International Journal of Applied Electrical and Electronics Engineering
Volume 2, Issue 2, 2026

A NOVEL APPROACH FOR INTERNET CONGESTION CONTROL USING AN EXTENDED STATE OBSERVER

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Research Article

Date of Submission: 20-04-2026 Date of Acceptance: 15-05-2026 Date of Publication: 19-06-2026

ABSTRACT

Since congestion is the primary cause of computer network performance deterioration, controlling congestion has emerged as one of the core problems in computer networks. The method to stop the network's performance from deteriorating as a result of variations in its traffic load is called congestion control. Ineffective resource use might result in network failure in the absence of adequate congestion management techniques. Therefore, congestion management is an attempt to adjust a network's performance to variations in traffic load without negatively impacting users' perceived utility.

In order to enhance the efficacy of congestion control on TCP/IP networks by predicting the uncertainties and disturbances in the network, this study presents a unique technique for internet congestion management employing an Extended State Observer (ESO) in conjunction with proportional-derivative (PD) control.

The limitations of various classical observers, such as the Disturbance Observer (DO), are also covered in this study, along with how ESO overcomes them by applying the concept to real-world non-linear systems. The simulation demonstrates that the extended state observer performs much better when handling dynamic uncertainty and network parameter fluctuation.

Index Terms: TCP/IP, Disturbance Observer (DO), Extended State Observer (ESO), Proportional-Derivative (PD).

INTRODUCTION

The Internet has historically relied on an end-to-end mechanism and adopted a best effort philosophy. End users carry out complex tasks, keeping the network's core routers simple and expandable. Additionally, this approach facilitates user software updates. Therefore, the majority of the Internet's existing functionality is found in end-user protocols, namely in Transmission Control Protocol (TCP). This approach has been successful so far, but as networks have developed and traffic volume has multiplied, routers must be active in congestion management, especially when there is a lot of traffic. In order to minimize packet loss caused by congestion, a traditional design method using a multi-path Energy Efficient Congestion Control Scheme was used in [1] by integrating congestion estimate techniques while accounting for queue size, contention, and traffic rate. However, this open-loop method makes it impossible to implement an effective control.

Numerous feedback control system models of computer networks have been presented in an effort to identify efficient methods for congestion management. Through intermediary routers, TCP/IP creates a closed loop between the end hosts that depends on implicit input of congestion information through acknowledgements. Recent years have seen the proposal of the Active Queue Management (AQM) system [2]. Congestion control and congestion avoidance are two approaches to these problems. Congestion control will be covered in this as it aids in reactive planning via the use of feedback techniques. Random Early Detection is perhaps a more popular AQM technique [3]. While RED is able to

identify and react to long-term traffic patterns, it is unable to identify short-term traffic loads. [4], heuristic functions are often used to change parameters in RED, which lowers the likelihood of identifying uncertainty and disruptions in network parameters. In order to address the aforementioned shortcomings, [5] demonstrated that a proportional controller in conjunction with a Smith predictor yields an accurate model of Internet traffic and congestion management with assured stability and effective congestion control. The hybrid fuzzy-PID controller, a fuzzy controller-based active queue management (AQM) method [6], demonstrates that the novel hybrid fuzzy PID controller outperforms PID and random early detection (RED) controllers. A strong 2-DOF PID control was used in [4] to further enhance performance and improve congestion management. Hobenbichler's method provided a clear explanation of a linear gain scheduling utilizing PID as provided by T. Alvarez in [7] stability area.

Meanwhile, a well-known classical observer called the Disturbance Observer (DOB) was established in [8] with an artificial delay. However, DOB can only function effectively under the ideal assumption of slow fluctuating noise or constant disturbances, i.e., d_ = 0, which is thoroughly detailed in section III that follows.

A new AQM system that supports TCP flows and prevents severe congestion owing to uncertainties and disruptions in network parameters introduces a contemporary observer known as an extended state observer (ESO) in response to the aforementioned shortcomings in different techniques. Due to its ability to manage the internal dynamics and external disturbances of a non-linear plant from its input-output data, ESO has been used in a variety of sensitive plants, including nuclear reactors and space applications like NASA's flywheel [9]. In keeping with this, this research uses ESO to solve the problem of predicting network parameter disturbances.

