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APPLYING PROPORTIONAL–INTEGRAL–DERIVATIVE CONTROLLERS ON WIRED NETWORK TCP'S QUEUE TO SOLVE ITS INCOMPATIBILITY WITH THE WIRELESS AD-HOC NETWORK

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ABSTRACT

This paper offers a solution to the problem of incompatibility of the TCP designed for networks with fixed routers and the Ad-hoc network, which sometimes its mobile hosts act as routers causing a routing failure. In order to overcome this obstacle, this work presents three Ad-hoc TCP novels. The first novel is adding a controller to Ad-hoc TCP queues; this controller works as a memory in the TCP's queue by saving the change rate of the previous error signals, then using it as a measure to change future error signal conduct. The second one is a comparison among the three Ad-hoc TCPs, which use different controllers, TCP PI/PD/PID. Finally, the models show promising results since all three Ad-hoc TCPs' results surpass the traditional TCP's result. Besides, the comparison process specified the best Ad-hoc TCP among the three, and that is the TCP/PID with Rise Time=3.472 ms, Overshoot=5.851%, Undershoot= -0.8264%, and Setting Time = 0.15 sec.

I. INTRODUCTION

The wireless Ad-hoc Network inconsistency with the fixed wire communication infrastructure has become a headache in the last years, especially in Mobile Ad-hoc [1]. So because of the dynamic nature of Mobile Ad-hoc, which leads to unpredictable behavior, communication becomes insufficient [2]. One of the inconsistency problems is that the TCP cannot recognize between the lost packet and the route failure and considers both of them as congestions. Therefore, the TCP shows a tendency for a lower rate compared to the network transmission rate [3]. TCP responsibilities are delivering packets from the recourse to the destination in the same order without packets' gaps and with errors-free, fixing the congestion, and controlling the data flow [4]. To specify the transmission rate to control the congestions and data flow, the TCP must get feedback from the receivers [5]. Therefore, the researchers try to apply a new algorithm that is called the Active Queue Management algorithm (AQM) to the traditional TCP to overcome these problems [6],[7]. The most important AQMs' functions are early congestion discovery and network status reporting; this is done whenever the router's queue reaches the limit by signaling incoming packets [8-10]. Then, AQM provides feedback packets to the source as soon as getting an overflowing notification, so the source takes the right actions [11],[12]. It is true that AQM is an effective mechanization for detecting early congestion and giving a prior alert of the current state of the network by signaling incoming packets before router queues fill up, but its current algorithms have main problems. For example, because of the understanding of different systems' dynamics requirements of the RED algorithm, this algorithm becomes unsteady and sensible to the controlling factors of the network [8]. Therefore, many researchers have been trying to improve the AQM by applying different expert systems and controllers, such as genetic algorithm, fuzzy neural networks, proportional controllers, etc. Wherefore, many analyses and works cover the AQM schemes, such as solving the AQM problems by integrating the backstepping control technique into the wireless network TCP [13], New RED-type [14], and Fuzzy and PID for Congestion Avoidance [15]. On top of that, AQM schemes complement TCP congestion-control mechanisms in reducing queuing delay and packet loss and improving network throughput [16]; each of these techniques obtains significant network performance by decreasing packet loss and delay time by controlling TCP's queues at congestion links. Furthermore, many studies apply optimization techniques for designing wireless network TCP. In these techniques, certain parameters are managed to measure the TCP performance, such as parameters are data retransmission and delivery speed (bit/sec) [17]. For instance, the paper [18] and [19] implemented a GA technique; others applied Fuzzy logic [20] and [21]; additionally, the particle swarm optimization technique is applied by [22] and [23]. So, these optimization techniques are applied with PI control technique [24]; PD control technique [25]; or PID control technique [26],[27]. For an example of applying TCP protocols for wireless network based on traditional TCP/IP with a controller, in [18], the authors applied transmission control protocol and active queue management (TCP/AQM) where the AQM applies the proportional-integral (PI) controller and genetic algorithm (GA). More example, [8] suggested applying Biogeography Based Optimization (BBO) to tune the PI's parameters in which the PI is used as an AQM. Meanwhile, [6] reached the result that the variations of the packet loss are trivial in the case of network parameters modification. Their research is based on fractional PID (FPID), AQM, and designing a robust controller that can master TCP's congestions. Besides, the experiment outlines less FPID queue length fluctuation and packet drop than PI and PID queues. Furthermore, [28] applied fuzzy logic on PID, which is used as an AQM, so the congestion, packet loss, and delay time will be reduced using nonlinear systems. In [10], the researchers used a PI controller to improve the AQM mechanism to solve the traffic problem between the diverse IoT networks. So they apply a packet classification via marking the IP that holds the packet as a priority or non-priority for the IoT network. Then, the AQM saves only the priority packets enclosing that they are not removed by keeping the queue status under its maximum capacity. And this is accomplished by dropping about half of the transmission, which is the non-priority packets since the IoT's main task is transferring the instructions to the remote devices. Regardless of any improvement approach, this work aims to found a solid base for designing an Ad-hoc TCP where researchers can build on it to improve wireless TCP protocols using any optimization or artificial intelligence technique to solve the problem of the continuously mobile routes hoc changing [1],[2]. This is accomplished by applying the simulation technique (MATLAB SW) on the three controllers PI, PD, and PID that are used as AQM with traditional TCP. So, by comparing the simulation results of the three controllers, the study specifies the best controller for an Ad-hoc network. To our knowledge, this work is the first study for founding an Ad-hoc TCP based on applying the optimal controller as an AQM queue. This paper is organized as follows: section 1 introduction, section 2 methodology, section 3 Simulation Results, and section 4 conclusions.

