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Improving TCP/AQM Network Stability Using BBO-Tuned FLC

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ABSTRACT

One of the modern technologies used to improve the performance of various systems, including communications networks and the Internet, is the technology based on biogeography (BBO) that many researchers in the field of automation and control have shed light on. Fuzzy logic is one of the expert systems that has dealt with its use in control systems by many researchers within different applications. The current work has shed light on the mechanism of using The Biogeography Based-Optimization (BBO) technique for adjusting FLC parameters is called (BBO-FLC). The simulation was performed using Matlab program and the researchers adopted the technique as part of the stability of TCP network. The performance of the techniques used in the optimization process can be identified by comparing the results of each case, such as the proposed technique, with other types represented by the traditional control type Proportional–integral–derivative controller (PID). The possibility of using modern and intelligent optimization techniques for the optimal controller is tested using a tuning process for the parameters of the fuzzy type expert controller with the help of the biogeography-based optimization (BBO) technique. The contributions of the research are to verify the possibility of improving the performance by comparing the behavior of the system for the proposed test and simulation cases by obtaining the prescribed level and without exceeding the permissible values.

1. Introduction

Currently, the Internet is used significantly, which has made it a focus of interest for companies and researchers in the field of networks and communications [1]-[3]. As with other systems, there are problems during the transmission and reception of data. Among the problems are the speed of the system's response and the delay of data during the transmission and reception channels in a slow management process that is considered unless it is treated [4]-[6]. Among the methods that are relied upon to treat Internet network problems and the delay in receiving data is the method of adding control protocols to the paths and channels of stations according to controls that manage and solve the expected congestion problem using appropriate transmission and reception algorithms such as (TCP / IP) [7]-[9]. In feedback systems to determine the state of the system and compare it with the reference and determine the rate and percentage of noise or error and work to eliminate or reduce it with the case of obtaining a high-accuracy and speed response [10]-[12]. The increasing demand for network usage and the large amount of data exchanged between the sending and receiving sides generates a high load, which makes delays likely and congestion in the process of receiving information [13]-[15]. To reduce damage and improve performance, the system is supported by control systems. Control systems improve system performance and can achieve response speed, reduce overshoot rates, and speed stability of the system, which are standards for measuring performance [16]-[18]. One of the important challenges of any system is to raise the level of performance and high efficiency that gives reliability. To achieve this, work is done to improve the performance of systems by conducting studies, research, experiments, and building simulation models and tests whose results are analyzed to serve the interest of obtaining reliable and highly efficient systems [19]-[21]. Currently, among the systems used by people of different ages, young and old, educated or uneducated, cultured or uneducated, are Internet systems.

After selecting a specific system to represent a real network or similar to it, the mathematical model is built and its representation is the transfer function as one of the methods used to know the behavior of the system [22]-[24]. An initial test case is done through simulation programs such as MATLAB to identify the system in the absence of feedback at the open loop. The other case is to develop a model for the closed loop system with specifying the operating conditions of a linear system and another non-linear system in addition to the two test cases of the presence and absence of control systems to study more than one test case and compare them through the simulation results [25]-[27]. The comparison cases depend on measurement criteria. There are also indicators to handle the error according to algorithms that are relied upon, including absolute integration, called IAE, integration of the square of the time error (ITAE) and integration of the square of the error, called ISE. The routers must be organized, which work to put the appropriate paths and store packets and information or data and manage their queue. Currently, work is underway to design and build a simulation model to analyze the system response through steps to track the system states for changing operating conditions to reach a high-quality and fast-response model to show improvement in the performance of the work of organizing and managing congestion. Using advanced, expert and traditional techniques to manage the system including congestion and need to manage data queue and optimization based in addition to control systems TCP/AQM protocols [28]-[30].

The research is a crucial topic for solving the new problems that were investigated in this study and some previous studies and can be adopted in future studies. Among the proposed studies that were tested are those that dealt with communication and Internet systems in addition to highlighting control systems that help in enhancing the performance and stability of TCP/AQM network. Conclusions can be drawn about the trade-off between control units, robustness and tuning despite the complexity of different systems including communication networks and the Internet. Control requires a tuning process to make the control units suitable for improving the performance of the system to be controlled. Currently, tests have been conducted proposed by the researchers in this study to include all components of the system with the proposal of traditional and expert control methods (fuzzy logic) and advanced optimal BBO and comparing them to choose the best. The results showed that the performance of the optimal BBO controller is better than the expert and traditional. Tests were conducted to include preparing and improving the system by designing parameters that suit the efficient system, including the number and size of the population and migration rates to and from the original homeland and the possibility of producing mutation to be compatible with real systems that represent Internet networks and communication systems in real time. The speed of performance of functions with optimal parameters at a lower cost through tuning rules in the proposed control unit and it is suggested to conduct future tests to verify the possibility of applying them to adjust the expert control unit of the artificial neural network type. It is very important to conduct tests and compare their results to verify and evaluate the performance of each test case with different control systems.

In order to control and improve the communication operation using a high-level, high-performance and efficient network by adding control systems of different types, traditional, expert and advanced optimization. The simulation was conducted using MATLAB, adopting an active queue management model in network transmission, using the control protocol (TCP/AQM), and for test cases that include both linear and non-linear system types.

2. Method

Linear and nonlinear systems need control systems to handle the errors resulting from noise and disturbances that occur in the system. Algorithms that rely on artificial intelligence have emerged, some of which are compatible with industrial systems. To simulate the behavior of the system with changing environmental conditions, the BBO optimization algorithm is one of them. The proposed optimization algorithm is based on a principle based on biogeography, which can be used to adjust the parameters of the traditional PID controller as well as the expert controller due to its advantages. The researchers present the BBO algorithm as a control unit to adjust the parameters of the expert controller as a unit characterized by being strong in handling errors in nonlinear systems. Also, linear systems require a traditional control unit to handle the error, while nonlinear systems need intelligent or expert units such as fuzzy logic or advanced optimization such as BBO. It is suitable for real-time applications because it is powerful and able to improve the performance of various systems and changing operating conditions. It is also characterized by being effective in handling disturbances and noise based on the requirements of the appropriate behavior of the system. Tests were conducted for the proposed simulation model representing different cases of linear and non-linear characteristics to verify the effectiveness of the system and compare them to choose the best. The results showed the superiority of the proposed method and the effectiveness of the system compared to other methods.

The problem and solution are the basis for starting a justified work that can be viewed by specialists. The problems of low performance of a system operating at low efficiency are considered one of the most important systems that are being worked on in order to address the low efficiency of the system and try to raise its efficiency level. The focus is also on addressing the energy levels of the systems and how to provide them [31]-[33]. In the current era and the recent past, improving the performance of systems is the main concern of all researchers in the world through the process of controlling energy levels as well as adopting the appropriate design and solving complex problems that are between theories and analyzing the behavior of systems and appropriate algorithms that are adopted to address the problems of those systems such as the problem of organizing the transmission and reception of data that are transmitted in the transmitters of communication systems according to multiple transmission and reception channels [34]-[36].

