A GRAPHICS INTERFACE FOR INTERACTIVE SIMULATION OF PACKET-SWITCHED NETWORKS

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ABSTRACT

In the past, the simulation of a communication network, was usually performed using the batch processing mode. In this paper we present a more attractive way to design and evaluate a packet-switched network: the interactive simulation of the network using computer graphics to present the network states over a simulated time interval.

The concept of a software defined network is implemented, allowing the use of an already existing network for a specific application related to distributed control systems. Moreover, the package presented could be used as a real-time network control system.

1. PROBLEM DEFINITION

In order to design the desired simulator, we had to focus on a particular aspect of computer communications: a distributed computer network for data acquisition and control, using the packet-switched technology. In many cases, computer control systems may be described as a hierarchy of computers distributed over thousands of kilometers.

These networks can be represented as two-layer systems. The first layer is the physical network, and the second layer the software defined network. The physical layer incorporates all the hardware and software requirements of an operational network such as links, node processors, buffers, communication based operating systems, etc. On the other hand, the functional layer is more relevant to the proposed application. The architecture of a control system is often based on a tree-like hierarchy, requiring that the flow of information be set accordingly. In our application the functional structure will be hierarchical, thus creating a hierarchical flow of information.

2. METHODOLOGY OF DESIGN AND PERFORMANCE EVALUATION

With two layers to design and evaluate, it is understood that there are different performance criteria for each layer. Usually, the physical network used would be an already existing one, such as the Canadian DATAPAC network [8]. The main area of interest would be to design a software defined network in order to meet the requirements of a distributed computer control system.

The design and performance evaluation of computer communication systems usually focus on the sharing of resources and on the resulting queues. Normally there are two ways to evaluate these network queues: either create an analytical model or a simulation model. In many cases it may be necessary to create both types of model.

2.1 Analytical modelling

Analytical modelling is based on the abstraction of systems so that operational research and other tools of applied mathematics can be used to the develop equations characterizing system performance [3]. Once the equations are developed, they can be solved by iterative numerical methods to produce the desired performance results under selected constraints. Depending on the complexity and the number of contraints involved, the analytical model can be more or less difficult to evaluate.

A theoretical approach using queuing theory is a cost effective and practical technique to analyze the performance of a distributed computer control system. Networks of queues have been studied extensively in the literature in the past few years and a number of different models have been developed. The model we present here is a simplification of a model suggested by Samari and Schneider [1].

The model consists of one node and its output links, as shown in figure 1. The intervals between the arrival times of

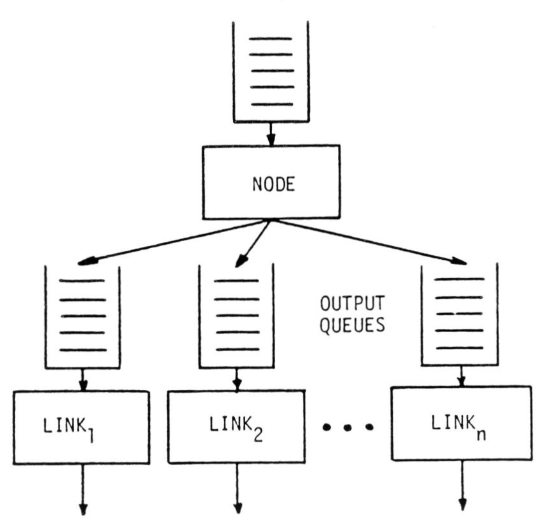

Figure 1: Queuing model for a node processor and its output links.

packets entering the node follow an exponential distribution, the processing time at the node is fixed and there is only one input queue. This node can be modelled as an M/D/1 system, and using the same notation, the links can also be modelled as M/D/1 systems. Such a model can be made much more complex by adding more nodal processors, or by including priorities on packets. But this is not our goal; we have chosen a simple case in order to describe the kind of analytical modelling required for a packet-switched network.

