A Hybrid Random Early Detection Algorithm for Improving End-to-End Congestion Control in TCP/IP Networks

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***Abstract*— The successful operation of the present Internet depends mainly upon TCP/IP which employs end-to-end congestion control mechanisms built in the end hosts. In order to further enhance this paradigm of end-to-end control the Random Early Detection algorithm (RED) has been proposed, which starts to mark or drop packets at the onset of congestion. The paper addresses issues related to the choice of queue length indication parameters for packet marking/dropping decisions in RED-type algorithms under varying traffic conditions. Two modifications to RED are proposed: (i) use of both instantaneous queue size and its Exponential Weighted Moving Average (EWMA) for packet marking/dropping and (ii) reducing the effect of the EWMA queue size value when the queue size is less than min_{th} for a certain number of consecutive packet arrivals.**

The newly developed Hybrid RED algorithm can effectively improve the performance of TCP/IP based networks while working in a control loop formed by either dropping or marking of packets during congestion epochs. New guidelines are developed for better marking/dropping of packets to achieve a faster response of RED-type algorithms. The hybrid RED algorithm has been tested using ns-2 simulations, which show better utilization of network bandwidth and a lower packet loss rate.

***Index Terms*—Congestion control, Hybrid RED algorithm, EWMA queue size, packet loss rate, link utilization.**

I. Introduction

TCP is a reliable end-to-end transport protocol, widely used in the current Internet for such diverse applications as email, Usenet news, remote login, file transfer, some streaming audio and video protocols and www. As a result of this widespread proliferation and integration of TCP/IP code in commonly used operating systems, such as Unix, Linux and Microsoft Windows, it constitutes a major portion of the current Internet traffic.

The growth of networks operating under TCP/IP has been unprecedented. The critical factor in the robustness of the current best effort Internet turns out to be end-to-end congestion control mechanisms. In this mechanism TCP constantly adapts itself to available bandwidth, slowing down the data transfer rate when it detects congestion and speeding up again when there is no congestion. Traditionally these end-to-end congestion control mechanisms were incorporated only in the end host so as to aid in upgrading the software and keeping the functions of core routers simpler. However, due to the present mammoth size of the Internet, the unreliability of developers in implementing the standard TCP congestion control algorithms in their Internet applications and the problems caused by attackers, it has been suggested to involve routers in performing the vital task of congestion control in the Internet see; e.g. [2], [3] and [4].

Presently, most widely used routers employ a Droptail policy which has the inherent limitation of inability to convey congestion information to the end host. Furthermore, they have other well known problems such as flow synchronization; see [5] and [6]. Thus, an alternative mechanism is desired, at the congestion prone routers, to detect the onset of congestion and accordingly send feedback to the end hosts, forcing reduction in their data sending rates. Thereby, congestion and consequent loss of packets is reduced. The congestion feedback from a router can be conveyed back to end hosts by Explicit Congestion Notification (ECN), to form so-called Active Queue Management (AQM); see [7]. Recently several algorithms have been proposed to address the problem of congestion control at the routers; see [8], [9] and [10].

This includes Random Early Detection (RED) algorithm, which was first proposed in [5]. Later its use was recommended in IP routers for the implementation of AQM [2]. RED has also been implemented in commercially available routers, such as Cisco AS5200, 4000, 4500 and 4700 [11]. It is believed that RED routers will solve the major problems in existing drop-tail routers such as synchronization of flows and will support quality of service by providing intelligent marking of packets [2]. The performance of RED is dependent upon the proper tuning/matching of its four intertwined parameters $\{min_{th}, max_{th}, max_p, w_q\}$, defined in Subsection 2.1, to the three parameters influencing congestion: bottleneck link bandwidth, number of TCP flows and round-trip time.

Central to the operation of RED is the EWMA mechanism, [12, Chap. 5, 55-65], for controlling the instantaneous queue size that acts as a Low Pass Filter (LPF) to absorb transient traffic bursts. It is used in conjunction with a piecewise linear marking/dropping probability function to get the desired functionality. This paper presents two modifications to the use of EWMA by RED which are shown to improve its performance under sudden change in traffic load from high to low values. Since the new algorithm combines use of both instantaneous and EWMA queue sizes, it is named Hybrid RED. The performance of the newly developed algorithm is determined by running ns-2 based simulations.

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The rest of the paper is organized as follows. In Section II a brief overview of the basic RED algorithms, and a discussion of their queue behaviour is presented. Section III discusses related work. Standard RED based on EWMA queue size is analyzed in Section IV. The Hybrid RED algorithm is derived in Section V. Section VI contains simulation results and performance analysis of Hybrid RED. Finally Section VII summarizes our conclusions.

II. Background

We first briefly review the two basic forms of the existing versions of RED algorithms and then discuss how they influence the queue properties.