2.1. Mathematical Model of TCP/AQM Wireless Networks

In Fig. 1, Fig. 2 to Fig. 3 networks, Block diagram and controller for TCP/AQM [37]-[39]. Equations that mathematically represent the network of a nonlinear system with TCP protocol can be written for a network by considering the average window size and queue length and represented by a dynamic model of the system mathematically in the equations (5), (6) w refers to the size of R, which represents the TCP window, which can be written mathematically as $R = q/C + T_p$, where q is the length of the queue in seconds, N is the load factor, C is the link capacity, p is the packet signal probability, and T_p is the propagation delay. Optimization techniques depend on the lifestyle of living organisms, and thus systems are modeled on the basis of choosing the best. When there are many solutions, the focus is on choosing the best solution after conducting multiple iterative attempts according to conditions that change to suit real time. When choosing a specific algorithm, it can also be inspired by biogeography to represent a set of solutions, each solution has a specific feature and performance indicator, and whether it is suitable for housing as a habitat, and quality standards are determined to determine the best among the solutions [40]-[42]. Such as the appropriate environment that suits the number of people on the one hand and the required migration rates, and whether they represent low or high indicators due to an increase or decrease in the population. The process of linking the fitness function is considered through sorting between the available solutions and choosing the best with the appropriate optimization process for migration rates and indicators and deviations from the solutions from time to time. It can be represented mathematically and to express it, the migration and island migration equations are used and symbolized as in equation one and equation two [43]-

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[45]. The rates are symbolized by the symbols μj and λj, the first represents the immigration rate and the second represents the immigration rate per person, while j and I represent the maximum possible immigration rate; and E represents the maximum immigration rate; and to express the number of species of individuals of the migrating population, the symbol j is used, while the maximum number of those species is expressed by the symbol n. The algorithm is of the BBO type, in which mutation is used to multiply species and obtain the increase, as well as obtaining the diversity of the population, from which it is possible to obtain the best solutions]. The mutation factor can be modified randomly, and by relying on the mutation factor rate, it can be symbolized by the symbol mj as in equation (3). The mutation includes the rate mj for species of j number and its maximum rate can be symbolized by mmax while the maximum loads symbolized by Pmax for the number of species in addition to the symbol Pj to represent the number of those possible species for the habitat j and it can be represented mathematically as in the equation (4). Migration and displacement are attributes that are part of the proposed algorithmic system for habitat j and their rates can be represented mathematically as μj+1, λj+1 and for types including μj-1, λj-1 which can contain j+1 type or j-1 type which represents the migration and displacement rate for habitat j as in the equation (4) [46]-[48].

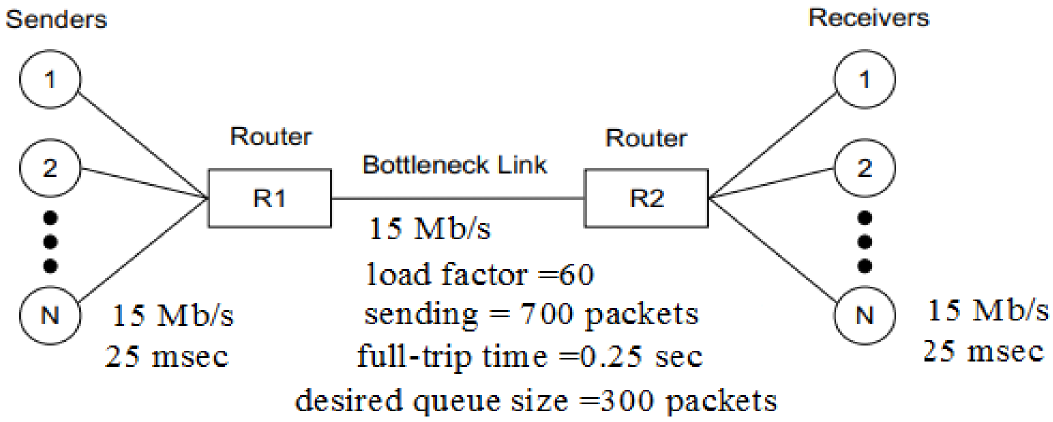


Fig. 1. TCP / AQM networks [49]-[51]

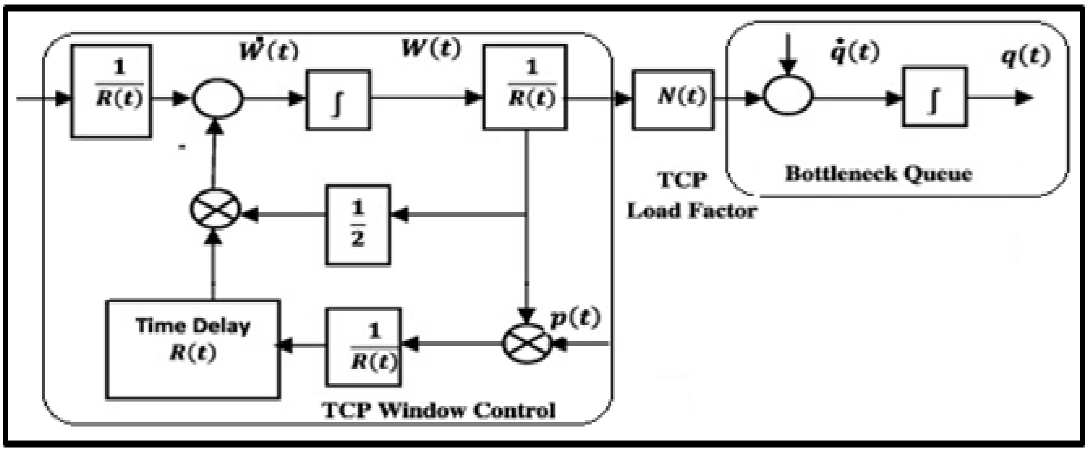


Fig. 2. Controller of TCP / AQM [52]-[55]

