$ applied proportional integral controller in the forward path. In essence, PI is a phase-lag compensation element, which makes the crossover frequency decline and the phase margin augment. PI is quite applicable to such systems that require high steady state precision rather than fast response. This is why the PI controller is sluggish in response. A PI controller has a transfer function of the form

$$G_1(s) = \frac{1 + \tau s}{Ts} \qquad (4)$$

where τs is the feedback error and Ts is the Total element.

There are two commonly used feedback compensation techniques position feedback and tachometer feedback. In order to avoid calculating the aggregate packet arrival rate and to improve the responsiveness of the system, adopted the former in the inner loop of the block diagram. The transfer function of position feedback is

$$G_c(s) = K_h$$

where K_h is the number of feedback which is constant.

The rules for designing a stable and robust RQM algorithm are provided. Three coefficients in $G_1(s)$ and $G_2(s)$ need to be determined separately and based on the previous discussion, K_h should satisfy. So the equation becomes

$$|G_2(jw)|K_h \gg 1$$

$$K_h \gg \frac{\sqrt{(T_1^2 w^2 + 1)(T_2^2 w_2 + 1)}}{K_m} \qquad (5)$$

The above inequality gives the lower bound for K_h. Although K_h is related to the number of active flows and propagation delay, the restriction is substantially loose. If K_h is two or three magnitudes larger than the lower bound determined by a certain network, it will be applicable for a broad network condition.

A proposition for the design of a stable compensation system is provided below.

Proposition 1: When using proportion integral compensation in the forward path and position feedback compensation in the inner loop respectively, if T and τ satisfy

$$T \geq \frac{(R^+C)^3\tau}{8\sqrt{2N^2}}, \tau \geq \frac{1}{w_g} \qquad (6)$$

Where

$$w_g = 1/\sqrt{T_1 T_2} \qquad (7)$$

So far, a novel modified RQM algorithm with feedback compensation has been obtained. The transfer function of the drop probability is

$$p(s) = \frac{1 + \tau s}{Ts}\delta q(s) - K_h q(s) \qquad (8)$$

So, MFPIP can keep the queue around the target value with constrained oscillations. The packet drop probability is updated in a constant frequency, typically around 200Hz. Furthermore, the performance of MFPIP is not very sensitive to the value of the frequency.

III. Experimental Results

The proposed modified RQM with feedback is evaluated with the existing RQM. To measure the performance of a system, packet loss, queue size, unloaded buffer size, End-to-End delay, bandwidth utilization and jitter value are taken into consideration. In this section, the performance of modified RQM with feedback is compared with the existing RQM based on those parameters

4.1. Packet Loss

The packet loss caused by modified RQM with feedback and existing RQM are compared. Figure 4.1 shows the packet drops in different times when the number of packet flows is 400. Once the queue converges to the reference value, both of them incur no significant drops for packet flows when modified RQM with feedback is used. The reason is that the queue scarcely hits the buffer limit in steady state. However, in the transient period, existing RQM drops relatively large number of packets as a result of frequently occurred overflows.

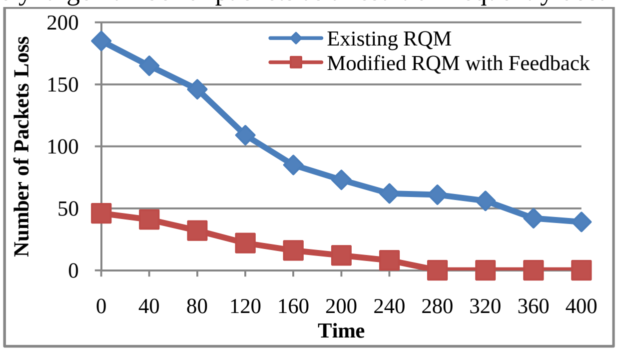

Figure 4.1: Packet Loss Comparison

4.2. Impact of Queue Size

In this experiment, the queue size of modified RQM with feedback and existing RQM is compared. The number of packet flows at the beginning and 100 additional packets arrive at the link 30 seconds later. As shown in the figure, the queue size of modified RQM with feedback climbs to the highest point when the number of packet flow increases. Once the number of packet flow increases suddenly, the queue size increases as before and converges slowly once again.