A. RED Algorithm

The basic version of RED uses the following LPF with a constant w_q (called queue weight, or smoothing factor, or forgetting factor), to calculate the EWMA, $\bar{q}$, of the instantaneous queue size q:

$$\bar{q} \leftarrow (1 - w_q) \cdot \bar{q} + w_q \cdot q; \tag{1}$$

see [5]. In equation (1), w_q determines the time constant of the LPF which in effect determines the length of memory used in the averaging process [13]. One can split equation (1) into the two components: (a) contribution of the present value of instantaneous queue size q, which is represented by the term $w_q \cdot q$, and (b) contribution of the previous value of EWMA queue size, given by the term $(1 - w_q) \cdot \bar{q}$. It shows that as w_q is increased, the contribution of q increases, or memory decreases, and vice versa. The linear marking/dropping probability function of the basic RED algorithm can be expressed algebraically as:

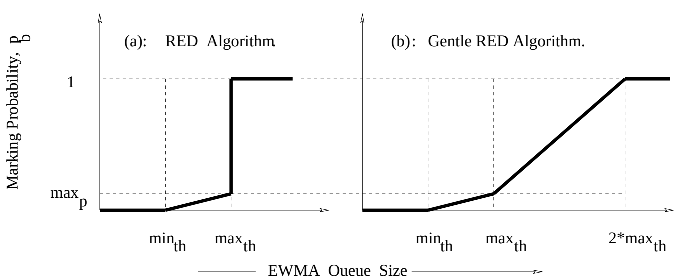

Fig. 1. Packet marking/dropping probability curves of the basic RED, Fig. 1 (a), and Gentle RED, Fig. 1 (b), [1].

$$p_b = \begin{cases} 0, & \text{if } \bar{q} < min_{th}; \\ 1, & \text{if } \bar{q} \geq max_{th}; \\ \frac{\bar{q} - min_{th}}{max_{th} - min_{th}} \cdot max_p, & \text{if } \bar{q} \in [min_{th}, max_{th}]. \end{cases} \tag{2}$$

where min_{th}, max_{th} are minimum and maximum thresholds for EWMA queue size, respectively, and max_p is the maximum value of packet mark/drop probability; see Figure 1 (a). For a buffer size B, it is generally recommended to use $max_{th} < B$, $max_{th} = 3 \cdot min_{th}$, $max_p = 0.1$ and $w_q = 0.002$, see [5]. The discontinuity in maximum mark/drop probability, max_p, at $\bar{q} \geq max_{th}$ in equation (2) may cause violent oscillations in the instantaneous queue size q; see [14] and [15]. In general, the operation is critically dependent upon the proper selection of four intertwined parameters, $\{min_{th}, max_{th}, max_p, w_q\}$; see [5] and [16] for parameter settings of the basic RED.

B. Gentle RED Algorithm

The gentle version of RED was proposed to avoid the sudden jump in probability function in (2) by modifying it as follows:

$$p_b = \begin{cases} 0, & \text{if } \bar{q} < min_{th}; \\ 1, & \text{if } \bar{q} \geq 2 \cdot max_{th}; \\ \frac{\bar{q} - min_{th}}{max_{th} - min_{th}} \cdot max_p, & \text{if } \bar{q} \in [min_{th}, max_{th}]; \\ \frac{\bar{q} - max_{th}}{max_{th}} \cdot (1 - max_p) + max_p, & \text{otherwise}; \end{cases} \tag{3}$$

see [17]. The probability that the intermarking time, X, is equal to number of packets, n, that arrive after a marked/dropped packet (until the next packet is marked/dropped) is given by: Prob$[X = n] = (1 - p_b)^{n-1} \cdot p_b$. It shows that X is a random geometric variable with $E(X) = 1/p_b$, which can mark/drop packets at irregular time intervals and may leads to global synchronization of TCP flows, [5].

Thus, both (2) and (3) will result in an undesirable geometrical pattern for marking/dropping of incoming packets. Therefore, it is desired that X should be a uniform random variable, which can be achieved by using the following expression:

$$p_a = \frac{p_b}{1 - count \cdot p_b}, \tag{4}$$

where $count$ is the number of unmarked packets that have arrived since the last marked/dropped packet; for more details see [5]. It is clear that the operation of both versions of RED algorithm, as given by (2) and (3), is crucially dependent on the use of the EWMA queue size $\bar{q}$. In a later section it will be shown that $\bar{q}$ is not by itself an ideal indicator of congestion events in a router and thus leads to non-optimal performance, due to unnecessary packet marking/dropping.

The instantaneous queue size, q, in RED routers varies between zero and the buffer size B. When q hits zero, a period of under-utilization of the bottleneck link bandwidth begins. On the other hand, when q reaches the upper limit B, all of the incoming packets will be dropped, and such forced drops will require retransmissions. This process will lead to congestion. Transient periods of bursty traffic can cause wide fluctuations of q, which can be diminished by introducing the EWMA mechanism.

C. EWMA Tuning

The use of EWMA for packet marking/dropping in conjunction with a simple linear function requires an optimal value of queue weight, w_q [12] and [5]. If w_q is too large then transient congestion will not be filtered out, and if it is too small then $\bar{q}$ will respond too slowly to enforce the desired changes in p_b. Larger values of w_q also encourage oscillations in the queue size. Assuming that the queue was initially empty and has grown to an instantaneous size of L packets, i.e. $q = L$, over