Issues in Simulation and Modelling of Communication Systems

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Abstract: - This paper examines issues in simulation of communication systems and their application for such systems. Application of simulation to voice, data, integrated networks, and wireless networks are discussed. It explores which simulation is best to be used for various communication systems. Monte Carlo simulation, deterministic and stochastic simulation, discrete-event and continuous simulation, and rare event simulation are discussed. The replication and batch-means methods used to determine the simulation run time are discussed.

Key-Words: - **simulation methods, simulation run-time, stochastic simulation, warm-up period**

1 Introduction

The operation of communication networks is usually evaluated using simulation techniques which, unlike analytical methods, use fewer assumptions. The complexity of modern communication systems is another driving force behind widespread use of simulation techniques [1, 2]. Simulation avoids errors involved in complex mathematical analysis. In most cases, they assess the effect of random inputs, such as, random path delays in wireless systems.

Computer simulation is most useful when used in combination with analytical and hardware measurements results. The result of analytical techniques could be refined using computer simulation, where a more detailed system model is built using computer software. In all stages of system design, simulation can have an important role from initial conceptual design to various stages of feasibility study, case studies, detailed design, testing, and implementing [3].

Performance modelling by simulation generally includes the following steps: (a) obtain a valid simulation model of the system; (b) develop, test, and verify simulation software; (c) obtain and analyse data. All of these steps are explored in this paper.

The organization of this paper is as follows. In next section, the application of simulation in communication systems is explained. Section 3 covers simulation model. Section 4 outlines the simulation types followed by simulation methods in section 5. The last section presents conclusions.

2 Application of Simulation in Communication Networks

Simulation of communications systems was initially used in high-cost systems, such as geostationary (GEO) satellites, or other high risk areas. Simulation now plays an important, much broader role, in system design, implementation, and performance modelling of communications systems. Simulation has been used to study various aspects of telecommunications systems (protocol evaluation, traffic engineering, dimensioning, BER analysis, frame error rate investigations, S/N ratio studies, etc.). It has also been used to study the voice, video, data and integrated traffic in both fixed and wireless networks.

2.1 Application of simulation in voice networks

K. Erlang first observed that the telephone system could be modelled using Poisson arrivals and exponential call holding times [4]. As there are a certain number of circuits and calls are not queued, the voice network can be modelled as a M/M/K/K queuing system, where K is the number of circuits (servers) each serving a call. The probability of loss versus the Erlang traffic is tabulated (traffic tables) and graphed in telecommunication texts. Simulation using a M/M/K/K queuing system provides the same results as the Erlang-B formula.

2.2 Application of simulation in data networks

A data network can be regarded as a network of queues. The delay and throughput of the LAN data networks is analysed using a queuing system model. The performance of LAN/WAN equipment such as switches, routers and bridges is analysed using the queuing model. Simulation of the queuing systems is used to investigate the performance evaluation of various media access control schemes such as Polling, CSMA/CD (used in Ethernet LANs), and Token Passing (used in Token ring LANs) [5].

2.3 Application of simulation in integrated networks

Simulation is used to evaluate the networks that integrate voice, video and data traffic on the same network infrastructure [6]. Examples are ATM and W-CDMA networks. Simulation is used in congestion control, buffer dimensioning, delay, QoS evaluations, and throughput analysis of such networks.

2.4 Application of simulation in wireless systems

Simulation and modelling has been used in performance modelling of wireless LANs and WANs. Some examples of the use of simulation by researchers in performance analysis of wireless cellular systems are in antenna evaluation, multi-user detection, interference analysis [7], capacity analysis [8], 3G design, vehicle based W-CDMA, Rician fading channel, and Nakagami fading channels evaluations.

The first step in simulation is to build a simulation model that is described next.

3. The simulation model

Advances in computer systems have made it possible to build and run sophisticated computer simulation models. However, It is important to build a simulation model that best describes the real system. The simulation model can be built with different degrees of complexity. Depending on the required degree of accuracy, the time allowed to build the model, and the simulation time accepted, a judgment must be made on how complex the model should be [3]. If the model is too simplified, it might cancel some vital system characteristics that could produce incorrect results.

