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Research paper

Adaptive ARX Rate Controller for multi hop MANET

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Abstract

TCP is a well-known transport protocol developed for wired networks. But, TCP does not work well in multi-hop MANET due to burst nature. It further leads to severe intra-flow interference which reduces the throughput. In this paper, by using classical control theory, a rate based congestion control algorithm is proposed. For multi-hop MANET the number of outstanding packets in the end-to-end path should not exceed the upper bound of bandwidth delay product that is equal to h/4 where h refers to Round trip hop-count. This value has been taken as reference in our algorithm. Our algorithm regulates its sending rate based on the feedback received from plant (Multi-Hop MANET) to meet the objective point. The proposed system is estimated using ARX model where the output obtained from our system is verified against the estimated values using MATLAB coding. We also evaluate our algorithm against TCP using ns2.35 Simulator in terms of Throughput, Delay, Contentions and Packet Drop Rate

Keywords: *MANET; ARX; Transport protocol; Intra flow interference; Rate controller*.

1. Introduction

Mobile Ad hoc Network (MANET) is prevalently deployed in various scenarios where instantaneous connectivity becomes essential. It is very useful for emergency operations like disastrous evacuation, military communication and flood relief. MANET can also be used for quick communication among a group of people in a video conference or get-to-gether presentations. Multi hop ad hoc networks are well used in areas like VANETs, Wireless sensor networks, wireless mesh networks and home networking. However, wireless environment brings some peculiarities which affect the development of such networks. The most important of them is the shared nature of wireless communications that leads to Collisions and data drops.

MANET is a collection of dynamic, self-configured and radio-equipped wireless nodes without any infra structure. In MANET, source and destination nodes are located multiple hops apart from each other. This requires every intermediate node to act as a router that receives and forwards the data towards the destination node.

Though TCP was so powerful but it was not applicable for Mobile Ad-hoc Network due to various reasons. The burst delivery of TCP congestion control algorithm intensifies the link layer contentions and causes severe collisions among the nodes in decentralized Multi-hop Wireless Ad Hoc Networks. TCP uses ACK clocking mechanism. Whenever TCP receives an ACK, linearly it increases the congestion window size and it delivers the couple of packets together which initiates overloading of network. TCP does not keep track of the time when the last packet was sent. It does not consider whether the current set of packets will lead to any interference amongst them.

Routing protocols such as AODV, DSR and DSDV, assign the same route to the to-and-fro paths of DATA-ACK packets associated with a TCP connection. Further it add up to the contention levels where the acknowledgements (ACK) that compete with the data packets for medium access in the reverse path. Multiple TCP connections make the scenario even bad. TCP source meets frequent timeouts followed by retransmissions during these events. The effect of heavy link layer contentions is illustrated in a rate based congestion control mechanism is used to control the Intra Flow contentions and reduce its effect in the network.

This rate based control algorithm estimates the rate of packets transmissions in the network using feedback from the destination and controls the congestion in MANET.

