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The FN Quadratic Marking/Dropping Probability Function

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***Abstract*—The gateway queuing performance depends on the marking/dropping probability function chosen. This function plays an important role in managing the gateway buffer. It maps the current congestion level to marking/dropping probability that is applied to each arriving packet. Active queue management mechanisms drop arriving packets probabilistically before the gateway buffer gets full. Fast Congestion Notification (FN) mechanism is a proactive queue management mechanism that marks/drops packets before a buffer overflow happens to avoid congestion. FN avoids the queue overflows by controlling the instantaneous queue size below the optimal queue size, and control congestion by keeping the average arrival rate close to the outgoing link capacity. Upon arrival of each packet, FN uses the instantaneous queue size and the average arrival rate to calculate the packet marking/dropping probability. This paper presents the derivation of the FN quadratic marking/dropping probability function based on the assumption that the average packet arrival rate changes during the control time constant period with the constant acceleration.**

Keywords- Active Queue Management (AQM); Random Early Detection (RED); Fast Congestion Notification (FN); Packet Drop/Mark Probability; Gateway Buffer

I. Introduction

Active Queue Management (AQM) refers to a family of packet dropping mechanisms for router queues [2]. AQM has been designed to support end-to-end congestion control in packet networks. The principle of AQM is to pro-actively drop packets in a router in anticipation of congestion. Such packet losses are further interpreted (through acknowledgements or timeouts) by TCP sources as a request to reduce their sending rates [3]. In AQM mechanisms, packets are dropped based on the load of the flow aggregate, with no knowledge of the individual flows that compose that aggregate [2]. Active queue management policies (AQM) employs preventive packet drop before the gateway buffer gets full [4]. Drop-Tail, which is one of reactive queue management policies, is currently widely developed in the Internet routers. It introduces several problems, such as global synchronization, on the Internet. Active queue management policies, such as Random Early Detection (RED), are expected to eliminate global synchronization and improve Quality of Service (QoS) of the networks. The promised advantages of AQM are increase in throughput, reduce the delay, and avoid lock-out. AQM provides preventive measures to manage the router queue to eliminate the problems associated with passive queue management. In an AQM mechanism, the probability of the preventive packet drop is proportional to congestion levels. Preventive packet drop provides implicit feedback method to notify the traffic senders of the congestion onset [5]. As a reaction, senders reduce their transmission rate to moderate the congestion level. Arriving packets from the senders are dropped randomly, which prevents senders from backing off at the same time and thereby eliminate global synchronization

Figure 1 shows the system model for active queue management schemes. As illustrated in figure 1, arriving packets are probabilistically dropped according to a dropping probability function $P(Q_{cur})$. Packets that are permitted to enter the gateway buffer are served according to their time of arrival. The dropping probability function is a function that maps the congestion indicator of the actively managed buffer to dropping probability. The obtained dropping probability determines the arrival packets' dropping intensity at the current congestion condition [2].

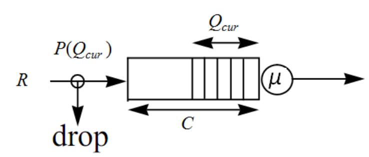

Figure 1. System Model for Active Queue Management Mechanisms

II. Random Early Detection (RED)

RED is the default AQM mechanism that is recommended by IETF for the Internet routers [6], which was proposed by Floyd and Jacobson [1] in 1993. RED has been designed to eliminate unfair treatment of individual flows, and global synchronization problems.

RED introduces two new elements in the queue management scheme: (i) the average queue size estimation, and (ii) a marking/dropping function.

A router implementing RED detects congestion early by computing the average buffer length (*avg*) and sets the two queue thresholds (Max_{th} and Min_{th}) for packet drop

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(see figure 2). The average buffer length at time t, is defined as $avg(t) = (1-w)\, avg(t-1) + wq(t)$, is used as a control variable to perform active packet drop. The $avg(t)$ is the new value of the average buffer length at time t, $q(t)$ is instantaneous buffer length at time t, and w, which is normally less than one, is a weight parameter in calculating *avg*.