Among the performance criteria we find the utilization factor of the node (ρ_N), and of each link (ρ_L), the average waiting time (including service) at the node input queue (t_{qN}), and at each link input queue (t_{qL}). Using the same notation as Martin [2], the following equations characterize these performance parameters.

$$\rho_N = S\lambda_N \quad (1)$$

$$t_{qN} = S\left[1 + \frac{\rho_N}{2(1-\rho_N)}\right] \quad (3)$$

$$t_{qL} = \frac{1}{\mu C_L}\left[1 + \frac{\rho_L}{2(1-\rho_L)}\right] \quad (4)$$

where:

S: average service time at the node in seconds.

λ_N: total input traffic at the node in packets/second.

λ_L: total input traffic at a link in packets/second.

C_L: the link capacity in bits/second.

$1/\mu$: the average packet length in bits.

Equations (1) through (4) are mainly used to evaluate the behavior of the physical resources. In order to evaluate the performance of the functional layer, characterized by the flow of information, we had to model the functional traffic. A packet sent from a functional node to another will take a route determined by the physical network, but the source and destination of the packet must be such that the hierarchy is respected.

The following equations are used to model the functional traffic. The concept of this model was presented by Samari and Schneider [1], with application to the physical network.

a) traffic at the functional node i:

$$\lambda = \mu_i + \gamma_i \quad (5)$$

where

λ: the total incoming traffic in packets/second

μ_i: the total internal traffic at node i

γ_i: the total external traffic at node i

$$u_i = \sum_{j=1}^{N} \sum_{k=1}^{N} \gamma_j * DPT(j,k) \quad (6)$$

$$j = K, \quad j = i, \quad j\varepsilon \text{ funct path } (j \rightarrow k,i)$$

N: the number of functional nodes.

DPT (j,k): the destination probability table, giving the probability that a packet be sent from node j to node k.

jε funct path(j → k,i): node j belongs to the functional path from j to k, passing through node i.

b) traffic on a functional link:

S: source
D: destination

$$\lambda_{SD} = \sum_{j=1}^{N} \sum_{k=1}^{N} \gamma_j * DPT(j,k) \quad (7)$$

$$j = D, [j\varepsilon \text{ funct path } (j \rightarrow k,S)] \cap [j\varepsilon \text{ funct path } (j \rightarrow k,D)]$$

Network mathematical modelling is generally the first step in network performance evaluation, because of the direct relationship between the model parameters and the performance measurements. In most cases, this kind of modelling is too limited for the requirements of a real network; discrete event simulation becomes a good alternative.

2.2 SIMULATION

The principal advantage of simulation is its great generality and flexibility. The complexity of the simulation model increases linearly with the network complexity, which is not the case for analytical modelling [3]. Criteria such as the implementation of a sophisticated protocol or a dynamic routing technique are extremely difficult to analyse, but simulation proves to be a useful tool in these cases.

Discrete event simulation can be described as a series of events associated with the network functions. [4, 5, 6, 7] Typical events are the generation of a packet, the end of transmission of a packet or the statistical accumulation of events, just to name a few. A simplification of the model used is represented at figure 2.

- packet generation at a node
- (1) enter the node
- wait for service
- wait for end of service
- has packet arrived at destination
  yes: remove it
  no: perform routing, get next node
- wait for transmission
- wait for end of transmission
- go to (1)

Figure 2: Simplified simulation model for a packet-switched network.

The simulator was written in Fortran 77 because of the need for short processing time. All mathematical manipulations are done with integer type variables, thus shortening the processing time.

Even if it is possible to evaluate the performance of a network using simulation only, the design of an analytical model should prove very useful for program verification and the validation of results.

2.3 Performance results

The performance evaluation of a distributed computer network is done by a statistical analysis of resource and queue behavior. When the simulation model is appropriate and gives satisfactory primary results, the next step consists of carefully selecting the most sensitive parameters. These parameters should facilitate the accumulation of valuable information related to certain performance criteria, which include the total traffic at each node and link, the utilization factor of physical resources, the average queue length, etc. Some of this information may be relevant to the physical layer, but the need for information related to the functional structure is as just as important.

In order to compare the performance evaluation using analytical modelling or simulation, and also to differentiate the physical layer from the functional layer, we find at tables 1A and 1B a comparison of the total flow at each node. It can be seen that the analytical results are slightly higher. The physical and functional architectures can be found in figures 3 and 4.

