A PERFORMANCE EVALUATION INDEX SYSTEM FOR MULTIMEDIA COMMUNICATION NETWORKS AND FORECASTING FOR WEB-BASED NETWORK TRAFFIC*

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Abstract

This paper presents a new index system for the performance evaluation and network planning of multimedia communication systems using measurement on actual systems to support several different traffic types. In this index system, we develop an expert system to evaluate the performance of such multimedia communication networks including channel utilization and call blocking probability and packet delay, and apply the network planning methods to optimize the networks and forecast the demand of the growing multimedia communications systems. Two important planning problems for the multimedia communication systems are presented: optimization problem for construction of the world system and forecast problem for increasing traffic demands. We first discuss analysis methods, performance measures for the multimedia communication systems. Then, we describe network planning methods for the multimedia communication systems and give some efficiency network planning methods. Finally, we present some results studied in traffic forecast for the campus network and show the effectiveness of these methods.

Keywords: Performance evaluation, network planning methods, index system, traffic forecast, multimedia communication systems

1. Introduction

As telecommunications and computer communications continue to converge, traffic of data messages and real-time video is gradually exceeding telephony traffic. This means that the multimedia communication networks must be able to provide diverse quality of service to each type of user, such as voice, data messages, video, etc., and many of the existing connection-oriented or circuit-switched networks will need to be

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upgraded to support packet-switched data traffic and all other type traffic. In particular, advancements in multimedia communications and information technology allow people from all places of the world to share information. One of the most significant enablers for the ongoing multimedia communications revolution is the Internet.

The performance evaluation and network planning are the key tools in reliable multimedia communication operation. Multimedia communication networks to support several different traffic types have become so complex that intuition alone is not sufficient to predict their performance and mathematical modeling has come to play an important role. Mathematical models of system performance range from relatively simple ones, whose solution can be obtained analytically, to very complex ones that must be simulated (Pidd 2002).

Performance planning modeling is widely used, not only during design and development, but also for configuration, tuning, and capacity planning purposes (Liang & Li 2000). Of course the overall system performance is affected by the performance characteristics of the various subsystems and ultimately the individual hardware and software components that constitute the system. Therefore, the design of new hardware and software components has system performance planning implications that should not be ignored. Once particular multimedia communication systems have been built and are running, the performance of the system can be evaluated by measures, using hardware and/or software monitors, either in a user environment or under controlled benchmark conditions. However, to evaluate the performance of a system, subsystem, or component that cannot be measured, for example, during the design and development phases, it is necessary to make performance predictions based on educated guesses or to use models as an aid in making performance predictions. The interactions in present-day communication systems are so complex that some form of modeling is necessary in order to be able to predict and understand communication system performance.

One of the principal benefits of performance planning modeling, in addition to the quantitative predictions obtained, is the insight into the structure and behavior of the system that is obtained while developing a model. It is particularly required during system design. The modeler demands abstract the essential features of the design and this process leads to increased understanding and may result in the early discovery and correction of design flaws. On the one hand, performance planning attempts to achieve the best fit between anticipated demands for the multimedia communications services and the resources available. Therefore, performance planning becomes very important for multimedia communication networks, especially in today's environment of rapid increasing subscriber demands and technology development (Suganuma, et al. 2003).

On the other hand, optimal planning and

design of multimedia communication systems is one of the important areas of study in the network engineering. Usually the optimization problem involves two major unknowns to be determined: network routing (or capacity assignment) and network planning. While the planning problem of multimedia communication systems is different from that of generic networks, since we have to find a solution which optimizes a prespecified objective function while satisfying design constraints such as network demand projections for node pairs and survivability requirements by considering human factors.

The performance evaluation of a multimedia communication system may involve such factors as cost, availability, reliability, serviceability, and security. The main tasks of performance evaluation include proposing the indices system for the evaluation, selecting comprehensive evaluation methods, testing the real data and establishing computer evaluation support system (Gu & Tang et al. 1998).

