The Drop Activation Function of the Fast Congestion Notification (FN) Mechanism

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***Abstract*:** Fast Congestion Notification (FN) one of the proactive queue management mechanisms that practices congestion avoidance to help avoid the beginning of congestion by marking/dropping packets before the router's queue gets full; and exercises congestion control, when congestion avoidance fails, by increasing the rate of packet marking/dropping. 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 Drop/Mark Activation Function, which is an internal (built in) function of FN marking/dropping probably function, and shows the conditions under which the FN will trigger a probabilistic packet marking/dropping. This paper shows that the FN's drop activation function is given by $L(R_i, Q_{cur}) = (R_i - \mu).T - (Q_{opt} - Q_{cur})$ which compares the predicted and required/allowed changes in the queue level, over a time period, to decide whether to attempt or not to attempt packet dropping. $L(R_i, Q_{cur}) = 0$ defines the set of the drop activation threshold , the set of (average rate, current queue size), (R_i, Q_{cur}), points for which the required/allowed and predicted decrease/increase in the queue level exactly equal each other and that identify the boundary between the drop region ($L(R_i, Q_{cur}) > 0$), the sets of points at which the packet dropping is attempted, and the no-drop region ($L(R_i, Q_{cur}) < 0$), the set of points at which the packet dropping is not attempted.

***Keywords*:** Internet Congestion, Active Queue Management (AQM)*)*, Fast Congestion Notification *(*FN*)*, Packet Mark/Drop Probability**.**

1. Introduction

Adaptive protocols such as the Transmission Control Protocol (TCP) operate end-to-end congestion control algorithms [1]. These protocols adjust their transmission rate based on sign of congestion from the network by marking or dropping packets [2]. Adaptive connections reduce their transmission rate upon detecting congestion while non-adaptive connections continue injecting packets into the network at the same rate. Whenever adaptive and non-adaptive connections compete, the non-adaptive connections, due to their aggressive nature, take a larger part of bandwidth, thereby dispossessing the adaptive connections of their fair share. This gives rise to the need for queue management policies at intermediate gateways [3] which provide protection for adaptive connections from aggressive sources that try to consume more than their "fair" share, ensure "fairness in bandwidth sharing and provide early congestion notification.

Queue management algorithms manage the length of the packet queues by dropping packets when necessary or appropriate [4]. The efficiency of queue management mechanisms depends on how well their control decisions, on packet admission to the queue and congestion control directing, will help in satisfying their objectives regarding congestion avoidance and control. These decisions are implemented and compelled during the design of the packet mark probability and the mark activation functions. Packet admission and congestion control directing control decisions are dependent on each other. Based on the drop activation characteristic, the queue management policies can be classified into two categories. The first category is *reactive (passive) queue management policies*, which do not employ any preventive packet drop before the gateway buffer is flooded. The second category is *proactive* (*active*) *queue management policies(AQM)* which employ preventive packet drop before the gateway buffer gets full [5].

AQM schemes have the following goals: low buffer occupancy resulting in small queuing delays, low queue length jitter, low packets losses and high link utilization. An AQM scheme would make a good choice of packet marking/dropping at each congestion level (measured by queue length for example) [6] so that the aforementioned goals are realized. The second desirable feature of a good AQM scheme is its robustness. A robust AQM scheme would require little tuning by a network operator and would remain inherently stable to traffic fluctuations [7].

2. Related Works and Motivation

Congestion in the packet switched networks is related to the buffer overflow event. Whenever gateway buffers start to overflow, the network is said to be experiencing congestion and whenever the network gets congested, the buffers start to overflow. This motivated the active queue management policies designers to consider monitoring and control of gateway queue sizes as the major objective of these algorithms. The basis of their decision has been the observation that maintaining low steady state queue sizes guarantees high availability of buffer space at the gateways to be used for housing of temporary traffic increases which assists with avoiding the beginning or worsening of congestion. Dropping packets and sending early congestion notification to traffic sources enable controlling the queue size. Early congestion notification instructs the traffic sources to reduce their transmission rates to help in controlling the queue size.