II. METHODOLOGY

The novelty of this work is centered on solving the problem of incompatibility of the TCP designed for wire communication with an Ad-hoc network because of the dynamic nature of mobile Ad-hoc as mentioned above [29]. To solve this problem, this work tries to add memory for the TCP's queue to store the previous states, so it can make a decision based on them in case of congestion, mobile movement, etc. To make this memory, a controller has to be used as a memory tool for the TCP system. So, as a memory, the controller is designed with feedback from the current state of the queue that gives information about the queue bottleneck and congestion problem [30]. The second originality of this research is that makes a comparison between different TCP network systems that use different controllers since there are three types of them to select the optimal one for the Ad-hoc network.

II.1THE TCP MODEL FOR AD-HOC NETWORK

This section represents an illustration of the TCP's model that is applied by this study. So, this model is designed by two nonlinear differential equations (1) and (2), which illustrate the TCP work dynamic in relation to the rate of TCP window size and queue length [8],[31].

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

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

where $\dot{w}$, $\dot{q}$: w, q time-derivative (in packets); R: full-trip time transmission (in sec); w: window size rate; q: queue length rate; C: link Capacity (in packet/second); T_p: promulgation delay (in sec); N: number of session; p: packet sign probability.

Note: $R = \frac{q}{C} + T_p$

All above variables are actually the control input, which is used to lower the transmission rate while maintaining the queue bottleneck problem, and they are supposed to be non-negative. So, from eq. (1), the additive increase 1/R and the multiplicative decrease w/2 are used in the congestion management algorithm to assess the window size rate throughout the TCP flow. Meantime, eq. (2) is the accumulative dynamics of the queue length as the rate of transmission surpasses the link capacity [8]. Equation (3), which is derived from eq. (1), represents the saturated input eq. and its p upper-lower boundaries are between 0-1. Based on equations (1) and (2), Fig.1 depicts the TCP Ad-hoc network's flow control scheme. Equation (4) is the I/O transfer function that is applied in the three TCP/ PI, PD, and PID Ad-hoc network models that are designed by this study [31].

$$sat\left(p(t-R(t))\right) = \begin{cases} 1, & p(t-R(t)) \geq 1 \\ p(t-R(t)), & 0 \leq p(t-R(t)) < 1 \\ 0, & p(t-R(t)) < 0 \end{cases} \quad (3)$$

$$\text{Transfer Function} = \frac{157.8s^3+4389s^2+3153s+4.336e^{04}}{s^4+1.095s^3+20.1s^2+10.84s+99.77} \quad (4)$$

