Modelling Ethernet for Real Time Communication

Pranav Arora (B14CS025)
Vijay Kumar Paliwal (B14CS040)
Guide: Dr. Venkata Ramana Badarla
Indian Institute of Technology, Jodhpur

I. Abstract

In modern times, as we are scaling our systems in terms of size and amount of information. Most of the real time industrial systems use Ethernet because of its high reliability and deterministic properties. Due to limited bandwidth, we face a tradeoff between cost in terms of bandwidth and cost in terms of delay and other QoS parameters in the network. We have studied the problem of modelling some QoS parameters in Ethernet for real time communication. Specifically, we target studying end to end delay incurred by any packet in the network in worst case. We first studied modelling of average delay in given Ethernet network. Then, we studied the trajectory approach for estimating worst case response time, given the network and traffic flows specifications. Also, we made a small observation to be able to calculate upper bound on the traffic rate of a flow, given upper bound on end to end delay of each flow. We have found a direction of work to upper bound the response time if trajectory approach is not applicable.

II. Introduction

In this project, we have used trajectory approach for estimating upper bound on worst case end to end delay of all flows in given ethernet network. We have completely implemented the existing trajectory approach model to generate as output, the upper bound on worst case response given the network and traffic specifications as inputs. Then we have used the positive relation between traffic rate and worst case response time to estimate the maximum admissible traffic rate of a flow, given worst case response time of each flow. Further, we have found the cases when trajectory approach can not be applied and proposed a different scheduling for upper bounding worst case response time for certain important flows. Our future work will be to find out mathematical conditions on traffic rates, when the trajectory approach is not applicable and to provide better alternate strategies to upper bound the response time.

A. *Overview and Problem Statement*

In recent real time communication system like AFDX (Avionics Full Duplex Network), train communication systems and many more, we see application of Ethernet for reliable service requirements. Due to limited bandwidth, we face the tradeoff. If we want to work with limited bandwidth, then we might need to compromise with some QoS parameters, otherwise bandwidth itself is a cost. Because, we have limited bandwidth and resources, we need to find the guarantees for QoS parameters in our network, specially in real-time systems. Some of important parameters for real-time system could be delay between transmitting data packet and receiveing at the destination. Ethernet, being reliable and simpler to model than wireless networks, can be modelled using precise theoretical modelling. For example, we can upper bound the propogation delay incurred by a packet on a link, while as this may not be possible for wireless network simply because of its unreliability. So the problem we wish to hit on is the problem of finding guarantees on QoS parameters in Ethernet which is critical for real-time communication.

B. *Motivation and Scope*

We have seen that, although we have been improving in terms of network capacity, security and many other aspects. Also, there has been lot of work towards estimating average delay in given network. But not very much work has been done for worst case delays analysis, which is crucial for any real-time communication system. Also, existing work for computing the QoS parameters for worst case are designed for specific applications like AFDX etc. We have generalised the same approach for general Ethernet. And developing better approaches for giving tighter guarantees is yet an open area.
Modelling complex topologies, flows and queues seem very interesting and challenging. And all existing approaches consider several assumptions. For example, the approaches for calculating worst case response time assume that any two consecutive packets in any flow arrive after a minimum interarrival time only. Such assumptions make the modelling and analysis simpler but limit the applicability of the same. Therefore, generalising the model upto as much as we can is again open to be explored.

III. Literature survey

First we studied basics about Ethernet and various other networks adn their applications. We then started with modelling the queues at single node[1]. This paper uses GI/G/1 model for modelling queues at single node. The MAC layer protocol they assume is IEEE 802.3az, which is EEE (Energy Efficient Ethernet). This protocol was developed for reducing energy requirements when the node is not transmitting any data. The protocol suggests two modes, burst transmission mdoe and frame transmission mode, whose comparative performance in terms of energy saving and average queueing delay is measured in the paper. This paper gives an illustrative idea about how we can model queue with a not so trivial protocol. After that we moved on to modelling delay propogation in train communication network which is a special case of general ethernet network [2]. The presented analysis provides us with a complete modelling of average queueing delay in general network. The reading gives an idea of how making certain assumptions e.g. assuming the traffic to follow Bernoulli distribution can simplify the analysis. Also, we could understand estimating average case end to end delay in general network with any topology [3]. Now we move on to our study of modelling worst case end to end delay in given network. There exist many end to end delay analysis methods for real-time switched Ethernet networks[4]. Simulation approach is based on extensive simulation of the model of network and provides distribution of the delays. This approach is expected to lead to optimistic bounds on worst case end to end delay with non-zero probability, because the worst-case delay for each flow is very rare and is likely to be missed by this approach. Other approach model-checking is also not a very scalable approach. Network calculus based approach provides good delay bounds but may be more pessimistic than trajectory approach in higher traffic rates [5]. Therefore, we will studied the trajectory approach completely. Further we studied the modelling of worst case buffer size required at each node in the network [6]. This leads to the idea of when the queue sizes may grow to infinity if not handelled, which is unique contribution of this project.