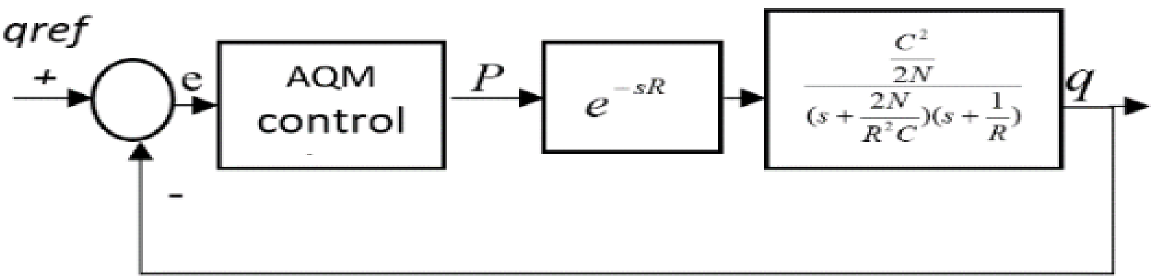


Fig. 3. Block diagram of TCP / AQM [56]-[58]

$$\lambda_j = I\left(1 - \frac{j}{n}\right) \tag{1}$$

$$\mu_j = \frac{E.j}{n} \tag{2}$$

$$m_j = m_{max}\left(\frac{1 - p_j}{p_{max}}\right) \tag{3}$$

$$\dot{p} = \begin{Bmatrix} -(\lambda_j + \mu_j) + p_j + \mu_{j+1}\, p_{j+1} & j \leq 0 \\ -(\lambda_j + \mu_j) + p_j + \lambda_{j-1}\, p_{j-1} + +\mu_{j+1}\, p_{j+1} & 1 \leq \; j \leq 0 \\ -(\lambda_j + \mu_j) + p_j + \lambda_{j-1}\, p_{j-1} & j = n \end{Bmatrix} \tag{4}$$

$$\dot{\mathrm{w}}(\mathrm{t}) = \frac{1}{\frac{\mathrm{q(t)}}{\mathrm{C}} + \mathrm{T_p}} - \frac{\mathrm{w(t)}}{2}\frac{\mathrm{w}(\mathrm{t} - \mathrm{R(t)})}{\frac{\mathrm{q(t-R(t))}}{\mathrm{C}} + \mathrm{T_p}}\mathrm{p(t - R(t))} \tag{5}$$

$$\dot{q}(t) = \begin{cases} -C + \dfrac{N(t)}{\frac{q(t)}{C} + T_p} w(t) & if\ q(t) > 0 \\ max\left\{0, -C + \dfrac{N(t)}{\frac{q(t)}{C} + T_p} w(t)\right\} & if\ q(t) = 0 \end{cases} \tag{6}$$

2.2. Biogeography-Based Optimization

When there are a number of solutions and these solutions differ for any problem, a filtering process is carried out to choose the best solution. Due to the presence of many differences and variations and to provide the possibility of developing an algorithm that follows the optimal solution for it. The repetition process is relied upon according to standards that provide measures of performance quality and show the accompanying improvement. Many development techniques have been developed according to algorithms that manage the process of obtaining improvement using a developed algorithm, and among those algorithms are those that depend on the contexts and behaviors of living organisms. Among the most important and best of those developed algorithms and techniques are those that maintain a set of candidate and new solutions and identify a candidate solution from among them for each problem. The existing optimization can be selected, tested and described in addition to verifying it using biogeography (BBO) because it has the advantage of being applied to a wide category and is different and multiple to provide solutions to many problems. Parameters of algorithm of biogeography-based optimization shown in Table 1.

This type of analysis can be done by identifying the basic principles, which include a description and mathematical representation of the biogeography algorithm. This algorithm has the potential to develop and produce other types according to the variables of the surrounding environment. One of the basic principles of the life of a living organism is how to live with spatial and temporal conditions that suit natural diversity. Migration is one of the factors affecting the life of living organisms, including animals, fish, birds, or insects that require choosing the best place among the islands. When there is a friendly and suitable environment for life, then it can be said that it has a high index (HSI). The suitability index depends on the variables (SIVs) that characterize the index, including temperature and rainfall rates, as well as plant diversity and others. When there is a high index, it is possible to provide a habitat for many species, and thus migration to these places is considered a suitable and attractive place to live, and vice versa, when the suitability index is low, the solution is migration from these places, which creates a problem that imposes migration. The BBO algorithm is based on the assumptions of migration as a result of random changes and effects, which may lead to the extinction of living organisms in their original habitat and their departure to any other habitat that is considered a candidate solution to the problem. Due to the presence of variables and effects for many places, more than one solution may be available, and thus it is necessary to choose the best among them.

From the above, we can draw a conclusion as a basic principle for the algorithm. The suitability index is linked to the population index and the number of immigrants. High immigration is linked to a low index of spatial and temporal environmental suitability, while the opposite is true when the environment is suitable with a high index and there are no noticeable immigration rates or it can be said that there are very low immigration rates.

A model can be developed that shows the migration of the population to their original homeland, including the number of species and the rate of migration to the place (migration to it) and migration from the place (immigrants from it). Other considerations can also be made, including the maximum rates of migration from the place and to the place. Probabilities can be made that include the absence of a population, which means the migration of all the population, as well as the largest number inhabiting the place with a low immigration rate. Model of immigration and emigration probabilities with the maximum immigration and emigration rates shown in Fig. 4.

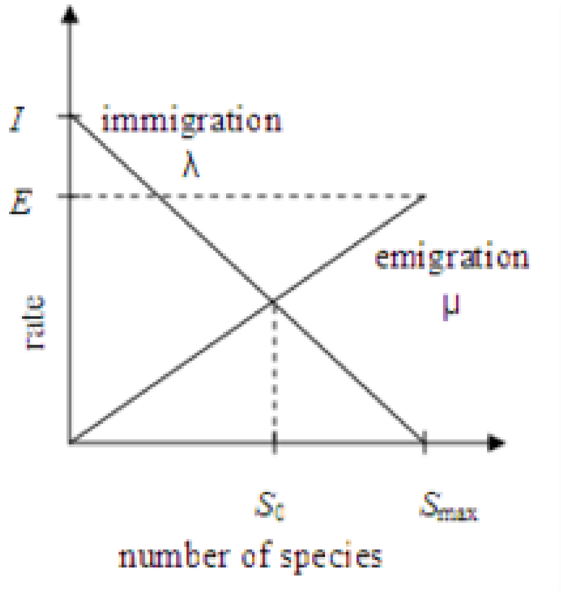


Fig. 4. Model of immigration and emigration probabilities with the maximum immigration and emigration rates

Table 1. Parameters of algorithm of biogeography-based optimization

Symbols	Titles
λ	immigration probabilities
μ	emigration probabilities
I	maximum immigration rate
So	equilibrium species count
Smax	maximum number of species that the island can support
λk	probability of replacing a given independent variable in the candidate solution
μk	probability that is proportional to the emigration probability

2.3. Algorithm of Biogeography-Based Optimization

Algorithms rely on key factors to perform their function by identifying the best solution among many solutions, thus selecting solutions, verifying and ensuring that the best candidate solutions are not lost for generations. Another factor can also be mentioned, which is obtaining mutation in each generation by replacing the worst solutions and saving the best ones.