This paper is structured as follows. The TCP/IP protocol's non-linear modeling is presented in Section II. The disturbance observer's limitations are briefly discussed in Section III. The mathematical method for determining uncertainty using a non-linear extended state observer and associated control parameter is described in Section IV, along with a simulation of the same. By integrating feedback control, or ESO+PD, in Section V, the concept of a robust control is extended from Section IV. Section VI concludes the discussion.

I. TCP/AQM ROUTER DYNAMIC MODEL

In this section we will be briefly discuss about the proposed non-linear model of TCP/IP protocol and linearizing the same for controller design.

A. Nonlinear model

As in the literature, a nonlinear model of TCP/AQM [10] [8] of a single congested router with a transmission capacity *C* is given as

$$\dot{W}(t) = -\frac{W(t)}{2}\frac{W(t-R(t-R(t)))}{R(t-R(t))}p(t-R(t)) + \frac{1}{R(t)} \quad (1)$$

$$\dot{q}(t) = \begin{cases} \frac{N(t)}{R(t)}W(t) - C, & q(t) > 0 \end{cases}$$

$$\max 0,\ q(t) = 0 \tag{2}$$

where W & q is the maximum window size and average queue length(i.e. buffer size), they are the positive bounded quantities i.e.,$W \in [0, \overline{W}]$ and $q \in [0, \overline{q}]$. The congestion of window size is increased after every round-trip time $R(t)$. $p(.)$ denotes the (input function) packet drop probability $p(t)\ \Xi[0, 1]$ and output is queue velocity$\dot{q}$ To linearize equation(1) following assumptions are made[4]

- active TCP session N(t) are time invariant

i.e. $N(t) \Xi N$.

- transmission link capacity are time invariant

  i.e. $C(t) \Xi C$.

- time delay argument t — Ron queue length q is assumed to be fixed to t — R_0then the linearize model of equation(1) results into

$$\dot{\delta W}(t) = -\frac{N}{R_0^2 C}(\delta W(t) + \delta W(t - R_0)) - \frac{1}{R_0^2 C}(\delta q(t) + \delta q(t - R_0)) - \frac{2C}{2N}\delta q(t - R_0) \tag{3}$$

$$\dot{\delta q}(t) = \frac{N}{R_0}\delta W(t) - \frac{1}{R_0}\delta q(t) \tag{4}$$

where W(t) and $\dot{q}(t)$are the incremental variables w.r.t operating point as a function of $f(R_0, W_0, p_0, q_0)$ with a desired equilibrium queue length q0 is given by

$$\begin{cases} R_0 = \frac{q_0}{C} + T_p \\ W_0 = \frac{R_0 C}{N} \\ p_0 = \frac{2}{W_0^2} \\ q_0 = \text{target queue lenght} \end{cases} \quad (5)$$

This lead to a nominal model, and is given as

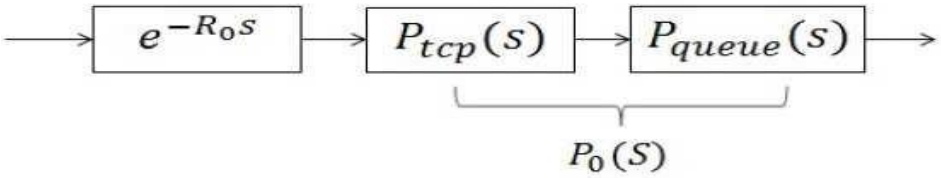


Fig. 1. Linearized model of TCP/AQM networks

$$G(s) = P_{tcp}(s)P_{queue}(s)e^{-R_0 s} \quad (6)$$

whereG(s) is the transfer function of the plant of TCP/AQM network which includes second-order system and time delay element as shown in Figure: 1
Where $P_{tcp}(s)$ and $P_{queue}(s)$ are given as

$$P_{tcp}(s) = \frac{\frac{R_n C^2}{2N_n}}{s + \frac{2N_n}{R_n^2 C}} \quad (7)$$

$$P_{queue}(s) = \frac{\frac{N_n}{R_n}}{s + \frac{1}{R_n}} \quad (8)$$

Therefore from equation (7) (8) & figure: 1 G(s) can be stated as

$$G(s)P_0(s)e^{-R_0 s} = \frac{\frac{C^2}{2N}}{\left(s+\frac{2N}{R_0^2 C}\right)\left(s+\frac{1}{R_0}\right)} e^{-R_0 s} \quad (9)$$