With the control of queue sizes as their main objective, the active queue management policies proposed and researched previously, use some measure of the queue occupancy level as their sole control decision criteria. They compare this measure to a set of thresholds for performing control decisions such as congestion detection, drop activation, and drop probability adjustment.

A number of active queue management policies have been proposed, such as random drop [8], early packet discard [9], early random drop [10], random early detection (RED) [11] and its variations (FRED [12], stabilized RED (SRED) [13], and balanced RED (BRED) [14]), BLUE [15], REM [16], PI controller [17], and AVQ [18].

RED is the default AQM mechanism that is recommended by IETF for the Internet routers [4], which was proposed by Floyd and Jacobson [11] in 1993 to reduce link congestion and global synchronization by earlier congestion notification. Unfortunately, it has been shown that the performance of a RED router is very sensitive to link's traffic load and its parameter setting, and it is hard to reduce the queue fluctuation by only adjusting RED's parameters [19]. A router implementing RED detects early by computing the average buffer length (*avg*) and sets the two queue thresholds (Max_{th} and Min_{th}) for packet drop. 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 1 shows the RED gateway buffer.

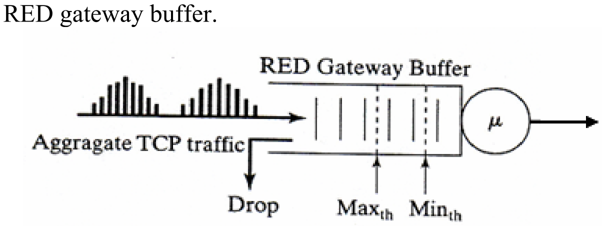

Figure 1. RED Gateway Buffer

3. Fast Congestion Notification (FN)

The Fast Congestion Notification (FN) [20] mechanism is a proactive queue management mechanism that marks/drops packets before a buffer overflow happens to avoid congestion FN marks (if ECN) / drops (if non-ECN) the arriving packets before the buffer overflows, to effectively control: (i) the instantaneous queue length below a the optimal queue length to reduce the queuing delay and avoid the buffer overflows, and (ii) the 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 arriva1 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 [21]. Figure 2 shows the FN gateway buffer.

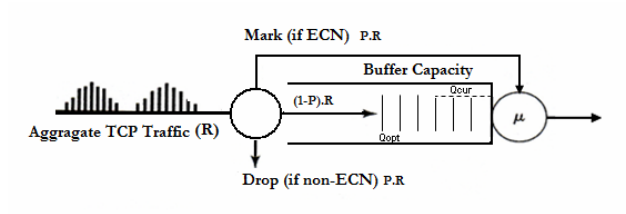

Figure 2. FN gateway buffer

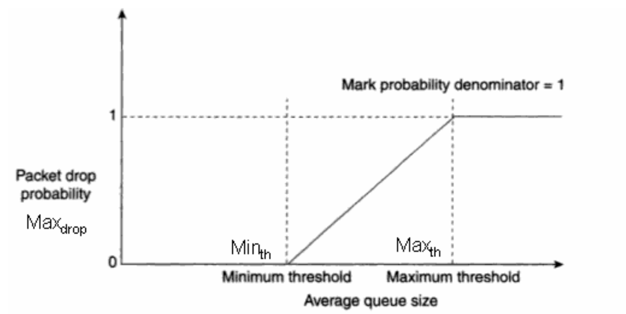

Figure 3. RED Packet Drop Function

4. Packet Drop Probability

Packet drop probability function determines the probability that the packet is dropped when the 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.