The BBO algorithm can be represented to include mutation and is described as a population size of N can be seen in Fig. 5. The process of adjusting variables to find solutions depends on using the population size, which can be small or large. The performance depends on the population size, which can be determined as an initial creation and identifying the candidate and appropriate solutions that depend on the problem. A criterion can be set to evaluate the objective function to get rid of the problem according to new guesses and solutions to improve performance and solve the problem. A hypothesis can be set for a population group as the beginning of a generation and variables can be set to create an immigrant group and a temporary group.

```
Initialize a population of N candidate solutions {x_k}
While not(termination criterion)
    For each x_k, set emigration probability μ_k ∝ fitness of x_k, do
        with μ_k ∈ [0,1]
    For each x_k, set immigration probability λ_k = 1 − μ_k do
    {z_k} ← {x_k}
    For each individual z_k(k = 1,···,N) do
        For each independent variable index s ∈ [1,n] do
            Use λ_k to probabilistically decide whether to immigrate to z_k
            If immigrating then
                Use {μ_i} to probabilistically select the emigrating
individual x_j
                z_k(s) ← x_j(s)
            End if
        Next independent variable index: s <- s + 1
        Probabilistically mutate z_k
    Next individual: k <- k + 1
    {x_k} ← {z_k}
Next generation
```

Fig. 5. The BBO algorithm

2.4. Expert Controller (FLC)Tuning by Smart or Optimum (BBO) [59]-[61]

Implementing for FLC Parameters Tuning by BBO, the BBO algorithm is used to find the optimal solution from a set of solutions using 100 iterations and assuming the existence of 100 random habitats, the variables of the expert controller FLC can be encoded in fuzzy logic with three variables to include the first variable with the symbol X1, the second variable with the symbol X2, and the third variable with the symbol X3 to represent the problem for which the optimal solution is to be chosen. The algorithm works according to a test procedure that represents the system performance for each iteration by simulating the system model using the MATLAB m-file program, in addition to the fact that fuzzy logic consists of two inputs, including error and error change, as well as the output of the expert controller, and it depends on a set of rules that link the inputs and output of the expert controller FLC.

To work on tuning the expert controller using the optimum in order to improve the performance of the system, it is necessary to build a simulation model of the system that includes the expert FLC and the optimum BBO. The optimum BBO is written in MATLAB m-file format and represents an optimization algorithm and is linked to another file that represents the expert FLC with a tuning representation to choose the optimal values for the variables (X1, X2, and X3). To verify the performance of the system, it can be compared with other methods to find out the best, as the figures show the results of test cases according to a process that uses an FLC with two inputs and two outputs in addition to the FF representation as in the equation (7):

$$\mathrm{FF} = \mathrm{ITSE} = \int_0^t t \times e^2(t)dt \tag{7}$$

All previous and current studies depend on the iteration process in improving performance by using algorithms known as performance improvement algorithms, some of which depend on approximation, others on pricing, and also some depend on shrinkage and some on semi-definite relaxation in improvement. All of them depend on one approach, which is taking samples of real parameters of actual systems operating in real time for any semi-wireless communications with a non-linear system and specifications for transmission and reception channels and error or noise signal rates as inputs and working to produce an improvement in performance to obtain improved outputs for the system.

For example, about load and no load with different controller that show in Fig. 6, Fig. 7, Fig. 8, Fig. 9. Fig. 6. shows the workspace of BBO-FLC, Fig. 7 shows the set of input and output fuzzy Rules and set of Fuzzy If-Then Rules, Fig. 8 shows the memberships and Fig. 9 shows the surface of FLC.

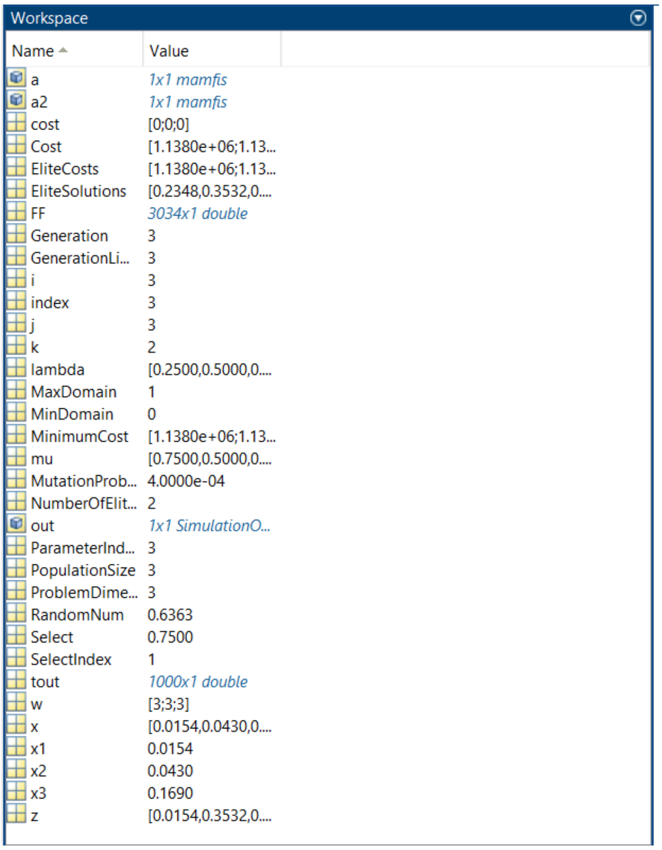
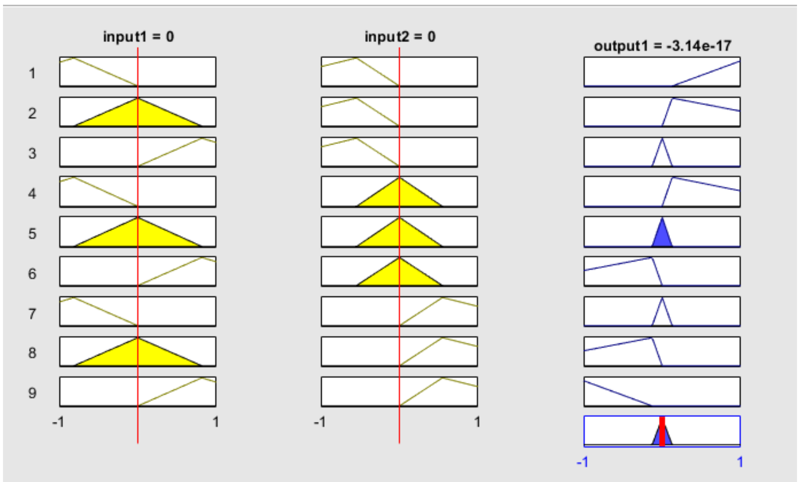
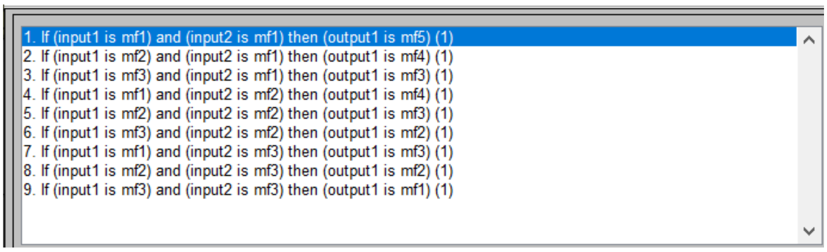