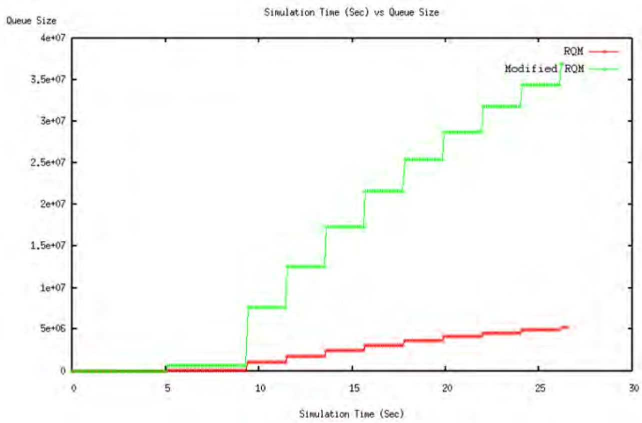

Figure 4.2: Queue Size Comparison

4.3. Unloaded Buffer Size

During the transmission of data packets in a wireless network, adequate buffer size is required for each node to temporarily store the packets not ready to be sent out. From the figure 4.3, it is observed that the unloaded buffer size of the modified RQM with feedback is low when compared with the existing RQM. The low unloaded buffer size indicates that the modified RQM provides maximum utilization of the available buffer size. The existing RQM has the limitation in using the available buffer size properly, but this has been overcome by the modified RQM and hence provides the maximum utilization of the available buffer size.

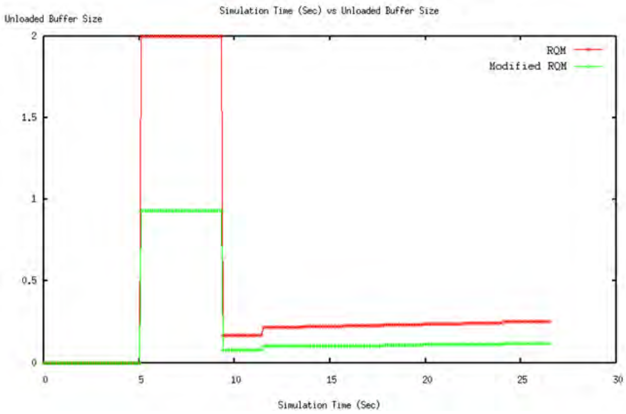

Figure 4.3: Comparison of Unloaded Buffer Size

4.4. Bandwidth Utilization

The specific amount of bandwidth is necessary to transmit a packet from sender to receiver in wireless environment. The bandwidth utilization of the proposed modified RQM with feedback is compared with the existing RQM. From figure 4.4, it is clear that the proposed modified RQM with feedback utilizes only less amount of bandwidth when compared with the existing RQM. This leaves the huge amount of bandwidth to be used for further transmission of data packets

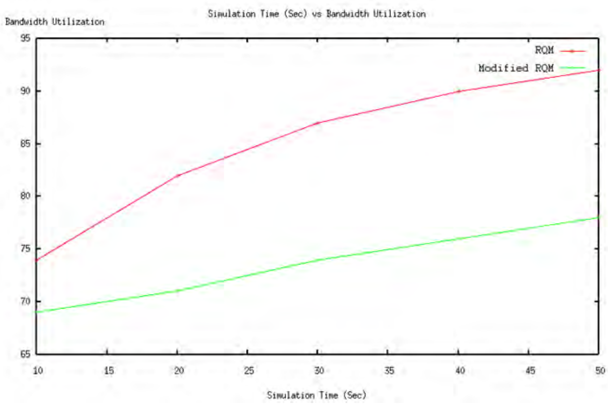

Figure 4.4: Comparison of Bandwidth Utilization

4.5. End-to-End Delay

Data transmission seldom occurs only between two adjacent nodes, but via a path which may include many intermediate nodes. End-to-end delay (EED) is the sum of delays experienced from the source to the destination.