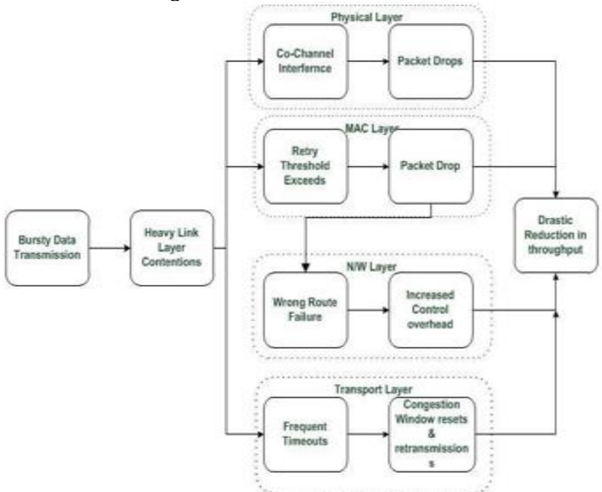

Fig.1 Effect of interference over multi hop ad hoc network

Figure1 Shows the Impact of Interference at each layer which reduces the Throughput. This is the Effect due to heavy link layer contentions. Control System Theory is used which creates a Cross Platform between Closed Loop Systems and MANET.A Closed loop system is a feedback system which uses the Output to control the rate of inputs to achieve the desired result. A Set Point is set which is the rate desired to achieve finally, and according to which the feedback is controlled. Such feedback controllers are more effective to achieve the desired goals. The rest of the paper is organized as follows, Section II describes the background of existing work and in Section III, explains the basics of ARX model. In section IV discussed about the key elements of proposed design in detail. Then evaluated the performance against TCP and validated in Section V and finally Section VI describes about the conclusion and future work.

2. Related Works

This section describes the proposals suggested to the problem of contention over multi hop MANET. The solutions are implemented as transport layer or cross layer or MAC layer approaches by the authors. Hirosuki et al [1] proposed a model for packet transmission rate using Round trip time and validated the accuracy. Using system identification the round trip time dynamics determines the coefficients of the ARX model.Constantin volosencu [2] presented a short survey on modern sensor networks, distributed parameter systems and estimation techniques by using AI tools.

Xu et al. [3] presented the reasons of inability of the protocol towards multi-hop networks. In this article they present two problems called TCP Instability and unfairness which is existing in IEEE 802.11 based multi-hop wireless ad-hoc network. Mohammad Haeri et al, [4] proposed a new TCP delay based congestion control algorithm developed a model in the absence of explicit congestion notification and captures the network delay dynamics from TCP source view.

Hiroyuki Ohsaki et al, [5] proposed a system identification by treating the network seen by source and destination hosts as black box. The end to end delay dynamics modelled as a SISO increases the delay dynamics. Radha et al [6] proposed that the time interval between the deliveries of successive data packets is dynamically measured by four hop propagation delay. Appropriate correction factor are collected from intermediate nodes. They uses this mechanism to analyze the performance of the algorithm with respect to TCP New Reno and improvements are also shown.

Adams et al [7] have presented a method to characterize the delay and the loss of a transmission link end to end multicast measurements. Gianniakis et al [8] presented a state art algorithms where the communication between the sensors over single hop noisy links for consensus based estimation in as hoc WSN. This framework uses two types of filtering called kalman and adaptive filtering.

In the paper [9], it is considered the problem of estimating the field at arbitrary positions of interest, where there are no sensors, from the irregularly placed sensors. The sensor network on a graph is mapped by introducing the concepts of interconnection matrices, system digraphs, and cut point sets, real-time field estimation algorithms are derived.

Sundaresan et al. [10] contemplated a trailblazing transport protocol, for mobile ad hoc network. By the queuing delay, this protocol performs rate based transmission incurred at each intermediate node. Sundaresan et al. [11] expressed the problems of IEEE 802.11 standard over MANET and says that it is not suitable for multi-hop network. They also mentioned about the changes that are needed to be made to make the standard suitable at MAC layer.

Fu et al. [12] analyzed the cause for packet drops in multi hop MANET and contention and buffer overflow are two primary factors are responsible for packet loss. They maintain the optimum TCP congestion window size based on the probability of link layer loss. Pen yang et al, [13] proposed an algorithm implemented as the congestion controllers in the routers.

Jin et al, [14] presented an approach for end to end congestion control in the absence of explicit feedback and delay based algorithms become the preferred method as networks scale up in capacity.

Xin Ming Zhang et al. [15] proposed a cross layer solution that adapts the congestion window size with the help of contention status from the network. The Bandwidth Delay product is calculated based on Congestion RTT rather than contention RTT, only if link failures is not caused by worst contention status. This method is used to avoid congestion window overshooting problem in TCP. The contention RTT is measured from the intermediate nodes using queuing delay, which is a metric for reflecting contention.

In this paper [16] reduces the unstationarity noise on the derived packet delay at a packet level time scale and the aggregated network traffic is not stationary.