Fig. 6. The workspace of BBO-FLC

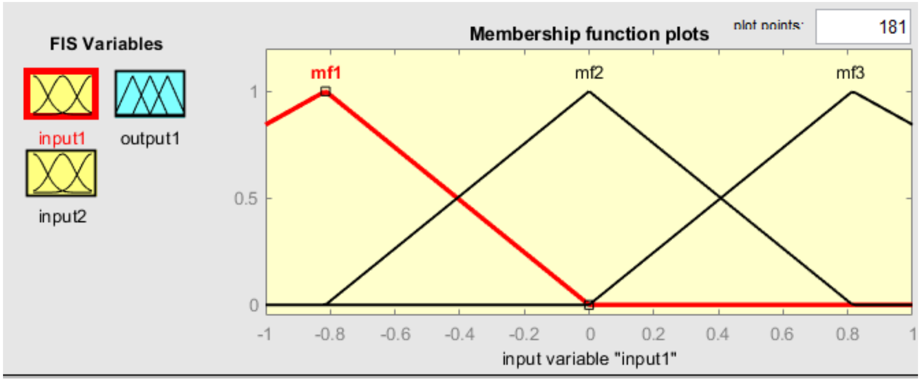


a. Set of input and output fuzzy rules

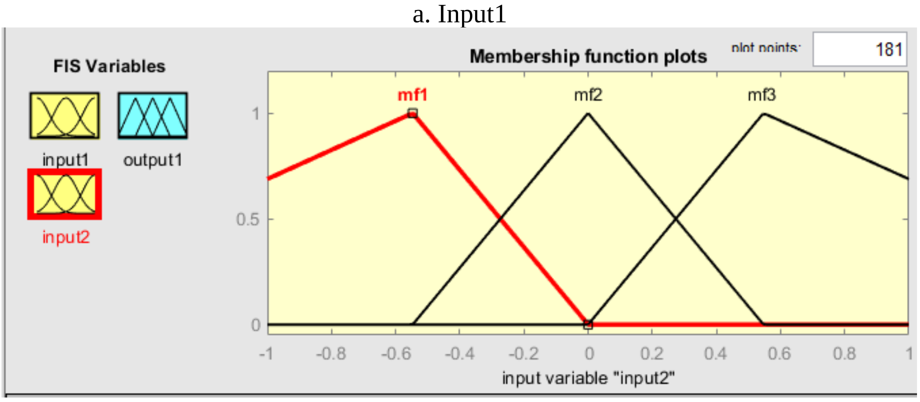


b. Set of fuzzy if-then rules

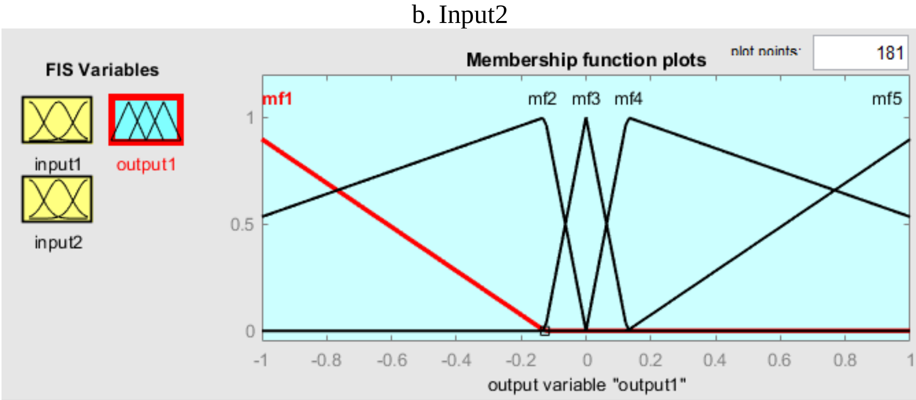
Fig. 7. Fuzzy Rule



a. Input1



b. Input2



c. Output

Fig. 8. FLC memberships

This research presents two contributions, the first is to understand the performance of the system behavior by implementing a simulation under variable operating conditions. The second contribution is to improve the performance by adopting methods to control the management and organization of the congestion occurring in the network using MATLAB. The system was operated in an initial state without load and without any control systems to know its operating characteristics and determine the response without feedback to understand the behavior of the system in this state. Other operating conditions, including constant load and variable load conditions, were relied upon to determine the faulty and non-linear behavior of the system. To improve the performance and address the problems of variable operating conditions, control systems were used. The researchers were able to verify the possibility of improving the system performance by using control systems under variable operating conditions.

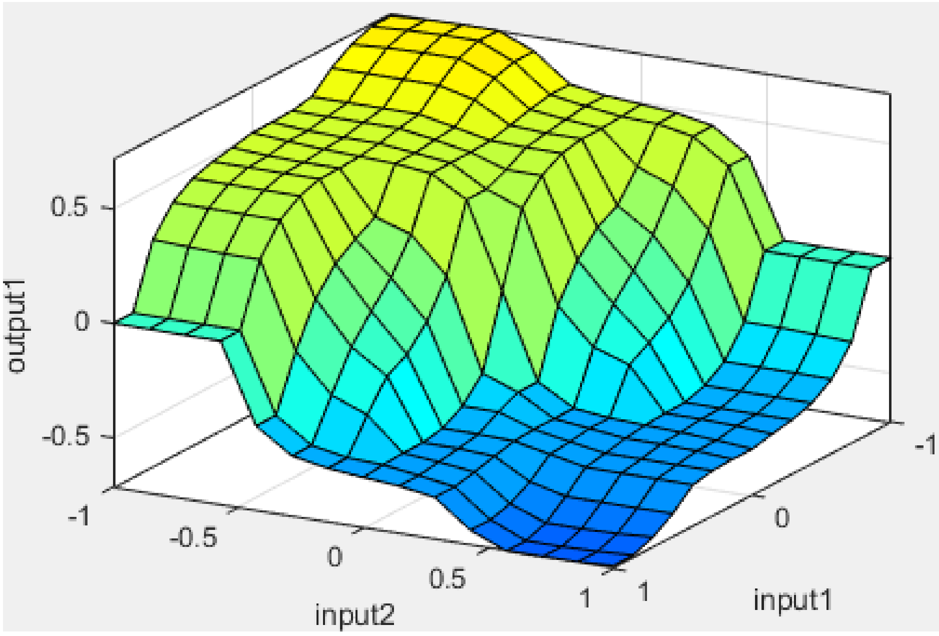


Fig. 9. The surface of FLC

3. Simulation Model and Results

There are two part in this section include model part that show in the next step and after that it found the result it in the next it.

3.1. Simulation Model

In this part there are two state of the system include open loop and second the closed loop that shown in Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14. The open loop is don't has the feedback but the closed loop has feedback. The closed loop has two section first section is without control and the second with control. In this work have two types first is classical control by PID controller second by using advanced optimal BBO-Fuzzy Controller.

