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Jaymeen R. Shah
Prairie View A & M University

Mirza B. Murtaza
Middle Tennessee State University

Vipul K. Gupta
Saint Joseph's University

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Knowledge-based simulation model for performance analysis and reliability of computer networks

Jaymeen R. Shah*
Prairie View A & M University

Mirza B. Murtaza
Middle Tennessee State University

Vipul K. Gupta
Saint Joseph's University

ABSTRACT

Modeling and analysis of performance of computer networks is essential for ensuring smooth operation of an organization's networks and preventing major failures. Mathematical analysis and simulation modeling are the common procedures for network system performance analysis. In this paper, a knowledge-based simulation model is developed that can be used for predicting network performance and reliability.

INTRODUCTION

More organizations are adopting the "boundaryless organization" model. General Electric's Chairman, Mr. Jack Welch, has described this model as "where we knock down the walls that separate us from each other on the inside and from our key constituencies on the outside" (Hirschhorn & Gilmore, 1992; Quickel, 1990). This organizational model implies that communication within and outside the organizations are more open. One of the most common methods of communication adopted by organizations that reduces communication barriers is e-mail. E-mail, a type of groupware, may be used within an organization to send internal memos, update teammates regarding project status, request travel vouchers, etc. This method of communication helps organizations in not only reducing communication barriers, but also in automating tasks that waste employees' time, thus increasing employee productivity. Local area networks and wide area networks are used for transmitting e-mails and other information within and outside the organizations. Local area networks are also essential to implement document-based groupware products like Lotus Notes. These software products allow teams to integrate their knowledge,

* Corresponding author

work processes, and applications to attain improved business effectiveness. Organizations are growing in size because of acquisitions and mergers, thus more and more employees are using an organization's local area network for internal communication. As the load on the organization's local area networks increase, to ensure enhanced communication among employees, and between employees and applications, it is essential that the organization's networks are efficient and reliable. To achieve network efficiency and reliability it is necessary for organizations to model and analyze their network's performance before and after it is implemented. Thus, the issue of network efficiency and reliability has become extremely important.

Performance analysis of computer networks is now no longer a consideration of the network manager alone. The increasing use of e-mails, document-based groupware products, and client/server applications is dependent on efficient and reliable computer networks. The end-user satisfaction of client/server systems depends heavily on the timeliness of information (Guimaraes & Igarria, 1997). Therefore, database administrators and top managers are as concerned with a computer network's performance as network managers were in the past.

Traditionally the measure for network reliability has been network connectivity. That is, the measure of reliability is based on the fact that whether all the operational nodes of the network are connected or if a fraction of all the operational nodes are connected. The analysis of connectivity problem has been discussed extensively in the literature (Bertsekas & Gallager, 1992). However, the problem being NP-hard, it is difficult to solve this problem within a reasonable amount of time. Present-day communication networks are generally built using very reliable components and improvements have also been made in the area of networking protocols (Kubat, 1989). Most of the networks have some form of redundancy built in so that the messages can be re-routed in case of some component failure. Therefore, considering these facts it is important to not only consider the connectivity issue but also regard certain unacceptable delays in transmission as network failures. Transmission delays can happen due to several reasons like component failure (complete or partial), congestion, buffer overflow, etc. Connectivity measures are especially important for telecommunications networks where availability of components for message processing is vital for good network performance. In this type of networks, the component unavailability may be caused either due to the failure of a component or blocking of incoming traffic to a overloaded element of the network by a network control mechanism (Kubat, 1989).

Modeling and analysis of computer networks is important since it helps determine in advance, without actual implementation of the network, how the network with a particular configuration will perform. There are several ways in which network system performance analysis can be performed. Mathematical analysis and simulation modeling are the common procedures. Mathematical models are expected to provide exact solution, however, generally that is not the case as the problem of network analysis belongs to the NP-hard class of problems, thus solution obtained for reasonable size of a network is approximate even if the analysis is exact (Kleinrock, 1993). Spragins (1984) studied several network reliability models and concluded that approximate modeling is the only realistic approach for network modeling and analysis. In this paper, a knowledge-based simulation model is presented that can be used for predicting network performance and reliability.