Xin Ming Zhang et al. [17] puts forth a rate control algorithm, channel utilization and contention ratio are factors which controls the congestion window size. These values are calculated by their transmit/receive time and waiting time of intermediate nodes. The sole purpose of the above mentioned approaches is to strive for the control of the window size.

ElRakabawy et al. [18] discussed a layered approach using interference delay it performs rate based transmission and variance of recently measured RTTs. The proposed work determines the inter packet delay by utilizing the interference delay.

In [19], the authors have proposed a fast algorithm to construct a CMRP (Circulant Modulated Rate Process) for traffic modeling.

3. ARX Model

In time series modeling, an **Auto Regressive model with eXternal input** (ARX) is an autoregressive model which has exogenous inputs and it relates the model with the current value of a time series:

- Past values of the same series; and
- Current and past values of the exogenous series — externally determined series that effects the series of interest.

In addition, the ARX contains an "error" term which relates fact to the knowledge of the other terms. It was unable to predict the values exactly of the time series. Such a model can be stated algebraically as

$$y_t = F(y_{t-1}, y_{t-2}, y_{t-3}, \ldots, u_t, u_{t-1}, u_{t-2}, u_{t-3}, \ldots) + \varepsilon_t \quad (1)$$

Here *y* is the variable of interest, and *u* is the externally determined variable. In this scheme, determined variable *u* helps to predict variable of interest y. Here ε is the error term (sometimes called noise). The function *F* is nonlinear function.

To determine the transfer function H(z) of discrete-time system as in Figure 2 in identifying least square least, it converts the problem into the vector least-square problem. This is ended using the ARX model constructed as below.

The z-transforms of the inputs and outputs of the system in Fig. 2 are related by

$$\frac{Y(z)}{U(Z)} = H(Z) = \frac{\alpha_m z^m + \alpha_{m-1} z^{m-1} + \ldots + \alpha_1 z + \alpha_0}{z^n + \beta_{n-1} z^{n-1} + \ldots + \beta_1 z + \beta_0} \quad (2)$$

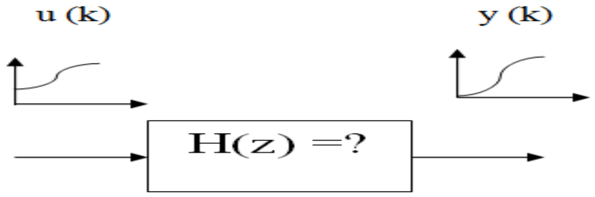

Fig.2: System identification from input/output experimental data

where αi and βi are the coefficients of numerator and denominator polynomials of H(z). By Multiplying the z(n) with the numerator and denominator of H(z) then we obtained the transfer function expressed in negative powers of z:

$$\frac{Y(z)}{U(z)} = \frac{\alpha_m z^{-n+m} + \alpha_{m-1} z^{-n+m+1} + \dots + \alpha_1 z^{-n+1} + \alpha_0 z^{-n}}{1 + \beta_{n-1} z^{-1} + \dots + \beta_1 z^{-n+1} + \beta_0 z^{-n}} \quad (3)$$

and therefore,

$$Y(z) + \beta_{n-1} z^{-1} Y(z) + \dots + \beta_1 z^{-n+1} Y(z) + \beta_0 z^{-n} Y(z) = \alpha_m z^{-n+m} U(z) + \alpha_{m-1} z^{-n+m-1} U(z) + \dots + \alpha_1 z^{-n+1} U(z) + \alpha_0 z^{-n} U(z) \quad (4)$$

Taking inverse z-transform we obtain

$$y(k) + \beta_{n-1} y(k-1) + \dots + \beta_1 y(k-n+1) + \beta_0 y(k-n) = \alpha_m u(k-n+m) + \alpha_{m-1} u(k-n+m-1) + \dots + \alpha_1 u(k-n+1) + \alpha_0 u(k-n) \quad (5)$$

This can be re-written compactly as

$$y(k) = \varphi(k).\theta \quad (6)$$

where the (n+m+1) vector θ contains the transfer function coefficient and the vector past inputs and outputs, i.e.,

$$\theta := [-\beta_{n-1} \ \dots \ -\beta_1 \ -\beta_0 \alpha_m \alpha_{m-1} \ \dots \ \alpha_1 \alpha_0 \ ]$$
$$\varphi(k) := [\, y(k-1) \ \dots \ y(k-m) \ u(k-n+m) \ \dots \ u(k-n) \ ]$$

The vector is called as regression vector and the equation is called as ARX model, called as Auto-Regression model with eXogenous inputs.

