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BBO tuned PI controller for the stability of TCP networks

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ABSTRACT

The congestion is the most important issue that effects on the performance of data transition over internet networks. One of the important techniques developed is active queue management (AQM) that prepares an efficient congestion control by reducing losing packets, queue size, and energy consumption. Therefore, AQM technique deemed as a base of many congestion control algorithms schemes. This work suggested the using of proportional integral (PI) controller as an AQM and then use an optimized control system such as biogeography-based optimization (BBO) with PI controller as (BBO-PI). The optimal control (BBO-PI) is characterized by access to design and fine-tuning of defining the shapes of the optimal parameters of PI controller. The BBO algorithm was implemented by using the mathematical system model by M-file/Matlab and Simulink. The simulation results showed the best performance for the transmission control protocol (TCP) network when compared the system with using the PI controller and using optimal control (BBO-PI), the ratio of enhancing the system with using of BBO-PI better than using a PI controller only in terms of rising time is 1.11, settling time is 2.85 and overshooting is 85%. Therefore, the proposed method was very fast and required few iterations.

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1. INTRODUCTION

In internet services, applications and quality of service (QoS) [1] the standard communication protocols such as transmission control protocol (TCP) is the most widely used, therefore, the success of the internet depends on the best design of TCP, but the TCP still represent the bottleneck in throughput of internet network, due to large latency of the network, packet losses in-network, and delay time in-network. So with those problems there in wireless links (Wi-Fi, LTE, 3G, WiMAX) [2]-[5], the TCP tends to send with low rate than the network design allows. Today TCP is considered one of the substantial protocols of the internet protocol (IP) [6], [7] set, it guarantees the error-checked, well-ordered, during movement the packets of information among networks. TCP is accountable for rearrangement the received packets and delivering it to its destination without data gaps or errors [8], [9].

TCP includes other essential functions such as controlling congestion on the internet network and ensuring that the receiver doesn’t get inundated with much data (flow control). Both congestion control and flow control need a form of the transmission rate conditioning based on feedback from the receiver [10], [11]. Therefore, in this work, we focused on both congestion control and flow control by optimizing the controlling approaches them. The optimizing TCP [12], [13] is achieving by controlling some available parameters and this leads to improvement of the total performance of the protocol. TCP performance measure in generally by using a few key metrics, such as delivery speed (bit/sec) and retransmission the data that represent repeated data send on the network [14], [15].

Many studies took up to improve the performance of TCP network, used some optimization techniques such as genetic algorithm (GA) [16], [17], fuzzy logic (FL) [18], [19], and particle swarm optimization (PSO) [20], [21]. With traditional control techniques such as proportional integral derivative (PID) [22], [23], proportional integral (PI) [24], or proportional derivative (PD) [25]. Biogeography-based optimization (BBO) [26], [27] is one of the important optimization techniques which depended in this paper, it has important features will mention later.

In 2008 and from biogeography inspired, Ma and Simon [28] advanced a new algorithm known BBO. It can be used for a natural process also can be modelled it to reach to optimization approach. BBO is one of the modern intelligence techniques that are used to improve the functioning of systems due to the ability to tune the parameters in varied applications. Sheikhan *et al*. [29] used two (ANN)-based controller techniques to adaptive the queue in TCP networks, the proposed controllers include two optimization algorithms GA and PSO, it depends on radial bias function (RBF) with an error-integral term to robust the work of RBF, the results showed the effectiveness of proposed controllers in issues of packet loss and outperforms drop tail. Sabry and Kaittan [30] suggest used grey wolf optimizer (GWO) algorithm with a fuzzy-PI controller as an active queue management (AQM) for controls congestion in internet routers and for fulfilling faster response and reduce the steady-state error, the simulation results showed good stability for the proposed controller with the ability to reach a fast response with different loads for the network. Fajri and Ramli [31] are proposed to use a nelder-mead simplex (NMS) method to get the best parameters of the PID controller to enhance the work of TCP/AQM router system, the results of this work appeared the effectiveness of combination between NMS and integral of time-weighted absolute error (ITAE) criterion on other criteria in sense of control for congestion in a network. Li *et al*. [32] are considered a novel AQM scheme for TCP network, when they using integral back-stepping technique (IB) and minimax method with a suitable condition and conformable control, the simulation results showed are not only used to deal with perturbations produced by user datagram protocol (UDP) streams but the convergent time of the signals can also be shortened. Wang *et al*. [33] proposed an approach consist of the backstepping-like procedure and fuzzy approximation manner to satisfying the values of the transient and steady-state error. The results state the effectiveness of the proposed approach when analysis for stability showed that all signals within the closed-loop are uniform, semi-global and bounded.

