# Optimized Industrial Automation Network for Efficient Productivity Using Quality of Service Policy Mechanism (QPM)

**Article** · June 2019

DOI: 10.20370/prwp-re56



**2 authors:**

Emmanuel Ogbodo
Nnamdi Azikiwe University, Awka


Ifeyinwa Ogbodo
Nnamdi Azikiwe University, Awka

*Covenant Journal of Informatics & Communication Technology. Vol. 7 No. 1, June, 2019*

**ISSN: p2354 – 3566 e 2354 – 3507 DOI: 10.20370/prwp-re56**

**An Open Access Journal Available Online**

# Optimized Industrial Automation Network for Efficient Productivity Using Quality of Service Policy Mechanism (QPM)

**Emmanuel Utochukwu Ogbodo & Ifeyinwa Faith Ogbodo**

Nnamdi Azikiwe University, Awka, Nigeria
*Contact(s).* ogbodoeu@ieee.org, ifeyinwaobudulu@yahoo.com

**Received: 08. 03. 2019 Accepted: 14. 05. 2019 Date of Publication: June, 2019**

***Abstract***— In this paper, the complexity of industrial automation network when compared to the traditional IT corporate organization network or campus network, was first described. The challenges and components of industrial automation network have been highlighted. Hence, in order to overcome the challenges in the industrial automation network, the network was optimized by incorporating Quality of Service (QoS) Policy Mechanism (QPM) model in the network design. Existing mechanisms such as transmission control protocol (TCP) to deal with these problems, and the limitations of relying only on TCP were then discussed. The potential to improve the industrial automation network in the perspective of industrial internet of things (IIoT) has been reported in this paper as a further investigation in the future works. Simulation results were presented which showed that the optimized industrial automation network using QoS Policy Mechanism model gives higher performance throughput than the congestion control algorithm of the conventional TCP and the traditional network.

***Keywords/Index Terms*** — Differentiated Service (DiffServ), Industrial Automation Network, Modeling and Simulation, Quality of Service (QoS), QoS Policy Mechanism (QPM).

## 1. Introduction

One of the most crucial building blocks of Industrial automation network and control systems is Quality of Service (QoS). According to RFC2386 (Crawley *et al.*, 1998). QoS could be defined as a set of service requirements to be met by the network while transporting a packet of data stream from source to destination. In line with the notion of QoS, is an agreement or a guarantee by the network to provide a set of measurable pre-specified service attributes to the user in terms of delay, jitter, available bandwidth, packet loss, etc. Generally, organizational or industrial automation network are designed to support the best-effort service with no guarantees of associated QoS. Therefore, when a packet is lost in a network, the sender simply retransmits the lost packet. QoS guarantees a certain level of performance requirement to a data flow in accordance with requests from the application program. QoS guaranteed are important if the network performance is critical, especially for real-time industrial automation processes and control systems deployed in a large variety of industries, such as automotive, pharmaceuticals, consumer goods, pulp and paper, oil and gas, and energy.

Industrial automation processes and control systems are very demanding because it encompasses so many process plants/production facilities and network infrastructure integration. For example, production facilities may be of a very simple device with limited software and processing capabilities, which makes them susceptible to network-related disruptions or poor communication. In addition, a very quickly changing manufacturing process for example, a paper mill, or complex automation for example, multi-axis robot, demand very high levels of determinism in the industrial automation and control system. These then require real-time communication from the network infrastructure. Hence the network infrastructure deployment to support Industrial Automation Processes is quite complex and more challenging than traditional IT network infrastructure for corporate organization or campus network. This is because most manufacturing plants and process control operations require response at a very fast rate in Nano seconds; consequently, any poor network deployment may hamper its efficient operations.

Furthermore, industrial automation process and control system contains the following:

- Enterprise Area such as enterprise applications to exchange production and resource data. This is where the centralized IT systems and functions exist.
- Enterprise resource management: business-to-business, and business-to-customer services typically reside at this area. Often user's access systems exist here. For example, end-hosts access a certain resource (such as an ERP, SAP or Oracle application or webpage from www.ieee.org, a video on YouTube, etc.,) on the Internet. It is important to ensure that they do not overwhelm network infrastructure devices (such as routers, control systems servers etc.), and are able to efficiently utilize network resources, and achieve fairness.