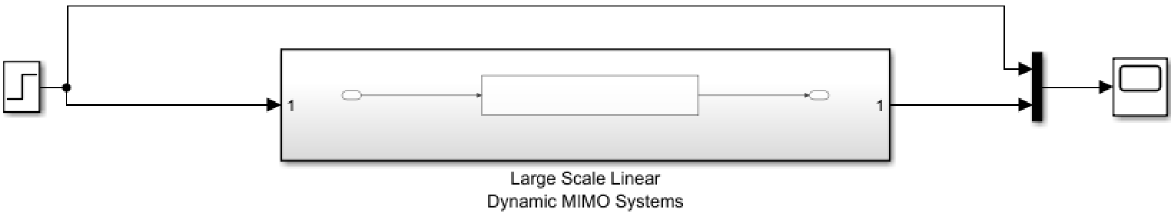


Fig. 10. Open loop system without feedback

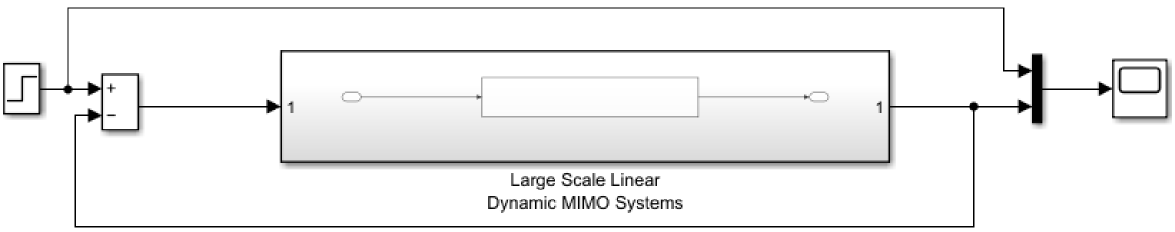


Fig. 11. Close loop system (CLL) without control

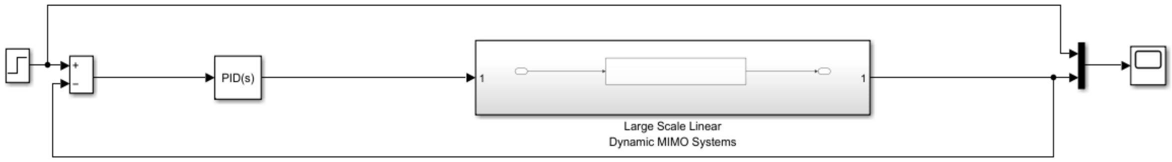


Fig. 12. Close loop linear system with PID controller

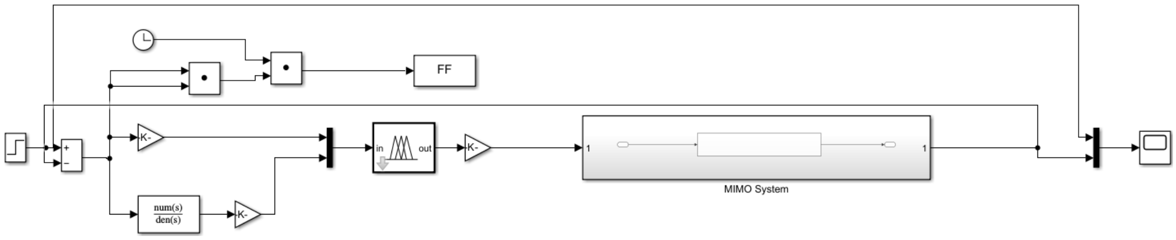


Fig. 13. Close loop linear system with BBO-FLC

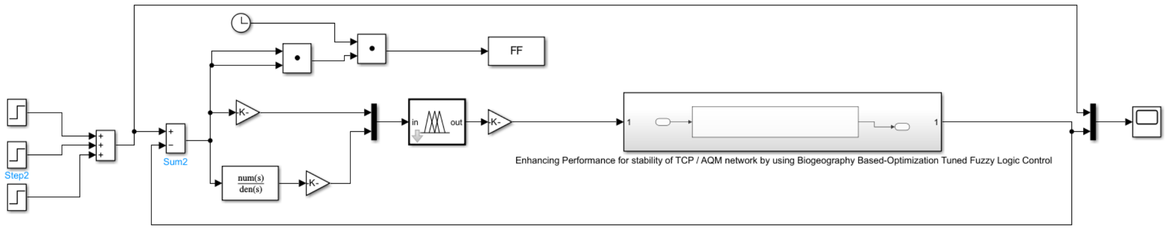


Fig. 14. Close loop non-linear system with BBO-FLC

3.2. Simulation Results

In this part there are two state of the system include simulation result for open loop and second the simulation result for closed loop s. The simulation result for open loop is don't has the feedback but the simulation result for closed loop has feedback. The simulation result for closed loop has two section first section is simulation result for without control and the second simulation result for with control. In this work have two types first is simulation result for classical control by PID controller second by using simulation result for advanced optimal BBO-Fuzzy Controller. Simulation results can be seen in Fig. 15, Fig. 16, Fig. 17, Fig. 18, Fig. 19, Fig. 20. Comparative controller of system and without controller system shown in Fig. 21.