4. System Design

Performance studies of different Transport protocols focussed to control the congestion to avoid the packet drops. But however each protocol uses different ideas to reduce congestion. Mostly congestion is controlled by Window based transmissions. Since MANET works with different scenario due to mobility rate based transmissions suits to be the best way to control Congestion. Our Algorithm uses Rate based transmissions where periodic transmissions of data is done based on the rate generated. The sender does not wait for the ACK for the DATA sent, instead waits periodically to send data irrespective of receiving ACK.

However this may lead to increase the congestion in the Network because of sending the packets continuously. To avoid this, a parameter is considered to track the number of outstanding packets in the network .The count of packets in the network is controlled in order to avoid congestion and packet drops. The outstanding packet count is given as

$$BDP = kN \quad (7)$$

where N is round trip hop count. The upper bound of BDP of a chain cannot exceed kN and is the reduction factor. In our algorithm we assume k as 1/4

Addition to this factor, the four-hop propagation delay is also considered in our algorithm. The successive packet delivery time interval should be calculated in such a way that it must not be large. Since it may not utilize the bandwidth of the network which leads to contention among them. Hence this time interval is calculated based on the four-hop propagation delay of both Data and ACK.

Each intermediate node at every fourth hop is made to record the time at which the packet arrives to it at MAC layer and forwards the packet to next hop. Similarly the Source and Destination node also records the time at which the packet left and received. All the nodes saves the timestamps at the packet header which is further added to ACK's header and sent back to source. The Source node calculates the maximum of timestamps of both forward and reverse direction that is, of both DATA and ACK packets. This timestamp value is the maximum four hop propagation delay which is used to find the time interval between transmission packets. The calculations made to determine the time interval is given as

$$fhd_1 = ts_1 - ts$$
$$fhd_2 = ts_2 - ts_1$$
$$fhd_{\frac{h}{4}} = ts_{\frac{h}{4}} - ts_{(\frac{h}{4}-1)}$$

$$fhd(i) = \max(ts_1, ts_2, \dots \dots, ts_{\frac{h}{4}}) \quad (8)$$

every fourth intermediate node and fhd(i) is the maximum four hop delay of the given link at a specified time. Similarly the delay of ACK is also calculated in the same way.Once the maximum four hop delay for both DATA and ACK is estimated, the next step is to find the exponential mean which is used to determine the time interval of transmission between successive packets. The calculation of the exponential mean is given as follows

$$fhpd(i) = fhd_f(i) + fhd_r(i)$$
$$expmean(fhpd(i)) = \begin{pmatrix} k * fhpd(i) + (1-k) * \\ avg(expmean(fhpd(i-1)), \\ expmean(fhpd(i-2)), expmean(fhpd(i-3)) \end{pmatrix} \quad (9)$$

is the calculated time delay needed between the successive packet transmission delay. The value of k is taken as 0.6 and 1-k as 40. This indicates that the current delay factor depends 60 percent of current delay and 40 percent of recent three delays.

To manage the successive transmission delay, a periodic timer can be used to control the time delay between sending packets. When the network reaches its maximum BDP the delay is increased and packets are not allowed to transmit until ACK is received. By this way the Intra flow Contentions and the network Congestion is reduced.

The architecture diagram of proposed system consists of,

- Controller - Controls the feedback output to achieve Set Point and send it as the input to the Plant.
- Plant - Indicates MANET which provides the output values and which is needed to be controlled.
- Estimator- Estimates the factors required by the Controller using values from Plant.
- ARX - Estimated Output based on the system.
- Validator - Validates the Measured Output from the PLANT and estimated Output from ARX Model.