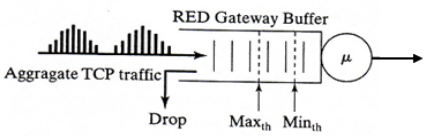

Figure 2. RED Gateway Buffer

A. RED Packet Drop Probability

The dropping function is used to anticipate congestion by dropping packets before the queue is full, instead of waiting for the buffer to overflow. Packet drop probability function determines the probability that the packet is dropped when the mark/drop activation function imposes drop procedure initiation and the drop position function selects the specific packet to be dropped. For example in drop-tail, the chosen packet which is the packet at the tail of the queue is dropped with probability one.

In RED, the probability of dropping packet, P, is calculated by $P = Max_{drop}((avg - Min_{th}) / (Max_{th} - Min_{th}))$

The RED algorithm includes two computational parts: computation of the *average buffer length* and calculation of the *drop probability*.

The RED algorithm involves four parameters to regulate its performance. Min_{th} and Max_{th} are the queue thresholds to perform packet drop, Max_{drop} is the packet drop probability at Max_{th}, and w is the weight parameter to calculate the average buffer size from the instantaneous queue length. The average buffer length follows the instantaneous buffer length. However, because w is much less than one, *avg* changes much slower than q. Therefore, *avg* follows the long-term changes of q, reflecting persistent congestion in networks. By making the packet drop probability a function of the level of congestion, RED gateway has a low racket-drop probability during low congestion, while the drop probability increases the congestion level increases [5].

The packet drop probability of RED is small in the interval Min_{th} and Max_{th}. Furthermore, the packets to be dropped are chosen randomly from the arriving packets from different hosts. As a result, packets coming from different hosts are not dropped simultaneously. RED gateways, therefore, avoid global synchronization by randomly dropping packets.

The performance of RED significantly depends on the values of its four parameters [7], Max_{drop}, Min_{th}, Max_{th}, and w. Figure 3 show the RED drop probability function.

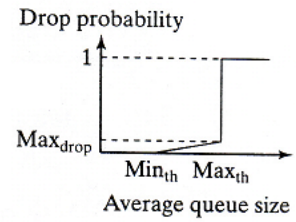

Figure 3. RED Drop Probability Function

RED uses four parameters and one state variable to regulate its performance. The state variable is the average buffer length, which is defined as $avg = (1 — w)\, avg + wq$ and works as a low pass filter (LPF) [1]. In the above expression, w is a weight parameter and q is the instantaneous queue size of gateway buffer. The average buffer length controls the active packet drop in the RED queue. The advantages of using average queue length to control active packet drop are: (i) accumulating short-term congestion, and (ii) tracing long-term congestion.

Nevertheless, the low pass filter characteristic of average queue is also featured with slow-time response to the changes of long-term congestion in networks. This is harmful to the throughput and delay performance of RED gateway. For example, after a long-term congestion, the average buffer length stays high even if the instantaneous queue is back to normal or low; RED will, therefore, continue dropping packets even after the end of congestion [8] resulting in low throughput. The slow response of the average queue length will result in the throughput restoring slowly after heavy congestion [9]. A larger value of w can improve the response time, but at the expense of the RED queue tracing short-term congestion, which is against the AQM principle.

III. FAST CONGESTION NOTIFICATION (FN)

The FN [10] queue management algorithm randomly marks (if ECN) / drops (if non-ECN) the arriving packets before the buffer overflows, to effectively control the:

- instantaneous queue length below a the optimal queue length to reduce the queuing delay and avoid the buffer overflows
- average traffic arrival rate of the queue in the proximity of the departing link capacity to enable the congestion and queue length control

FN integrates the instantaneous queue length and the average arrival rate of queue to compute the drop probability of the packet upon each arriving packet, as described in the following sections.

The use of the instantaneous queue length in conjunction with the average queue speed (average arrival rate) can provide superior control decision criteria for an active queue management scheme [11].