This paper is organized as follows: Section 2 discusses the operation and performance evaluation of local area networks, specifically Ethernet networks; Section 3 provides an overview of knowledge-based simulation along with its application to performance evaluation of Ethernet-based local area networks; and Section 4 contains conclusions and recommendations.

OPERATION AND PERFORMANCE EVALUATION OF LOCAL AREA NETWORKS

The focus of discussion in this paper is Ethernet type of local area networks. Ethernet is considered the most successful local area networking technology of the last twenty years (Peterson & Davie, 1996). The Ethernet frame (Figure 1) can be up to 1500 bytes long. However, a frame must contain at least 46 bytes of data at the minimum. The basic operation of an Ethernet protocol, which is implemented in the network adapter, can be summarized as follows:

- a) When the adapter has a frame to send and the line is idle, it transmits the frame immediately. The maximum length of the frame ensures that an adapter will not occupy the network for a long time. Additionally, an adapter must wait for 9.6 microseconds before transmitting another frame, thus giving opportunity to other adapters on the network to transmit.
- b) On the other hand, if an adapter has a frame to send and the line is busy, it waits for the line to become idle and then transmits immediately. This is called a 1-persistent protocol since an adapter with a frame to send transmits with probability 1 whenever a busy line goes idle. Alternatively, a p-persistent protocol uses a probability $0 \leq p \leq 1$ to retransmit after a line becomes idle.

Figure 1. Ethernet Frame Format

Preamble	Destination Address	Source Address	Type	DATA	CRC
64	48	48	16		32

(bits)

- c) If two adapters begin sending frames at the same time, either because both found the line to be idle at the same time or both have been waiting for a busy line to become idle, the two frames are said to "collide" in the network. If an adapter detects collision, it stops transmitting and waits a certain amount of time and tries again. Each time an adapter tries to transmit but fails, it doubles the amount of time it waits before trying again. This strategy is called exponential backoff. The adapter gives up after a certain number of tries and reports a transmission error to the sending station.

Generally, Ethernet networks work well under low loads, a utilization rate greater than 30% is considered heavy. Additionally, the number of stations connected to an Ethernet is kept less than 200 (Peterson & Davie, 1996).

The performance of a local area network is generally measured in terms of channel utilization, delay, power, and effective transmission ratio. These measures are briefly discussed below.

- a) Channel Utilization refers to the ratio that denotes how much actual data is transmitted on a network of a particular channel capacity. Some part of the channel capacity is used up by such overhead items as retransmission and acknowledgments. Let channel capacity be denoted by R , which is maximum data transmission rate, and throughput denoted by S , which is the amount of "user data" that is carried by the network. The channel utilization, U , is the ratio of throughput to channel capacity (i.e., $U = S/R$).
- b) Delay D is the sum of service time S plus the time W spent waiting to transmit all messages ahead of it plus the actual propagation delay T_p (i.e., $D = W + S + T_p$).
- c) Power, on the other hand, combines throughput and delay into single function and it suggests an appropriate operating point for individual networks. Thus, power p is total message arrival rate for the network, λ , divided by delay D (i.e., $p = \lambda/D$).
- d) Effective transmission rate is another useful performance which is equal to $P_L / (R \cdot D)$, where P_L is the mean packet length in bits.

KNOWLEDGE-BASED SIMULATION APPLICATION TO LOCAL AREA NETWORKS

Problems in complex domains, like designing a local area network, can be solved by combining exact analysis with less precise heuristics. Local area networks may be designed with the aim of satisfying one or more objectives like minimizing queuing delays, access times, propagation delays, or retransmissions required for successful message transmission. As the problem of local area network analysis belongs to the NP-hard class of problem, it is difficult to perform exact performance analysis of a local area network. Two principal methods available for analyzing complex local area networks and predicting their behavior are simulation and knowledge-based systems.