This work proposes using a proportional integrity controller (PI) with the BBO algorithm as an AQM for internet routers in TCP networks. The optimization method BBO was used in this work to tune the PI controller parameters to reach closely an optimal performance of the PI controller to reduce the effect of congestion in TCP networks. The work goes toward fulfilling a stable queue length, improve latency to prevent TCP failure or slowing down.

The remainder of this paper is organized as: section 2, include the simulation model for TCP/AQM system with BBO-PI. The simulation results wrote down in section 3. The conclusion of this paper is in section 4.

2. SIMULATION MODEL FOR TCP/AQM SYSTEM WITH BBO-PI

The system of TCP/AQM that depended in this work shown in Figure 1. The system includes routers, sources, and standardized control networks. Table 1 shows the parameter values of the TCP/AQM system and the (1)-(5) represent the mathematical design of the TCP/AQM system.

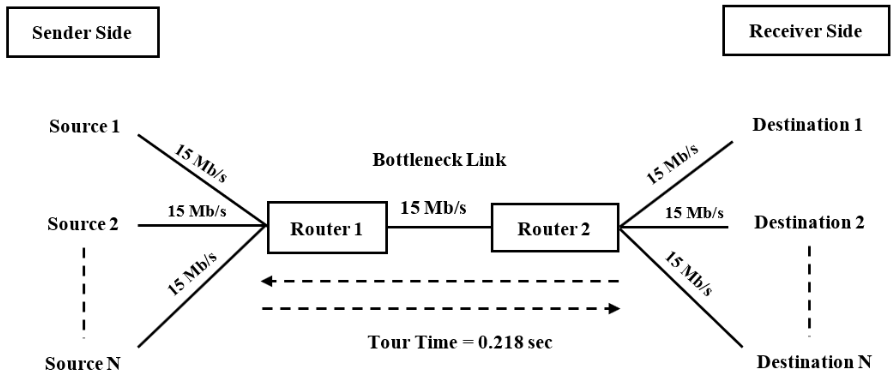

Figure 1. The TCP/AQM network topology

Table 1. Parameter values of the TCP/AQM system

The promulgation delay	Link capacity 3750 packet/secs	TCP session number	Packet size	Maximum queue length in router 1	The desired queue size	The round-trip time
$T_p = 0.2$ seconds	$C = 15$ Mbps	$N = 60$	500 byte	$q_{max} = 700$ packets	$q_{des} = 300$ packets	$R = 0.253$ seconds

$$“\dot{w}(t) = \frac{1}{\frac{q(t)}{C}+T_p} - \frac{w(t)}{2}\frac{w(t-R(t))}{\frac{q(t-R(t))}{C}+T_p}p(t-R(t))” \quad (1)$$

$$“\dot{q}(t) = \begin{cases} -C + \frac{N(t)}{\frac{q(t)}{C}+T_p}w(t) & if\ q(t) > 0 \\ max\left\{0, -C + \frac{N(t)}{\frac{q(t)}{C}+T_p}w(t)\right\} & if\ q(t) = 0 \end{cases}” \quad (2)$$

$$T.F = \frac{122.8s^3+3299s^2+2455s+3.252e^{04}}{s^4+1.136s^3+20.14s^2+11.26s+99.8} \quad (3)$$

$$F(s) = \frac{q(s)}{p(s)} = \frac{\frac{C^2}{2N}e^{-sR}}{(s+\frac{2N}{R^2C})(s+\frac{1}{R})} \quad (4)$$

$$sat\left(p(t-R(t))\right) = \begin{cases} 1, & p(t-R(t)) \geq 1 \\ p(t-R(t)), & 0 \leq p(t-R(t)) < 1 \\ 0, & p(t-R(t)) < 0 \end{cases} \quad (5)$$