Poor QoS of network controlled tems architecture in an industrial automation process ecosystem can lead to network congestion which can be devastating for a data transmission system as it manifests itself as exhaustion of resources that are critical to the operation of the system. These resources can be CPU, buffer space and bandwidth etc. Though Network Quality of Service (QoS) and advance congestion control protocol to handle the problem of congested network in an industrial automation process ecosystem has been a difficult target to achieve for quite a while. Due to this difficulty in the achievement, QoS has not been widely deployed in today's industrial automation networks. Therefore, the three most commonly adopted techniques to provide congestion control and QoS today are physical network isolation, network over provisioning and restricting certain nodes to transmit at the maximum capacity. Data Center and Network Operating Centers (NOC), for instance, have dedicated networks with specialized hardware and communication protocols for each class of traffic, e.g., Fiber Channel for storage, Infiniband for High Performance Computing (HPC) traffic and Ethernet channel for low traffic. In some cases, networks are highly overprovisioned by subscribing for higher bandwidth as large as more than 5 times in order to support the required QoS to serve the entire network fabric. However, these solutions do not only lead to increased installation costs but also significant increase in management and maintenance costs. In addition, multiple dedicated networks cannot leverage statistical multiplexing of traffic from different applications leading to poor utilization of available network resources even for low traffic and best effort network service.

To overcome the challenges stated above, the problem of congestion control in an industrial automation network is approached from the perspective of mechanism design. The design of network congestion control and QoS mechanism have been recently getting lots of attention as it is highly desirable to serve traffic from multiple applications and large scale industrial network so as to optimize the flow of information in an industrial automation processes.

## 2. Related Works

In this section, we review a number of distinct approaches of congestion control and QoS which have recently emerged in various perspectives. Most of the network congestion control mechanisms use the TCP as a network congestion control protocol (Jacobson, 1998). TCP was very helpful preventing congestion in the early time of the Internet and before the emergence and widespread of other types of network and networking technologies evolution.

In spite of its success in avoiding congestion in the early times of the Internet, TCP is now increasingly difficult to withstand the growing Internet and network technologies. In addition, TCP either under-utilizes or over-utilizes the network bandwidth causing the download time to be too long than necessary. The limitation of TCP in congestion control ovehigh bandwidth consuming product networks has been reported in (Brakmo *et al.*, 1994), (Lakshman & Madhow, 2005), (Katabi *et al.*, 2002). It was showed that many packet losses can result in throughput degradation. The same papers also showed that TCP is not suitable towards flows with high round trip delays. TCP is also not good for short-lived flows as seen in (Cristianodi, 2008), since the limited bandwidth is dominated by long-lived flows with large grown window size. However, TCP is now showing performance limitations and the need for new transport protocol designs has become increasingly important (Bonald *et al*., 2000), (Yee-Ting, 2007). This need has risen from TCP's inability to meet the challenges brought about by the

Other works as in (Chen *et al*., 2002; Lakshman & Upamanyu, 2005; Cristianodi, 2008) handled QoS support based on the DiffServ architecture by employing the implementation of Bandwidth Broker (BB) framework which is a QoS management framework that eases the extendibility of other QoS mechanisms such as Multiprotocol Label Switching (MPLS).

## 3. Methodology

### 3.1 Overview

The method adopted in the context of QoS Policy Mechanism (QPM) model for optimization of industrial automation network is modeling and simulation based on discrete event systems. A

tremendous growth in the range of link capacities, latencies, and Bit-Error Rates (BER) and also due to increased diversity in applications and their requirements especially in industrial automation process applications.

model is the body of information about a system gathered for the purpose of studying the system. The information that will be gathered in the design of this work is mainly network and QoS parameters. Hence the method of modeling and simulation will be used which is based on discrete event system specification formalism- DEVS, adopted from (Wainer & Rodrigo, 2011). DEVS combines the advantages of a practical approach with the rigor of a formal method; in which one consistently use models throughout the development cycle as shown in the figure 1.

