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Simulation model of ACO, FLC and PID controller for TCP/AQM wireless networks by using MATLAB/Simulink

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ABSTRACT

The current work aims to develop a suitable design for control systems as part of a queue management system using the transmission control protocol/and active queue management (TCP/AQM) protocol to handle the expected congestion in the network. The research also aims to make a comparison between the different control methods, including the traditional proportional integral derivative (PID) and the expert fuzzy logic control (FLC), as well as the optimal ant colony optimization (ACO) that is used according to the performance improvement criteria to reach the best values for parameters the traditional controller (kd, ki, k p), where the addition of the performance indicator time-weighted absolute error (ITAE) was adopted. The use of this method without any other optimization algorithm that can be applied to adjust the parameters of the PID to verify the possibility of improving performance and enhance that with experience and to know the level of improvement for this particular system being the subject of the study. The results showed the superiority of the optimal ACO over both the FLC expert and the conventional PID, as well as the superiority of the FLC expert over the traditional PID.

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1. INTRODUCTION

Internet has wide use and attention, and solving its problems has recently become a confirmed demand for specialists and researchers [1]. Besides, computers around the world are connected to the Internet and the transmission and reception process is managed using control protocols [2]. So, one of the these controls is the transmission control protocol (TCP/IP) [3]. It is applied after setting appropriate algorithms to manage the system through the queue that controls and solves the expected congestion problem by adopting the closed loop, which is represented by the feedback mode [4]. The feedback signal is compared with the reference signal to determine the error and try to get rid of it or reduce it with the fastest response and the highest quality [5].

The congestion problem decreases the network's speed through packet transmission and data arrival delay [6]. Therefore, work on congestion control requires exerting efforts to reach a solution that helps reducing damage [7]. Control systems are adopted as supporting systems placed as part of the proposed system to determine how to improve performance [8]. Thus, there must be performance criteria to measure the level of performance [9], such as the stability area, the overshoot rate, the rise time, and the steady state time [10].

The performance test algorithms are developed based on the use of error and placed within indicators [11], [12]. Algorithms are chosen and the system is tested by adopting it as part of the solution [13], [14]. The first indicator is built by taking absolute integration and is called IAE, the second is by taking the time-error-square integration (ITAE) and the third indicator is by adopting the error-square integration and it is called ISE in the transmitter[15].

The internet contains routers, and one of its tasks is to store data or packets, i.e., put an active queue management (AQM) queue before conducting [16]. The routing process after the required path is available, which includes through an algorithm that fits its work [17]. In the present work, to obtain an acceptable and relatively high-quality performance by conducting simulations to determine the stability zone [18]. The stability of the system requires a procedure to build an appropriate mathematical model, build a working algorithm [19]. It is applied in simulation, and test different control systems to obtain a design that benefits from reaching a different system in terms of performance and quality to a better state than the absence of a system use case without it [20].

The development in control systems has found various techniques that are called automatic control techniques [21]. Such as ant colony optimization (ACO) called ant colony, i.e., the optimal ant colony algorithm [22]. These techniques are used in many industrial applications. Previous studies have recently proven, and the current study confirms the possibility of using automated control systems to reach an optimal solution in the parameterization of traditional proportional integral derivative (PID) controller [23]. It is used as congestion management controller on the internet with TCP/AQM control protocol. It is proposed to conduct a tuning process for the PID parameters to show an improvement in the performance of the work of organizing and managing congestion [24]. Figure 1 shows the block diagram of TCP/AQM with ACO-PID controller [25]

Among the recent applications of the optimal algorithms that have been applied to adjust PID control parameters, such as: their application in the field of controlling non-linear systems using particle swarm optimization-PID (PSO-PID) and grey wolf optimization-PID (GWO-PID) technique and other techniques. Also in other studies, it is used in applications that need to regulate voltage by adopting PSO-PID technology and adjusting speed and accuracy. And adjusting the location of the electric motor, moving and changing the position of the robot, as well as the frequency, using the GWO-PID technique [26]–[31].