Where $\dot{w}$ and $\dot{q}$ is the time-derivative of w and q respectively. W = rate of TCP window size, R = measured in seconds, $R = \frac{q}{C} + T_p$, q = rate of queue length, C = capacity of the link, N = session number, T_p = promulgation delay, p = packet sign probability. Figure 2 shown the controller model for TCP/AQM system and Figure 3 depicted the block diagram of TCP/AQM System. The PI controller used as an AQM to control congestion in TCP networks, the (6) clarify the factors and constant gain parameters of the PI controller. Figure 4 shows the Simulink model of the PI controller (AQM) for TCP network.

$$s(t) = K_P e(t) + K_I \int_0^t e(t)dt \quad (6)$$

Where: $e(t)$ = the error signal between (the input reference and the process output), $ec(t)$ = the change of error signal, K_P = proportional constant gain, and K_I = integral constant gain.

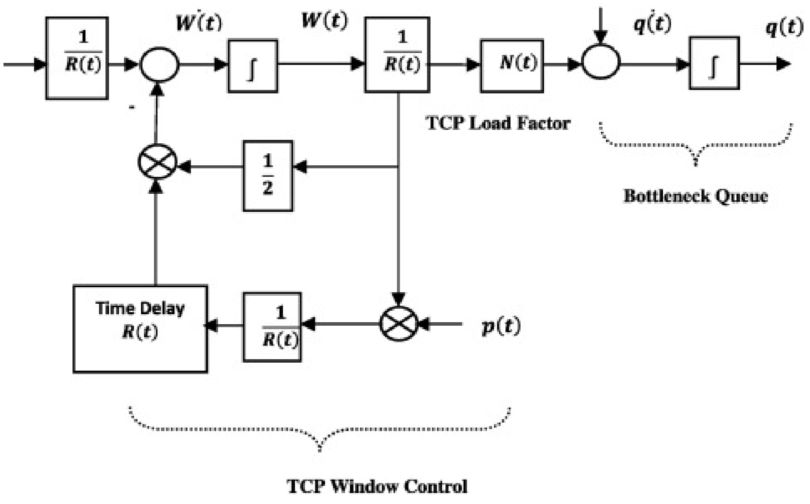

Figure 2. Schematic model of a controller with a TCP network

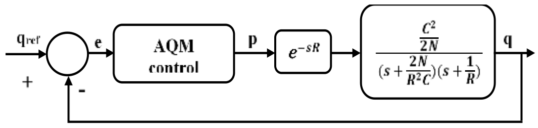

Figure 3. System block diagram of TCP/AQM network

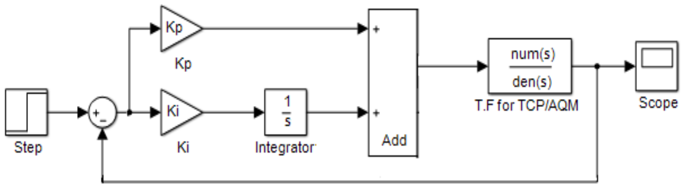

Figure 4. Simulink model of PI for TCP network

The performance of the PI controller as an AQM is not enough for TCP networks, so it needs optimization technique such as BBO to improve its work. BBO tune the parameters of the PI controller to reach the best performance for TCP/AQM system. Figure 5 shows the Simulink model of BBO-PI for TCP/AQM system. The BBO is a heuristic algorithm recently developed, its working principle is based on the mathematical study of biogeography, it was shown an impressive performance on numerous known benchmarks [34]. Such as many evolutionary algorithms, BBO works on the principle of probability, the probability of an individual participating in an advantage with the rest of the population is proportional to his fitness. The probability of an individual acquiring a trait from the rest of the population decreases with fitness, for more details about BBO see [35]-[38].