IV. Methodology

There were mainly three stages in this project. In first stage, we studied the problem of modelling average queueing delay at single node and in general network topology. We implemented these models and compared the theoretical results with simulation results. For single node modelling we compared the performance of the two modes (frame transmission and burst transmission mode). In second stage, we studied existing approaches to model worst case end to end delay in general Ethernet network. We found out that the trajectory approach is currently known best model for modelling approach. We implemented the trajectory approach. This implementation takes as input the specifications of general network and gives worst case response time of each flow as specified below.
Input specifications:
1. Lmax and Lmin (Upper and Lower bounds on network delay between any two nodes in the network)
2. Set of flows
Number of flows, Number of nodes
Flow specifications:
(Flow No.) (Minimum Interarrival Time) (No. of nodes visited by flow) (List of nodes in the path of flow)
A table of size (No of flows * No of nodes)
entry(i,j) = Max processing time of packet of flow i on node j

We then comapred the theoretical results with simulation results in many secnarios. The implementation of trajectory approach is available at https://github.com/paliwalvijay/trajectory-appraoch .

V. Experiments and Results

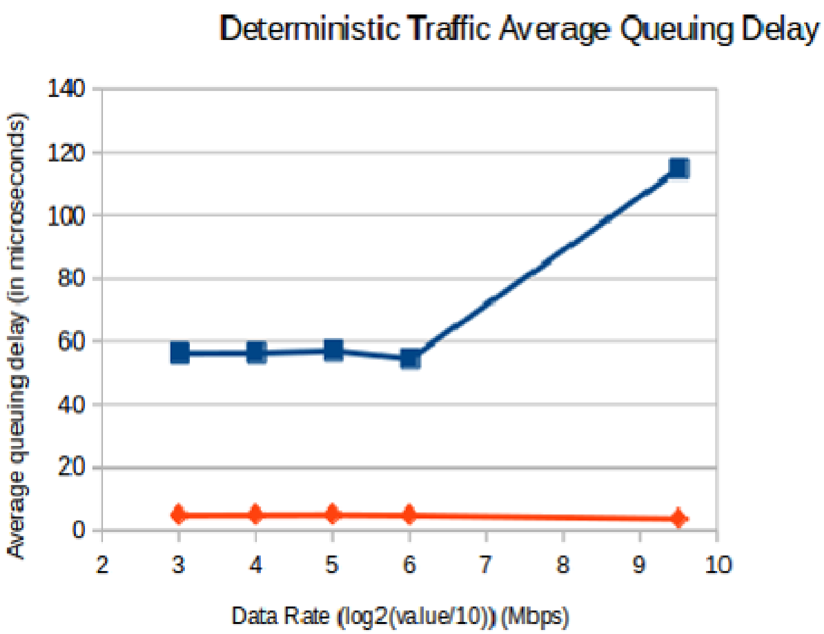

Fig. 1a. Comparision for queueing delay

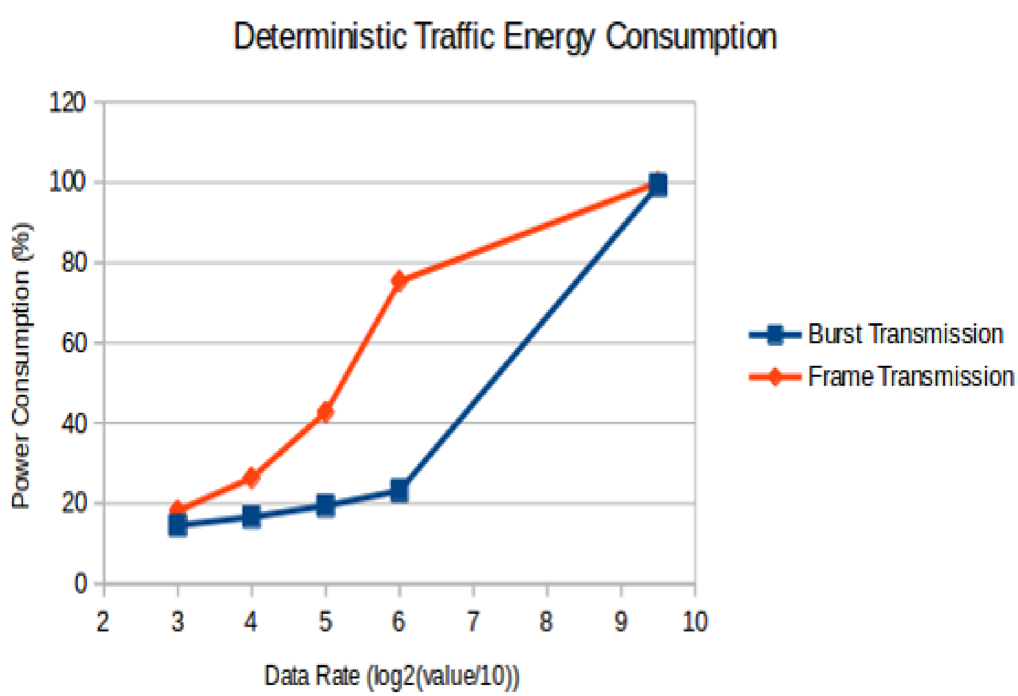

Fig. 1b. Comparison of energy requirements

Fig. 1. Comparing burst and frame transmission modes for single node

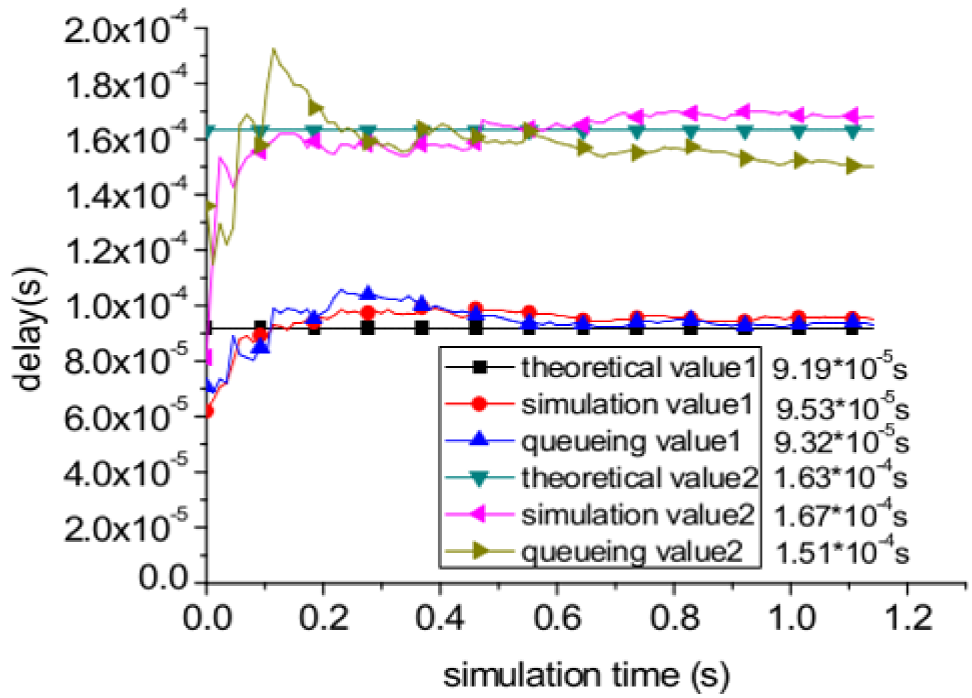

Fig. 2. Average end to end delay in general network

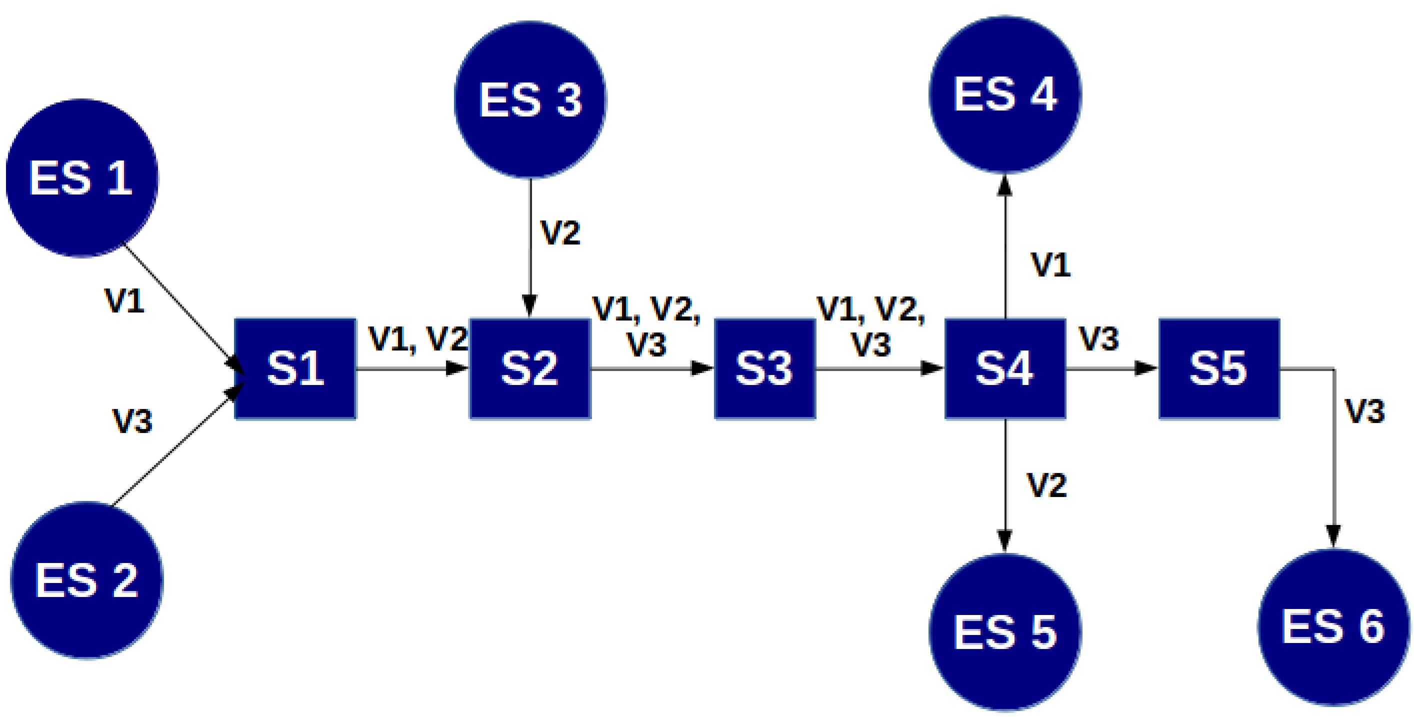

Fig. 3. Test scenario for trajectory approach for worst case response time

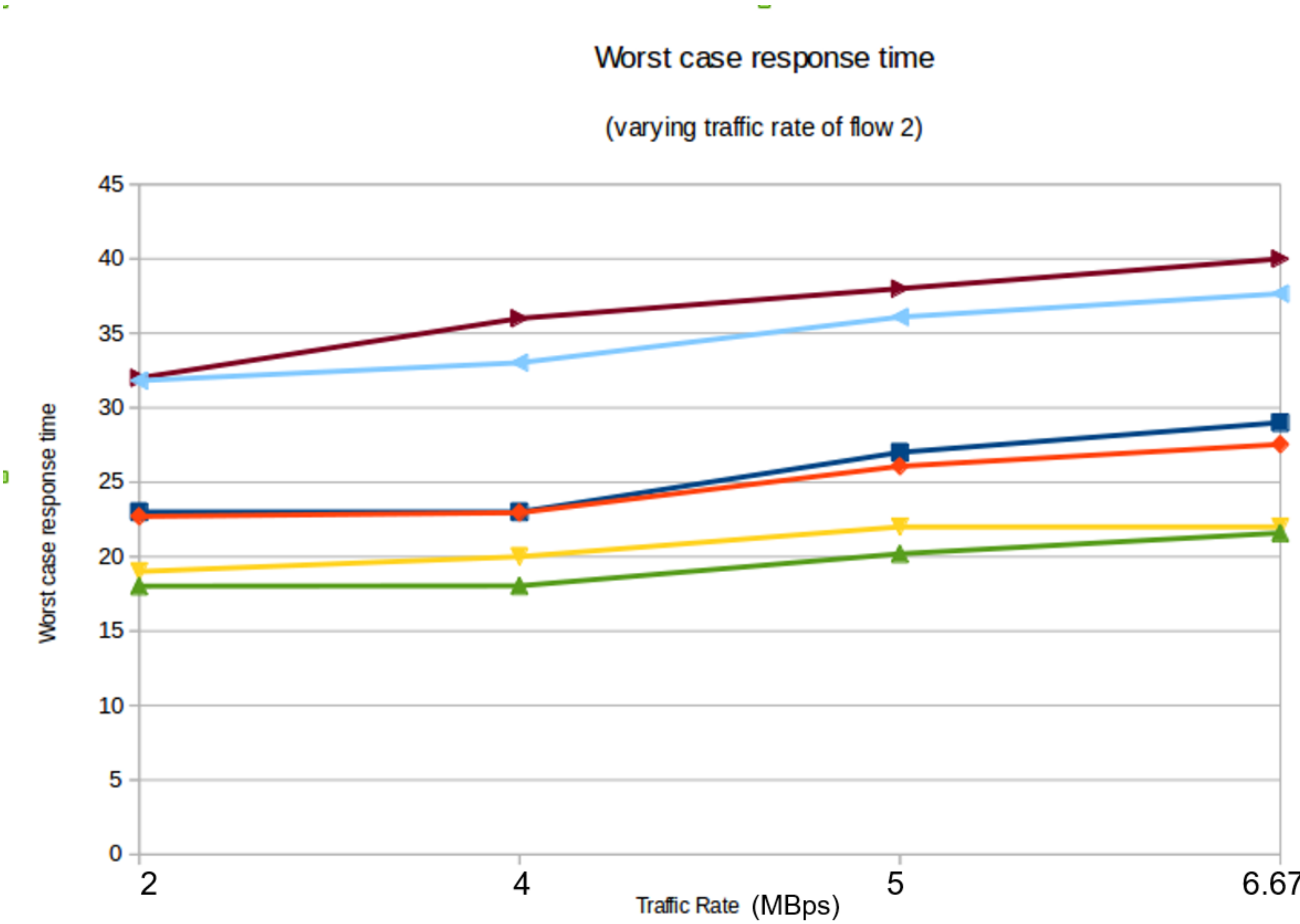

Fig. 4. Comparison of theoretical values to simulation results

As is clear from the graphs, the results are as expected.

VI. Shortcomings in trajectory approach

