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Research Paper

Application of Packet Arrival Rate for Prediction of Queue Management

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Abstract

In this paper, we predict the change in the packet arrival rate at the link through the analysis of the network congestion control mechanism. An appropriate expression for dropping probability is derived based on this prediction to stabilize the queue length to the desired value. Its analysis of the stability is also carried out, and the necessary and sufficient condition for the system to be stable is presented.

Keywords: Network congestion control; Active Queue Management(*AQM*); Packet arrival rate; Prediction; Stability

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1. Introduction

With the growth of computer networks, excessive request for the limited network resources results in more and more serious congestion. Network congestion avoidance and control [1] gathers increasing attention in the past three decades. Transmission Control Protocol (*TCP*) and Active Queue Management (*AQM*) are the effective congestion control mechanisms at the end hosts and links, respectively.

In this paper, the prediction of packet arrival rate is derived from the analysis of the network congestion control mechanism. A new *AQM* algorithm named as Straightforward *AQM* (*SFAQM*) is proposed based on such a prediction.

2. Prediction of the change of packet arrival rate

Consider a system where there is a single congested router with a transmission capacity of C. Let N *TCP* flows (compliant with protocol of *TCP* Reno) traverse the router, labeled $i = 1,...,N W_i(t)$, $V_i(t)$ and $R_i(t)$ denote the congestion window size, packets ending rate and Round Trip Time(*RTT*)of flow $TCP_i(i = 1,...,N)$ at time $t > 0$, respectively. Let $\lambda(t)$ denote the packets arrival rate at the router at time $t > 0$, then

$$V_i(t) = W_i(t)/R_i(t), \qquad (1)$$

$$\lambda(t) = \sum_{i=1}^{n} V_i(t), \qquad R_i(t) = r_i + q(t)/C, \qquad (2)$$

where r_i is the Round Trip Propagation Time(*RTPT*) of TCP_i, $q(t)$ is the queue length at the congested link, and $q(t)/C$ models the queuing delay.

The *TCP* strategy has the characteristic of Additive Increase and Multiplicative Decrease(*AIMD*) [**?**]. Corresponding to *TCP*'s multiplicative decrease phase, if a packet is dropped, the congestion window size of TCP_i will decrease to $W_i(t)/2$, and the sending rate becomes $V_i(t)/2$. Corresponding to its additive increase phase, if a packet is acknowledged, the TCP_i will increase its window size $1/W_i(t)$, and the sending rate increases with $1/(R_i(t)*W_i(t))$. Thus, the expectation of the increment of the arrival rate at the router will be:

$$\Delta\lambda(t) = \frac{1}{W_i(t)R_i(t)}(1 - p(t-\tau)) - (V_i(t)/2)p(t-\tau) \qquad (3)$$

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where $\tau > 0$ represents the time delay from the moment that the packets are dropped or acknowledged to the moment that the host receives the information.

the expressions for the expectations of the sending rate $V_i(t)$ and window size $W_i(t)$ will be developed.The proportion of the packets that are generated by TCP_i is $V_i(t)/\lambda(t)$. Hence,the expectations of the send rate and window size are respectively

$$\overline{V}(t) = \sum_{i=1}^{n} V_i(t)\frac{V_i(t)}{\lambda(t)} \geq \frac{(\sum_{i=1}^{n} V_i(t))^2}{N\lambda(t)} = \frac{\lambda(t)}{N} \quad (4)$$

$$\overline{W}(t) = \sum_{i=1}^{n} W_i(t)\frac{V_i(t)}{\lambda(t)} \geq \frac{(\sum_{i=1}^{n} V_i(t))^2 R}{N\lambda(t)} = \frac{\lambda(t)R}{N} \quad (5)$$

the variables $W_i(t)$, $V_i(t)$ and $R_i(t)$ have been estimated for (3). Let the packet dropping probability be updated once in every time interval and the number of arriving packets and the dropping probability at the congested router be $m(t)$ and $p(t)$, respectively. Note that the dropping process of each packet is independent of the process of other packets during each sample interval. Recalling *Eqs.*(4)(6), the expectation of the increment of arrival rate at the router will be:

$$\overline{\lambda}(t+\tau) \geq \sum^{m(t)} W_i \frac{N(1-p(t))}{\lambda(t+\tau)R_i^2(t+\tau)} - \frac{\lambda(t+\tau)p(t)m(t)}{2N} \approx \frac{N(1-p(t))m(t)}{\lambda(t+\tau)R^2} - \frac{\lambda(t+\tau)p(t)m(t)}{2N} \quad (6)$$

3. New AQM algorithm

Assume that the number of packets that will arrive at the router in the interval related to time $t > 0$ is $m(t)$. The arrival rate is $\lambda(t+\tau)$ when the congestion information arrive at the hosts at time $t+\tau > 0$, the desired arrival rate at the link is $\lambda_{ref}(t+\tau)$, and then we obtain

$$\lambda(t+\tau) + \Delta\lambda(t+\tau) = \lambda_{ref}(t+\tau). \quad (7)$$

To achieve the desired queue length q_{ref}, the desired arrival rate at the router should be

$$\lambda_{ref}(t+\tau) = C + (q_{ref} - q(t))/\alpha. \quad (8)$$

Here, α is a parameter related to the time cost to control queue length to the desired value. Using (6) in (7), we obtain

$$p(t) = \frac{\lambda(t+\tau) + \frac{m(t)N}{\lambda(t+\tau)R^2} - \lambda_{ref}(t+\tau)}{(\frac{\lambda(t+\tau)}{2N} + \frac{N}{\lambda(t+\tau)R^2})m(t)} \quad (9)$$

