



Performance and Stability Analyses of TCP Queue Based Computer Network

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Authors' contributions

This work was carried out in collaboration between both authors. Author MIA designed the study, performed the simulation and wrote the first draft of the manuscript. Author CBM managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

This research work centers on the performance and stability analysis of the TCP queue based network system. The TCP is a vital organ in every wireless network and due to the increasing reliance on the wireless network by most human activities, it has suffered from different forms of disturbances most especially traffic congestion which eventually results to data loss or total collapse of the network. Many works were reviewed on the TCP model and the methods proposed to improve the performance of the TCP networks. However, from the review, the TCP queue model was not examined based on its performance and reliability, to ascertain the real behavior of the system without the control measures. The step function time domain plot and bode frequency domain plot analyses measures were employed in this work. From the simulation results, the TCP queue with time delay model recorded a 0% overshoot and settling time of 1.96e+03 seconds. With the high settling time the system performance will be very poor as a result of very slow response and it cannot support the recent high data traffic. Therefore, the system will not be able to solve the problem of congestion due to its slow response. The system also recorded a negative gain margin of -71.9dB, hence; the system is unstable and not reliable.

Keywords: TCP; queue; network traffic; network congestion; computer network.

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1. INTRODUCTION

Lately computer communication networks through the Internet have become common widely and globally employed and the amount of data communicated in computer networks is increasing rapidly daily because of the increasing demand and reliance on the internet for everyday activities of people, industries, offices, organizations etc. The rapid increment of amount of data causes difficulty of smooth data transfers in computer networks and this difficulty is described as data traffic congestion. This congestion in computer networks is pointed out as important problems which must be solved in order to achieve optimal function of the network. The reliable and efficient exchange of information across the Internet has been a key ingredient to its explosive growth and utilization. At the heart of this information exchange is the Transmission Control Protocol (TCP). Under TCP, a sender has authority to set its transmission rate using a window flow-control mechanism. The sender continuously probes the network's available bandwidth and increases its window size to garner maximum share of network resource. For each successful end-to-end packet transmission TCP increases the sender's window size.

Conversely, TCP cuts the window in half whenever a sender's packet does not reach the receiver. Such packet losses can affect network performance by decreasing the sender's effective transmission rate and increasing delay due to packet retransmission. TCP, which is a usual protocol to communicate each computer in Internet, has the mechanism to avoid congestion in computer networks [1]. TCP detects congestion by checking acknowledgements or time-out processing and adjusts TCP window sizes of senders [2,3,4]. But this control method has demerits such as low efficiencies of communications because this method uses the mechanism to avoid congestion after congestion once appears in computer networks [1].

However, congestion is a common challenge of the high traffic communication network such as the internet which cannot be totally avoided. In order to determine the technique for the improvement of the effectiveness and reliability of the network to be able to handle the growing complexity of the network and the data traffic, the TCP network dynamic model must be analyzed. In this work, the TCP network dynamic model was analyzed in time and frequency domains in

order to examine the speed of the network (i.e. how fast it can settle back to its steady state after encountering disturbance), the stability of the system based on the stability margin characteristics.

Section one presents the introduction of the work and section two presents the literature review. Section three and four present the methodology and results respectively, while section five presents the conclusion.

2. LITERATURE REVIEW

In recent times, communication through the internet has developed to carry data, voice and video traffic and due to the rate of rise in the traffic there has been researches aimed at improving the functionality of the communication systems in order to maintain optimal performance of the system even in the future. Internet congestion occurs when the aggregated demand for a resource (e.g., link bandwidth) exceeds the available capacity of the resource [5]. Resulting effects from such congestion include long delays in data delivery, waster resources due to lost or dropped packets, and even possible congestion collapse [6]. Therefore it is very necessary to avoid or control network congestion. Internet congestion control has two parts: 1) the end-to-end protocol TCP and 2) the active queue management (AQM) scheme implemented in routers [7]. AQM can maintain smaller queuing delay and higher throughput by purposefully dropping packets at intermediate nodes.