4.1. RED Packet Drop Probability

RED packet drop probability is a linear function of the average queue size. It also based on the minimum threshold Min_{th}, maximum threshold Max_{th}, and mark probability denominator, which is the fraction of packets dropped when the average queue depth is at the maximum threshold Max_{th}, see figure 3. 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-

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drop probability during low congestion, while the drop probability increases the congestion level increases [22].

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 [23], Max_{drop}, Min_{th}, Max_{th}, and w.

4.2. FN Packet Drop/Mark Probability Function

The FN linear drop/mark probability function [24], [25] 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 2. The FN drop/mark probability, P, is calculated by

$$P^{(i)} = \frac{((R_i - \mu).T\ ) - (Q_{opt} - Q_{cur})}{R_i.T} = \frac{\Delta Q_u - \Delta Q_d}{Q^+} \qquad (1)$$

To show how the designed drop probability function allows the two decisions regarding average arrival rate control and queue length control interact with each other, the drop probability function can be written as a sum of two components :

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

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

$$P^{(i)} = P_R^{(i)} + P_Q^{(i)} \qquad (2)$$

The (P_R) component expresses the average arrival rate effects and the (P_Q) component form the instantaneous queue length effects. The relative influence of each decision control on the other is specified by the relative sizes of the two components of the drop probability function, (P_R) and (P_Q). This depends on the degree to which the arrival rate differs from the outgoing link capacity and the instantaneous queue length from the optimal desired queue length.

5. Fn Mark/Drop Activation Function

FN packet mark/drop probability function has an internal (built-in) mark/drop activation function. The FN mark/drop probability function compares the expected change in the buffer due to packet arrivals and departures (ΔQ_μ) without random marks/drops over the period of time constant (T) against the required/allowed change (ΔQ_d) in the buffer over the same time period. Depending on the comparative sizes of the traffic arrival rate (R) and departure rate (μ) at the gateway, the prediction may show increase, decrease, or no change in the buffer over the time constant period. Correspondingly, based on the relative sizes of the instantaneous (Q_{cur}) and the required optimal (Q_{opt}) queue sizes, the FN mechanism may allow an increase, require a decrease, or demand the queue not to grow further than its current level that matches the required optimal queue size. Table 1 below illustrates the expected and allowed/required changes in the queue level. In comparing the expected and the allowed/required changes in queue level, the FN drop/mark probability function may present nine different states.

Condition	Description
$(R - \mu).T > 0$	Expected Increase: $\lvert (R-\mu).T \rvert$
$(R - \mu).T = 0$	Queue Level remains unchanged
$(R - \mu).T < 0$	Expected decrease: $\lvert (R-\mu).T \rvert$
$Q_{opt} - Q_{cur} > 0$	Allowed Increase: $\lvert (R-\mu).T \rvert$
$Q_{opt} - Q_{cur} = 0$	No Increase Allowed & No Decrease Required
$Q_{opt} - Q_{cur} < 0$	Required Decrease: $\lvert (R-\mu).T \rvert$

Table I. Expected & allowed/required queue level changes

Each state composes of pair combinations of the three different states for each of the two quantities listed in Table 1. Section 5.1 describes the states together with the mark/drop probability formula and whether the mark/drop probability is positive (⊕), negative (Ө), or zero (0) in each scenario. A positive drop probability means that FN will trigger marking/dropping drop a packet while a negative or a zero mark/drop probability indicates that the packet will be permitted into the gateway buffer.

5.1. Queue Level Changes & FN Mark/Drop Probability Function

- **Scenario 1**:

If the expected increase in the queue level is $(R-\mu)T>0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} > 0$, then the FN marking/dropping probability $(R_i - \mu).T - (Q_{opt} - Q_{cur}) / R_i.T$ will be:

A. Positive value (⊕) if $\lvert (R-\mu).T \rvert > \lvert (Q_{opt} - Q_{cur}) \rvert$, which means the expected-increase > allowed-increase.