After reviewing the network and the available information that enabled us to represent it mathematically, as well as to see the improvement of its performance. The three methods were chosen to verify and enhance the possibility of improving the performance of the system. By adopting the control using the traditional method, expert systems and the optimal advanced controller. It is proposed to test the network with three methods that will be detailed later in the network simulation in the third paragraph and the simulation results in the fourth paragraph. Therefore, the conclusions reached by obtaining the simulation results and comparing between the three proposed cases can be drawn up [32]–[35].

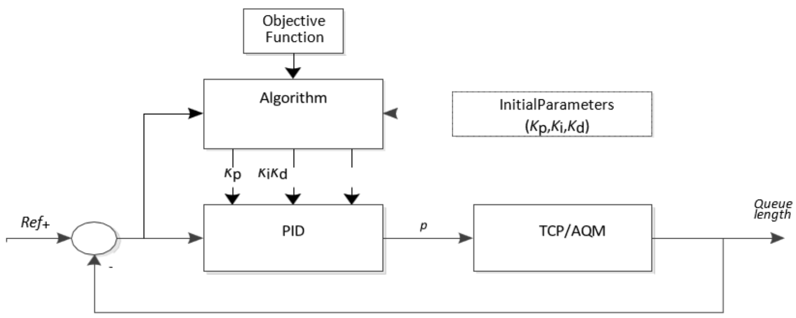

Figure 1. The block diagram of TCP/AQM with ACO-PID controller

2. SIMULATION MODEL OF TCP/AQM WIRELESS NETWORKS

The system is simulated after setting the special specifications for building the transfer function that represents it, in addition to the control systems, which can be placed in a block diagram of its parts and an illustrative diagram of the work steps. The stability zone is tested from the time of the steady state and the percentage rate of the over-and under-overrun before stability occurs. Algorithms are developed for each case to reach suitable parameters by improving the performance of the system in the different simulation cases, which will be mentioned in the next paragraphs to the possibility of improving system performance in managing network congestion. The simulation model in the transform function. The modeling of the flow support vectors and the transform function of the internet are sequenced in a mathematical representation based on the system. Configuration diagrams of the network, which can be represented in the following:

The basis of approximation can be put in the description of the network by mathematical representation, such as the size of the window and the amount of change by increasing or decreasing, and therefore we need to put a symbol for the normal or changing state in terms of increase or decrease. The packet and its amount, increase or decrease, also put a special symbol for it. The delay and wait list have its length, its arrival rate, its capacity, the maximum or minimum window size and the buffer. After placing the symbols that represent the network parameters and by linking them to each other through their functions, they can be linked with mathematical relationships. Table it represents the symbols of the parameters and the mathematical equations represent the relationship between them. Through the analysis and design of the system behavior and the values that describe the network parameters, we can reach an equation that represents the network with a transformation function, and the proposed control systems can also be added to it to get the system response. The simulation needs to represent a model that simulates the behavior of TCP. Mathematical equations are used to represent it, taking into account the changes that occur in the network, as it is considered a nonlinear system. In Figure 2, the congestion avoidance situation can be represented by a TCP block diagram [36]–[38].

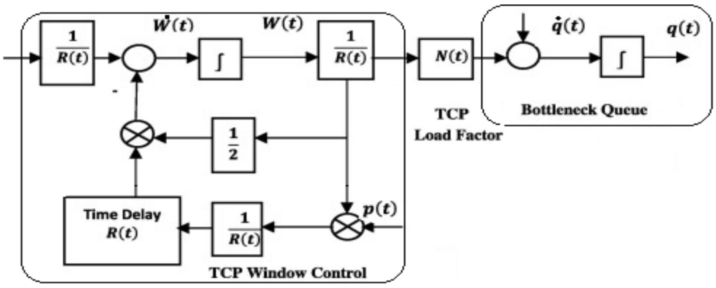

Figure 2. A TCP block diagram

As shown in (1) represents the relationship between the beam and the window and the dynamic response of the control protocol with the changes that occur. As shown in (2) represents the relationship between the queue and the time rate for packets to arrive, the size of the window, the link capacity and the storage capacity. It is possible to test the feedback work to control the organization of the protocol work and control the dynamics of the work of the queue [39]-[41].

