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협대역 사물 인터넷 환경에서 웹 객체의 평균 전송시간을 추정하기 위한 해석적 모델

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Analytical model for mean web object transfer latency estimation in the narrowband IoT environment

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요 약 본 논문은 TCP 혼잡제어 메커니즘의 슬로우-스타트 단계에서 웹 객체의 평균전송 시간을 추정하기 위한 수학적 모델을 제안한다. 평균 지연은 네트워크의 종단 사용자가 필요로 하는 중요한 서비스 품질이다. 제안하는 모델의 적용대상은 작은 윈도우 크기로 인해 패킷손실이 슬로우-스타트 구간에서만 발생하는 멀티-홉 무선 네트워크와 대역폭이 작은 사물 인터넷을 대상으로 한다. 모델은 초기 윈도우 크기와 패킷 손실률을 고려하여 지연시간을 구한다. 제안한 모델은 주어진 패킷손실에 대해 라운드 트립 타임과 초기 윈도우 크기에 따라 주로 영향을 받게 되며, 종단 사용자가 사물 인터넷 응용 서비스에 요구하는 응답시간을 추정하는 데 적용될 수 있다.

주제어 : 웹 객체 전송 지연, 혼잡제어, 패킷 손실, IoT 서비스

Abstract This paper aims to present the mathematical model to find the mean web object transfer latency in the slow-start phase of TCP congestion control mechanism, which is one of the main control techniques of Internet. Mean latency is an important service quality measure of end-user in the network. The application area of the proposed latency model is the narrowband environment including multi-hop wireless network and Internet of Things(IoT), where packet loss occurs in the slow-start phase only due to small window. The model finds the latency considering initial window size and the packet loss rate. Our model shows that for a given packet loss rate, round trip time and initial window size mainly affect the mean web object transfer latency. The proposed model can be applied to estimate the mean response time that end user requires in the IoT service applications.

Key Words : Web object transfer latency, Congestion control, Packet loss, IoT service

1. INTRODUCTION

The web object transfer latency affects end-end delay. Typically, object transfer latency is affected by data size and transmission time according to transmission rate of link as well as by TCP congestion control mechanism. The common functions of congestion control mechanism are slow-start, congestion avoidance, timeout, and fast retransmission[1].

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Padhye[2] considered large amount of data transmission on steady state over TCP. Most of TCP connections for HTTP data transmission, however, are short for small amount of data instead of large one in current internet environment. Connection setup or slow-start time dominates the performance of web in this environment. Noticing this phenomenon, Cardwell[3] extended the above steady state model but he did not consider delay of TCP after time-out. Jiong[3] enhanced the model of [4] considering slow-start time after timeout of retransmission. However, since the above models assumed wideband network, they are not able to be applied to the narrowband network environment, which this paper considers. Narrowband environments including multi-hop wireless network does not allow fast retransmission of data due to the very small size of window[5]. In this paper, we assume the multiple packet losses loss occurs in the slow-start phase only due to small window. Lee[6,7] proposed the web object latency model for the narrowband network. However they did not present the detailed procedure. This paper extends our previous work[7].

The estimated mean object latency in this paper can be used as a benchmark for the IoT service design.

2. MODELING FOR MEAN OBJECT TRANSFER LATENCY

We assume that sizes of web objects are identical and received packets are transmitted in an upper layer in terms of window unit. Let the size of an object to transfer be Bytes and sender maximum segment size(SMSS) *sgmt* bytes, then the number of packets to transfer for an object is $N=\lceil \Theta/sgmt \rceil$. When the probability of a packet loss is p, the expected number of total packet loss is $\alpha=\lceil np \rceil$ in terms of binomial distribution.

Any packet loss occurs during either slow start or congestion avoidance period. We can identify the packet loss period by comparing, for any k^{th}(k=1,2.. α) packet loss, the possible number of packets(A_k, k=1,2..,α) to transmit until the threshold(TH_k, k=1,2,..,α) at which congestion avoidance starts.

For the data to be transmitted before k^{th} packet loss, N_k(N_k=N for k=1), the expected number of packets sent(X_k: k=1,2,..,α) including the lost packet until the packet loss is given by Equation (1).

$$X_k = \frac{1-(1-p)^{N_k}}{p} + (1-p)^{N_k} + 1 \qquad (1)$$

$$k = 1,2,\cdots,\alpha$$

The initial value of congestion window(*wnd*) is suggested as 2×*sgmt*, 3×*sgmt*, and 4×*sgmt*[1]. Initial slow start threshold(TH_1) is set arbitrarily high and TH_k are set to

$$TH_k = max\left(\frac{FlightSize}{2}, 2 \times sgmt\right) \qquad (2)$$

$$k = 2,3,\cdots,\alpha$$

Here, *FlightSize* represents the amount of data that has been sent but not yet cumulatively acknowledged. In our paper, we set *FlightSize* to *cwnd* by considering worst case.