The amount of data to be processed and analysed for the performance evaluation is quite large. Generally, the results are outputted in the form of printed tables or graphs. It is understood that the simulation program would have been run in a batch processing mode. A more attractive way of doing this would be to run the simulation interactively with a graphics interface for instantaneous display of network behavior.

Table 1A Physical Traffic in packets per second.

	Analytical	Simulation
Winnipeg	42.2	40.5
Halifax	25.8	23.7
Toronto	84.6	80.1
Vancouver	24.0	22.1
Ottawa	65.0	61.5
Montreal	58.0	56.6
Edmonton	24.0	22.8
Kingston	31.6	29.0

Table 1B Functional Traffic in packets per second.

	Analytical	Simulation
Winnipeg	24.0	22.7
Halifax	25.8	23.6
Toronto	90.4	85.5
Vancouver	24.0	22.1
Ottawa	65.0	61.5
Montreal	69.6	66.1
Edmonton	24.0	22.8
Kingston	25.8	23.9

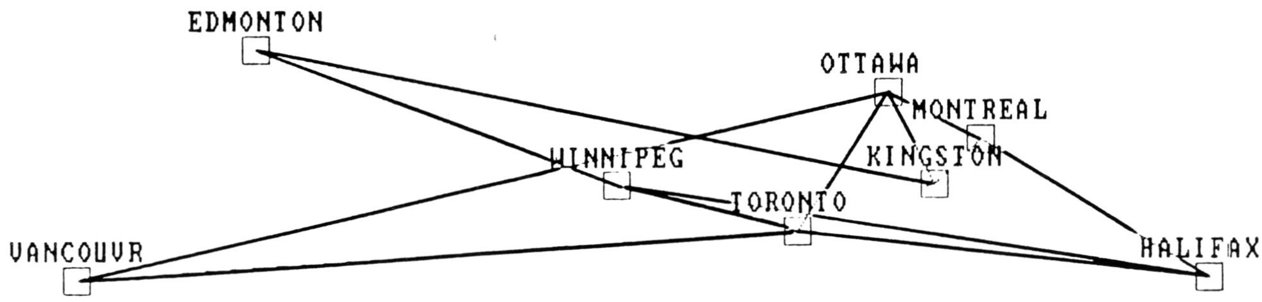

Figure 3: Physical structure of the network.