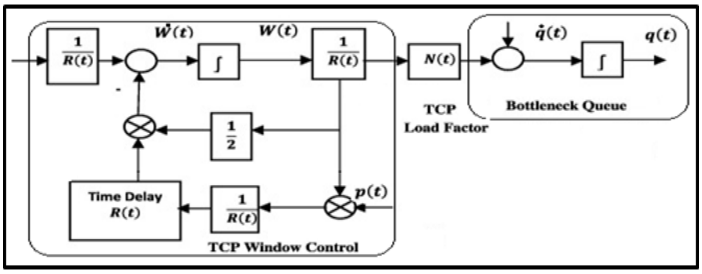

Figure 1: Schematic model of a controller with the Ad-hoc TCP network.

Source: Authors, (2024).

II.2 TCP/PI CONTROLLER

Figure 2 is the PI controller diagram that is performed by the Ad-hoc TCP network.

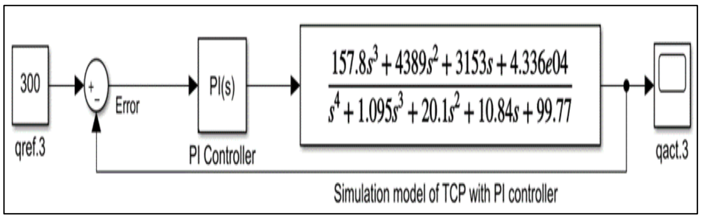

Figure 2: The simulation model of PI controller for Ad-hoc TCP network.
Source: Authors, (2024),

The aim of adding the proportional controllers in general and PI controller in particular to the AQM is to rise the efficiency of the router functionalities via supporting the queue by decreasing the loss and delay of the packets and increasing throughput. PI is usually used in industrial fields. When it is applied as a part of the TCP controller, the signal is proportioned to the gain and error integrals. Besides, its integral process removes the steady state error in the TCP system [32-34]. The below equation, eq. (5), is applied by the PI:

$$u(t) = k_p\, e(t) + ki \int e(t)dt \qquad (5)$$

where: kp, ki : proportional and integral gain constants respectively.

e(t): I/O error signal

u(t): PI output

II.3 TCP/PD CONTROLLER

PD task is taking the right actions to change the next error signal conduct by measuring the change rate of the previous error signals, which is proportional to the control signal. As a result, the transient response and system stability are improving, and the overshoot is decreasing [35]. Eq. (6) represents. The general formula of the PD controller applied by this study in the TCP Ad-hoc network:

$$u(t) = k_p\, e(t) + k_d \frac{de(t)}{dt} \qquad (6)$$

Where kd is the derivative gain constants.

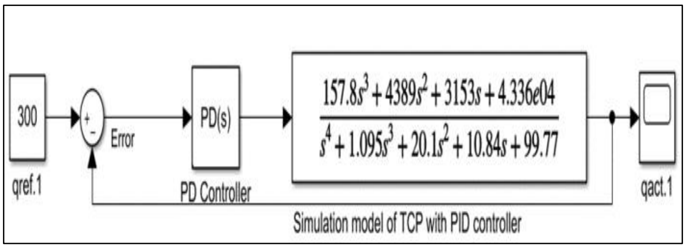

Figure 3: The simulation model of PD controller for Ad-hoc TCP network.
Source: Authors, (2024).

II.4 TCP/PID CONTROLLER

A PID is a tool that is utilized by industrial processes to manage their variables such as speed, flow, and pressure. The PID Controller consists of two control techniques: First, the D control technique, which has a feedback loop technique to keep the PID process variables under control. Second, the I control technique, which supports the D control technique to enhance the prediction of the PID controller and controls the buffer overflow [35-38]. These two techniques are illustrated in Figure 4. In this work, the below PID's eq. (7) is used in the TCP for Ad-hoc network:

$$u(t) = k_p e(t) + ki \int e(t)dt + k_d \frac{de(t)}{dt} \qquad (7)$$

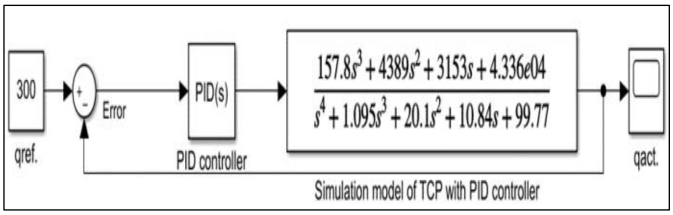

Figure 4: The simulation model of PID controller for Ad-hoc TCP network.
Source: Authors, (2024).