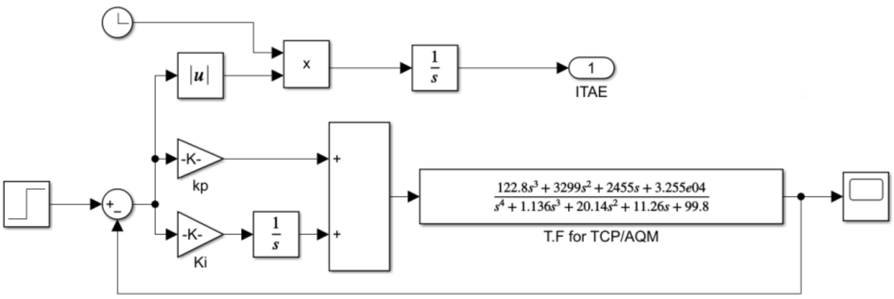

Figure 5. Simulink model of BBO-PI for TCP network

3. SIMULATION RESULTS

The simulation model of this work is shown in Figure 6, the figure exhibits the model details which contain the TCP/AQM network with two types of controllers: 1- PI and 2- BBO-PI. The simulation results presented in Figure 7, Figure 8, and Figure 9. Figure 7 show the performance curve for the TCP/AQM network with PI controller. Figure 8 show the performance curve for the TCP/AQM network with BBO-PI controller and Figure 9 exhibit the performance curve for the TCP/AQM network with both PI and BBO-PI controller to make a comparison between them. Table 2 appears the comparison between the performance of TCP/AQM network when using a PI controller and using BBO-PI controller. From Table 2 can see the difference in the results for rising time, settling time and overshooting percentage. Leads to a difference in the performance of TCP/AQM network, the performance of TCP/AQM network with BBO-PI controller is better than the performance with PI controller. The TCP/AQM network is more stability when using BBO-PI controller than using a PI controller.

Table 2. The result values to compare the TCP/AQM network performance with BBO-PI and PI controller

System response parameters	PI controller	BBO-PI controller
Rising time	0.05	0.045
Settling time	0.2	0.07
Overshooting	25.2 %	0.3 %