A_k(k=1,2,...,α) is the number of packets sent until TH_k. The packets are transmitted in the manner *wnd*, 2×*wnd*, 4×*wnd*, 8×*wnd*, ⋯. (*wnd*=2,3,4) for k=1 and *wnd*×1, *wnd*×2, *wnd*×4, *wnd*×8, ⋯, (*wnd*=1) for $k \geq 2$ exponentially, respectively. Therefore, A_k is given by Equation (3).

$$A_k = \begin{cases} 2^{\lceil \log_2 TH_K + 1 \rceil} & if\, TH_k = 2^j \\ 2^{\lceil \log_2 TH_K + 1 \rceil} - wnd + TH_k & if\, TH_k \neq 2^j \end{cases} \qquad (3)$$

Now, we can determine where k^{th} packet loss occurs. That is, if $X_k \leq A_k$, packet is lost during slow start period.

3. MEAN OBJECT TRANSFER LATENCY DURING SLOW-START PHASE

Generally, we need n windows in order to completely send the object. Generally n can be expressed in terms of the transmission data amount(Z) and initial window size(wnd).

$$n = min\{k: wnd\times(2^0+2^1+\cdots+2^{k-1}) \ge Z\} \quad (4)$$
$$= \left\lceil \log_2(1+\frac{Z}{wnd}) \right\rceil$$

Because X_k is sent until k^{th} packet loss, the window number(n_k) which includes X_k is given by Equation (5).

$$n_k = \left\lceil \log_2(1+\frac{X_k}{wnd} \right\rceil \quad (5)$$

$$wnd = 2,3,4\ for\ k=1, \quad wnd = 1\ for\ k \ge 2$$

Congestion window size corresponding to the window number, n_k is given by Equation (6).

$$TH_k = wnd\times(2^{n_k}-1) \quad (6)$$

$$wnd = 2,3,4\ for\ k=1, \quad wnd = 1\ for\ k \ge 2$$

The maximum number of packets sent until n_k^{th} window is given by Equation (7).

$$B_k = wnd\times\left(\sum_{j=0}^{n_k-1} 2^j\right) = wnd\times(2^{n_k}-1) \quad (7)$$

$$wnd = 2,3,4\ for\ k=1, \quad wnd = 1\ for\ k \ge 2$$

By considering wnd, we can extend the number of server stalls when the object contains an infinite number of segments like as Equation (8).

$$m = max\left\{k: \frac{sgmt}{\mu}+rtt-\frac{sgmt}{\mu}\times wnd\times 2^{k-1} \ge 0\right\}$$
$$= \left\lfloor \log_2\left(1+\frac{\mu\times rtt}{sgmt}\right) \right\rfloor + 1 - \log_2 wnd \quad (8)$$

Therefore, given the transmission data amount (Y) and wnd, slow start time is given by Equation (9).

$$ST(Y) = \rho(rtt+\frac{sgmt}{\mu}) - wnd\times(2^{\rho}-1)\frac{sgmt}{\mu}$$
$$\rho = min(m, n-1) \quad (9)$$

Here, μ and rtt represent the link bandwidth and round trip time between sender and receiver respectively. Now we consider the transmission(Y), retransmission, and the remained data amount(N_{k+1}) for transfer before the next packet loss when multiple packet losses occur in one window at k^{th} packet loss. It is clear that $X_k \le A_k^{th}$, $X_k \le N_k$, and $X_k \le B_k$ from Equation (2), (3), and (7).

Therefore, web object transfer time when the k^{th} packet loss occurs during slow start period is sum of slow start time of Y, transmission time of Y, and retransmission timeout and given by Equation (10).

$$OT_k^{slow} = ST(Y) + \frac{Y\times sgmt}{\mu} + R \quad (10)$$

Retransmission timeout(R_{to}) is mostly given by 3/2×rtt ,but this value can be adjusted. At the next step, we compute X_{k+1} in Equation (1) by using N_{k+1} given in Table. New TH_{k+1} is given by Equation (11).

$$TH_{k+1} = \max\left(\frac{TH_k}{2},\ 2\times sgmt\right) \ k = 2,3,\cdots,\alpha \quad (11)$$

In addition, upon a timeout *cwnd* must be set the loss window, which equals to one full size segment(SMSS). That is, *wnd* must be set to 1×*sgmt* in Equations (1)~(9).

4. CONCLUSIONS

In this paper, we present the iterative model to find the mean web object transfer latency in the narrowband environment such as multi-hop wireless network. Our work assumes that packet loss occurs in the slow-start phase of TCP congestion control mechanism. The model iteratively finds the latency based on the packet loss rate and the number of packets to be transmitted. It also considers the initial value of congestion window and multiple packet losses in one window. Our model can be applied to determine the web object size to satisfy end user's target response time in the IoT application. Future works include more elaborate model in multiple users environment.

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