Congestion Control in Distributed Networks - A Comparative Study

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Abstract. Network congestion is characterized by delay and packet loss in the network. Increase in the rate of data transmissions as a result of increase in load, declines the throughput. Controlling congestion in network is an attempt to avoid overloading of any of the link capabilities of the intermediate nodes in the network by incorporating measures as reducing the rate of transmission or window size. This paper describes the comparison of different methods used in communication networks for controlling congestion to ensure effective communication. This study shows that the cross layered architecture with stochastic approach is providing an effective control over congestion and the response of the quality parameters is remarkably good in critical traffic situations.

Keywords: Congestion, Layered architecture, Cross layer, Deterministic model, Stochastic model.

1 Introduction

Congestion is an important issue in networks and significantly affects network performance. Congestion control is the key functionality in any communication networks. Controlling congestion leads to high utilization of network capacity, control congestion inside the network and ensure Quality of service [1]. The congestion control algorithms that are designed for wired networks are not directly applicable to wireless or distributed networks. In wired networks the capacity of each link known and the rate constraint is fixed. The rate constraint refers to the rate at which the source generates traffic, is less compared to the rate of the link. In distributed networks the capacity of each link varies [1]. The factors that judge the capacity of links are signal interference levels and power levels of independent link. One of the major TCP control components is the TCP congestion control; it controls the sender's packet transmission rate based on whether or not the network path is congested. The aim of the congestion control is to keep the buffer at least minimally occupied, to preserve fair resource allocation, and to prevent or avoid collapse of the network.

The idea of this paper is to focus the readers with a sketch of the main issues, challenges and techniques in these areas and also identify the open problem to community. The paper is organized as follows. Section 2 deals with the frame works for

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congestion control. Section2.1 compares the layered approach and cross layer approach to avoid congestion. Section 2.2 introduces two mathematical models to address congestion control which is a comparative study. The final section 3 presents the concluding remarks, and the perspectives for further research.

2 Frame Works for Congestion Control

In this paper, framework for modeling the behavior of distributed networks to control congestion is discussed. Two frame works for congestion control namely layered architecture and the cross layered architecture of distributed networks are discussed. The discussion proves that the cross layered architecture is more effective in controlling congestion and provide better QoS than the layered approach. The main objective is to formulate the mathematical framework associated with a stochastic analysis to control Congestion in networks since the network exhibits randomness in its behavior. Therefore cross layer architecture with a stochastic model prove to be the effective method to control congestion in distributed networks.

2.1 Layered Approach vs. Cross Layer Approach

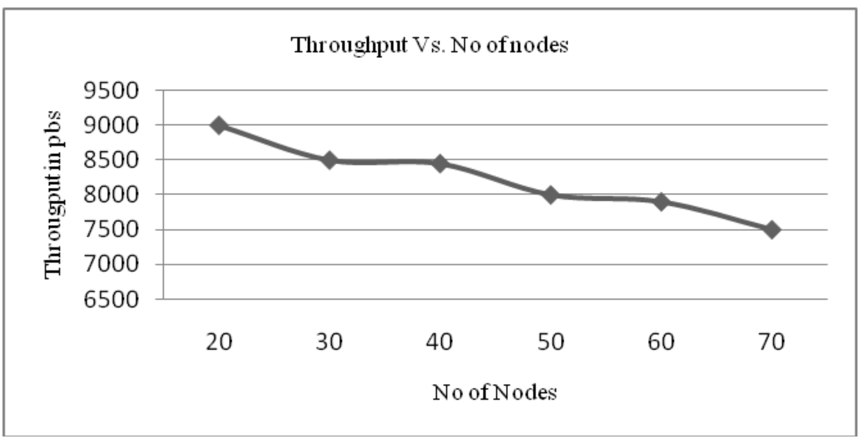
Network architecture determines functionality allocation rather than just resource allocation. M. Chiang et.al [2007] show that layered architectures form one of the most fundamental structures of network design. They adopt a modularized and often distributed approach to network coordination. Each module, namely layer, controls a subset of the decision variables, and observes a subset of constant parameters and the variables from other layers. [2]Each layer in the protocol stack hides the complexity of the layer below and provides a service to the layer above. [2]Intuitively, layered architectures enable a scalable, evolvable, and implementable network design, while introducing limitations to efficiency, fairness and potential risks to manage the network.