This paper presents a new index system for the performance evaluation and network planning of multimedia communication systems using measurement on actual systems to support several different traffic types. In this index system, we develop an expert system to evaluate the performance of such multimedia communication networks including channel utilization, call blocking probability and packet delay, and apply the network planning methods to optimize the networks and forecast the demand of the growing multimedia communication systems. Two important planning problems for the multimedia communication systems are presented: optimization problem for construction of the world system and forecast problem for increasing traffic demands. We first discuss analysis methods, performance measures for the multimedia communication systems. Then, we describe network planning methods for the multimedia communication systems and give some efficiency network planning methods. Finally, we present some results studied in traffic forecast for the campus network and show the effectiveness of these methods.

In Section 2, we discuss the performance evaluation for the multimedia communication networks. In Section 3, we describe our index system for the performance evaluation of the multimedia communication networks. In Section 4, we describe the features of the performance evaluation. The subsystem for performance analysis and the subsystem for network planning in the expert system are presented in Sections 5 and 6, respectively. Finally, we conclude with a brief summary in Section 7.

2. Performance Evaluation for Multimedia Communication Networks

In this section, we mainly focus on discussion of performance evaluation methodologies for multimedia communication systems which converge the public switched telephone network (PSTN) and packet networks for carrying all types of traffic including voice, data, video and other multimedia. In particular, the rapid growth of the Internet, the widespread use of packet networks for transport of voice services, and the need to provide access to conventional PSTN telephony services via the Internet have created a need for interworking between networks. Integration of network planning based the system performance evaluation in converged networks increases operability and maintainability while providing economies of scale. Previously, telephony services were developed in a closed environment, using proprietary software and interfaces.

Future multimedia communication networks will be characterized by new and evolving architectures where packet-switched, circuit-switched and wireless networks are integrated to offer subscribers an array of innovative multimedia, multiparty applications. Equally important, it is expected that the process to develop multimedia communications applications will change, and no longer solely be the domain of the multimedia communication networks or service provider.

The multimedia communication systems converging PSTN and packet networks are combinations of components with different functions and provide variety supports to people. Performance evaluation of multimedia communication systems is very important, especially as it is a rapidly changing environment. Firstly we set up an index system for system performance evaluation to support system planning and upgrade.

3. Index System for Performance Evaluation of Multimedia Communication Networks

Social and business activities have become significantly depending on multimedia communication for carrying all types of traffic including voice, data, video and multimedia. Therefore, system performance of such multimedia communication networks affects on those activities. System performance of the multimedia communication networks includes utilization, call blocking probability, waiting time and network management. Current researches mainly concern on the system performance design of a multimedia communication network by generally using simulation and analytic techniques, which are significant to achieve the network performance, but are incapable to show the operation performance of a multimedia communication network (Yue, et al. 1998, Liang & Li 2000, Yue and Matsumoto 2002). We aim to improve the operation performance of the converged communication networks, to satisfy the requirements of all types of traffic. Firstly we concern developing a performance evaluation system to observe operating performance of the multimedia communication networks using measurement on the systems characterized by new and evolving architectures. Through the index system, we can compare the system performance of different networks in different time.

3.1 Constructing Performance Evaluation System

We follow the process as shown in Figure 1 to develop and run the performance evaluation system.

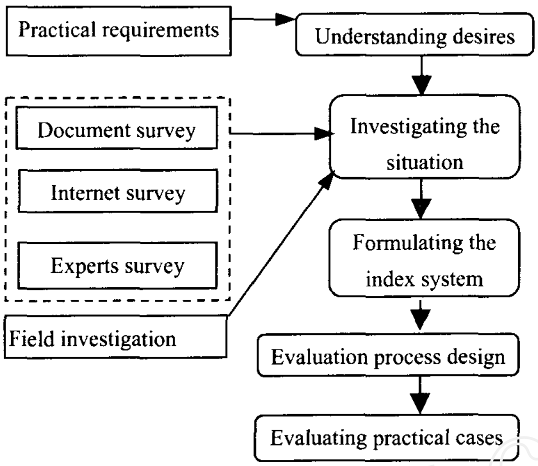

Figure 1 Working process of performance evaluation system

Firstly surveys including document survey, Internet survey and expert survey are taken to acquire as much as indices for relevant system or components evaluation. Sometime, field investigation is also required. Then Delphi-like method is applied to collect the opinions about the designed index framework based on surveys and investigations. Finally an integrative index system for evaluation with three layers is constructed with more than 60 indices.