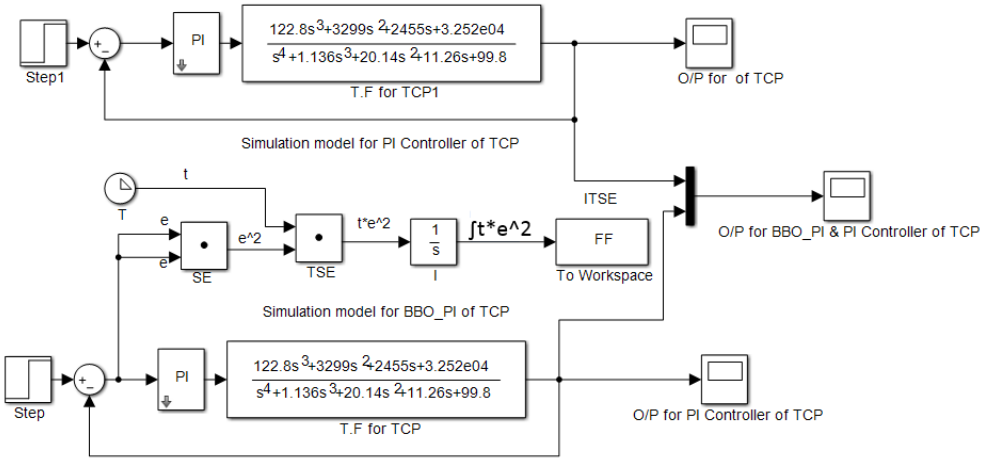

Figure 6. Simulation model for BBO-PI and PI controller of TCP network

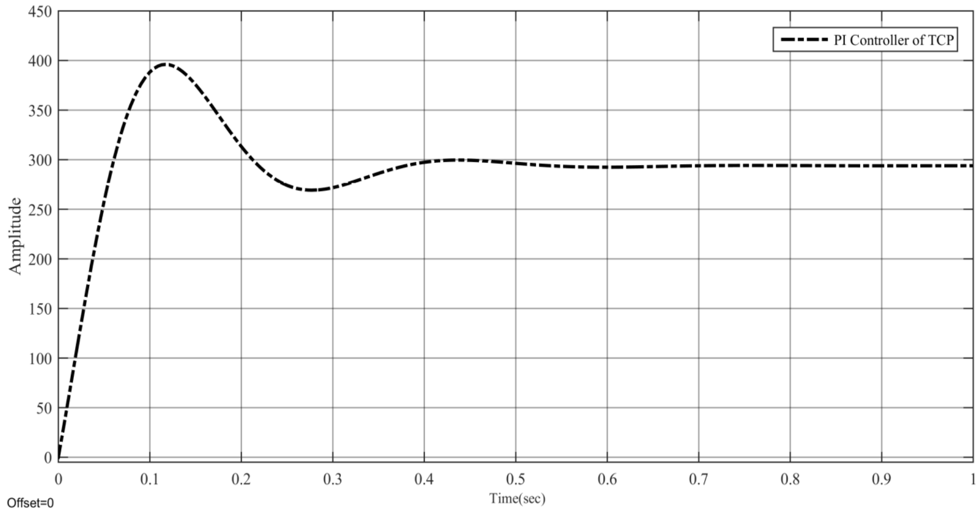

Figure 7. Simulation results for PI controller of TCP network

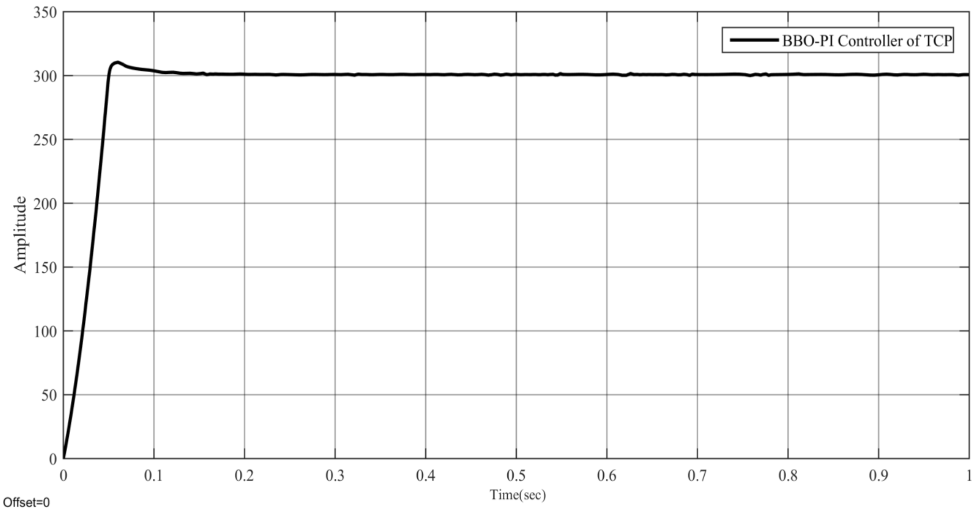

Figure 8. Simulation results for BBO-PI controller of TCP network

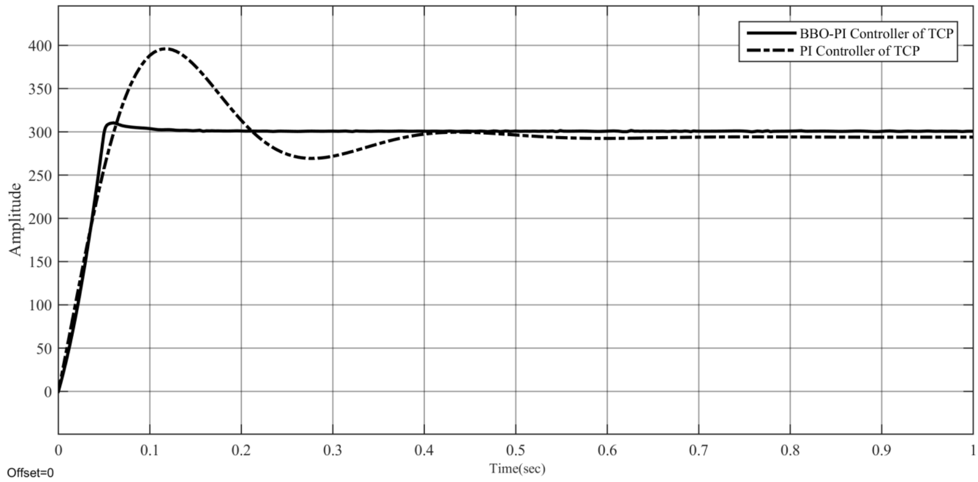

Figure 9. Simulation results for PI and BBO-PI controller of TCP network

4. CONCLUSION

The optimization of TCP based network applications and services performance by using one of the modern intelligence techniques became distinctly matter upon the quality of internet networks by speeding throughput, using large capacities, reducing retransmission rates, and decreasing the latency in the network. Also, an optimization solution for TCP leads to two important results, treating the issue of packet loss in last-mile networks, treating congestion in last-mile networks and decreasing the period of arriving at available bandwidth. The performance of the network has been improved through the use of BBO-IP controller, and this was evident through the simulation results.

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