We estimate the arrival rate $\lambda(t)$ by counting the number of arriving packets $m(t)$ at time $t > 0$ as follows:

$$\lambda(t) = m(t)\delta, \quad (10)$$

where δ is the length of the sampling period. Considering this, (9) can be expressed as

$$p(t) = \frac{m(t+\tau) + \frac{m(t)N\delta^2}{m(t+\tau)R^2} - mref(t+\tau)}{(\frac{m(t+\tau)}{2N} + \frac{N\delta^2}{m(t+\tau)R^2})m(t)} \quad (11)$$

where $m(t)$ and $m(t+\tau)$ are the number of arriving packets during the interval related to time t and $t+\tau$ respectively,and $m_{ref}(t+\tau)$ can be expressed as

$$m_{ref}(t+\tau) = C\delta + (q_{ref} - q(t))\delta\alpha. \quad (12)$$

The last task is to estimate $m(t)$ and $m(t+\tau)$. In this paper we predict $m(t)$ and $m(t+\tau)$ through simple analysis.The value of $m(t)$ is predicted as the exponential weighted moving average (*EWMA*) of $m(t)$. Since $m(t+\tau)$ should change from $m(t)$ to $m_{ref}(t+\tau)$, $m(t+\tau)$ is predicted as a value between $m(t)$ and $m_{ref}(t+\tau)$. Hence, $m(t)$ and $m(t+\tau)$ are expressed as

$$m(t) = (1-\omega_1)m(t-\delta) + \omega_1 m_0 \quad (13)$$

$$m(t+\tau) = (1-\omega_2)m(t) + \omega_2 m_{ref}(t+\tau). \quad (14)$$

4. Stability

The fluid-flow models have been widely used to describe the *TCP* and queue dynamics, such as [2, 3]. In this paper the model introduced in Low et al. [4]. is used because it has the same value of dropping probability as *SFAQM* at the operating point, which will be mentioned later. According to the demands of the analysis in this paper,we consider a network with one bottleneck link, with only one *TCP* flow from each endhost.Furthermore, the variation of *RTT* is ignored. The model is as follows:

$$\begin{cases} \dot{W}_i(t) = \frac{W_i(t-R)}{R}(1-p(t-R))1/W_i(t) - \frac{W_i(t-R)}{R}\frac{W_i(t)}{2}p(t-R) \\ \dot{q}(t) = -C + \sum_{i=1}^{N}\frac{W_i(t)}{R} \end{cases} \quad (15)$$

where $W_i(t)$ is the window size of TCP_i at $t > 0$, R is the RTT defined in (4), $p(t)$ is the packet dropping probability,and $q(t)$ is the queue length at the link.As we are interested in the average behavior of the flows instead of any specific one, $V_i(t)$ is approximated to the expected packets ending rate $V(t)$ of flows.Using (1) in this model,(15) can be rewritten as follows:

$$\begin{cases} \dot{V}(t) = \frac{V(t-R)}{R^2 V(t)}(1-p(t-R)) - 1/2V(t-R)V(t)p(t-R) \\ \dot{q}(t) = -C + NV(t) \end{cases} \quad (16)$$

Taking (V,q) as a state and p as the input, the operating point (V_0,q_0,p_0) is defined by $\dot{V}(t) = 0$ and $\dot{q}(t) = 0$, hence

$$\dot{V}(t) = 0 \Longrightarrow p_0 = \frac{1}{V_0^2 R^2/(2) + 1} \quad (17)$$

$$\dot{q}(t) = 0 \Longrightarrow V_0 = C/N. \quad (18)$$

Recall the *SFAQM* algorithm. Rewrite (11) by substitution of (10),(12), and (14) as

$$p(t) = \frac{[(1-\omega_2)\lambda(t) + \omega_2\lambda_{ref}(t+\tau)]^2 + N\delta\lambda(t)/(R^2) - \lambda(t)\lambda_{ref}(t+\tau)}{(\frac{[(1-\omega_2)\lambda(t)+\omega_2\lambda_{ref}(t+\tau)]^2}{2N} + N/R^2)\lambda(t)\delta} \quad (19)$$

When the system is at the steady state, the queue occupation is stabilized at the reference value q_{ref}. The packet arrival rate is stabilized at link capacity C, and the desired packet arrival rate λ_{ref} is also stabilized at C according to (8). Then, packet dropping probability will be:

$$p_0 = \frac{1}{C^2R^2/2N^2 + 1} \quad (20)$$

Linearize (16) and (19) at the operating point,then we obtain

$$\begin{cases} \dot{V}(t) = -\frac{C}{N(C^2R^2/2N^2+1)}\delta V(t) - C^2/2N^2\delta p(t-R) \\ \dot{q}(t) = N\delta V(t) \\ \delta p(t) = \frac{\partial p}{\partial \lambda}\delta\dot{q}(t) - 1/\alpha\frac{\partial p}{\partial \lambda_{ref}}\delta q(t) \end{cases} \quad (21)$$

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