3.2 Integrative Index Framework for Performance Evaluation

Basically the input, output and outcomes are considered for comprehensive evaluation of a system (Klenier 1997). Figure 2 shows three layers of evaluation indices.

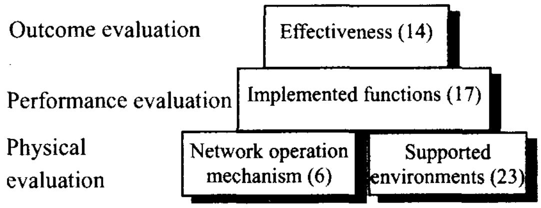

Figure 2 Three layers of evaluation indices

(1) Physical evaluation, which consisted of operation mechanism (6 indices) and supported environment (23 indices) of the multimedia communication network.

(2) Performance evaluation for system (17 indices).

(3) Economic, social and user's evaluation which reflect the overall contributions of the system (14 indices).

There is a tradeoff in identifying the indicators regarding the technological development and feasibility. The logic structure and first level measures of the index framework for the performance evaluation of multimedia communication systems is as shown in Figure 3.

3.3 The Evaluation Process Design

We can set up different indicators for the multimedia communication systems. The solution not only refers to an array of indices but also includes the measures and valuation methods of those indices. Different evaluation tasks will result different index solutions, which construct an index alternative base. The computerized evaluation process is as follows:

[Step 1] Choose an existing index alternative from alternative base according to the evaluation tasks. If there is no proper alternative in the base, select indices directly from index base to form new scenarios and search for new solutions or select a similar alternative for modification.

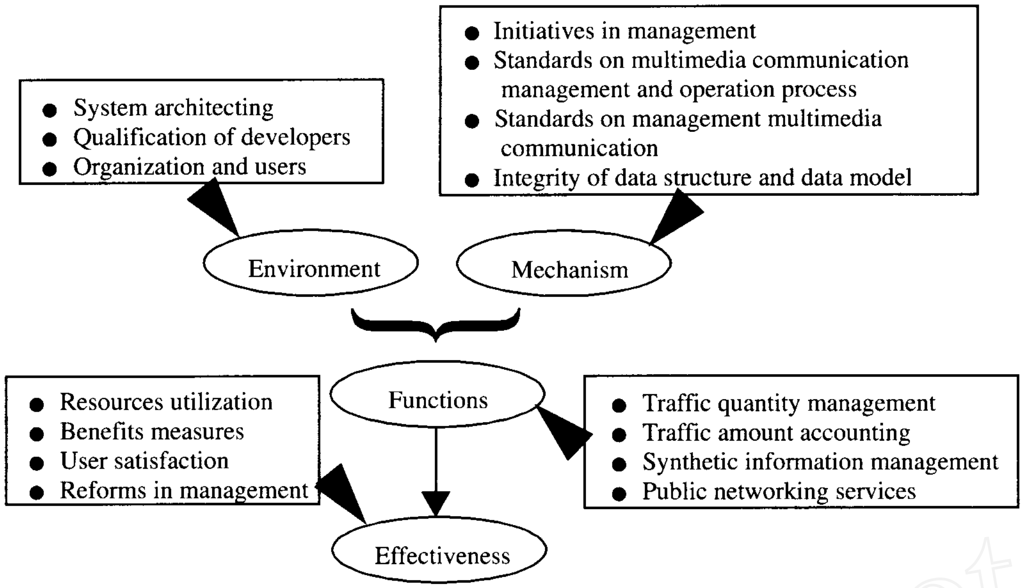

Figure 3 Framework of evaluation index system

[Step 2] Give the name, method of evaluation, operational definition of those newly added indicators.