The EED metric by itself can be used as an efficient routing metric, since it effectively captures not only the queuing delay at the network layer but also the retransmission delay. Figure 4.5 shows the comparison of EED of the existing RQM and the modified RQM with feedback. From the figure, it is clear that the modified RQM with feedback has very low delay when compared with the existing RQM.

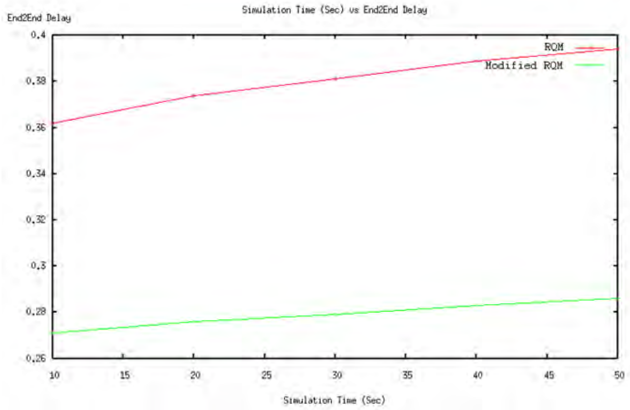

Figure 4.5: End-to-End Delay Comparison

4.6. Network Jitter

Jitter is the variation in the time between packets arriving, caused by network congestion, timing drift, or route changes. Packet delay jitter may result from packets taking different paths to their destination to avoid congested areas or failed links. However, jitter is primarily caused by varying queuing delays encountered by packets at routers (nodes). This variation is considerably reduced in the modified RQM. This can be observed from the following graph (Figure 4.6). The jitter value of the existing RQM is above 2.3 at the beginning stage and it increases greatly after 40 Sec whereas the modified RQM has very low jitter value (under 1.8) when compared with the existing RQM.

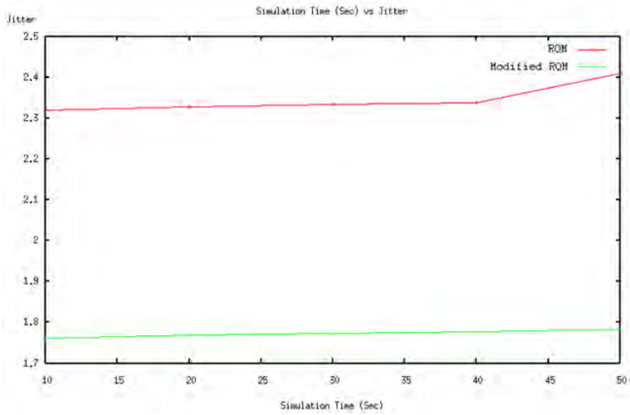

Figure 4.6: Jitter Value Comparison

IV. CONCLUSION

In this work presented a modified RQM algorithm with feedback called MFPIP, which can be implemented easily. The performance of MFPIP is evaluated by simulations and compared with existing RQM. The results show that modified RQM algorithm with feedback (MFPIP) is superior to existing RQM under almost all traffic conditions. The improved responsiveness and robustness gained by modified RQM algorithm with feedback is mainly due to the introduction of feedback compensation element. By correctly choosing the feedback parameter, the error incurred by the inaccuracy in the linear system model is eliminated. Moreover, the sensitivity to system parameter variations is also alleviated. The modified RQM with feedback is evaluated against RQM based on the performance metrics such as packet loss, queue size, unloaded buffer size, End-to-End delay, bandwidth utilization and jitter value. Modified RQM algorithm with feedback can keep the queue length near the reference value with small oscillations under widely various traffic conditions. The proposed approach to modify RQM is simple and straightforward.

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