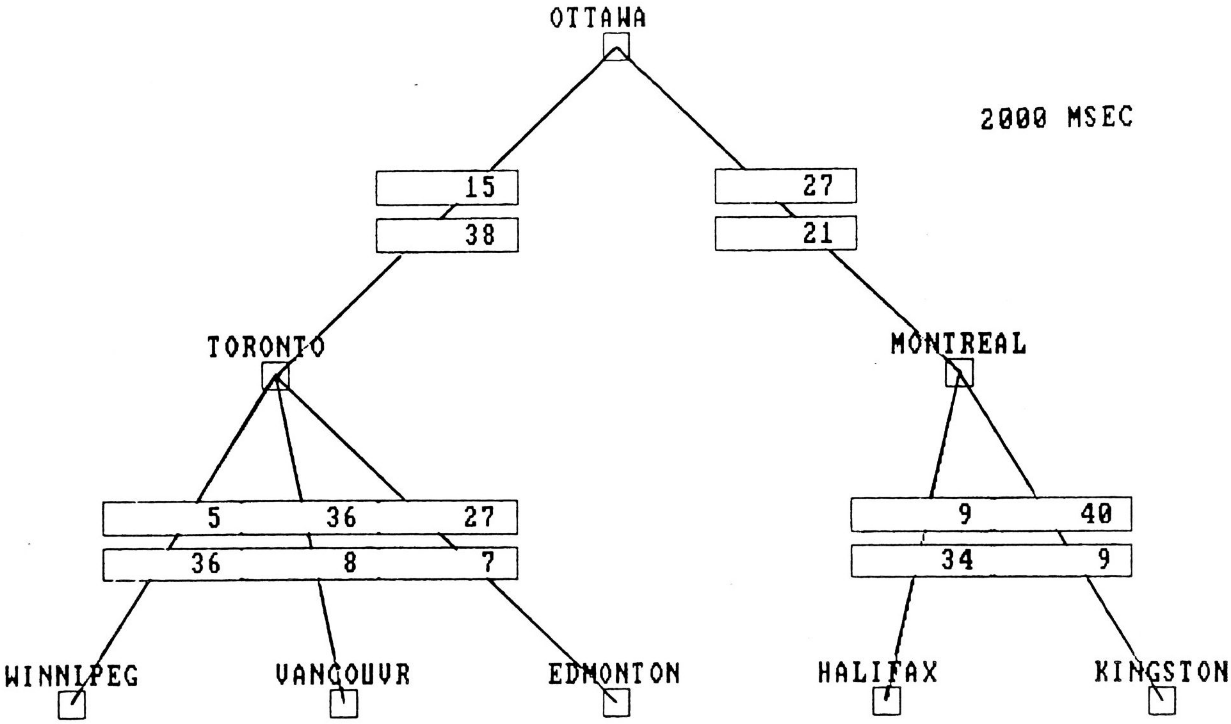

Figure 4: Functional structure of the network.

3. A GRAPHICS INTERFACE FOR INTERACTIVE SIMULATION

The graphics software attached to the simulator has been developed on an IBM PC micro-computer, linked to a main frame (IBM 4341), using the PC to emulate a Tektronix 4010 work station (storage tube graphics terminal). In order to create motion, the software had to be modified so that parts of the screen could be erased and redrawn. Such procedures would not be possible on a real Tektronix 4010 graphics terminal, justifying in part the use of a micro-computer.

At the beginning of the simulation the physical and functional architectures are read from a file which can be updated by the user during the simulation, and are processed in order to get a displayable format. The graphics interface is divided into three parts: the display of the physical structure according to the geographical position of each node, the display of the functional structure and the display of simulation results as a set of histograms.

All three displays can be used either at the end of a simulation interval or during the simulation interval, where the values of selected parameters will be updated regularly. A menu is provided before each simulation to allow the user to select the parameter to be evaluated, and to select one of the three displays available. At the end of the simulation interval, the same menu is presented enabling the user to visualize the accumulated statistics. The simulation clock is displayed in the upper right corner of the screen on all displays.

3.1 Display of the physical layer

The physical network display consists mainly of lines and squares. Each node is represented by a square, labelled with it's geographical position (i.e. Montreal, Ottawa,...), and the lines joining the nodes represent the physical communication links. The resulting display is a geographical representation of the network. Sometimes a group of physical nodes are located close together, so in order to decongest the crowded area, a zoom option is available. This option allows the user to either view the whole network or to select a zoom on one or more nodes, thus concentrating on the behavior of the selected nodes only.

In the event that the designer wishes to use the physical network display during a simulation interval, he will see the numerical value of the selected parameter. at each displayed node or link, As the simulation progresses, the values will be updated according to the network state. Figure 3 shows a physical network display with no selected parameters.

3.2 Display of the functional layer

The functional structure display uses the same format as the physical network display, except that nodes are not represented according to their geographical position, but according to their level in the control hierarchy. Because all physical nodes are not necessarly members of the hierarchy, their could be fewer functional nodes than physical nodes.

The simulation can handle a maximum of 30 nodes, but with 30 functional nodes, the screen could easily be congested and very difficult to read. Therefore, a zoom option has been implemented. The zoom option allows the user to select the display of the whole hierarchy, or of a sub-tree of the hierarchy. Figure 4 shows an example of a functional structure display, with a selected parameter related to functional links.

3.3 Display of histograms

The use of the histogram display enables the designer to peek at any layer of the network, physical or functional. The selection of this display at the end of a simulation interval will produce a standard graphic representation using histograms. The most attractive part of this display comes when it is selected for a dynamic simulation. The histograms will be displayed as a static graphic representation, but as the simulation progresses, the heights of the histograms will vary according to the value of the selected parameter, thus creating a motion effect. Using this display, the designer can easily detect the most congested area of the network, without knowing the exact value of the selected parameter, and make appropriate changes (Figure 5).