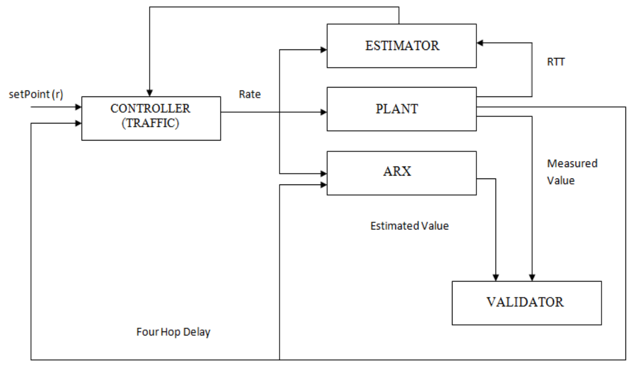

Fig.3: Architecture Diagram

We also perform a validation of the proposed system in MATLAB. The output of the system is given to ARX model where the model estimates the output of the given system. These estimated values are used to verify the values of the system and the error function is determined. This error or Loss function shows the variation of the Measured and Estimated system. Using this validation the proposed system is verified of its functionality.

5. Results and Discussion

In this chapter the performance is evaluated against TCP over the proposed cross - layer transport protocol shortly called as CLTSP. Performance analysis is carried out considering both ideal condition with no mobility and also with less mobility. Our objective is to control the intra flow contention among the nodes, in this section, it have been evaluated that the various parameters of a single transport layer connection with path length ranging from 1 to 13.

A. Throughput

In Figure 4, we measure throughput in terms of kilo bytes per second .It specified as by the destination the number of bits received per second. When the hop count increases, the contention region is distended, so the throughput of TCP comes down rapidly but in the proposed method is able to perform better than TCP. Initially throughput of CL-TSP is slightly fewer for one hop and two hops connection. If the number of hops is less than four then for every one end to end delay, CL-TSP sends a packet. When it is exceeds four, out of interference delay comes into depiction. Higher throughput has been achieved once the CL-TSP. The throughput of CL-TSP is 100% added than TCP in 7 hop counts.

B. End to end delay

Figure 5 represents End to End delay is defined as from source to destination the time period taken for the packets to travel. End to end delay can also be viewed as the sum of processing delay, queuing delay, contention delay and propagation at every intermediate node in the path. Our method CLTSP spaces out the packet delivery with sufficient interval which minimizes the queuing delay and contention delay of the packet in the intermediate nodes which leads to outstanding performance in terms of end to end delay. The average end to end delay is 5 to 6 times lesser than other discussed two protocols.

C. Number of collisions

In Figure 6 we represent the number of collisions. While transmitting two packets at the same time, interference occurred. While transmitting Request To Send (RTS), Clear To Send (CTS) and Data packets are used to calculate the number of collision drops. The proposed method uses rate based transmission congestion status which decreases the collisions significantly. The collision is nil when the hop count is less than 5, this is because of four hop propagation delay had been treated as inter packet delivery period. Compared to other methods the number of interferences is less in the proposed work as shown in figure.

D. Packet Delivery Ratio

Figure 7 represents Packet Delivery Ratio (PDR) defined the ratio of the received packets to the transmitted packets. PDR of our method is consistently high in our method. The PDR of TCP is very less for three hops flow.

E. Number of Packet Drops

In Figure 8 we analyze the various reasons for packet drops later in the same section. The number of packet drops increases because of the intra flow interferences and congestion in absence of mobility and bit errors in the network. The effort has largely reduced the packet drops by reducing contention.

F. Number of misinterpreted route failures

In Figure 9 the number of misinterpreted route failures is measured as number of route discoveries that have been executed by source with the assumption of route failures. The intermediate nodes in the path initiate route discovery procedure during the link failure that occurs due to severe contentions. The misinterpreted route failure increases the control overhead which underutilizes the bandwidth and reduces throughput.