In order to illustrate the effectiveness of ESO method, a numerical situation will be presented by taking network parameter of [4] as $C = 3750 packets$/sec, $q_0 = 175 packets$, $T_p = 0{:}2 sec.$ For load of N = 60 TCP sessions, $p_0 = 0{:}008$& substituting the same in equation (5) we get $W_0 = 15 packets$, &$R_0 = 0{:}246$.

II. CHEN'S DISTURBANCE OBSERVER

For simplicity of analysis of Disturbance Observer let us consider a linear time-invariant, continuous-time dynamic system of TCP/AQM in equation (9) model as

$$\dot{x} = Ax + Bu + Bd \quad (11)$$

$$y = Cx \quad (12)$$

Where, A,B are the nominal system matrices considering no uncertainties and d is a constant or slow varying input disturbance which is to be estimated.

A. Mathematical modeling Constant Disturbance

Considering z_1 to estimate of d the equation (35 in [11]) can be written as

$$\dot{z}_1 = z_1 + c_1 x_1 + c_1 \dot{x}_1 = 3 \quad (13)$$

$\dot{z}_1 = \dot{3} + c_1 (Ax + Bu + Bd)$ ..... from eqn8 (14)

Choosing $\dot{3}$ as - c_1 (Ax+Bu) - c_1Bd and sub in 10 we get.....

$$\dot{z}_1 = -c_1 (Ax + Bu) - c_1 B z_1 + c_1 (Ax + Bu) + c_1 Bd \quad (15)$$

$$= (d - z_1) c_1 B \quad (16)$$

where $d - z_1$ disturbance estimation error, denoting the same by η Equation 15 reduces to

$\dot{z}_1 = C_1 \eta$ ..... where $C_1 = c_1 B$ (17)

Thus, under the assumption that $\dot{d} = 0$ we can write,

$$\dot{5} = -z_1 = -C_1 5 \quad (18)$$

or

$$\dot{5} + C_1 5 = 0 \quad (19)$$

Thus by the property of linear differential equation If $C_1 > 0$ then $5 \to 0$. Thus error$\to$0 as we increases $C_1 \gg 0$ or $C_1 \to \infty$
This is well explained in Figure: 7.

B. Limitation of Disturbance Observer

The problem with this observer is that it fails when the assumption of $\dot{d} = 0$ is violated. Thus, under the assumption that $\dot{d}$ G 0 we can write,

$$\dot{5} = \dot{d} - \dot{z_1} \quad (20)$$

$$= \dot{d} - \dot{C_1} \eta \quad (21)$$

Or

$$\dot{5} + C_1 5 = \dot{d} \quad (22)$$

Thus by the property of linear differential equation if$C1 > 0$ then $5 \to \dot{d}$, which state that error dynamics never reduces to zero under conditiond$\dot{}$ G 0 which is rather a practical case.

III. NONLINEAR EXTENDED STATE OBSERVER

As can be seen from the preceding section, the focus was limited to slow-varying or continuous disturbances that either never happen or are not realistically achievable. Chinese scientist J. Han invented the Extended State observer, a well-known contemporary observer that extends the concept to actual non-linear systems. A distinct theoretical attraction is provided by extended state observers. Controllability, observability, dynamic responsiveness, and stability are ideas of both linear and non-linear systems that are closely tied to the associated theory, which also offers a context [11][12] in which these concepts interact. The plant's status and uncertainty may be estimated via an extended state observer [13].