B. Zero value (0) if $\lvert (R-\mu).T \rvert = \lvert (Q_{opt} - Q_{cur}) \rvert$, which means the expected-increase = allowed-increase.

C. Negative value (Ө) if $\lvert (R-\mu).T \rvert < \lvert (Q_{opt} - Q_{cur}) \rvert$, which means the expected-increase < allowed-increase.

- **Scenario 2:**

If the expected increase in the queue level is $(R-\mu)T>0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} = 0$, then the FN marking/dropping probability $(R_i - \mu) / R_i.T$ will equal to a positive value, which means an increase is expected but it is required to avoid the increase in the queue level.

- **Scenario 3:**

If the expected increase in the queue level is $(R-\mu)T>0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} < 0$, then the FN marking/dropping probability $(R_i - \mu).T - (Q_{opt} - Q_{cur}) / R_i.T$ will equal to a positive value, which means an increase is expected and a decrease in the queue level is required.

- **Scenario 4:**

If the expected increase in the queue level is $(R-\mu)T=0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} > 0$, then the FN marking/dropping probability $-(Q_{opt} - Q_{cur}) / R_i.T$ will equal to a negative value, which means the queue level is expected to remain steady and increase is allowed.

- **Scenario 5:**

If the expected increase in the queue level is $(R-\mu)T=0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} = 0$, then the FN marking/dropping probability $(0-0) / R_i.T$ will equal to zero value, which means the queue level is expected to remain steady and required to avoid an increase in the queue level.

- **Scenario 6:**

If the expected increase in the queue level is $(R-\mu)T=0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} < 0$, then the FN marking/dropping probability $-(Q_{opt} - Q_{cur}) / R_i.T$ will equal to a positive value, which means the queue level is expected to remain steady but decrease in the queue level is required.

- **Scenario 7:**

If the expected increase in the queue level is $(R-\mu)T<0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} > 0$, then the FN marking/dropping probability $(R_i - \mu).T - (Q_{opt} - Q_{cur}) / R_i.T$ will equal to a negative value, which means a decrease in the queue level is expected an increase in the queue level is allowed.

- **Scenario 8:**

If the expected increase in the queue level is $(R-\mu)T<0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} = 0$, then the FN marking/dropping probability $(R_i - \mu) / R_i.T$ will equal to a negative value, which means a decrease in the queue level is expected and it is required to avoid an increase in the queue level.

- **Scenario 9**:

If the expected increase in the queue level is $(R-\mu)T<0$ and the allowed increase in the queue level is $Q_{opt} - Q_{cur} < 0$, then the FN marking/dropping probability $(R_i - \mu).T - (Q_{opt} - Q_{cur}) / R_i.T$ will be:

A. Positive value ($\oplus$) if $|(R_i - \mu).T| < |(Q_{opt} - Q_{cur})|$, which means the expected-decrease < required-decrease.

B. Zero value (0) if $|(R_i - \mu).T| = |(Q_{opt} - Q_{cur})|$, which means the expected-decrease = required-decrease.

C. Negative value ($\ominus$) if $|(R_i - \mu).T| > |(Q_{opt} - Q_{cur})|$, which means the expected-decrease > required-decrease.

5.2. FN Mark/Drop Activation Function in (ΔQ_u, ΔQ_d) and (R, Q_{cur}) Plan

The aforementioned cases identify sets of (R_i,Q_{cur}) variables. The scenarios associated variable sets shape a complete partitioning of (ΔQ_u, ΔQ_d) plan into several domains which cover the plan completely as shown in figure 4.