The conventional layered protocols in distributed networks tend to suffer from the inability to distinguish between losses due to route failures and congestion because of the inflexible structure. To overcome the challenges of dynamic environment, protocols those rely on interactions between different layers are of more important. Sometimes it is necessary to have information from various layers in order to make decision in higher layers of the network. This may result in better decision making when it comes to routing, allocating resources, controlling congestion and scheduling [3] [4]. The cross layer design is a promising technique for performance improvement in distributed networks. Cross layering allows network layer which normally are unable to communicate in the traditional layered network models to share data [16]. The shared data may allow more intelligent decision making terms of congestion control Cross layer approach to congestion control do not require precise prior knowledge of the capacity of every link. In this approach to congestion control the network jointly optimizes both the data and the resource allocation at the underlying layers [6].The performance of TCP and MAC layer protocols of the layered architecture can be evaluated using metrics like throughput, Bandwidth delay product, Packet delivery ratio, and delay and Packet loss.

Throughput can be defined as the rate of successful message delivery over a communication channel [14]. This data may be delivered over a physical or a wireless channel and it is usually measured in bits per second (bit/s or bps), and sometimes in data packets. The table 1 shows the variation of throughput as the number of nodes increases. From the graph throughput vs No of nodes it can be noticed that the throughput decreases as the number of nodes increases in case of layered approach.

Table 1. Throughput Vs. No of nodes (Layered Architecture)

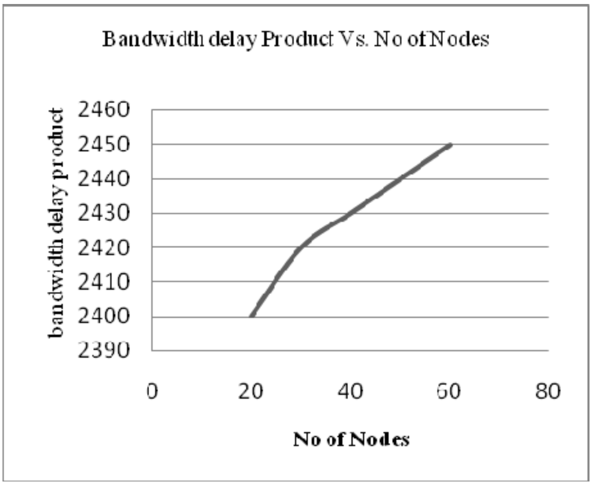
Sl.No	No of nodes	Throughput in pbs
1	20	9000
2	30	8500
3	40	8450
4	50	8000
5	60	7900
6	70	7500



Another parameter is Bandwidth-Delay Product which refers to the product of a data link's capacity (in bits per second) and its end-to-end delay (in seconds). As a result the amount of data measured in bits (or bytes) lost is equivalent to the amount of data that have been transmitted but not yet received at any given instant of time.

Table 2. Bandwidth delay Product Vs. No of Nodes (Layered Architecture)

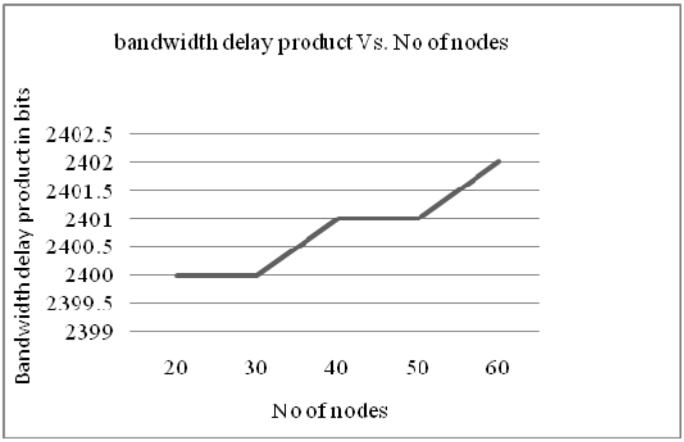
Sl.No	No of Nodes	Bandwidth delay Product in bits
1	20	2400
2	30	2420
3	40	2430
4	50	2440
5	60	2450