[Step 3] Reassign weights of those items at the same levels where new items added.

[Step 4] Confirm the evaluation index solution. If satisfied with the scenario, a solution is reached and also stored in the alternative base. If not, go back to Step 1.

[Step 5] Acquire scores for indices from a checklist that lists all selected indices, their measures and valuation methods. The users are required to give a score for qualitative index. For quantitative index, the index system runs its computation module.

[Step 6] Choose one method of integrative evaluation to produce a synthetic result. More methods can be in trial for comparison.

[Step 7] Before exit, confirm if new indices have been stored into index base or not. If do not exit, go back to Step 1.

The 7-step working process is an iterative process to find an appropriate solution for performance evaluation of the multimedia communication networks where the preferences of the users can be reflected by the index solution, and then by the final evaluation result. Furthermore, the measures and valuation processes of different indices also include the users' subjective judgment. The process to scenario establishment is modeling for imagines (scenarios of the concerned by the human beings), instead for insights of the multimedia communication networks, which are hardly and possibly modeled in human activity issues.

3.4 Valuation of Indices

The measures and valuation methods of those indicators about the input, output and outcome of a multimedia communication network in the index base should be confirmed before going to Step 5. Table 1 gives valuation methods of the indices.

Table 1 Valuation methods of indices

Index	What they mean?	Where to collect?	How to value?
Physical layer	(input) technical indices	documents, Internet, practical cases	testing, estimating
Perform-mace layer	(output) system performances	documents, expert survey, practical cases	testing, calculating
Effective-ness layer	(outcome) user participation, user satisfaction	documents, expert survey, practical cases	testing, experts' scoring

We use different methods for valuation in indices. For the indices in the physical layer we usually use the test and estimation method. In the performance evaluation layer the queuing network method is presented specifically for matching the requirement of multimedia communications business. In the queuing network method, we present the theoretical studies and development of the network modeling, and give some efficiency analytical methods to numerically evaluate the system performance and test the analysis results by computer simulations. In the effectiveness evaluation layer, we use the estimation and expert assessment methods.

3.5 Evaluation Methods

The evaluation methods can be divided into two kinds:

(1) Individual evaluation.

(2) Comprehensive evaluation.

For (1) we just select at first all indices for evaluation, then make valuation for each index, finally just show them in some table format in the computer. For (2) which usually is in the case of more than two indices, we should make integration or synthesis for them. A variety of evaluation methods are usually applied, such as comprehensive scoring approach, order number approach, ideal point methods, and analytical hierarchy process (AHP), etc. There are specific softwares used for some evaluation methods.

3.6 Computer Support System

A computer support system including Database, Index Base, Method Base and interface is implemented for the performance evaluation of the multimedia communication systems by Java, Visual C++ and Microsoft Access. The idea of installing the Index Base originated from the expert survey. Users of the performance evaluation system range from top level (computer center) and middle level (computer servers) to low level (end users). Even in the low level there are different types of users, like offices, houses and individual. So for carrying the evaluation work for different users from different levels we can choose the appropriate indices system from the Index Base at first. The computer support system for the performance evaluation of the multimedia communication systems will not only facilitate the evaluation of practical cases, but also provide a useful aid to compare evaluation methods, understand users' desires and improve the index framework.

4. Features of Performance Evaluation Layer

In the performance evaluation layer of the multimedia communication network technology, we apply an expert system to support the managers to evaluate the system performance even if they do not understand how to do to evaluate the system performance and forecast the new business.

According to the intrinsic characteristic of the multimedia communication systems, the dispersed geographic position of multimedia communication system's researchers, the unpredictability of the calamity places and the problem of collecting dispersed relieving personnel and material during the action, as well as the widespread and centralization of computer network, it is necessary to construct an expert system in computer system for the performance evaluation of the multimedia communication systems.