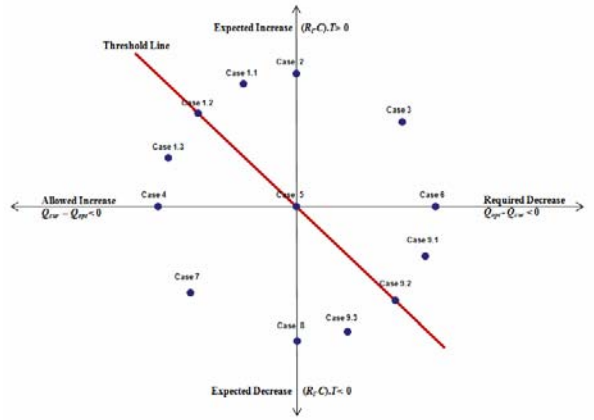

Figure 4. (ΔQ_u ,ΔQ_d) plan partitioning by FN mark/drop probability function

Case 5 identifies the plan origin. Cases 2, 4, 6, and 8 identify the two axes in the coordinate plan. Cases 1.2 and 9.2 identify the threshold line. Cases 1.1, 3, 9.1 identify the three domains above the threshold line. Cases 1.3, 7, and 9.3 identify the three domains below the threshold line. The threshold line indicates the set of (R_i , Q_{cur}) variables for which the expected and allowed/required change in the queue level correspond each other. The upper half part of the threshold line, depicting case 1.2 points, forms (R_i , Q_{cur}) combinations for which the expected increase equals the allowed increase in the queue level. The lower half part of the threshold line, depicting case 9.2 points, forms (R_i , Q_{cur}) combinations for which the expected decrease equals the required decrease in the queue level. Under both these cases, the calculated packet mark/drop probability is equal to zero and no need to trigger packet marks/drops. Therefore, the packets arriving under these conditions will be permitted into the gateway buffer. The points belong to domains below the threshold line specify the set of (R_i , Q_{cur}) variables for which either the allowed increase in the queue level is larger than the expected increase or the required decrease in the queue level is smaller than the expected increase, or increase is allowed while decrease is expected. In the 1.3 domain, the allowed increase in the queue level exceeds the expected increase in the queue level. On case 4 line, increase is allowed in the queue level while the queue level is expected to continue constant. In the case 7 domain, increase is allowed and decrease in the queue level is expected. On case 8 line, it is required for the queue level not to increase and decrease in the queue level is expected. In the 9.3 domain the expected decrease in the queue level exceeds the required decrease. Under these cases the calculated mark/drop probability is a negative value. Therefore, the arriving packet is permitted into the gateway buffer without starting random packet marking/dropping.

The points above the threshold line point out the set of (R_i , Q_{cur}) variables for which either the required decrease in the queue level is not accomplished by the expected decrease in the queue level or the allowed increase is exceeded by the expected increase, or decrease is required while increase is expected.

In the 1.1 domain, the expected increase is more than the allowed increase in the queue level. On case 2 line, it is required for the queue level not to increase while the queue level is expected to have increase. In case 3 domain, decrease in queue level is required while queue level is expected to increase. On case 6 line, decrease is required while the queue level is expected to remain constant. In the 9.1 domain, the expected decrease in the queue level is less than the required decrease. In these cases, the calculated mark/drop probability is a positive value and it is needed to trigger packet marks/drops. Hence the arriving packet will be marked or dropped with the computed mark/drop probability. These are illustrated in figure 5.