Over a past few years, problems have arisen with regard to Quality of Service (QoS) issues in Internet traffic congestion control [2,8,9]. AQM mechanism, which supports the end-to-end congestion control mechanism of Transmission Control Protocol, has been actively studied by many researchers in order to improve the performance of TCP. AQM mechanism controls the queue length of a router by actively dropping packets. Various mechanisms have been proposed such as Random Early Detection (RED) [10], Random Early Marking (REM) [11], BLUE [12], Adaptive Virtual Queue (AVQ) [13] and many others [14]. Their performances have been evaluated [14,15] and empirical studies have shown the effectiveness of these mechanisms [16]. During the last few years, significant researches have been devoted to the use of control theory to develop more efficient AQM. Using dynamical model developed by [17],

some P (Proportional), PI (Proportional Integral) [18], PID (Proportional Integral Derivative) [19] have been designed as well as robust control framework issued [20]. Nevertheless, most of these papers do not take into account the delay and ensure the stability in closed loop for all delays which could be conservative [21].

Time delay is one of the main features of the TCP system which must be considered in the design model in order to achieve a robust design. The study of congestion problem with time delay systems framework is not new and has been successfully exploited [21]. In [22], using Lyapunov-Krasovskii theory, the global stability analysis of the nonlinear model of TCP is performed. In [23], a delay dependent state feedback controller is provided by compensation of the delay with a memory feedback control. This latter methodology is interesting in theory but hardly suitable in practice [21]. In [24,25], robust AQM are derived using time delay system approach. The first one builds a state feedback controller based on Lyapunov-Krasovskii theory. The second one designs an output feedback in robust control framework [21].

3. METHODOLOGY

The fluid-flow model method was adopted for the TCP plant mathematical model which was used in the simulation of the work. The mathematical model of the TCP represents the physical dynamics of the system. This means that the model consists of the physical measurements of the parameters of the system. However, the mathematical model of every physical system cannot be a complete representation of the system. The fluid-flow model representation of the TCP network has been applied in many works and has been proved effective. In other to study the behavior of the TCP network based on the fluid flow model, network efficiency and reliability were analyzed using step function and stability margins. The step function technique was applied for efficiency analysis while bode plot was applied to analyze the system stability of the system.

3.1 Fluid-Flow Model of TCP Behavior

The dynamic model of TCP flows is developed by using a fluid flow model without considering slow start and timeout mechanisms [18]. Based on this system, a type of AQM is constructed, which takes into account delays into the network.

This model is described by the following non-linear differential equations [26]:

$$\begin{cases} \dot{W}(t) = \frac{1}{R(t)} - \frac{W(t-R(t))}{R(t-R(t))} p(t-R(t)) \\ \dot{q}(t) = \frac{W(t)}{R(t)} N(t) - C \\ R(t) = \frac{q(t)}{C} + T_p \end{cases} \quad (1)$$

where $\dot{W}(t)$ and $\dot{q}(t)$ denote the time-derivatives of $W(t)$ and $q(t)$, respectively. $W(t)$ denotes the TCP window size, $q(t)$ denotes the queue length in the router.

$p(t)$ denotes the probability packet marking/dropping ($p(t) \in [0,1]$). $R(t)$ denotes the round-trip time, $C(t)$ denotes the link capacity. T_p denotes the propagation delay. $N(t)$ denotes the load factor (Number of TCP sessions). The first differential equation in (1) describes the TCP window control dynamic and the second equation models the bottleneck queue length.

The queue length and window size are positive, bounded quantities, i.e., $q \in [0, \bar{q}]$, $W \in [0, \bar{W}]$ window size, respectively. Also, the marketing probability p takes value only in $[0,1]$.

In this model, the congestion window $W(t)$ increases linearly if no packet loss is detected; otherwise it halves. Although an AQM router is a non-linear system, in order to analyze certain types of properties and design controllers we need a linear model which is presented in this sub-section. To linearize equation 1, first it was assumed that the number of TCP sessions and link capacity are constant, i.e., $N(t) \equiv N$, $C(t) \equiv C$.

Taking (W, q) as the state and p as input, the operating point (W_0, q_0, p_0) is then defined by $\dot{W} = 0$ and $\dot{q} = 0$ so that

$$\begin{aligned} \dot{W} = 0, W_0^2 p_0 &= 2, \\ \dot{q} = 0, W_0 &= \frac{R_0 C}{N}, \\ R_0 &= \frac{q_0}{C} + T_p \end{aligned} \quad (2)$$

Linearizing equation 1 about the operating point to obtain:

$$\begin{cases} \delta \dot{W}(t) = -\frac{N}{R_0^2 C} (\delta W(t) + \delta W(t-R_0)) - \frac{R_0 C^2}{2N^2} \delta p(t-R_0) \\ \delta \dot{q}(t) = \frac{N}{R_0} \delta W(t) - \frac{1}{R_0} \delta q(t) \end{cases} \quad (3)$$

Where $\delta W = \dot{W} - W_0$, $\delta \dot{q} = q - q_0$, $\delta \dot{p} = p - p_0$ represent the perturbed variables around the operating point.