A. FN Packet Drop/Mark Probability Function

The two control decisions of packet admissions and congestion control directing could be made in isolation at the gateway. Nevertheless, they are not independent of each other and affect each other. Whether a packet is allowed to the buffer or not will affect the direction taken by the congestion control process over time. If a packet is dropped (marked) rather than being allowed to the buffer, a congestion notification is delivered and the congestion avoidance and control carries on to be exercised at the gateway. On the other hand, the control exercised to guide the direction and aggressiveness of congestion control at the gateway over time affects whether a particular packet will be allowed to the buffer. If the queue management policy decides the need to exercise more aggressive congestion control, then the newly arrived packet has to be dropped to provide early congestion notification.

Particularly, the goal is to design a drop probability function with a built-in drop activation function which will enable the two control decisions of packet admissions and congestion control directing to be made along with each other, rather than in isolation. This is accomplished by computing a single packet marking/dropping probability to enforce the two control decisions at the same time. The drop/mark probability function will determine the packet marking/dropping probability based on both decision criteria of instantaneous queue length and average traffic rate. Every packet will be subject to a random drop/mark where the drop/mark probability will depend on the condition of the gateway at the time of the arrival of the packet in terms of the instantaneous queue length at the gateway and the average traffic rate. Packets can get dropped (marked) even when the queue is lightly occupied if the traffic rate is very high and conversely packets may not be dropped (marked) even if the queue is heavily occupied but the arriving traffic is moderate. This allows congestion avoidance notification to be delivered as early as necessary even if the queue is empty, and to be suppressed even if the queue is near-full but the arriving traffic is manageable. A linear dropping/marking probability function presumes that the average aggregate arrival rate remains constant over a period of time used for computing the packet drop probability. The period of time used for computing the packet drop/mark probability will be referred to as the control time constant. The designs presented have a built-in drop/mark activation function. In other words, the decision criteria of average buffer arrival rate and instantaneous queue length are only implicitly compared to the predetermined thresholds of a desired optimal queue length and the outgoing link capacity through the computation of the drop/mark probability. A zero probability will indicate that the traffic characteristics and buffer condition are such that the expected growth in the queue level over the next control time constant period will just match the available buffer capacity and therefore no packets are required to be dropped or marked. A negative drop/mark probability will indicate that the expected growth in the queue level over the next control time constant period will be less than the available buffer space at the gateway. In this case, the gateway will be able to hold the expected growth without having its buffer and link capacity resources flooded. In both cases the arriving packet is allowed to the buffer.

1) FN Linear Packet Marking Probability

The linear marking probability function [12] is derived based on the assumption that the arrival traffic process remains unchanged over the control time constant period of length (T) seconds. In other words, it is supposed that immediately following the packet's arrival, the traffic continues to arrive at the fixed rate of (R) bits/sec, the estimated average arrival rate to the buffer computed upon the packet's arrival, for the period of the control time constant. The buffer has a capacity of (C) bits and is served by an outgoing link at a fixed rate of (μ) bits/sec. The packet drop/mark probability (P), is computed for, and applied to, every incoming packet, based on the above assumptions, with the goal of driving the instantaneous (current) queue length (Q_{cur}) to some desired optimal level (Q_{opt}) over the control time constant period (T). These are shown in Figure 4.

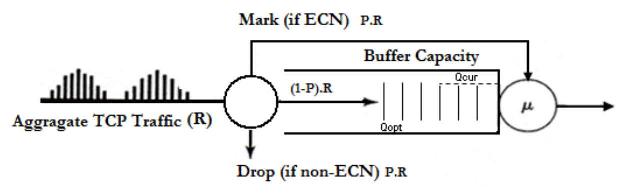

Figure 4. FN Gateway Buffer

Before deriving the FN linear drop/mark probability function, we specify some necessary quantities related to the queue, as follows:

- Increase in the queue due to packet arrivals (Q^+): Packets arriving at the buffer at a constant rate of (R) bits/sec over a period of time of length (T) seconds cause the queue size to grow by:

$$Q^+ = R.T \quad \text{bits.} \tag{4}$$

- Decrease in the queue due to packet transmissions (Q_μ^-): Packets are transmitted from the buffer at a rate of (μ) bits/sec. Over a period of time of length (T) seconds, a total of ($\mu.T$) bits are drained from the buffer and the queue level will be reduced by just as much:

$$Q_\mu^- = \mu.\, T \quad \text{bits.} \tag{5}$$

- Decrease in the queue due to random packet dropping/marking (Q_P^-): If packets are dropped/marked with a probability of (P) over the period of length (T) seconds, then (P) fraction of the total queue growth that would have resulted in the absence of random packet dropping/marking, ($R.T$), will be converted to queue drain:

$$Q_P^- = P.(R.\ T)\quad \text{bits.} \tag{6}$$

- Total decrease in the queue due to departures & random marking (Q^-): Total decrease in the queue due to packet transmissions and random packet marking is the sum of (Q_μ^-) and (Q_P^-):

$$Q^- = (\mu.\ T) + (P.\ (R.\ T)) = (\mu + P.\ R).\ T \quad \text{bits.} \tag{7}$$

- Change in the queue level due to arrivals & departures (ΔQ_μ): In the absence of random packet drops/marks, the queue growth and drain would be governed only by packet arrivals and departures. The change in the queue level would equal the difference of queue growth and queue drain:

$$\Delta Q_\mu = Q^+ - Q_\mu^- = (R.\ T) - (\mu.\ T) = (R - \mu).\ T \quad \text{bits.} \tag{8}$$

  A positive value indicates growth, a negative value indicates drain, and a zero value indicates the total growth and drain due to arrivals and departures to be equal, neutralizing the effect of each other.
- Total actual growth/drain in the queue due to arrivals, departures, & random marking (ΔQ_a).
- The total change in the instantaneous queue length is the difference of the growth due to packet arrivals and the drain due to packet transmissions and random packet drops/marks:

$$\Delta Q_a = (R.T) - ((\mu + P.R).T)) = ((R - \mu).T) - ((P.R).T)) \quad \text{bits.} \tag{9}$$

  A positive value indicates a growth and a negative value indicates a drain while zero indicates a steady queue level.
- Total allowed-growth/desired-drain in the queue (ΔQ_d): Depending on the relative sizes of the desired optimal queue length (Q_{opt}) and the instantaneous queue length (Q), their difference specifies the total allowed growth in the queue over the control time constant period, if the instantaneous queue length is smaller than the desired optimal queue length ($Q < Q_{opt}$), and it specifies the total desired drain, if the instantaneous queue length is larger than the desired optimal queue length ($Q > Q_{opt}$). If instantaneous queue length is identical to the desired optimal queue length, ΔQ_d computes to zero indicating the need to avoid queue growth, not requiring but also not forbidding queue drain: $\Delta Q_d = Q_{opt} - Q$ bits.

FN mechanism tries to direct the current instantaneous queue length (Q_{cur}) to the desired optimal queue length (Q_{opt}). The design and dynamics of the packet dropping/marking probability function determines the path that the instantaneous queue length follows in transiting from its current value to the desired optimal value over the control time constant period. Even though a variety of curves can be used as the path in designing the probability function, a good candidate is a straight line. Hence, upon the arrival of every packet, the drop/mark probability will be computed assuming that it is desired to direct the instantaneous queue length from its current value (Q_{cur}) to its desired value (Q_{opt}) along a straight line over a time interval of (T) seconds immediately following the arrival of each packet. The computed drop/mark probability for the newly arrived packet will be the rate at which packets will have to be dropped over the control time constant period to direct the instantaneous queue length from its current position to the desired optimal level if the traffic conditions would continue unchanged over that period. This is illustrated in Figure 5.