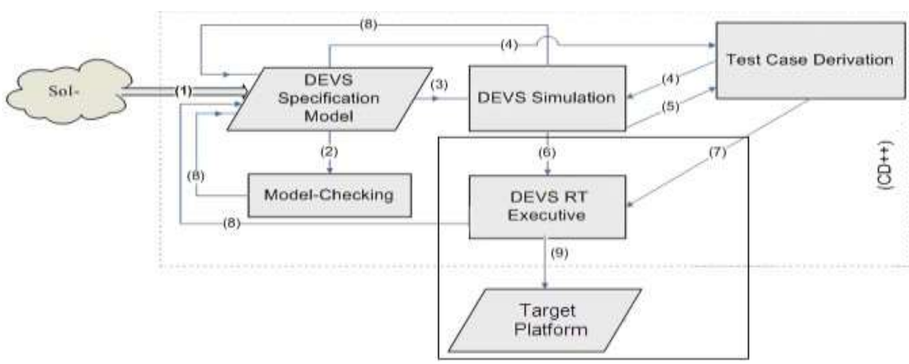



*Figure 1. Discrete event modeling development cycle*

### 1.2QoS Policy Mechanism (QPM)

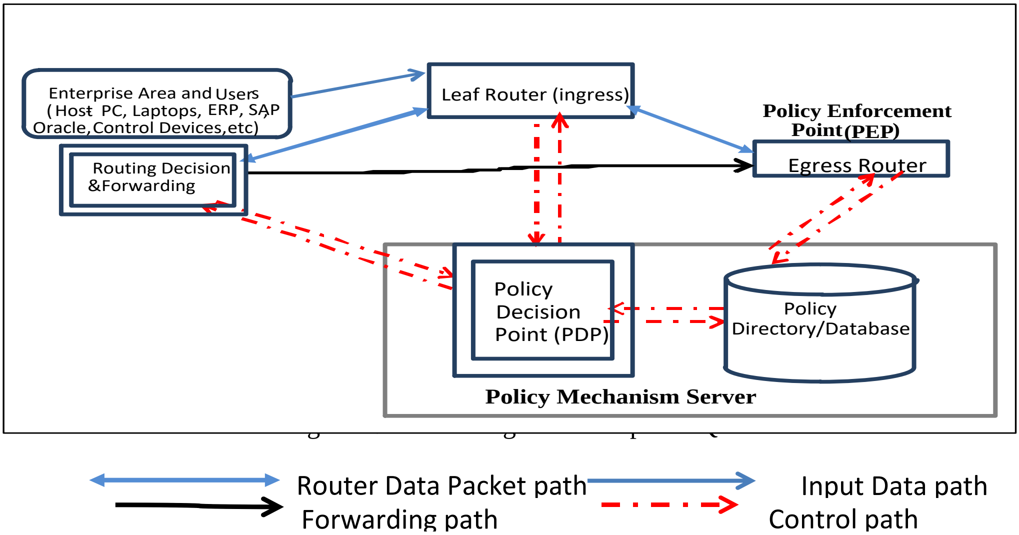
### 3.3 model

The model of QPM in an Industrial Automation network environment will address network congestion problems, network scalability, manufacturing plants and server centric failure. The model will be integrated in the Enterprise Composite NOC Model for an industrial automation processes. However, it will be based on Differentiated Services (DiffServ) Client-Server Architecture. Differentiated Services (DiffServ) is a proposed architecture for the Internet to support variable QoS requirements using a simple classification scheme. Unlike its counterpart model of IntServ (Integrated Services), the DiffServ framework does not need to maintain large state information in core routers, and only carries out aggregate resource reservation at edge routers. Therefore, DiffServ calls for a very special routing Framework and QoS from IntServ. Hence the QoS parameter such as bandwidth, packet loss, delay, jitter and latency are measurable quantities to be considered in this model. These parameters will be used in the evaluation of this work. The QPM model to be integrated in an Enterprise Composite NOC Model involves the following:

(1) Policy Mechanism Server consisting Policy Decision Point (PDP) and Policy Directory/Database.

(2) Policy Enforcement Point (PEP) comprising the edge routers and core (Routing Decision Entity). Rules are stored in the Policy Directory in a well-understood format or schema. These rules could specify for instance, the service category to be employed for a particular application, how much bandwidth is allocated to a particular flow or Type of Service (ToS) category, etc. The rules regulate access and use of network resources. The PDP entity downloads the policy rules.

The Routing Decision entity maintains the normal topology database to keep routers updated about changes in the network and to minimize routing between routers. It used the topology database to calculate QoS guaranteed routes and fast network convergence. It also inspects the DiffServ Code Point in the IP packet header to determine where to send the packet next and carries out forwarding. The edge router (ingress/egress) encounters packets flowing across the network by classifying, marking, dropping and shaping. It queries the decision entity for specific actions that are to be applied in conditioning the packet stream. The block diagram for this design architecture is illustrated in Figure 2. This architecture supports the outsourcing of policy decision making to a separate Policy Decision Point resident on a specialized policy mechanism server. The next section shall elucidate on the block diagram of the proposed design model.