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

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

The mathematical model can be completed with (3) to (5) to reach the transfer function. By substituting the values for the parameters, the transfer function can be written in the form that is used to perform the proposed tests in the current simulation.

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

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

$$T.F = \frac{1.17126e^5}{s^2+4.63s+2.173} \tag{5}$$

In this section, there are three parts of this work, first by using simulation model of PID controller for TCP/AQM wireless networks that show in Figure 3. Second by using the simulation model of FLC for TCP/AQM wireless networks that show in Figure 4. Third by using the simulation model of ACO for TCP/AQM wireless networks that show in Figure 5.

Figure 3 shows the simulation model of PID controller that was built by using the *T.F* of TCP in this model system with PID controller. The proposed model is used to perform the first simulation, where the system is represented using the transformation function. Moreover, the traditional controller is added, which is set to have its input as the error signal to be reduced or eliminated. To improve performance, the process of considering the controller parameters and controlling them is carried out. Toning process to get the best performance using this type of traditional control system, and install its data from the parameters of the controller and the specifications of performance indicators measured during the simulation process.

Figure 4 shows the simulation model of FL that was built by using the *T.F* of TCP in this model system with expert system type FLC. The proposed model is used to conduct the second simulation, where the system is represented using the transformation function. in addition, the fuzzy logic expert controller is added which is set to have its input as the error signal to be reduced or eliminated. To improve performance, the process of taking into account the number of its inputs and outputs is carried out. And control by conducting the simulation process, the best performance is obtained using this type of expert control system. And install its data from the controller parameters and performance indicators specifications measurement during the simulation process.

Figure 5 shows the simulation model of ACO controller that was built by using the *T.F* of TCP in this model system with optimal type ACO-PID controller. The third proposed model is used to perform the simulation. Where the system is represented using the transform function. Added console optimization for traditional console tuning parameters. Which is tuned to be a working algorithm that handles the error in the behavior of the system as a result of the transient state to reduce it in terms of time to rise and fall from the peak and stability. To improve performance, the process of taking into account and controlling the parameters of the controller is implemented. Tuning process to get the best performance using this type of control system optimized for traditional console parameters tuning. And fixing its data from the parameters of the controller and the specifications of the performance indicators measured during the simulation process.

Algorithm of ACO-PID optimization, to work on improving the network work using ACO by getting the best values for parameters of PID controller. The test is conducted through a simulation model that assumes the passage of a signal and a specific time as a default delay for control and performance monitoring. The case is also returned with other techniques to compare and determine the best. Thus, a suitable analysis and the required design can be obtained.

The algorithm simulates the behavior of ants that live in a colony. This algorithm is used to provide the optimal solution like many other advanced optimization algorithms. The behaviors of ants tend to find the shortest path, which helps to speed up the process of searching for the optimal in the least time. It has also been found that it is able to find a solution flexibility and appropriately to the most difficult circumstances.

Ants can find the good solution individually or collectively. They can make random decisions to find the best and optimal solution. They are also distinguished by choosing the shortest path to reach the optimal solution. Ants' behaviors can be included in steps to represent the algorithm. It can also be drawn in the form of a chart in which the ant's steps are sequenced, for example in its first step, the beginning, which is preparing for the behavior of a new road. It is possible to repeat the case by choosing the same path or another new path. Its development depends on the case. There is a case called reinforcement leads to optimization in proportion to the path taken.

The ACO algorithm can be used to reach the best values for Kp and Ki as well as Kd when it is intended to tune the PID controller. It goes through stages including taking the initial data and making the signal passing currency. Thus, the initial evaluation of the results can be obtained from the initial value to know the behavior and the effect of feedback. After applying the commands. The necessary can be achieved better by adjusting the signal and the effect of the console on it in improving performance. After initialization, which is the first, the update stage comes according to what has been reached.