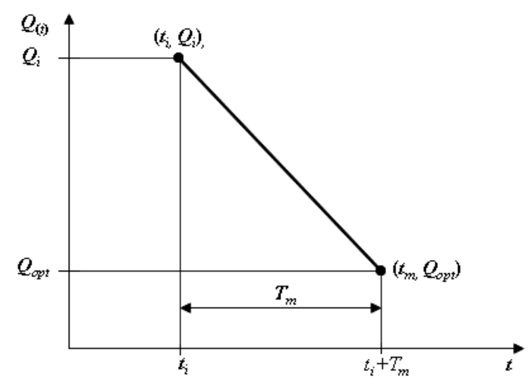

Figure 5. Queue Directing Control Dynamics

The packet dropping/marking probability is updated upon every packet arrival and depends on the difference between the traffic arrival rate and the outgoing link capacity and the difference between the current queue size and the optimal queue length. Upon the arrival of the i^{th} packet (Pkt_i), FN presumes that traffic will continue to arrive at the fixed rate of (R) over the next (T) seconds and computes the drop probability (P) as the fraction (Q_P^- / Q^+) of queue growth due to traffic arrival ($Q^+ = R_i.\ T$) over this period that has to be discarded by dropping/marking packets randomly. Packets are randomly dropped/marked to assist the outgoing link capacity in lowering the effective traffic rate to the buffer $((1 - P^i).R_i)$, to below the link capacity (μ) and in directing the instantaneous queue length (Q_{cur}) to the desired optimal level (Q_{opt}), over the period of length (T) seconds. Consequently, the drop/mark probability should be chosen such that the desired $(\{\Delta Q_d\}^{(i)})$ and actual $(\{\Delta Q_a\}^{(i)})$ changes in the queue over the period of time of length (T) will become equal:

$$\{\Delta Q_d\}^{(i)} = \{\Delta Q_a\}^{(i)} \quad (10)$$

$$Q_{opt} - Q_{cur} = \{Q^+\}^{(i)} - \{Q^-\}^{(i)} \quad (11)$$

$$Q_{opt} - Q_{cur} = \{Q^+\}^{(i)} - \{Q_\mu^-\}^{(i)} + \{Q_P^-\}^{(i)} = \Delta Q_u - \{Q_P^-\}^{(i)} \quad (12)$$

$$Q_{opt} - Q_{cur} = (R_i.T) - ((\mu.T) + (P^{(i)}.R_i).T)) \quad (13)$$

$$Q_{opt} - Q_{cur} = ((R_i - \mu).T) - (P^{(i)}(.R_i.T)) \quad (14)$$

The equation above can be solved for (P) to attain:

$$P^{(i)} = \frac{((R_i - \mu).T) - (Q_{opt} - Q_{cur})}{R_i.T} = \frac{\Delta Q_u - \Delta Q_d}{Q^+} \quad (15)$$

2) FN Quadratic Packet Marking/dropping Probability

For FN quadratic mark/drop probability function it is assumed that the average traffic arrival rate changes during the control time constant period but only with a constant acceleration (deceleration).

FN calculates the average traffic arrival rate (R) and the acceleration (deceleration) (A_i) of the average traffic arrival rate upon each packet arrival (Pkt_i). It is assumed that sources traffic will arrive continuously while the traffic rate will keep increasing (decreasing) at the fixed calculated acceleration (deceleration) over period of time (T). Before proceeding to derive the FN quadratic marking/dropping probability, we define the constant acceleration (deceleration) quantities as follows:

- Increase in the queue due to packet arrivals ($\{Q^+\}^{(i)}$): Packets arriving at the buffer at rate of (R) bits/sec over a period of time of length (T) seconds during which sources traffic changes with constant acceleration/deceleration cause the queue size to grow by:

$$\{Q^+\}^i = \frac{A_i}{2}(T)^2 + R_i.T \quad \text{bits.} \quad (16)$$

- Decrease in the queue level due to packet transmissions ($\{Q_\mu^-\}^i$): Packets are transmitted from the buffer at a rate of (μ) bits/sec. Over a period of time of length (T) seconds, a total of ($\mu.T$) bits are transmitted from the buffer and the queue level will be reduced by just as much:

$$Q_\mu^- = \mu.T \quad \text{bits.} \quad (17)$$

- Decrease in the queue due to random packet dropping/marking (Q_P^-):

$$\{Q_P^-\}^i = P^i.(\frac{A_i}{2}(T)^2 + R_i.T) \quad \text{bits.} \quad (18)$$

- Total decrease in the queue due to departures & random marking/dropping ($\{Q^-\}^i$): Total decrease in the queue due to packet transmissions and random packet marking is the sum of (Q_μ^-) and (Q_P^-):

$$\{Q^-\}^i = (\mu.T) + (P^i.(\frac{A_i}{2}\cdot(T)^2 + R_i.T)) \quad \text{bits.} \quad (19)$$