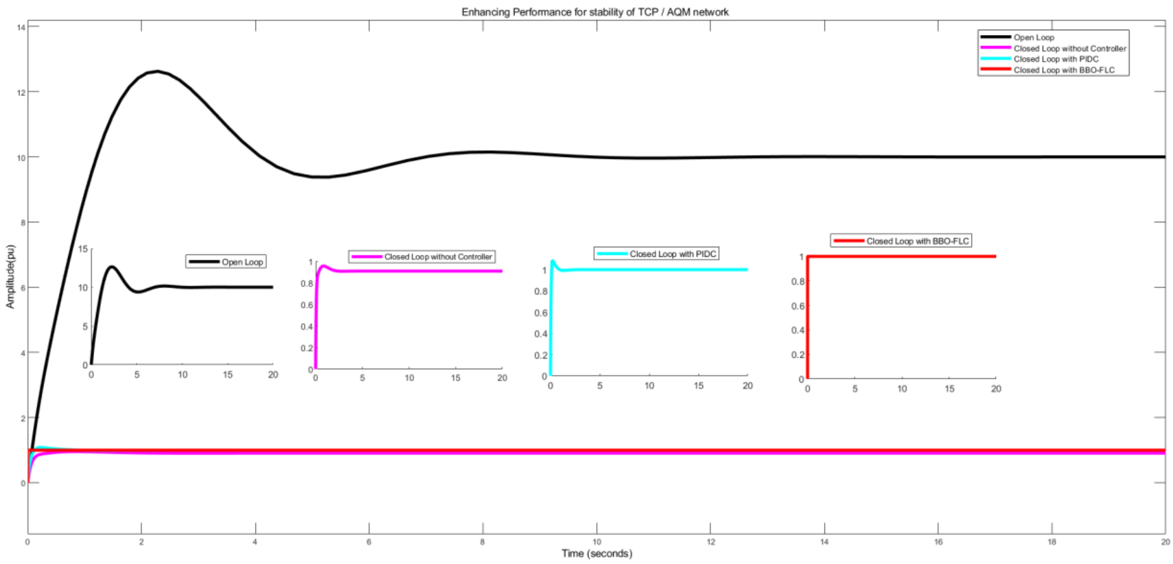


Fig. 15. Simulation results for open loop and closed loop

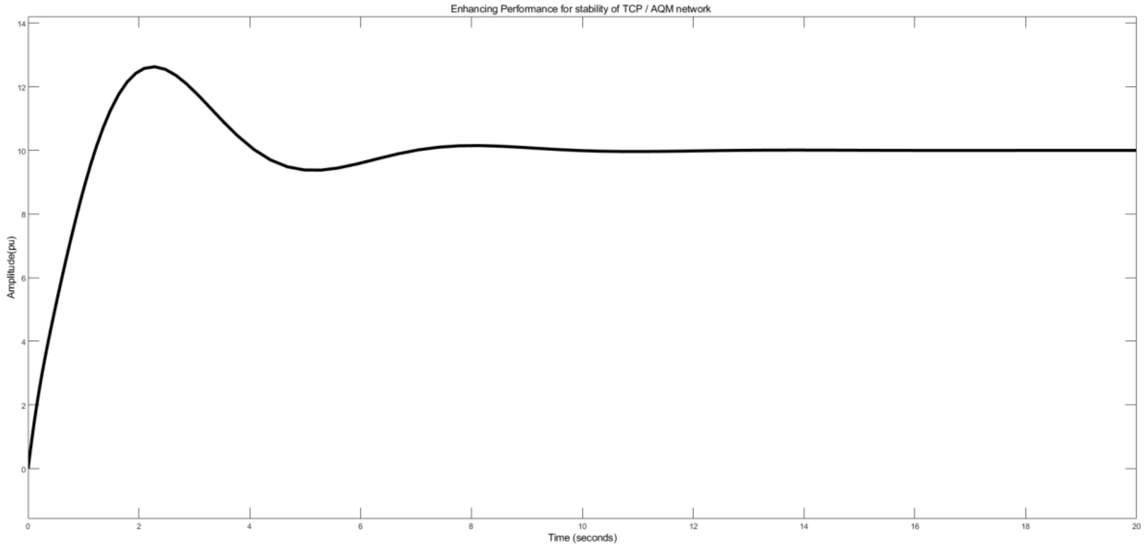


Fig. 16. Result for open loop linear system

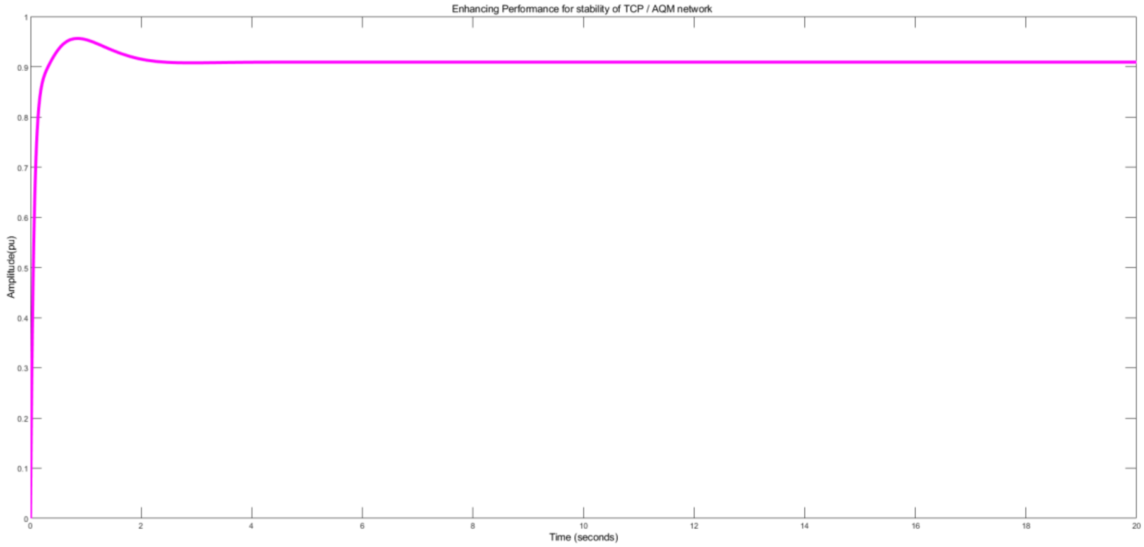


Fig. 17. Result of CLL System without controller

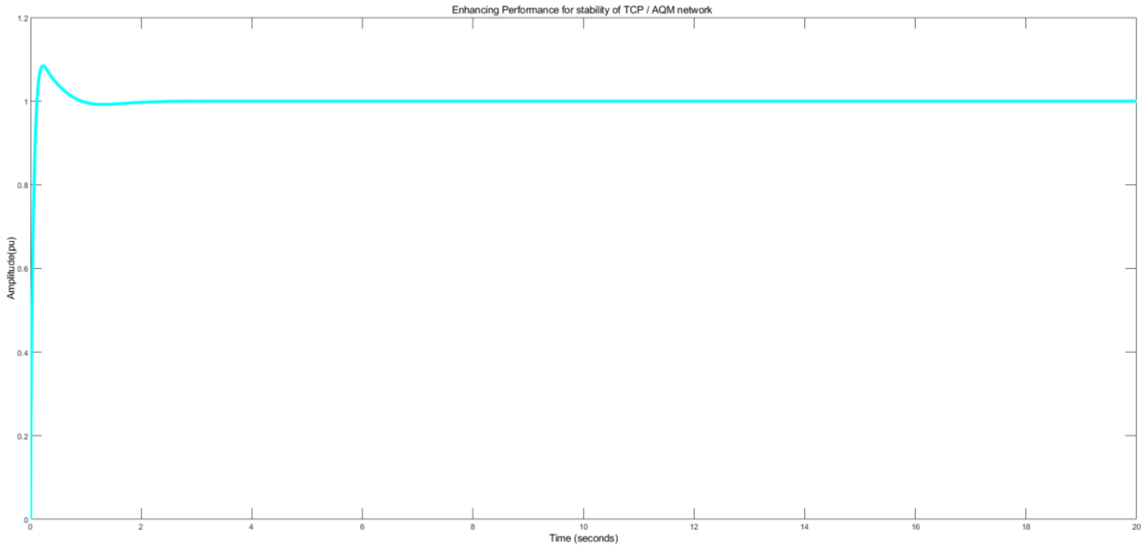


Fig. 18. Result for CLL system with PID controller

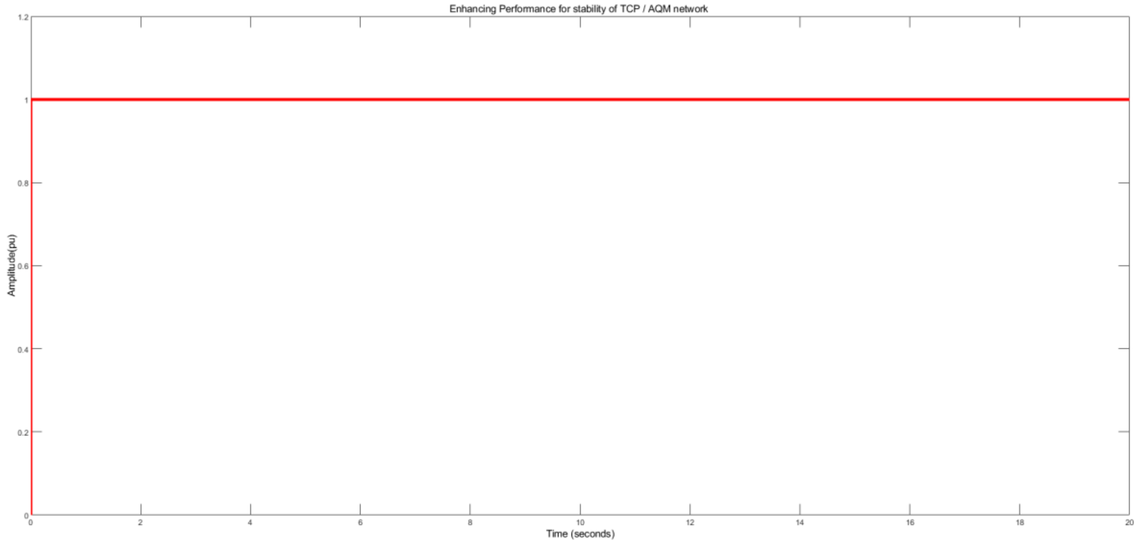


Fig. 19. Result of CLL system with BBO-FLC

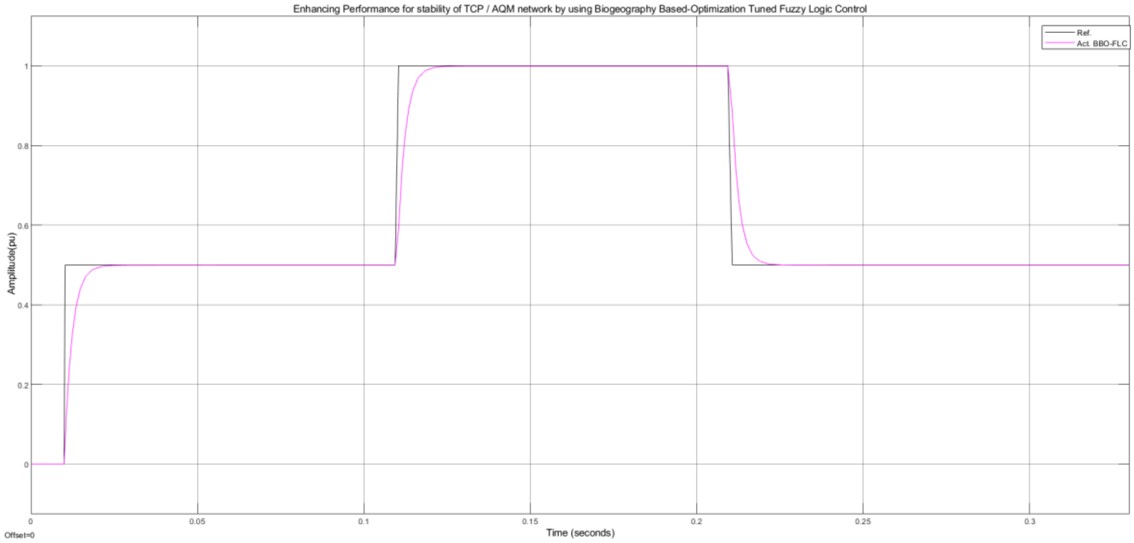
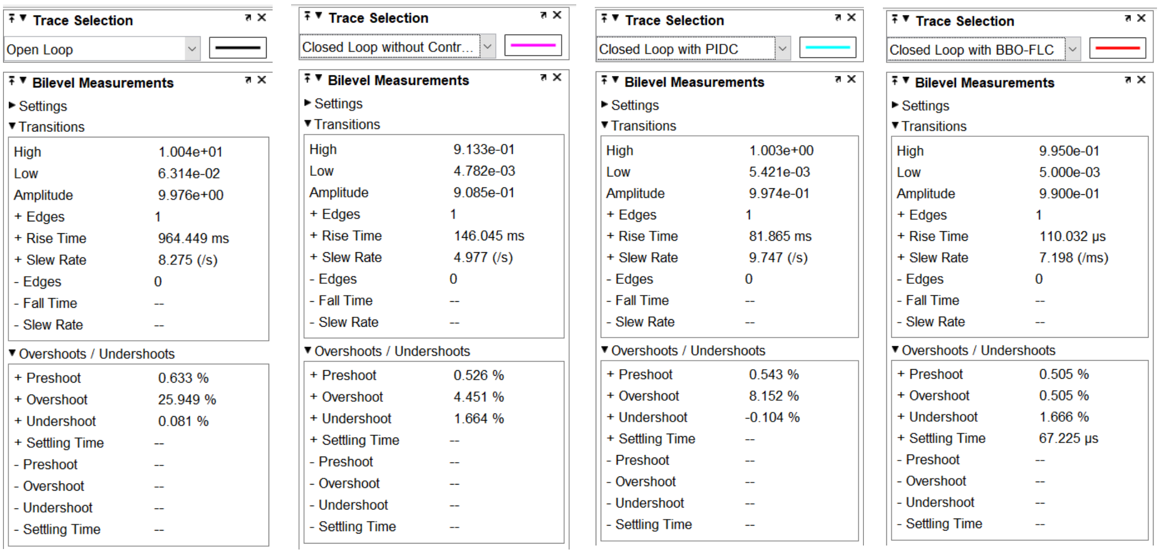


Fig. 20. Result for close loop non-linear system with BBO-FLC



a. open loop b. Close Loop c. PID Control d. BBO-FLC

Fig. 21. Comparative controller of system and without controller system

4. Conclusion

The tests showed within the researchers' proposals to conduct a simulation of a system that includes representation and building a model of the Internet and communications network and identifying the system's response, as well as showing the difference between them by comparing different control methods. The simulation results show the results of the proposed tests and it was found that the best among them is the improved BBO-FLC controller, which shows the required response and appropriate performance compared to the traditional one. Thus, a set of conclusions can be written according to the analysis process of the simulation results:

1. Developing a suitable design for the expert controller of fuzzy logic by adopting logical calculation algorithmically as well as traditional control units according to the concept of error and correctness, which is the traditional method.
2. The process of adjusting the expert controller using the advanced optimal type BBO is considered the best among other smart methods because it has proven to give high performance for the system's response with different operating conditions.
3. The proposed method provided a satisfactory solution to the system's response and in an appropriate time to reduce the error in the system.
4. The proposed method provided a flexible, robust and highly reliable control system as a result of the advanced prediction process in adjusting the FLC expert parameters.
5. The proposed method gave a stronger control system capacity in real time as a result of early prediction of the potential interference source.

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