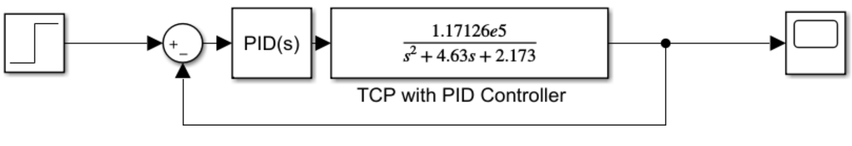

Figure 3. Simulation model of PID controller for TCP/AQM wireless networks

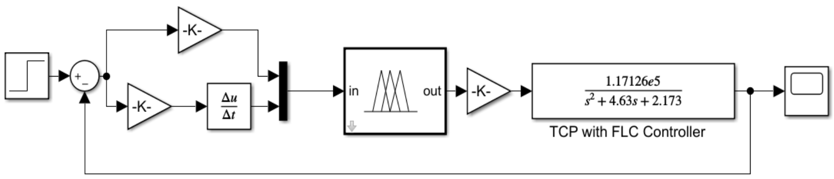

Figure 4. Simulation model of FLC controller for TCP/AQM wireless networks

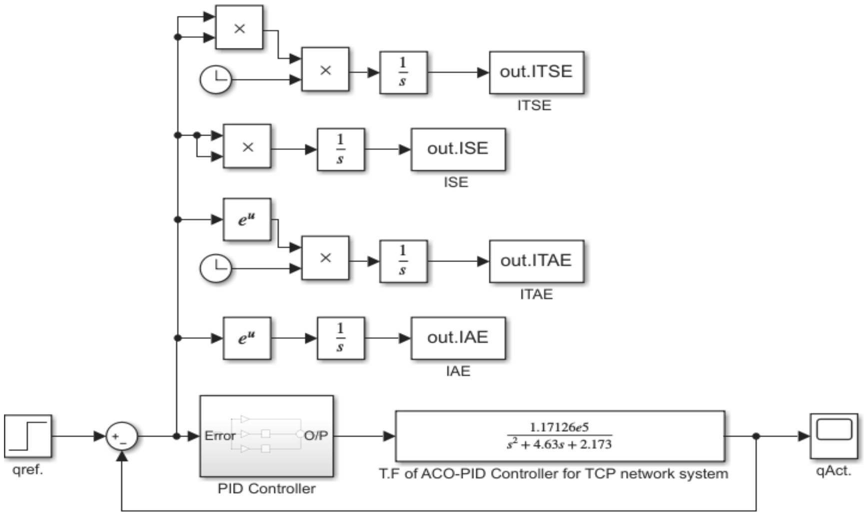

Figure 5. Simulation model of ACO-PID controller for TCP/AQM wireless networks

The ant colony algorithm has equations representing the stages of reaching a solution, such as initialization based on a similar stage to an old colony that found the solution, i.e., the result of previous experiences. It can be compared with the new colony to find the best between them. Determine the search area to provide the optimal solution. Leap, vector, coordinates and others will be mentioned in the mathematical equations according to the correlation and function of each. As shown in (6) can be written representing a single operation of the solution vector:

$$X_{\mathrm{t}}^{\mathrm{k(new)}} = X_{\mathrm{t}}^{\mathrm{k(old)}} \pm \alpha, \mathrm{t} = 1,2, \ldots.\mathrm{I} \tag{6}$$

where $X_{\mathrm{t}}^{\mathrm{k(new)}}$ is solution vector, $X_{\mathrm{t}}^{\mathrm{k(old)}}$ is solution vector from the former step, α is vector to find the length of jump, and t ant at cycle. As shown in (7) can be written representation of the focus of the search:

$$\bar{x_t} = x_t^{best} + (x_t^{best} \times 0.01) \tag{7}$$

where $\bar{x}_t$ is focus of the search and x_t^{best} is best solution.