For typical network conditions [18],

$$\frac{N}{R_0^2} = \frac{1}{W_0 R_0} \ll \frac{1}{R_0}$$

$$\begin{cases} \delta \dot{W}(t) = -\frac{2N}{R_0^2 C} \delta W(t) - \frac{R_0 C^2}{2N^2} \delta P(t - R_0), \\ \delta \dot{q}(t) = \frac{N}{R_0} \delta W(t) - \frac{1}{R_0} \delta q(t) \end{cases} \quad (4)$$

Considering the following dynamics and performing Laplace transform on equation 4, we have:

$$\begin{cases} G_{TCP}(s) = \frac{\frac{R_0 C^2}{2N}}{\left(s + \frac{2N}{R_0^2 C}\right)} e^{-sR_0} \\ G_{queue}(s) = \frac{\frac{N}{R_0}}{\left(s + \frac{1}{R_0}\right)} \end{cases} \quad (5)$$

where $G_{TCP}(s)$ is the TCP's dynamic, $G_{queue}(s)$ is the queue's dynamic.

Considering the transfer function of the plant dynamic which comprises of the G_{TCP} and G_{queue} as shown in Fig. 1, the output of the system is measured and analyzed in the simulation experiments. This model presents the dynamics of the queue and the congestion window as a time delay system. Taking into account this characteristic, it is expected to reflect the TCP queue behavior in control of congestion in the network.

$$G(s) = G_{TCP}(s)G_{queue}(s)$$

Multiplying through, $G(s)$ becomes:

$$G(s) = \frac{B}{Q(s)} e^{-R_0 s} \quad (6)$$

Where $B = \frac{C^2}{2N}$, $Q(s) = \left(s + \frac{2N}{R_0^2 C}\right) \left(s + \frac{1}{R_0}\right)$

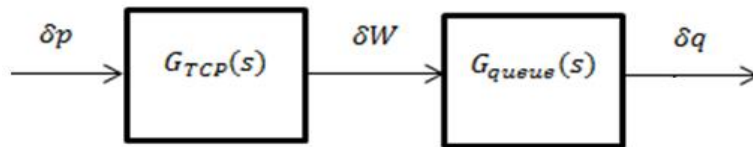


Fig. 1. Block diagram of the AQM system

As the network parameter $\{N, C, R_0\}$ are positive, where $R_0 > 0$ is the time delay, and $C(s)$ is the first order controller having the form.

3.2 Step Function Analysis of the Plant

The step function analysis [27] of the plant which comprises of the TCP and queue models in bode plot measures the stability characteristics of the plant before designing a controller for the plant. Since a plant is supposed to be stable before designing a controller for it, then it becomes very important to carry out this analysis before designing a controller for the system in order to achieve the aim of this research. The plant is also supposed to meet some other specifications as follows:

1. The stability margins, gain and phase margins must exist.
2. The gain margin must be less than the phase margin.
3. The loop gain must exist and greater or equal to zero.

4. RESULTS AND DISCUSSION

Figs. 2 and 3 show the TCP Queue responses in time and frequency domains respectively.

These were presented in order to study the TCP queue behaviors considering its time based performance such as the overshoot, settling time etc and the frequency based performance and stability.

From the results in Table 1, the settling time was still very high and the gain margin is still below 0dB which is not good for a physical system with much dynamic uncertainties and other forms of disturbances. The results of the analysis reveal that the TCP queue system on its own is not stable. Due to high level of disturbances associated with most wireless networks and the expected level of performance and reliability of such networks, a robust control [28] is recommended to improve the performance and stability of the system.