3.1 Simulation parameters

In the simulation model, simulation parameters such as random number generation seed, the precision required (or the simulation length), number of samples per iteration (for recursive or batch simulation), and the system parameters are specified.

3.2 Random numbers, probability distributions

In a simulation random numbers must be generated, due to randomness of the input data in the real system. Most algorithms create random numbers in the format [5]

$$X_n = (bX_{n-1} + c) \text{ modulus } m \qquad (1)$$

where X_n is the nth number in sequence, b, c and m are appropriately chosen constants. The above equation generates positive random numbers between zero and m. To generate random numbers between zero and one, X_n / m should be used. The random numbers generated between zero and one are uniformly distributed. To generate random number with other distributions, such as exponential, these uniform random numbers are converted using the relevant formulas.

3.3 Code writing and testing

The importance of writing and testing the actual code should not be taken lightly. It is usually not a straightforward matter even for experienced programmers [5]. A mistake in the software code could produce incorrect simulation results. For this reason and because of the time it takes to produce a well written simulation model, some pre-written programmes may be used. Examples of the simulation software are: *Ithink*, *matlab* and *commnet*. *Ithink* is a pre-written simulation software with a graphic facility that can be used to simulate consequent events. *Matlab* software is used to simulate communication systems and techniques using Monte Carlo Simulation. *Commnet* is another pre-written simulation software with graphic facility that is used to simulate the telecommunications systems. It can be used for traffic analysis and dimensioning of telecommunication systems.

4. Simulation Types

Monte Carlo simulation, deterministic and stochastic simulation, discrete event and continuous simulation, and rare event simulation are various types of simulations. Some texts such as [3] have used the Monte Carlo simulation for any simulation including random numbers. However, some texts [9] have restricted the definition of Monte Carlo to employing random numbers where the passage of time has no relevance. When the random numbers changes with time, the term stochastic simulation is used.

4.1 Deterministic and Stochastic Simulations

Simulation for when the input is fixed so that identical results can be obtained is called deterministic simulation [3]. Simulation where the random variables change with time is called stochastic simulation [1, 10]. Statistical behaviour of the random variable determines the accuracy of the results [4]. A stochastic process is a set of random variables that can be indexed according to time. *X(t)* is the state of the system at time *t*. For example, the number of calls in a telephone system changes according to the function of time. If time has discrete values, for example, 0,1,2….., the process is classified as a stochastic discrete-parameter process. On the other hand, if time can take any value in an interval, the process is called a stochastic continuous-parameter process [4]. Because in the stochastic simulation, the input data are random variables, the output results might vary depending on the simulation length. The analysis of the results must be performed in the stochastic simulation. In addition, the simulation model is an abstract model and the results are not as deterministic as the pro-type hardware model's results. Simulation needs to be run many times, with different random numbers, to provide sample results for analysis [5]. The traditional direct stochastic simulation method cannot be used effectively if the required events occur rarely. For example, if the chance of an event occurring is 10^{-10} (e.g. BER), it would take a long time to obtain a few events. In such cases, rare event simulation techniques are more appropriate.

4.2 Rare Event Simulation

The direct stochastic simulation technique can be used to analyse situations that result in the probabilities higher than 10^{-5}. However, the simulation of the events that do not happen often takes a very long time. For example the BER in communication systems can be very low, 10^{-10} [11]. Another example is the probability of cell loss in ATM networks that is also very low, in the order of 10^{-6} to 10^{-12}, depending on the type of service (voice, video or data). It would take a long time to run the traditional simulation techniques for such applications. One can expect that the number of observations needs to be at least one hundred times the inverse of the probability of loss in order to obtain results with reasonable confidence [12]. This means at least 10^{-8} to 10^{-14} statistically independent cells must be simulated in order to obtain a reliable estimate of the required probability of loss for ATM networks. However, it is possible to use a much smaller sample size and hence a reduced simulation time, and still obtain the result required by using rare event simulation techniques. These methods have been used for buffer dimensioning, calculating the low BER of communication networks, MTBF (mean time between failure) of some equipments with very low failure rate, in radar systems, and in simulation of multi-hop links in digital satellites. One simulation technique commonly used in simulating telecommunication systems with rare events is importance sampling [12].