First, according to the character of the multimedia communication systems, choose a program software for it, then install it into a network server. Second, set up an enormous and complete database for propagation education and calamity knowledge, a database for calamity experience, a database for various conditions during the action of calamity and other databases. Third, establish engineering computer network software for the multimedia communication systems, and use it in a computer network, cooperate with advanced scientific means and make practice use of them. The schematic diagram of the expert system is shown in Figure 4. We can use the following measures to build an evaluation model for a multimedia communication system. They are

- Traffic overflow rate
- Traffic blocking probability
- Outgoing traffic successful rate
- Packet delay
- Packet loss rate
- System utilization
- Buffer length
- Available outgoing circuit rate
- Average fault duration of switching equipment per channel, etc.

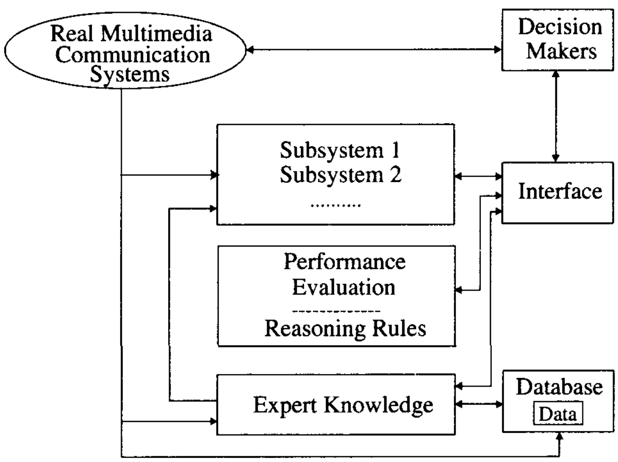

Figure 4 Diagram of expert system

The measures show operation information in different aspects. We can classify these measures, then synthesize them into a layered structure.

Here we present two subsystems in the part of Performance Evaluation in Knowledge Base of the expert system. One is for the performance analysis and evaluation of the multimedia communication systems with applying the queuing theory, computer simulation and other analytical methods. The other one is for the system planning of the multimedia communication systems with applying traffic forecast methods.

5. Subsystem in the Expert System for Performance Analysis and Evaluation

The main methods of performance evaluation and optimization for an existing connection-oriented or circuit-switched multimedia communication networks are the theoretical analyses using queuing network theory and computer simulation (Kleinrock 1975, Kleinrock 1976). Therefore, the joint research work by professionals related to the queuing theory and multimedia communication systems is necessary.

However, in fact, there are many limitations in the actual research of performance evaluation and optimization. It is very difficult to solve the listed problems if knowledge about queuing network theory is not applied:

(1) Construction of queuing network model that expresses practical multimedia communication systems.

(2) How use the data related to practical systems as input parameters of the model.

(3) Analysis of the queuing model and calculation of performance evaluation measures.

(4) How attain significant performance improvement through the use of analysis results.

(5) How traffic is distributed with respect to the protocol and origin and what is the traffic characterization.

We hope to use both queuing theory and expert system and then to give more real and flexible operation and evaluation and more wide purpose for the multimedia communication systems.

Queuing theory is an efficiency mathematical technology to model the stochastic systems to give numerical results to evaluate the system's performance. There are quality impairments particular to the communication networks such as queue length, waiting time, cell loss and delay variation, and so on. During communication network planning, therefore, various causes of quality impairments should be clarified. It is also necessary to determine the network performance parameters and design objectives with the aim of providing users with a satisfactory quality of service. Many researchers have studied many variants of queuing systems with vacations in recent years, which are useful for modeling computer and communication systems. For example, in most computer systems, the processor is shared among a number of jobs, and therefore is not available in all the time to handle one job type. From the viewpoint of one job type, the processor is busy with handling its type of work, and multi-queue system.