G. Routing Overhead

Figure 10 represents Routing Overhead and it is defined as the average number of control packets produced at the network layer for transmitting the one end to end data packet. The routing overhead is very high for TCP because of the increased number of misinterpreted route failures.

H. MAC overhead

Figure 11 represents MAC overhead. MAC overhead is defined as the average number of RTS or CTS packets transmitted for the transmitting end to end data packet. It reflects the congestion status of the network. MAC overhead is comparatively less in the proposed method.

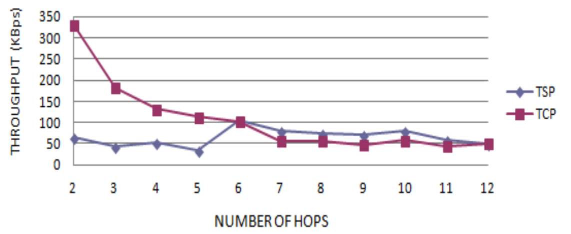

Fig.4: Throughput

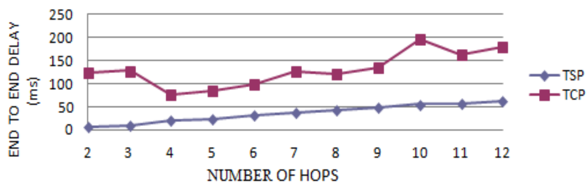

Fig.5: End to end delay

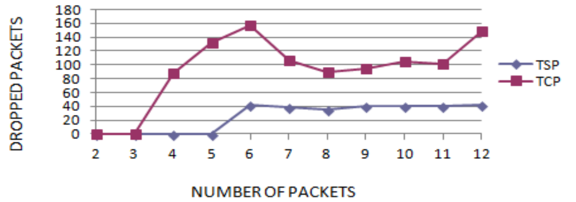

Fig.6: Number of Collisions

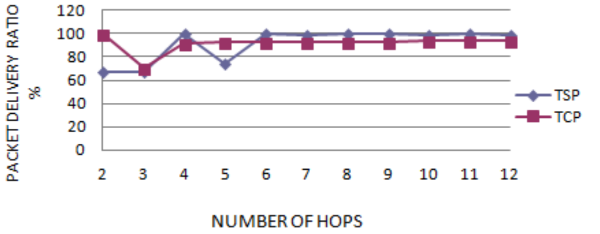

Fig.7: Packet Delivery Ratio

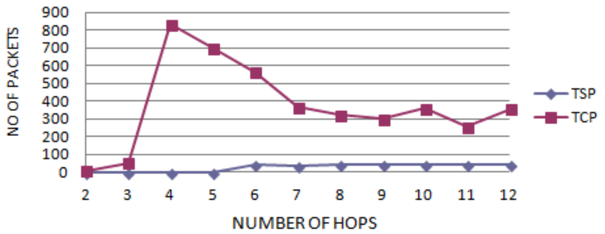

Fig.8: Number of Packet Drops

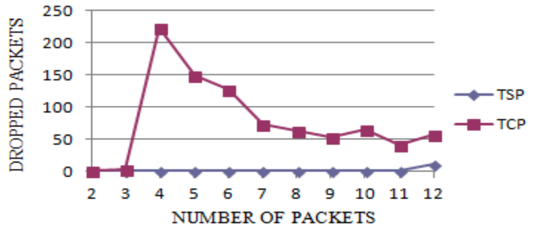

Fig.9: Number of misinterpreted route failure

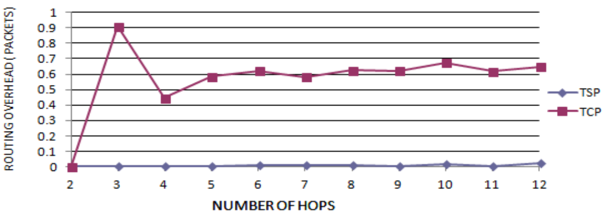

Fig.10: Routing Overhead

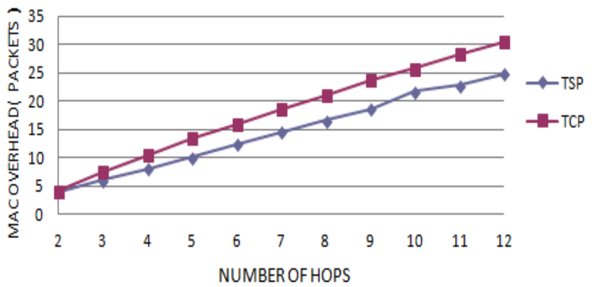

Fig.11: Mac Overhead

I. Mobility

Mobility is also evaluated with our proposed system. The evaluation is done with a grid of 5X5 nodes with limited mobility. The evaluation shows that the number of packets dropped by default TCP is more than the proposed system. However the proposed system throughput is less. Since our system considers static interference delay rate, the changing routes in mobile network uses the initial rate throughput the simulation. Hence further development is required for complex mobility scenarios.

Table.1: Mobility Evaluation

PERFORMANCE MEASURES	TCP	TSP
Packet delivery ratio	96.8462	99.0672
Average end-to-end delay	132.57 ms	19.7739 ms
Number of Route Failures	1	0
Total dropped packets	382	20
Packets lost due to no route	13	0
Packets lost due to CBK	153	11
Packets lost due to RET	77	8
Packets lost due to collision	139	1
Average throughput	200.76 kbps	120.45 kbps

J. Model Validation

Once the Plant is simulated then the next step is to evaluate and validate the output generated from the system. To perform this MATLAB tool is used where ARX model is implemented. The input and output values are stored in the file and given to MATLAB. The code uses the current and past inputs and also the past output values to determine the values of the model. The output is predicted and displayed as a graph and values.