A. Mathematical Modeling of ESO

In general the 2nd order non-linear equation is represented as

$$\dot{y} = (y, y^{\cdot}, w) + b_0 u \quad (23)$$

Where f (.) represent the dynamics of the plant+ disturbance,
w- is the unknown disturbance, *u* -is the control signal,
y -is the measured output,
b0 -is assumed to be given.
The Equation 19 was augmented as

$$\begin{cases} \dot{x}_1 = x_2 + b u \\ \dot{x}_2 = x_3 \\ \dot{x}_3 = h \\ y = x_1 \end{cases} \quad (24)$$

Here $f(y, y^{\cdot}, w)$ and its derivative $h = f^{\cdot}(y, y^{\cdot}, w)$ are assumed to be unknown, it is now possible to estimate
$f(y, y^{\cdot}, w)$ by using state estimator for equation 20. HAN proposed a non-linear observer.

$$\begin{cases} \dot{z}_1 = z_2 + g_1(e) + b u \\ \dot{z}_2 = z_3 + g_2(e) \\ \dot{z}_3 = g_3(e) \end{cases} \quad (25)$$

where $e = y - z_1$ z_3 is the estimate of the uncertain function
f (.).
g_1 *(.)*is modified exponential function given as.....

$$g_i(e, a_i, \delta) = \begin{cases} |e|^{a_i} sign(e), & |e| > \delta \\ \frac{e}{\delta^{1-a_i}}, & |e| \le \delta \end{cases} \quad (26)$$

Where.....

- α is chosen between 0 & 1
- $g_1$is the gain.
- ðis the small number used to limit the gain.
- β is the observer gain

B. State space representation of TCP/IP protocol

As seen from equation (28) &(25)for simplicity in simulation of ESO it is better to represent transfer function of TCP/AQM plant in the form of state space. Therefore equation (9) can be represented in the form

$$\dot{x} = Ax + Bu$$

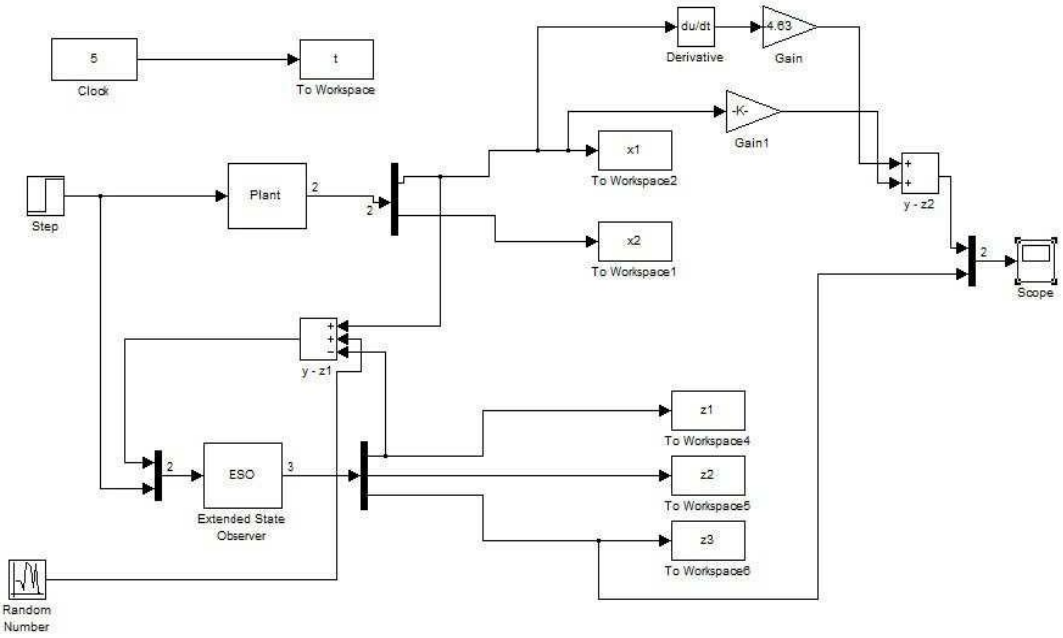
$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -2.173 & -4.63 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 133.91 \times 10^3 \end{bmatrix} u \quad (27)$$

writing Equation (27) in the form (28) we get

$$\text{Plant} \begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -2.173x_1 - 4.63x_2 + 133.91 \times 10^3 \\ \dot{x}_3 = h \\ y = x_1 \end{cases} \quad (28)$$

C. Estimation of unknown function

In this section we will estimate the unknown function as stated in equation (28). To make the simulation more practical we added random number to the o/p of the plant which is treated as noise in the network parameter.