Simulation is appropriate for problems that can be modeled analytically, and knowledge-based systems are appropriate for problems that can be expressed in the form of heuristics (Round, 1989). Simulation is a useful tool for predicting the behavior over time of a local area network with a particular set of design parameters. Generally, simulators generate numerical outputs, but leave the interpretation of the output values to the user. Further, if the user correctly interprets the simulation output and identifies some trouble spots in the local area network's performance, the simulator will not provide any assistance to the user regarding how to alleviate or eliminate these trouble spots in the local area network's performance. This limitation of the simulation approach may be overcome by using the approach of knowledge-based simulation. The knowledge-base component can interpret the simulation output, and propose changes in the design parameters to eliminate performance problems, if any.

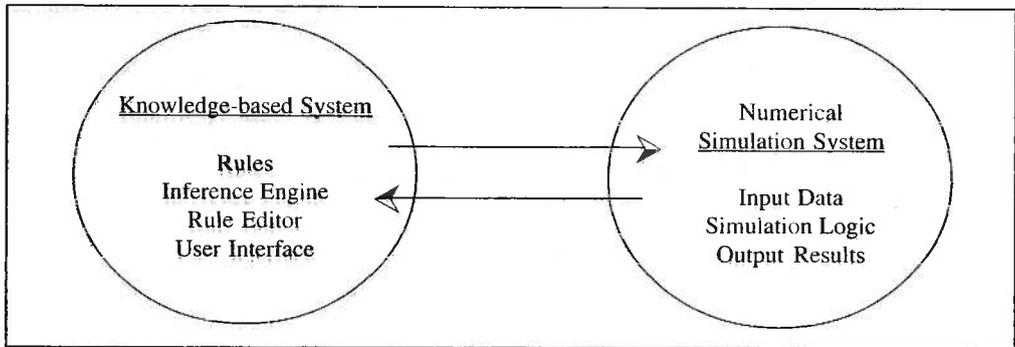
The design and analysis of a local area network involves both heuristics and analytical components, so it seems appropriate to integrate knowledge-base and simulation techniques to design and analyze a local area network. Some researchers have proposed comprehensive simulation models and methodology for performance analysis of local area networks (Sadiku & Ilyas, 1994; Chlamtac & Jain, 1984). However, these models are limited by the fact that the total number of possible local area network configurations even for a reasonable size network is very large. Thus, it is impractical to determine the local area network design that optimally satisfies the stated goal by evaluating the performance of all possible local area network design configurations using simulation. Due to this, a knowledge-based simulation approach seems to be more appropriate for designing a local area network. This type of system may assist a local area network designer in identifying a network configuration that may optimally satisfy the stated goal(s) of the local area network. Knowledge-based simulation models are essentially a hybrid of traditional numerical simulation and knowledge-based systems. There are several different types of knowledge-based simulation models, mostly defined based on the way information is passed between numerical and knowledge-base components. According to Round (1989), the four types of knowledge-based simulation models are as follows:

- a) Sequential integrated systems, where information flow is one way. In this type of system, both components are executed one after the other in sequence. The output from the knowledge-base component is used as an input to the simulation component, or vice-versa.
- b) Parallel integrated systems, where information is transferred back and forth, as needed, between the knowledge-base and numerical simulation components to assert facts or compute numerical results.
- c) Front-end knowledge-based systems, in which the knowledge-base component may be used to define parameters in order to generate scenarios for a numerical simulator. The knowledge-base component may also be used to interpret the output from the simulation.
- d) Rule-driven simulation predicts the future state of the system being studied by inferencing on the current state of the system, rather than executing the simulator. This type of integrated system is used when the knowledge about the problem domain is heuristic, and the desired outcomes can be presented in the form of overall trends or approximate classifications.

In this paper, the authors propose a parallel-integrated system for modeling local area networks (Figure 2). In this system, both the knowledge-based component and the simulation component function as independent entities. The two components pass data back and forth to each other as needed in order to assert facts or calculate numerical results.

The overall design of the system architecture proposed in this paper is presented in Figure 3. The local area network architecture used here is Ethernet or carrier-sense multiple access with collision detection (CSMA/CD). This is the most popular architecture for designing the local area networks. For a comprehensive look at local area networks and their simulation, the reader is referred to Sadiku and Ilyas (1994).