Although trajectory approach is the currently known best modelling approach, there are some cases when trajectory can not be applied. Trajectory appaoch is applicable only if the required buffer sizes are bounded i.e. network is stable. Therefore, we need to find when the network is stable. Also, in cases when the buffer sizes grow to infinity, we can follow alternate scheduling strategies so that we can upper bound worst case delay of some flows while denying packets from other not so important flows.

VII. Future Work

As results of our thorogh study of the problems and existing approaches, we are able to find some shortcomings in this approach, which need to be tackeled. We need to find general mathematical conditions when the queue sizes may grow to infinity in worst case. Also, we need to develop strategies to upper bound the worst case delay of flows with high priorities, while allowing to drop some low priority packets.
Also there is large open field of working towards loosening the assumptions in existing approaches to be able to model worst case end to end delay.

VIII. References

1. Sergio H., Miguel R., Manuel F., Candido L., “A GI/G/1 Model for 10Gb/s Energy Efficient Ethernet Links”, IEEE Transactions on Communications, vol. 60, no. 11,pp. 3386-3395, November 2012.

2. Xin Jiang, Linhan Guo, Sheng Hong, Jian Jhou, “Modelling Delay Propagation within Train Communication Network,” in Proc. 2015 Annual Reliability and Maintainability Symposium (RAMS).

3. Dimitri P. Bertsekas, Robert G. Gallager, “Delay Models in Data Networks” in Data Networks, 2nd ed. Prentice-Hall, 1992, ch. 3, pp. 149-269.

4. X. Lim, ”Worst-case delay analysis of real-time switched Ethernet networks with flow local synchronization”.

5. S. Martin, P. Minet, “Schedulability analysis of flows scheduled with FIFO: Application to the Expedited Forwarding class” in Proc. 20th IEEE International Parallel and Distributed Processing Symposium, pp. 8, 2006.

6. H. Bauer, J. Scharbarg, C. Fraboul, “Worst-case backlog evaluation of Avionics switched Ethernet networks with the Trajectory approach” in Proc. 24th Euromicro Conference on Real-Time Systems, pp. 78-87, 2012.

7. Out implementation of trajectory approach is available at https://github.com/paliwalvijay/trajectory-appraoch .