III. SIMULATION RESULTS

This simulation is an illustration of the efficiency of applying the controllers on the TCP's queue dedicated to Ad-hoc network by comparing three controllers, PI, PD, and PID, put in the TCP queue system. A MATLAB Software is utilized to decide the competence of the assumed controller and assesses its vulnerability to avoiding network overcrowding. Before the comparison between the three TCP/Controllers, fig. 5 represents the regular TCP's queue which shows the extreme congestion of the queue, and the nonfulfillment of the queue length specifications.

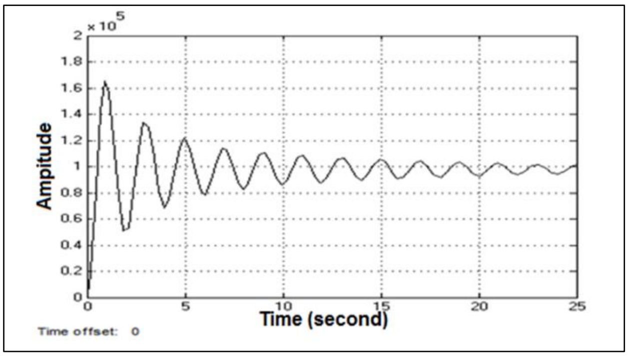

Figure 5: The TCP's queue without a controller.
Source: Authors, (2024).

The software is applied on the TCP's queue system, which includes one of the three controllers, then the process is repeated on the next system and so on, as shown in fig. 6, which actually, represents three figures in one:

1-TCP/PI Controller (dotted curve).

2-TCP/PD Controller (dashed curve).

3-TCP/PID Controller (continuous curve).

The MATLAB displays many given parameters for each controller, as can be seen in fig. 6, and fig. 7, but for comparison purposes, the Rise Time, Overshoot, Undershoot, and Setting Time parameters give the information that specifies the best TCP/Controller system for the Ad-hoc network among the three controllers.

Now, assume that the Ad-hoc network has a bottleneck with 16 Mb/s in 26 msec between two mobiles that act as hosts and routers at the same time, and they join to a bunch of receivers and transmitters. Based on Eqs. 1 and 2, take the Ad-hoc network factors: capacity link =16 Mb/sec; promulgation delay=0.22 sec;

Full-trip time =0.26 sec; load factor =60; in demand queue size =300 packets; and maximum queue length (at the sender) =740 packets. By applying these factors in the simulation model, the output results can be seen in figures 6 and 7, which are actually a comparison between the three TCP systems.

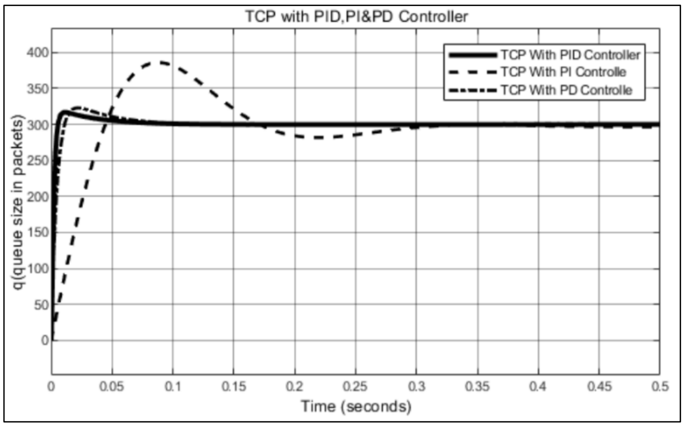

Figure 6: Three TCP Queue Systems, TCP with PI/PD/PID Controllers.
Source: Authors, (2024).