### *3.4 Description of the Component of the QPM Model Block Diagram*

The various components that made up the QPM model consisted of the following:

- The Policy Decision Point (PDP) - is a Linux software entity that manages resources for IP QoS services. It is responsible for control decisions according to a Policy Directory/Database. Based on such decisions it configures the edges and routers within the network domain. The algorithm is shown below:
- Traffic originating from the Enterprise Area and an end-host reached the ingress-router for being forwarded.
- The ingress-router finds that the priority information for the (IP, Application Type) pair and caches it. The ingress-router contacts the QoS PDP (through NETCONF PROTOCOL), requesting for the priority information.
- The QoS PDP, in turn, contacts the Directory Service (Policy Database) to query for the same.
- After receiving the response from the directory, the PDP return the corresponding priority back to the ingress router.
- The ingress-router thus marks the traffic appropriately.
- All the traffic with the same ToS field is handled in a similar way at the core-routers, in conformance with the DiffServ architecture.

**3.5 Discrete Event Simulation with OPNET IT Guru Academic Edition**

OPNET IT Guru Academic edition is used for simulation of Network. OPNET Modeler is the industry's leading network development software first introduced in 1986 by MIT graduate (OPNET Technologies, 2003; Hassan & Jain, 2003). OPNET allows to design and study communication networks, devices, protocols, and application. Modeler is used by the world's most prestigious technology organizations to accelerate the research and development (R&D) process.

## 4. Simulation Testbed for QPM Model

During the implementation stage of this research, the QPM model was simulated using OPNET IT Guru as a simulation tool. As stated earlier in the previous chapter, OPNET is an object-oriented modeling and simulation tool with Graphical User Interface (GUI) that enable relatively easy means of simulation and developing models from the actual world network. The experiment of the simulation testbed is shown in Figure 3 considering the QPM block diagram of Figure 2.

Experiments were performed over this testbed in two different scenarios viz: proposed QPM model scenario and existing network scenario without the model. The scenario for the proposed QPM model, the simulation was configured as discrete event simulation and utilizing the configuration of the QoS support.

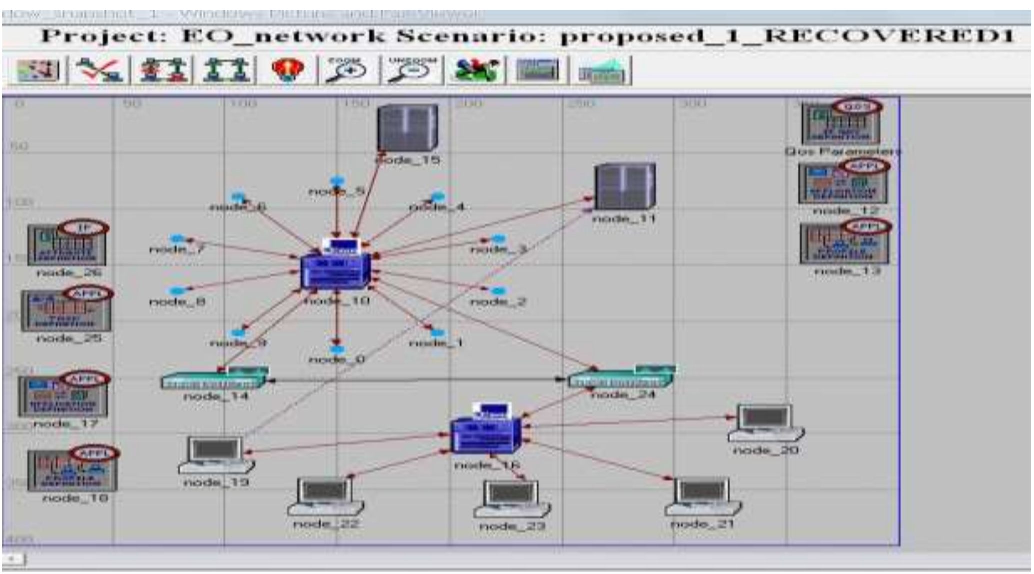



Figure 3. Simulation Testbed for Qpm Model

It was configured to mimic 60 minutes of network activities. Figure 4a & 4b shows the simulation speed and completed snap shot capture of the simulation runs. Figure 5 shows the result of the simulation runs in which QoS parameter such as delay (sec) graph plot was displayed.