Estimated using ARX from dataset z
Loss function 3.5122e-006 and FPE 3.52625e-006
Sampling interval: 1
The above clearly shows that the error or loss function of the estimated model is very less proving the proposed system follows exactly as ARX model. Table 2 has three fields are named as measured output, predicted output, error. Measured outputs are the values generated by the Plant which is the system under study. Predicted outputs are the values generated from the MATLAB code using ARX model concept. Error is the difference between the measured output and predicted output. From the error value it is evident that the measured output closely matches to the predicted output.

Table 2: Model Validation

Measured output	Predicted output	Error
0.0519	0.048464	0.003436
0.0524	0.049164	0.003236
0.0515	0.048704	0.002796
0.0508	0.048904	0.001896
0.0503	0.048664	0.001636
0.0497	0.048424	0.001276
0.0494	0.048804	0.000596
0.0492	0.049053	0.000147
0.049	0.049323	-0.00032
0.0489	0.049017	-0.00012
0.0489	0.048279	0.000621
0.049	0.048884	0.000116
0.0491	0.048571	0.000529
0.0489	0.048439	0.000461
0.0489	0.048694	0.000206
0.0488	0.048692	0.000108

6. Conclusion

TCP protocol is unsuitable for multi hop MANET due to its burst nature and it tails ACK clocking mechanism. Whenever it receives ACK, linearly it increases the window size then without considering the time interval of packet deliveries of a group of packets. This behavior of TCP primes to severe contentions that unnecessarily create route failures and collisions. We proposed a new cross layer transport solution which delivers data packets by reducing the contention and improving the spatial reuse. Finding the time period of inter packet delivery, four hop out of interference delay is taken as a primary metric. We evaluate the performance of the work contrary to TCP and it outperforms them in terms of throughput, end to end delay, control overhead, collisions and wrong route failures. Also the proposed system is assessed using ARX model which provided the solutions of finding the estimated outputs. Using the measured and estimated outputs it concludes the deviation is very less and the loss function is almost negligible. In the future, to gain a more in-depth performance analysis of the transport protocols and the extensive complex simulations could be carried out this project code for ad-hoc networks.

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