Figure 2. Overview of Knowledge-Based Simulation Systems (Parallel Integrated)



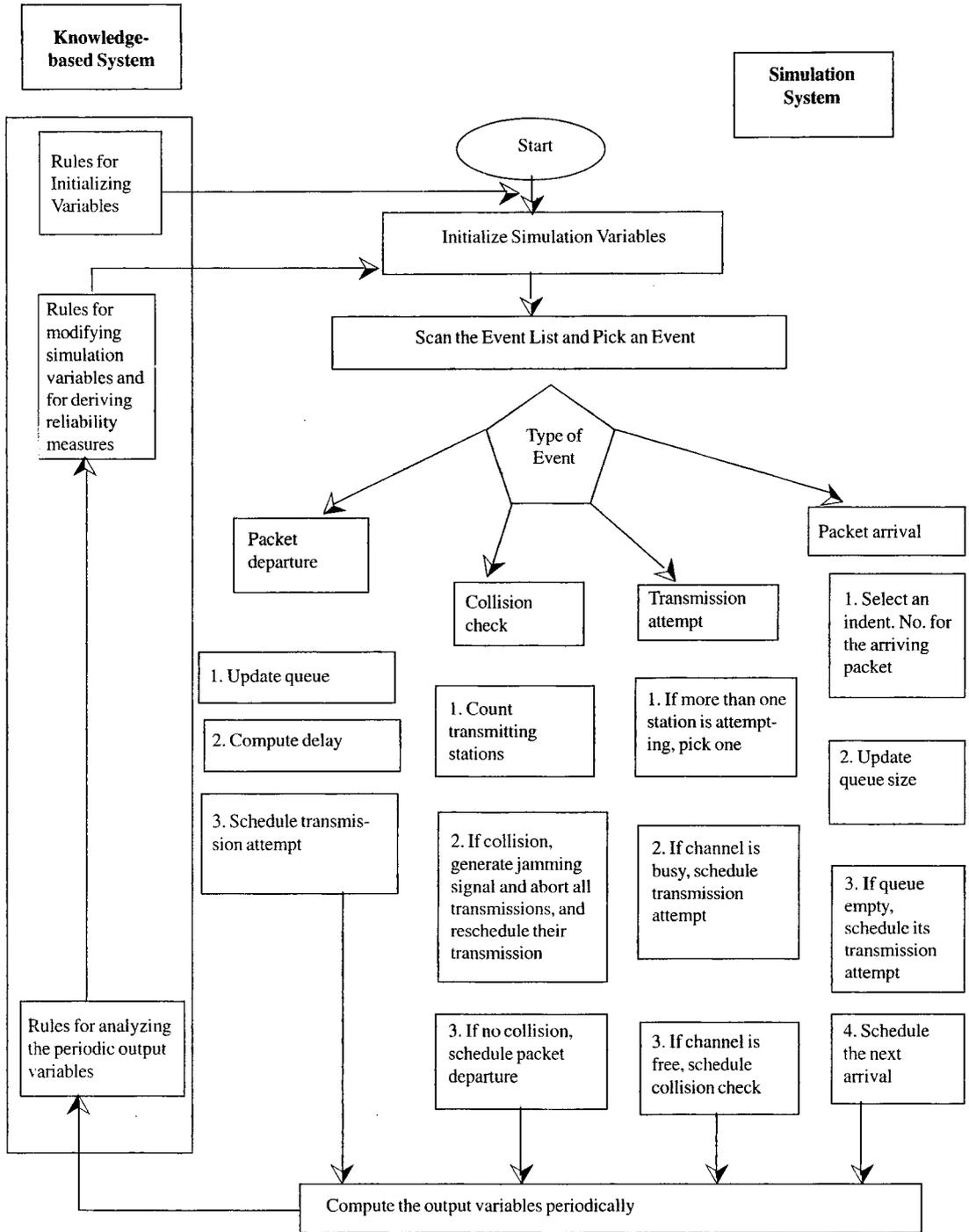
Traditionally, a simple numerical simulation model is utilized for the modeling and analysis of Ethernet LANs. This analysis requires several assumptions, some of these assumptions may be too simplistic and sometimes unrealistic. For example, few of the assumptions made by Sadiku and Ilyas (1994) are as follows:

- All stations generate the traffic at the same rate
- Packet lengths are fixed
- Transmission medium is assumed to be error-free, and any errors are only due to collisions
- The spacing between stations is the same
- The propagation delay is about 5 microseconds per kilometer of transmission medium

The authors believe that the use of a knowledge-based system along with the numerical simulation would help avoid some of the unrealistic assumptions.

The knowledge-based component of the system is the one that drives this simulation. At the start of this simulation, the knowledge-base determines values for initialization of variables. The database within the knowledge-base keeps information that is used to arrive at such values as the number of stations (users) in use during simulation, transmission rate, data packet length, number of packets to be transmitted during the simulation, and maximum buffer (queue) size at a station. As it is obvious from the above description of variables, it may be necessary to vary the values of some variables during the simulation process, e.g., number of stations and number of packets transmitted. This is not easily done in the traditional simulation models. Therefore the use of a knowledge-base is essential in a more realistic modeling situation. For example, a few simple rules can be used to determine appropriate arrival rate based on the time of the day, such as:

Figure 3. A Knowledge-Bases Simulation Model for Ethernet LAN



Rule [Morning Traffic]

IF simulation time is less than 120 minutes
THEN $current_arrival_rate = 1.3 * arrival_rate$

Rule [Lunch Hour]

IF simulation time is greater than 240 minutes and less than 300 minutes
THEN $current_arrival_rate = 0.4 * arrival_rate$

In addition to initialization of variables, another task that is performed by the knowledge-base is to continuously monitor such variables as average delay during a short time span (e.g., one minute or three minutes), number of collisions per short time span, number of retransmissions, and number of packets in buffer (queue), etc. This set of data is unnecessary to determine if a failure will occur or the delay in transmission will be greater than certain threshold value. These results will determine if there is a failure in the network. For example, knowledge-base rules such as those given below may be used to determine the performance of the network using numerical values outputted by the simulation component of the system.

Rule [High Delay]

IF $average_delay$ is greater than 0.05 seconds
THEN $network_delay$ is *too high*

Rule [Extreme Utilization]

IF $utilization_rate$ is greater than 0.40
THEN the $network_utilization$ is *extremely high*

Based on the proposed approach, the knowledge-based simulation system is used to model and analyze the performance of an initial local area network design, and if necessary, allow the knowledge-base component of the system or user to make stepwise refinements to the local area network design parameters. The knowledge-based simulation approach follows an iterative cycle to determine the local area network design parameters that optimally satisfy the design goals. The four steps in the iterative cycle are as follows:

- a) Start simulation using an initial set of local area network design parameters. These initialization parameters may be entered by the user or generated by the knowledge-base component of the system based on the stated design goals for the local area network.
- b) Determine the behavior of the local area network based on the current values of the design parameters using the simulation component of the system.
- c) Interpret simulation results using knowledge-base component, which may propose refinement(s) in the design parameter(s) value(s) of the local area network, if necessary.
- d) Refine the local area network design parameter values using the guidelines proposed by the knowledge-base component.

The knowledge-based simulation system cycles through the (b), (c), and (d) steps until the knowledge-base component interprets simulation results, and is satisfied with the performance of the local area network indicating that the proposed design goals are optimally achieved.

CONCLUSION AND RECOMMENDATIONS

This paper presents a knowledge-based simulation approach that can be used for performance analysis and for determining reliability of computer networks, especially local area networks. The advantages of this approach are that it allows consideration of organizations specific data and the knowledge gained in the past about specific network parameters, it allows for learning (the database/knowledge-base can be easily updated), and it is relatively simple to implement. This paper considered only an Ethernet type of local area network, the methodology can be easily applied to other types of local area networks and to wide area/metropolitan area or backbone networks.

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