Two basic problems arise in mathematical modeling: the problem of identifying a system and the problem of applying a model to the system analysis. The system identification consists of selecting a certain class of mathematical objects that describe fundamental properties of the system behavior. We use a class of stochastic sequential machines with hidden states that are governed by Markov chain and Markov renewal to model the multimedia communication systems. A multimedia communication network must be able to provide diverse quality of service to each type of user, such as voice, data messages, video, etc.

5.1 Subsystem for Performance Analysis and Evaluation

We first describe the subsystem for the performance analysis and evaluation using queuing network theory and computer simulation. It includes four parts as follows:

(1) Knowledge base of construction of system models which consists of knowledge of queuing modeling and knowledge of the multimedia communication systems.
(2) Knowledge base of performance improvement plans.
(3) Analysis component of models using analysis program of queuing network theory.
(4) Reasoning component.

The subsystem for system performance analysis and evaluation is shown in Figure 5.

The subsystem makes use of dialogue form. Users can obtain system performance measures such as waiting times of packet, average queue length, call blocking rate, bottleneck diagnosis etc. through input the parameters concerning the actual multimedia communication systems. Optimum network capacity, high level of quality of service, the degrees of congestion and performance improvement plans etc. can also be obtained. The subsystem with dialogue form applied queuing theory will be not only useful for performance evaluation of the present multimedia communication systems, but also applicable to make the performance prediction and optimum design of the future multimedia communication systems.

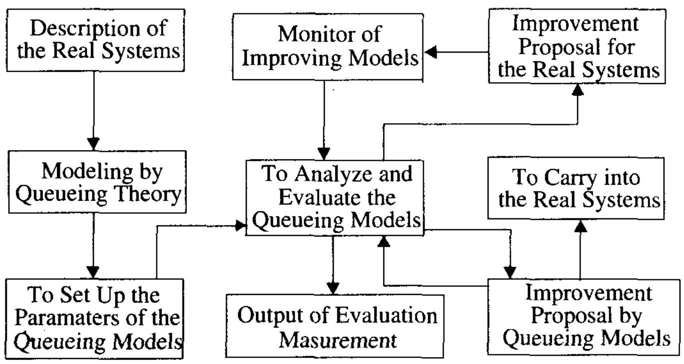

Figure 5 Subsystem for performance analysis and evaluation

5.2 Major Tool to Model and Analyze the Multimedia Communication System

In the subsystem for performance evaluation, we consider a multimedia communication system which consists of a population of N geographically distributed users (such as access points) connected by a channel or a number of channels, arranged according to some network topology with multiple access protocols. The multiple access protocols including the fixed assignment methods dedicate a fixed portion of the available channel capacity to each user. The most common forms of this technique are TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access) and CDMA (Code Division Multiple Access). In random access (contention) protocols, the entire bandwidth is presented to the users as a single channel (or multi-channels) to be accessed randomly. This means that collisions of messages can occur, and that colliding messages must be retransmitted. The random access protocols include Slotted ALOHA, CSMA (Carrier Sense Multiple Access), CSMA/CD (Carrier Sense Multiple Access with Collision Detection) and CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). Also, integrated properties of both the fixed assignment methods and random access protocols achieve higher performance utilization for diverse services. A multimedia communication system modeled by queuing systems can be described in terms of six components:

(1) The arrival process: this is a stochastic process describing how messages in a communications environment arrive into the system.

(2) The service process: this is a stochastic process describing the length of time that a channel (or channels in a communications environment) is occupied to transmit a message.

(3) The number of channels.

(4) The buffer: the limit to the number of messages that can be buffered to wait for transmission, including those currently being transmitted.

(5) The user population: the limit to the total number of users, including potential ones. This can be considered as part of the arrival process, since the number of potential users can change the rate of arrivals.

(6) The transmission protocol: the rule for deciding which user or users, within a communication system, to transmission.