In figure: 2gives the detail block diagram of estimating state, which is simulated in SIMULINKMATLAB and resulted are provided in Figure: 3. the profile generator is taken during the simulation initially as step input. The input is feeded to the usual plant and to ESO s as a reference input.

The difference of output of the plant x_1˙ and z_1˙ which is derived ultimately from z_3˙ as seen from Equation:25 is taken as input by ESO block, together with o/p difference, input and algorithm proposed in equation:25 & 26 the estimation z3 is carried out and plotted on scope along with output of plant. The detail description of parameters and plant and ESO is carried out in following subsection.

D. Adjustment of parameters α, β, δ

Calculation of α

Scale $\alpha_i$is chosen in between 0& 1, because it yields g_i high gain [14] [6]. In our case we consider for Equation: 26 as.....

- $\alpha_1 = 1.00$
- $\alpha_2 = 0.750$
- $\alpha_3 = 0.625$

Calculation of β Gain bi is adjusted by using pole-placement method. In our case by using matlab simulation by using **place (A' B' p)** command.$\beta_i$for Equation: 25 as.....

- $\beta_1 = 109$
- $\beta_2 = 3858$
- $\beta_3 = 44640$

Calculation of ð

ðis the small number used to limit the gain in the neighborhood of origin. In our case it is taken as for Equation: 26 as.....

- $ð = 10^{-3}$

Considering values in above subsection and substituting the same in Equation: 28, 25& 26 estimation is carried out in matlab for step in Figure: 3, its seen that z_3 (Z in Fig) converges to unknown function*f (.).*

ROBUST CONTROL

NESO from Figure 1 is assessed in a closed-loop feedback scenario, such the one shown in Figure 4, based on their open loop performance. We employed step and sine profiles in the simulation, and the profile generator offers the appropriate state trajectory in both y and $\dot{y}$. Considering

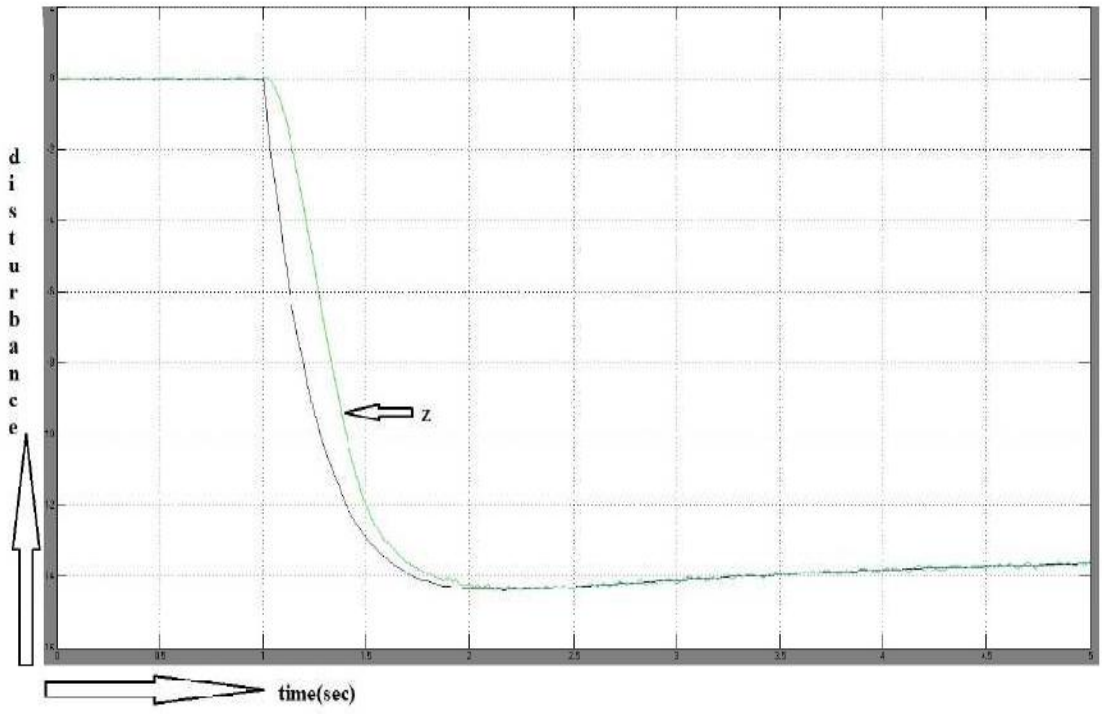


Fig. 3. Estimation of unknown function in presence of dynamic noise

the separation principle, the controller is designed independently(PD block in figure:4), assuming that all states are accessible in the control law. In the case of NESO, the extended