3. SIMULATION RESULTS OF TCP/AQM WIRELESS NETWORKS

In this section, there are three parts of this work. First, by using simulation model of PID controller for TCP/AQM wireless networks that show in Figure 3. Second, by using simulation model of FLC for TCP/AQM wireless networks that show in Figure 4. Third, by using simulation model of ACO for TCP/AQM wireless networks that show in Figure 5.

In Figure 6 show the simulation result of PID controller that built by use the *T.F* of TCP in this model system with classical controller type PID. In Figure 7 show the rise time(tr) in 9.04e-05 seconds, also show time steady state (tss) in 0.00214 seconds and overshoot amplitude 331 at 0.000367 second. In Figure 8 show the simulation result of FLC controller that built by use the *T.F* of TCP in this model system with expert system type FLC. In Figure 9 the rise time (tr) in 2.06e-07seconds, also show time steady state (tss) in 1.1e-06 seconds. In Figure 10 show the simulation result of ACO controller that built by use the *T.F* of TCP in this model system with optimal type ACO-PID controller. In Figure 11 the rise time (tr) in

2.71e-08 seconds, also show time steady state (tss) in 1.45e-07 seconds. In Figure 12 show the simulation response of ITAE with each iteration. Simulation result of ACO controller that built by use the *T.F* of TCP in this model system with optimal type ACO-PID controller.

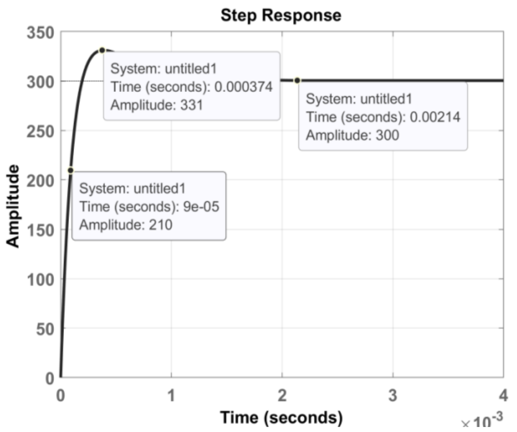

Figure 6. Simulation response of PID controller for *T.F* of TCP

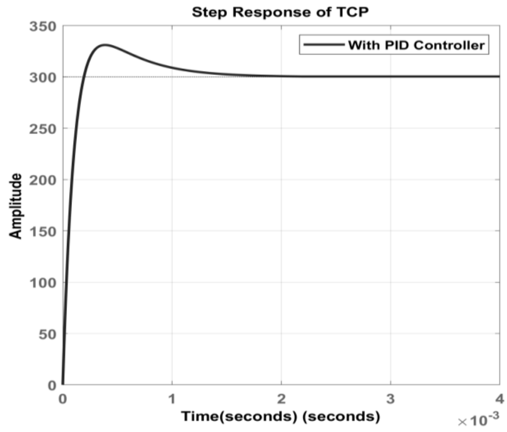

Figure 7. Simulation result with (tr, tss, overshoot) of PID controller for *T.F* of TCP