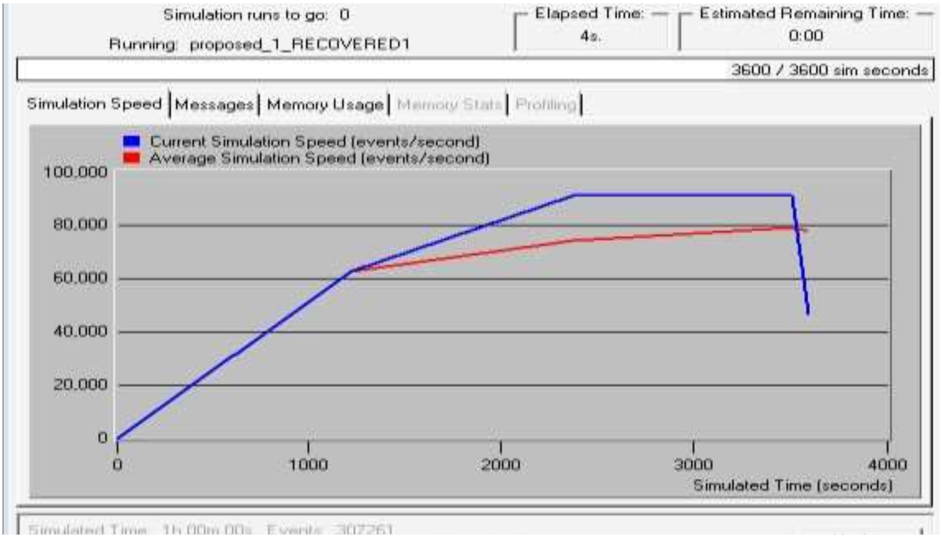


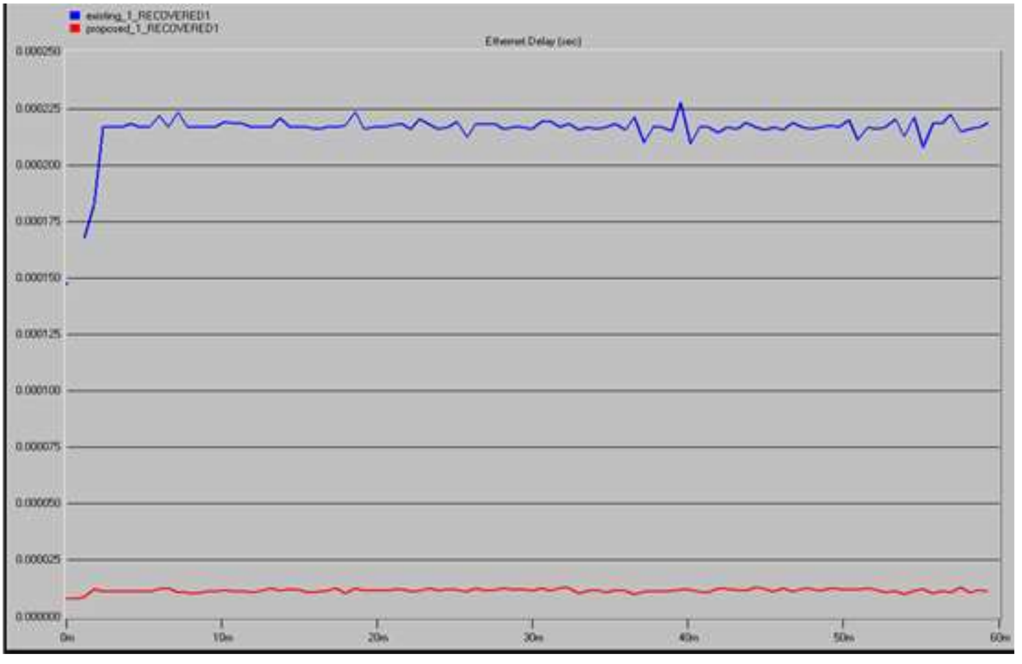

Figure 4a. Simulation Runs (Simulation Speed)

**5. Result and ANALYSIS**

Regarding the summary of the results, it is pertinent to say that the simulated results generated have no doubt validated the QPM model. As we can see the overall delay in the network was approximately in Nano seconds thereby controlling congestion and QoS support in the industrial automation network. Also the model helps to maintain appreciable throughput and guaranteed bandwidth throughout the network activities and industrial automated processes. For better understanding based on the results obtained the analysis and comparisons have been summarized as depicted in Table 1. This provides a list of key benefits of congestion control and QoS parameters relevant to an industrial automation networks by leveraging QPM Model.