state information, z_3, which converges to $x_3 = f(y, y, \dot{w})$is used to compensate for the unknown $f(y, y, \dot{w})$. In particular, the control law is given as

$$u = \frac{-z_3 + Ke}{b_0} \tag{29}$$

where $e = [v_1 - z_1 , v_2 - z_2]^T$ and K is the state feedback gain that is equivalent to a proportional derivative (PD) controller design, and $v_1 = x_1^*$ and $v_2 = x_2^*$where $x_1^*$is a plant i/p as shown in figure:4 Substituting (29) in (23)

$$\ddot{y} = (f(y, y, \dot{w}) - z_3) + Ke \tag{30}$$

K matrix can be determined via pole-placement [8][15] determining K matrix as

$$\begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \begin{bmatrix} 10 \\ -05 \end{bmatrix} \tag{31}$$

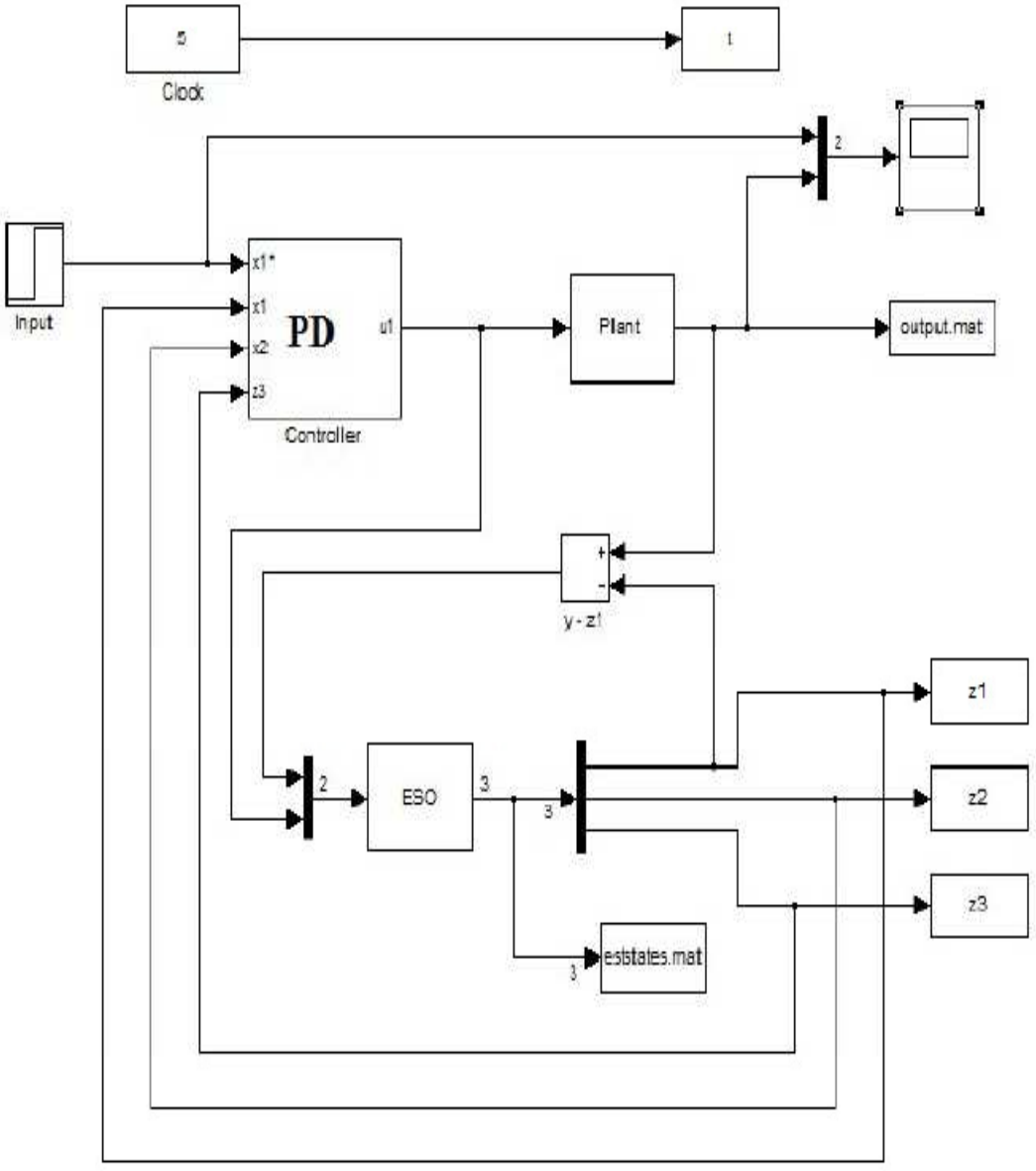


Fig. 4. Complete Robust control block.

A control o/p of network can be seen in figure: 5 for step input and to explain the beauty of ESO+PD for compensating o/p, a smooth control o/p can been seen in figure: 6 when sine i/p is applied and keeping the parameters same as that of step input.