- Change in the queue level due to arrivals & departures (ΔQ_μ):

$$\{\Delta Q_\mu\}^i = (\frac{A_i}{2}.(T)^2 + R_i.T) - (\mu.T) \quad \text{bits.} \quad (20)$$

- Required-Decrease/Allowed-Increase in queue level ($\{\Delta Q_d\}^i$):

$$\{\Delta Q_a\}^i = Q_{opt} - Q_{cur} \quad \text{bits.} \quad (21)$$

- Total actual increase/decrease in queue level due to arrivals, departures and random marking/dropping ($\{\Delta Q_a\}^i$):

$$\{\Delta Q_d\}^i = [(\frac{A_i}{2}.(T)^2 + R_i.T) - (\mu.T)] - P^i(\frac{A_i}{2}.(T)^2 + R_i.T) \quad \text{bits.} \quad (22)$$

FN concludes the mark/drop probability (P) as the fraction (Q_P^- / Q^+) of queue increase due to traffic arrival over the period of time that has to be discarded by marking/dropping packets randomly.

Thus, the drop/mark probability should be selected to make the required ($\{\Delta Q_d\}^i$) and actual ($\{\Delta Q_a\}^i$) changes in the queue level over the time period (T) equals each other.

$$\{\Delta Q_d\}^{(i)} = \{\Delta Q_a\}^{(i)}$$

$$Q_{opt} - Q_{cur} = \{Q^+\}^{(i)} - \{Q^-\}^{(i)}$$

$$Q_{opt} - Q_{cur} = \{Q^+\}^{(i)} - \{Q^-_\mu\}^{(i)} + \{Q^-_P\}^{(i)} = \Delta Q_u - \{Q^-_P\}^{(i)}$$

$$Q_{opt} - Q_{cur} = [(\frac{A_i}{2}.(T)^2 + R_i.T)] - [((\mu.T\ ) + (P^{(i)}.(\frac{A_i}{2}.(T)^2 + R_i.T)))] \quad (23)$$

$$Q_{opt} - Q_{cur} = [(\frac{A_i}{2}.(T) + R_i) - \mu].T + (P^{(i)}.(\frac{A_i}{2}.(T)^2 + R_i.T)))] \quad (24)$$

The last equation can be solved for P to achieve

$$P^i = \frac{[(\frac{A_i}{2}.(T) \quad + R_i.T) - \mu].T - (Q_{opt} - Q_{cur})}{(\frac{A_i}{2}.(T) + R_i).T} \quad (25)$$

It is clear that ($A_i/2.T+R_i$) is the average of the average traffic arrival rate over the time constant period of length T computed as the arithmetic mean of the average rate at the beginning of the interval (R_i) and the average rate at the end of the interval ($A_i.T + R_i$), based on the assumption that the rate will increase (decrease) with the constant acceleration (deceleration) of A_i bits/sec^2. Representing the arithmetic mean of the average arrival rate over the time constant period with $\overline{R}_i$, the packet marking/dropping probability can be written as:

$$P^i = \frac{[\overline{R}_i - \mu).T - (Q_{opt} - Q_{cur})}{\overline{R}_i.T} \quad (26)$$

IV. CONCLUSION

In this paper, we have presented the linear and the quadratic marking/dropping probability function of Fast Congestion Notification (FN) mechanism. We have showed the derivation of the FN quadratic probability function based on the assumption that the sources traffic arrival rate at the gateway changes during the control time constant period but just with a constant acceleration (deceleration).

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