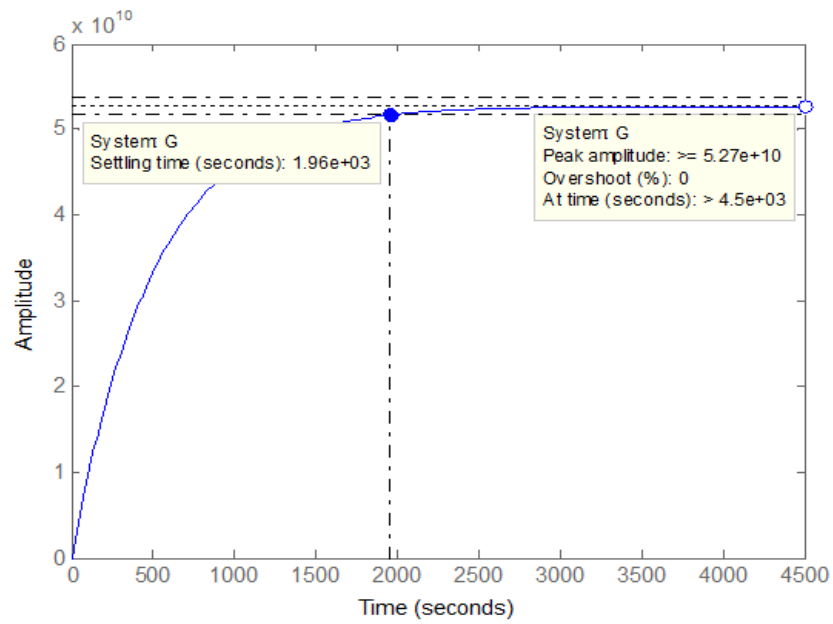


Fig. 2. TCP queue response vs time

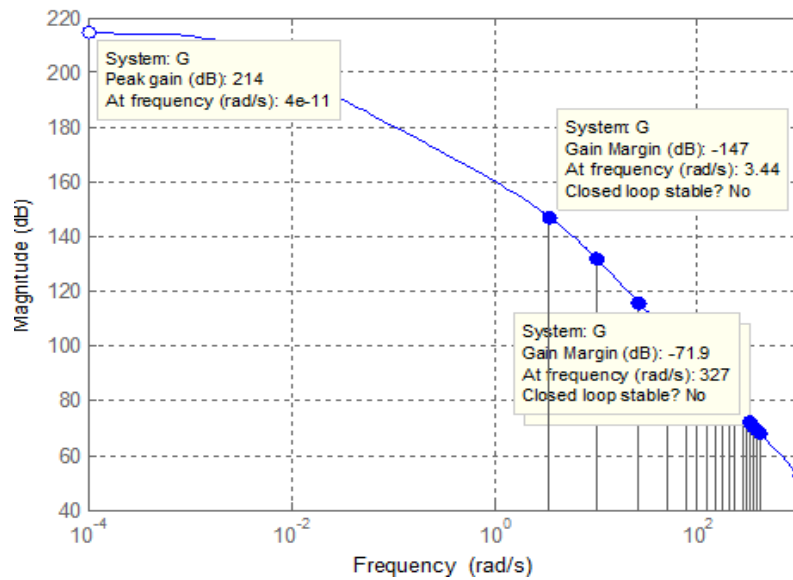


Fig. 3. TCP queue response vs frequency

Table 1. Summary of TCP Queue dynamic behavior

TCP Queue dynamic model characteristics	Values
TCP Queue percentage overshoot (%)	0
TCP Queue settling time (sec)	1.96e+03
TCP Queue peak amplitude	5.27e+10
TCP Queue gain margin (dB)	-71.9
Gain margin frequency (rad/sec)	327
Bandwidth	-
Closed loop Stability	Not stable

5. CONCLUSION

The aim of this research work which is to analyze the performance and reliability of the TCP queue dynamic model in frequency and time domain in order to study and ascertain the real behavior of the system was achieved successfully. The system analysis was carried out in MATLAB simulation platform.

From the simulation results, the TCP queue with time delay model recorded a 0% overshoot and a high settling time of $1.96e+03$ seconds. The 0% overshoot is good but with such high settling time the system performance will be very poor because the system response will be very slow and cannot support the recent high data traffic. As a result the system will not be able solve the problem of congestion due to its slow response. The system also recorded a negative gain margin of -71.9dB without a definite bandwidth, hence; the system is unstable. With these results therefore, the TCP queue plus time delay model cannot achieve good performance and cannot handle complex network congestions or other forms of disturbances without an external compensator or controller system. A robust controller should be developed for the TCP queue based wireless network to improve the performance and stability of the network.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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