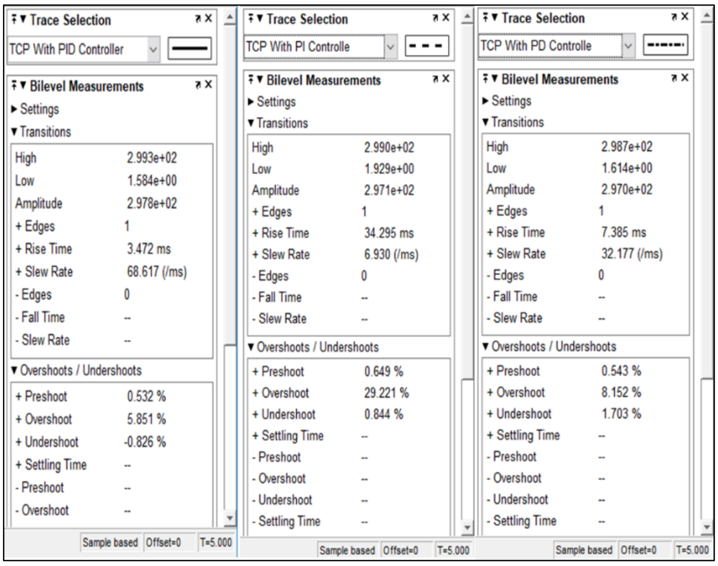

Figure 7: Given OutPut Parameters of TCP/PI, TCP/PD, and TCP/PID Controllers.
Source: Authors, (2024).

From Figure 7, the most important parameters (Rise Time (ms), Overshoot %, Undershoot %, and Setting Time (ms)) have been extracted as follows:

The Rise Time parameter is the time that the controller needs to reach 70% of the queue steady state = 0.7 × 300 = 210, so the Rise Times are 34.295, 7.385, and 3.472 for PI, PD, and PID, respectively. Therefore, TCP/PID system has the fastest Rise Time with 3.472 ms. For the two parameters Overshoot and Undershoot, the one with the closest peak to the steady state is the best parameter, so the Overshoots are 29.221, 8.152, and 5.851 for PI, PD, and PID, respectively. And the Undershoots are 0.844, 1.703, and -0.8264 for PI, PD, and PID, respectively. Again, TCP/PID controller with Overshoot 5.851% and Undershoot -0.8264% precedes the other two controllers. With the last parameter, the PI's Setting Time = 0.155, the PD's Setting Time = 0.35, and the PID's Setting Time = 0.15. Finally, the fastest controller's Setting Time = 0.15 sec is held by the TCP/PID controller as well.

IV. CONCLUSION

1-The TCP/PI model has the slowest speed response and the lowest stability of the three TCPs models.
2-Because of the D mode property of correcting the near future error signal path, the PD and the PID controllers improve the response time of the Ad-hoc TCPs.
3-PI, PD, and PID controllers are reliable devices to guess and manage the future TCP's error signal because of the feedback system.
4-D mode enables the TCP/PD and TCP/PID models to avoid queue overflow.
5-The reason that the TCP/PID model has better performance than the TCP/PD model is because of the I mode in PID which its integral process removes the steady state error in the TCP system and this will boost the prediction property of the D mode.
6-The simulation results manifest that the three TCP controller models (PI, PD, PID) to manage the TCP/Ad-hoc network inconsistency outperform conventional TCP.
7-The TCP/ controller models in this work are imperative to develop the Ad-hoc networks since applying these models on mobile devices that connect to Ad-hoc networks makes them reliable routers to extend the Ad-hoc covering area.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Yaser Ali Enaya, SalamWaley
Methodology: Yaser Ali Enaya, Mohammed Qasim
Investigation: Yaser Ali Enaya, Mohammed Qasim
Discussion of results: Yaser Ali Enaya, SalamWaley
Writing – Original Draft: Yaser Ali Enaya, SalamWaley
Writing – Review and Editing: Abdulamir Abdullah Karim.
Supervision: Abdulamir Abdullah Karim, Mohammed Qasim
Approval of the final text: Abdulamir Abdullah Karim

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