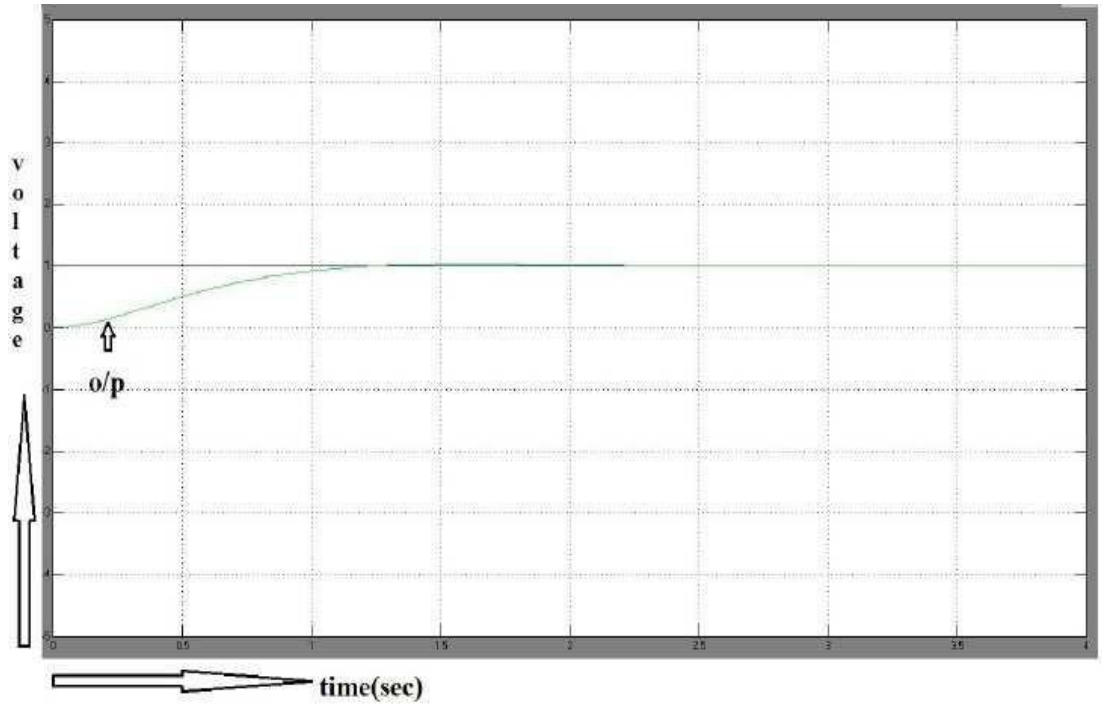


Fig. 5. O/p of proposed congestion controller ESO + PD when i/p is step signal

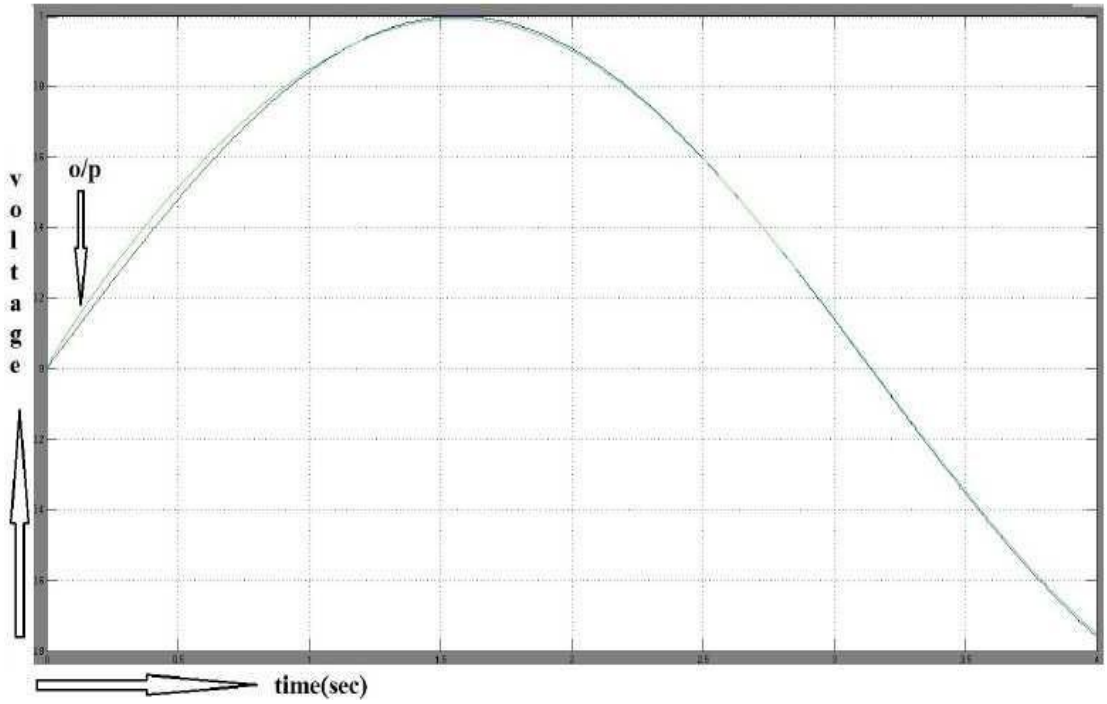


Fig. 6. O/p of proposed congestion controller ESO + PD when i/p is sine wave

CONCLUSION

1) The Disturbance Observer merely assesses the disturbances, not the plant's condition, as can be shown in section (III). Equation 22 shows that when the disturbance is not constant, i.e., d˙ G 0, DO fails to estimate the disturbances. As a result, Disturbance Observer is unable to function in real-world situations.
2) This study provides a unique AQM technique that supports TCP flows to prevent congestion in order to address the drawbacks of DOB and PID controllers. When network characteristics vary, ESO might use the following graphic to predict plant dynamics: 3. 3) ESO and PD control assist in making up for the TCP/AQM plant. As shown in figure 5, the dynamic system is guaranteed asymptotic stability. The introduction of ESO makes PD control tuning considerably easier.
4) Figures 2 and 4 show that strong control may be achieved simply by providing the plant's o/p together with reference i/p to ESO. Thus, as seen in o/p figures 3, 5, and 6, strong management is realistically possible even in the absence of plant knowledge.
5) A sensor that provides input to the controller to regulate the plant should ideally have a transfer function of unity, or Gs(s) = 1. However, in practice, the sensor generates phase lag, attenuation, and electromagnetic interference, which makes Gs(s) G 1. A little variation in Gs(s) might mislead the controller, distort the plant's output, and waste power. Figure 4 shows that sensor o/p is sent to ESO rather than the controller directly. The o/p of ESO, which is produced by adjusting the difference between the model and real o/p—that is, an observe state is fed to the controller—proves to be better than sensor o/p.

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