4.3 Discrete Event and Continuous Simulation

The simulation can be continuous or discrete. Continuous simulation is the modelling of systems where the state varies continuously with time. An example is the levels of oil in an unloading tanker and in the storage tank whose rate of change are described by differential equations. In the discrete event simulation, the state of the system changes instantaneously at specific points in time [9]. There are two methods to advance the simulation time, time-driven and even-even.

5. Simulation Methods

A variety of methods have been suggested to minimise the effect of the warm-up period (when the system has not reached stead-state) and provide results that could be used with a certain confidence. Three methods of simulation are replications method, batch means method, and regenerative simulations.

5.1 Method of Replications

In the method of replications, the simulation is repeated a number of times, each time with a different series of random numbers. Average values of the results are collected during each replication. The means are used in statistical analysis of the output results for a certain confidence interval. In replication methods, each replication has its own warm-up period and this would reduce the accuracy of the results [13]. If a single long simulation run is used, the warm-up period needs to be determined and removed only once. However, some authors have defended the method of replications as being more effective when warm-up period is removed in each iteration [14, 15].

Assuming K iterations of size n each, the iterations are:

$$(X_{11}, X_{12}, \ldots\ldots\ldots X_{1n}), \ldots\ldots\ldots, (X_{K1}, X_{K2}, \ldots\ldots\ldots X_{Kn}) \quad (2)$$

If w observations belong to the warm-up period in each iteration, the iteration means $\bar{X}_1, \bar{X}_2\ \bar{X}_3, \ldots\ldots\ldots\ldots \bar{X}_K$ are

$$\bar{X}_i = \frac{1}{n-w}\sum_{j=w+1}^{n} X_j \tag{3}$$

The estimated mean, $\bar{\bar{X}}$ (the average of averages) and variance of these averages for K iterations are

$$\bar{\bar{X}} = \frac{1}{K}\sum_{i=1}^{K} \bar{X}_i \tag{4}$$

$$\sigma^2(\bar{\bar{X}}) = \frac{1}{K-1}\sum_{j=1}^{K}[\bar{X}_j - \bar{\bar{X}}]^2 \tag{5}$$

The true mean $\bar{\bar{\mu}}$ is $\bar{\bar{X}} \pm 2.58\sigma/\sqrt{K}$ with 99% confidence and $\bar{\bar{X}} \pm 1.96\sigma/\sqrt{K}$ with 95% confidence [10]. The simulation is continued until the confidence interval required is achieved, i.e. for 99% confidence

$$\frac{2.58\sigma/\sqrt{K}}{\bar{\bar{X}}} < 0.01 \tag{6}$$

5.2 Batch-Means Method

In batch-means method [16], there is one long simulation run but observations are divided into batches. Thus, the results are obtained from a single simulation run time. The total number of observations in the simulation run is divided into K batches each with n observations i.e.

$$(X_{11}, X_{12}, \ldots\ldots. X_{1n}), \ldots., (X_{K1}, X_{K2}, \ldots\ldots. X_{Kn}) \tag{7}$$

If there are w observations during the initial warm-up period, the first observation of the first batch starts with $x_{11} = w+1$. Note that there is only one warm-up period. The selection of batch size versus number of batches can be an issue in batch-means method. The bigger the batch size, the fewer the number of batches required. Law and Carson [17] provide a method for determining the batch sizes.

5.3 Regenerative Simulation

Another simulation method is regenerative simulation. In regenerative simulation there is a state called the regenerative state that the system returns to, over and over again. The process starts anew probabilistically each time this state is visited. For queuing systems, this regenerative state could be when the queue becomes empty. The history of the system has no effect on the state of the system from that point onwards [18]. The main advantage of the regenerative simulation is that one does not need a warm-up period.

6. Conclusion

In this paper, the simulation and its application to communication systems was explained. It discussed the stochastic discrete (time or event driven) simulation for simulation of communication systems. Rare event simulation was outlined. It discussed the warm-up period and simulation run-time.

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