CONCLUSION

The graphics interface for the present simulation package is a key element since it allows excellent interaction between the network designer and its design tool, the simulation model. The large amount of intermediate results required to achieve the final results and desired network performance, favors the use of an interactive graphics display. Moreover, the results are strongly dependant on the geography; it is therefore natural to represent the designed network along with its actual topology.

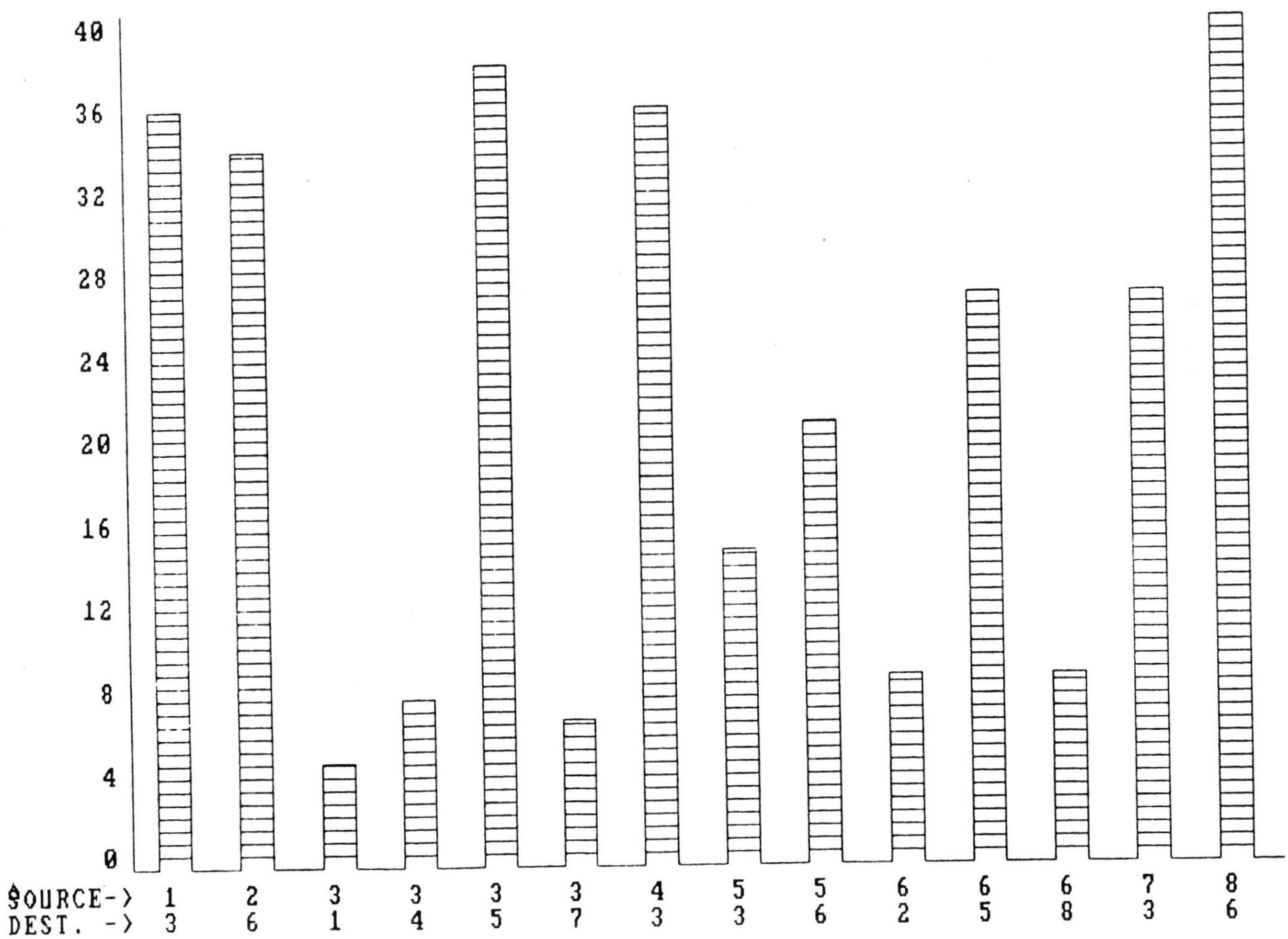

Figure 5: Dynamic histogram of the network traffic.

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