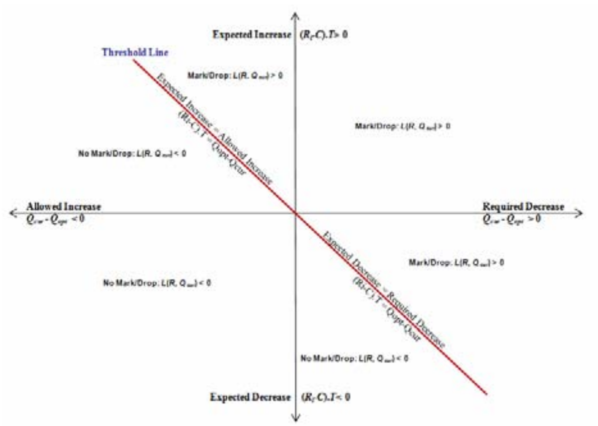

Figure 5. FN mark/drop activation function in (ΔQ_u ,Q_d) plan

The function $L(R, Q_{cur}) = (R - \mu).T - (Q_{opt} - Q_{cur})$ defines the mark/drop activation function for the FN mechanism. The set of (R_i , Q_{cur}) points for which $L(R, Q_{cur}) = 0$ identify the mark/drop activation threshold set which is the threshold line. When the (R_i , Q_{cur}) point occurs on the threshold line, the calculated mark/drop probability is zero, and hence, the arriving packet is permitted into the buffer without triggering a random packet mark/drop. The set of (R_i , Q_{cur}) points for which $L(R, Q_{cur}) > 0$ identify the mark/drop domain where the calculated mark/drop probability is positive and packet marking/dropping is triggered. The set of (R_i , Q_{cur}) points for which $L(R, Q_{cur}) < 0$ identify the no-mark/drop domain where the calculated mark/drop probability is negative, and therefore, the arriving packet is permitted into the buffer without triggering a random packet mark/drop.

Consequently, the FN mechanism triggers a packet mark/drop based on whether the calculated mark/drop probability is positive/negative or zero with no comparison required of the average traffic arrival rate and the instantaneous to particular mark/drop activation thresholds. Figure 6 shows the partitioning of the (R_i , Q_{cur}) plane into mark/drop and no-mark/drop domains by the $L(R, Q_{cur}) = 0$ activation threshold set.

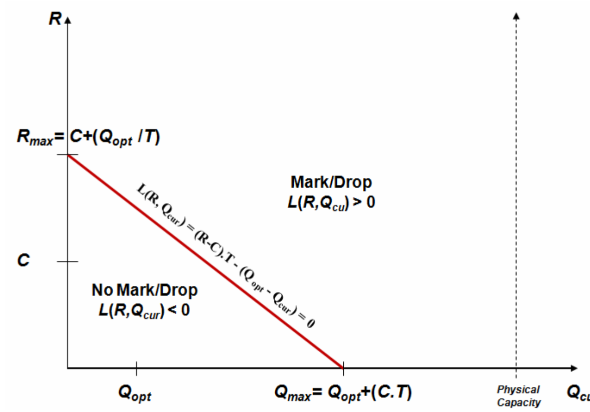

Figure 6. FN mark/drop activation function in (R , Q_{cur}) plan

When the (R_i , Q_{cur}) combination falls in the no-mark/drop area (figure), the arriving packet will be admitted to the gateway buffer any random packet marking/dropping being triggered. Conversely, if the (R_i , Q_{cur}) combination falls in the mark/drop area, the FN will trigger a probabilistic packet marking/dropping.

While the outgoing link of C (μ) bits/sec can transmit a maximum amount of $C.T$ bits during the period of time constant of length T second, if the queue does not increase due to no packet arrives (R=0) over the time constant period, then the largest queue size that can be directed to the required optimal queue size (Q_{opt}) over a period of time T, by packet transmission and without random packet marks/drops, would be $Q_{max} = (Q_{opt} + C.T)$. The largest arrival rate that can be accepted over a time period of length T seconds by the gateway buffer being transmitted by the outgoing link of capacity C bits/sec, would be $R_{max} = C + (Q_{opt} / T)$, if the increase in the queue level is not to exceed a maximum of Q_{opt} bits over that time period.

6. Conclusion and Future Work

This paper presents the drop activation function of Fast Congestion Notification (FN). We have shown that FN mechanism triggers a packet mark/drop based on the value of mark/drop probability (positive/negative or zero), which is calculated upon packet arrivals, with no comparison required of the average traffic arrival rate and the instantaneous to particular mark/drop activation thresholds. Our future work will provide a comparative analysis of FN performance after implementing it in simulated environments, and then comparing it to Random Early Detection (RED).

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