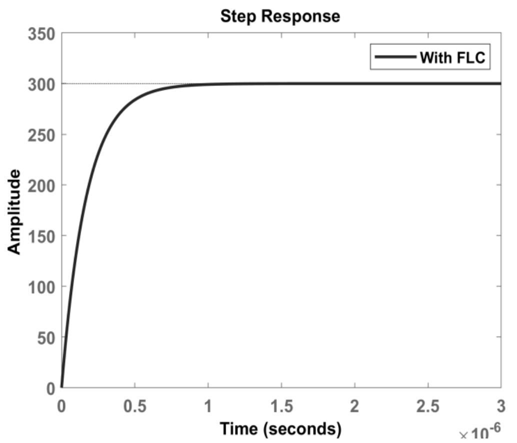

Figure 8. Simulation response of FLC controller for *T.F* of TCP

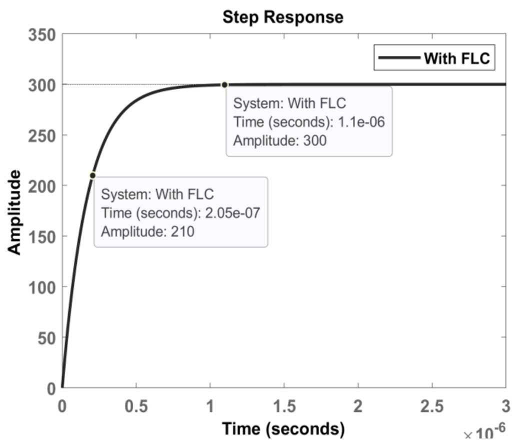

Figure 9. Simulation result with (tr, tss, overshoot) of FLC for *T.F* of TCP

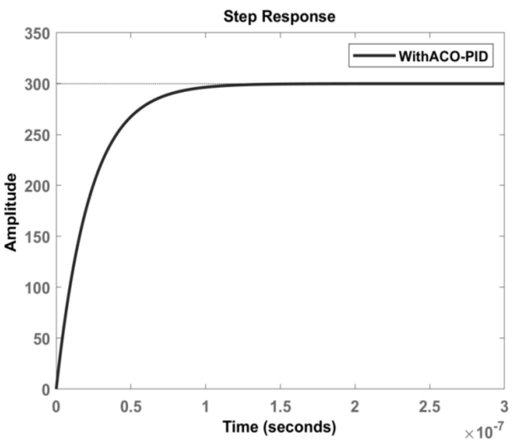

Figure 10. Simulation response of ACO controller that for *T.F* of TCP

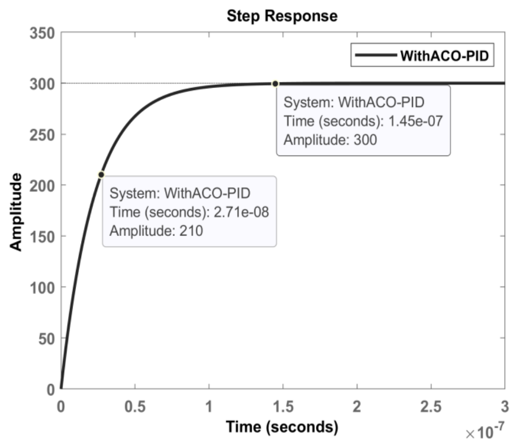

Figure 11. Simulation result with (tr, tss, overshoot) of ACO controller that for *T.F* of TCP

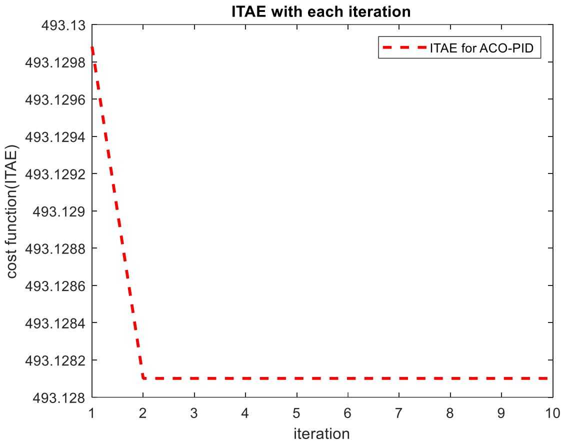

Figure 12. Simulation response of ITAE with each iteration

4. CONCLUSION

The possibility of improving the performance of the TCP protocol has been verified to avoid congestion caused by the large number or accumulation of data or packets to obtain high reliability that can be ensured by improving the performance of the protocol, which in turn improves the network work. The possibility of improving the performance of AQM queue management has been verified through process management storage and determining the appropriate path to direct the data to the appropriate party after the path is available. Adoption of the mathematical model that represents the behavior of the system and representation in the simulation helped to reach the appropriate choices to obtain acceptable performance.

The results showed the possibility of solving the problem in question, which is congestion and delay, and therefore work has been done on the stability of the system and reduce the delay. It can also be noted that this algorithm can be used with various control systems in control engineering, industrial applications and other applications. It can also be used in future works in many improvements, including improving fuzzy logic, and multiple optimizations.

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