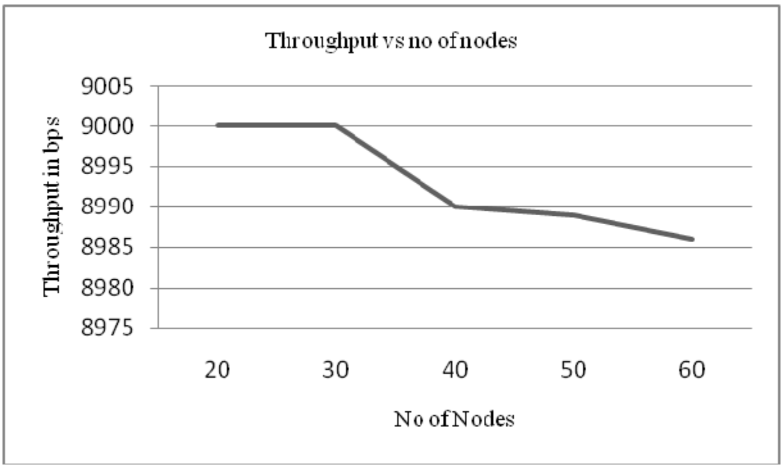


Consider the same set of nodes as layered architecture to study the network parameters like throughput, Bandwidth delay product in cross layer approach. The table 3 shows few sample data for throughput and bandwidth delay product and the number of nodes [14]. The graphs indicate that the variation in throughput as the number of nodes increases is just between 2% to 3% in cross layered approach. The cross layered architecture provides better reliability of data transmission compared to layered approach.

Table 3. Showing Bandwidth delay product, Throughput Vs. No of Nodes (Cross layered Architecture)

Sl.No	No of Nodes	Bandwidth delay product in bits	Throughput in bps
1	20	2400	9000
2	30	2400	9000
3	40	2401	8090
4	50	2401	8089
5	60	2402	8086





2.2 Deterministic Model to Control Congestion

The growing interest on congestion problems in high speed networks arise from the control of sending rates of traffic sources. Congestion problems result from a mismatch of offered load and available link bandwidth between network nodes. Such problems can cause high packet loss ratio (PLR) and long delays, and even break down the entire network system. High-speed networks must have an applicable flow control scheme not only to guarantee the quality of service (QoS) for the existing links but also to achieve high system utilization. The flow control of high-speed networks is difficult owing to the uncertainties and highly time-varying of different traffic patterns. The flow control checks the availability of bandwidth and buffer space necessary to guarantee the requested QoS. A major problem is the lack of information related to the characteristics of source flow. Devising a mathematical model for source flow is the fundamental issue. However, it has been revealed to be a very difficult task, especially for broadband sources. In order to overcome the above-mentioned difficulties, the flow control scheme with learning capability has been employed in high-speed networks [6]. But the priori-knowledge of network to train the parameters in the controller is hard to achieve for high-speed networks.

The study of Deterministic model show that the outcomes are precisely determined through known relationships among states and events, without any room for random variation. In such models, a given input will always produce the same output. While deterministic models have been shown to very [4] accurately predict the average Row rate [6], [7] such models cannot capture the variance in the rate process which may arise due to different sources of randomness. In real systems, there are two key sources of randomness. First, there can be unresponsive flows that do not react to congestion control. For instance, these could be traffic generated by UDP flows in the Internet or it could be web-mice, which are short flows which terminate before they can react to congestion control. Such unresponsive flows can be modeled as stochastic disturbances rather than deterministic model in the router. Second, the marking decisions at the router are probabilistic which again match with the stochastic nature.