Figure 4b Simulation Runs (Simulation Completed)

Figure 5. Simulation Results Comparison for Ethernet Delay




Summary/Comparison Of Existing Traditional Network and Qpm Model

| Feature/Benefits | traditional network | QPM Model |
|---|---|---|
| Guaranteed Bandwidth/Throughput Support | No | Yes |
| Low end-to-end, and Latency/delay | >10 micro seconds end-to-end.<br>> hundreds of seconds delay | < micro seconds end-to-end.<br>Approximately in Nano-seconds delay. |
| Eliminate retries and timeouts in the transmission | No (Congestion control based on TCP packet only). | Yes (Congestion control optimized with QPM) |
| Deterministic performance | No (QoS and congestion Management is based on dropping of packets. Link control is not class or flow based). | Yes (Granular, class-based link level flow control). |
| Fast deterministic transport performance | No (TCP transport is in conventional software, uses large window sizes, and therefore longer response times for handling congestion. | Yes (Congestion is handled proactively and adaptively through the use of QPM model implemented in the server. Hence shorter response time). |

## 6. Conclusion and Future Works

The QPM model incorporates several novel QoS and Congestion control mechanism that are tailored perfectly to address poor QoS in an Industrial Automation network. It was discovered that the model shows better performance throughput, service availability with lesser delay, network latency and response time. Hence this work has achieved network QoS requirement and as a result makes connectivity and operations in an industrial automation network to be carried out seamlessly in timely manner thereby contributing immensely to efficient productivity in the industries. Furthermore, integrating this model in an Enterprise Composite NOC model and utilizing Differentiated Service Client-Server architecture provides congestion free network, network QoS assurance and eliminates the problems and bottleneck associated with the existing conventional traditional network design in industrial automation network architecture.

Furthermore, optimization of industrial automation network in the approach of a novel network congestion control called QPM has been considered in this paper. The potential to improve the industrial automation network for efficient productivity can be investigated further in the perspective of industrial internet of things (IIoT) in our future work.

**Acknowledgment**

Thanks to Gilead Global System Technologies Ltd (GGSTL) for the provision OPNET IT Guru software and facility for the simulation testbed setup.

## References


Bonald, T. May, M. and Bolot, J. C. (2000). Analytic Evaluation of RED performance. IEEE INFOCOM 2000.

Bongkyo, M. Arhvami, H. (2003). DiffServ extensions for QoS Provisioning in IP mobility environments, in IEEE Wireless Communications, pp.38- 44.

Brakmo, L.S. O'Malley, S. W. and Peterson, L. L. (1994). TCP Vegas: New techniques for congestion detection and avoidance, in Proc. ACM Sigcomm.

Chen, J.C., McAuley, A., Sarangan,V., Baba,S., & Ohba, Y. (2002). Dynamic Service Negotiation Protocol (DSNP) and Wireless DiffServ, ICC'02, New York city.

Crawley, E., Nair, R., Rajagopalan, B., Sandick, H. (1998). A Framework for QoS-based Routing in the Internet. RFC 2386.

Cristianodi, F. (2008). Seminar on transport of multimedia streams over the wireless internet. University of Helsinki.

Ethernet-to-the factory 1.2 Design implementation guide, in: www.cisco.com/c/us/td/docs/solutios/Verticals/EttF/EttFDIG.html. Accessed July 24, 2014.

Henderson, T. R., Sahouria, E., Mccanne, S., Katz, R. H., and Katz, Y. H. (1997). Improving the fairness of TCP congestion avoidance. In IEEE Globecomm conference, pp. 539–544.

Jacobson. (1998). Congestion Avoidance and Control. In Proceedings of ACM SIGCOMM Symposium, (pp 314– 329) IEEE..

Katabi, D., Handley, M., and Rohrs, C. (2002). Congestion control for high bandwidth delay product networks. SIGCOMM Comput. Commun. Rev. 32, pp.89–102. IEEE.

Lakshman, T. V., & Madhow, U. (2005). The performance of TCP/IP for networks with high bandwidth-delay products and random loss. IEEE/ACM transactions on networking, 5(3), 336-350.

Nandita, D. Masayoshi, K., Zhang-Shen, R. & McKeown, N. (2005). Processor Sharing Flows in the Internet. In IW QoS.

Wainer, G. and Rodrigo, C. (2011). DEMES: A Discrete-Event methodology for Modeling and Simulation of Embedded Systems. SCS M&S Magazine – 2011 / n2 (April).

Yee-Ting, L., Douglas, L. & Robert, N. S. (2007). Experimental evaluation of TCP protocols for high-speed networks. IEEE/ACM Trans. Network, 15(5):1109–1122.