Table 4. Performance Comparison of various communication network models

Sl.No	Network Parameters	Layered architecture	Cross-layered architecture	Deterministic Model	Stochastic Model
1	Throughput	With the increase in the load there is wide variation in throughput between 15% to 20%	As the load increases variation in throughput is between 5% to 8%	With the increase in the load there is wide variation in throughput between 10% to 20%	As the load increases variation in throughput is between 2% to 3%
2	Bandwidth delay Product	Due to increase in the load the buffer capacity exceeds the limit and the excess data placed in the queue so the delay product decreases	It does not change more since due to interaction with all the layers congestion is controlled to some extend	Not much variation in this parameter	optimized performance
3	Packet Loss	More than 25% of the packet are lost	Only 5% of packets are lost	About 10% of packets are lost	2% of packets are lost
4	Packet delivery ratio	75% of packets are delivered Hence 70% of reliability is achieved	95% of packets are delivered Hence 90% of reliability is achieved	85% of packets are delivered Hence 75% of reliability is achieved	95% of packets are delivered Hence 95% of reliability is achieved
5	Delay	Due to highly congested links delay incurred is more than 25% of the packet processing time	Tolerable delay incurred more than 10% of the packet processing time	Moderate delay more than 5% of the packet processing time	Delay is very less compared to other approaches more than 0.5% of the packet processing time.

From the above table it can be analyzed that the primitive layered approach which forms the backbone of all innovative research work in networking does not provide best QoS to the networks. The cross layered approach comparatively provides better Qos the Layered approach. The cross layered architecture with a Stochastic model can control congestion in distributed networks to a greater extend and can provide a good QoS.

2.3 Stochastic Approach to Control Congestion

Stochastic Model is a mathematical modeling phenomenon in the areas of science and technology. [22]It presents contributions on the mathematical methodology, from structural, analytical, and algorithmic to experimental approaches. Stochastic processing networks arise as models to study behavior of distributed computer network systems. Common characteristics of these networks are that they have entities, such as jobs, customers or packets that move along routes wait in buffers, receive processing from various resources, and are subject to the effects of stochastic variability through such quantities as arrival times, processing times, and routing protocols. Stochastic learning and control system is the best to arrive at an efficient distributed network system which will address the problem of congestion in the massive networks system and also provide better QoS as shown in Table 4.

These models are based on independent observations. In this section we discuss some of the applications of stochastic process. The third generation mobile networks are based on IP protocols and provide services to real time applications like multimedia. These applications consist of super imposed on-off sources which lead to bursts of packet streams. [17] To ensure appropriate quality of service they have modeled the networks through approximation by markov modulate rate process. Statistical analysis of high speed communication networks in very heavy traffic e.g. LAN had shown that self-similarity and long range dependence of the underlying data as the two important features. The traffic behavior has been modeled as stochastic model associated with fractional Brownian motion, which is strictly appropriate for heavy traffic limits.

The wireless queuing systems consist of long range dependent arrivals and the service rates to these arrivals vary with the changes in the wireless medium.[19]It is found that the changes in wireless medium occur slowly so it is assumed that service rate vary slower than arrival rate. The different possible limit forms that arise for both the arrival and departure process are driven by Brownian motion or fractional Brownian motion. Sometimes the rate control problem that is associated with single server Makovian queuing system may consist of impatient customer under heavy traffic conditions. [20]This paper address the situation by allowing the system manager to dynamically control the arrival or service rate depending on the current state of the system. In the situation where the service is incomplete, the customer quit the queue before congestion occurs. [21]Stochastic Petri nets (SPN) are used to study the interaction of multiple TCP sources that share a common buffer. Tokens associated with SPN represent the buffer occupancy and congestion window size. The continuous-time Markov chain model with SPN provides realistic modeling of workload and system modeling to control congestion.

Our research area is mainly concerned with designing a stochastic model with cross layered architecture to control congestion in communication networks. From the research work discussed earlier it clearly states that network exhibits a random nature at all levels whether it could be at the source or router. Hence we conclude that a stochastic model would be the best feasible model to a study the behavior of distributed network to control congestion and provide better QoS.

3 Conclusions

Congestion plays a crucial role in deciding QoS of the distributed network. Cross layer approach proves to be better solution to control congestion as it allows more intelligent decision making on the randomness flow of traffic to attain better QoS. Stochastic variability in the network has dynamic behavior of the sending rates (particularly at the onset of limit cycles in a deterministic model) under various regimes, including the more realistic conditions of large delays and resource capacities. A stochastic network with cross layered architecture appears to be more appropriate for controlling the congestion due to randomness in the number of users present and the tasks they perform.

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