In the subsystem, we use a specific queue, the visits of the server to other queues and the switch-over times are considered as server vacations related to M/G/1 systems. This is because messages arrive in the system with a Poisson process, but service times are independent and identically distributed (i.i.d.) according to a general probability distribution function. We also use Markov Modulated Poisson Process (MMPP) model and the phase-type renewal process, the matrix analytical approach for the Markovian Arrival Process (MAP), switched Poisson process (SPP), etc. in a number of ways to model different traffic sources.

6. Subsystem for Network Planning

Network planning is very important, however, especially since this is a rapidly changing environment. In the subsystem for network planning, planning procedure for the multimedia communication systems is divided into three steps, say, Demand Forecast, Network Optimization, and Economic Analysis. To follow up changes in environment, feedback or recycling is necessary to maintain a realistic and executable planning. Communication services are evolving from conventional telephone services to broadband and multimedia (i.e., audio, video and data) services to meet the diversified needs of users. In response to this service evolution, multimedia communication networks are also evolving toward broadband ISDNs (B-ISDNs). Asynchronous Transfer Mode (ATM) becomes important as one of the key technologies for B-ISDN. ATM network performance planning is a rather new and important problem requiring in-depth investigation to achieve high quality in the implementation of B-ISDN.

The most important point is the method that should get "good" results close to the real world situation of the multimedia communication systems. For example, as the growth rate of number of subscribers is especially high in recent years, many "new" forecast models do not work well in forecasting. Anyway, we found out some methods, including the Grey System Model that gives better results. We use some forecast tools in predicting future system's demands. The accuracy of this prediction is essential to the resource provisioning in network development. The tools include: time series analysis, correlation and regressive models, Gray system model, and Fuzzy model. A dynamic system model is also established for the multimedia communication systems. Another example, the telephone network is still a hierarchical one, thus routing paths are not dynamically chosen but pre-defined and limited. In this situation, as the routing strategy, or so-called traffic allocation strategy is determined for each network structure. This will simplify the problem and Simulated Annealing (SA) goes into a perfect situation in solving it.

Network architecture is the base of optimization of network. Simulated Annealing algorithm can be applied to generate network architecture (Xin 1991). SA algorithm uses a self-search algorithm, which can automatically execute its task by a few parameters inputted by an operator. We should not only forecast the anticipated people's demands to achieve the best provisioning of limited resources, but also find a better way to develop it into a multimedia communication with functionality maximized and cost minimized.

The multimedia communications networks are combinations of components with different functions and provide variety multimedia communications services to users. Planning tasks in such an environment is a complex one. In present conditions, the multimedia communications networks include as telephone network which can be further divided into local network and long distance one, data network, including package switching, mobile radio network, ATM network etc. Our studies are related with these different areas.

6.1 Optimization of Networks

Network architecture is the base of optimization of multimedia communications networks. In the subsystem, we use SA algorithm to generate network architecture. SA algorithm uses a self-search algorithm, which can automatically execute its task by a few parameters inputted by an operator. The model of network architecture generation can be presented as follows:

$$\text{Min}: \sum_{i=1}^{M}\sum_{j=1}^{M} N_{ij} w_{ij} + \sum_{i=1}^{M}[\sum_{j=1}^{M}(N_{ij}+N_{ji})]S_i, \quad (1)$$

$$N_{ij} = C(F_{ij}, B_{ij}), \quad (2)$$

$$F_{ij} = \sum_{p=1}^{M}\sum_{q=1}^{M} f_{pq} Q_{pijq}, \quad (3)$$

$$P = h(A) \quad (4)$$

where

M: total number of nodes

N_{ij} : link capacity connected to node i and j

w_{ij} : cost fraction of unit capacity on link (i, j)

S_i : cost fraction of unit capacity on node i

F_{ij} : traffic allocated to link (i, j) [Erlangs]

B_{ij} : service degree of link (i, j)

f_{pq} : initial traffic allocated on link (p, q)

Q_{pijq} : initial traffic between node p and q shared by link (i, j)

$C(F_{ij}, B_{ij})$: link capacity obtained from Erlang Formula

P : any traffic allocation strategy

A : network structure matrix, where $A = \{a_{ij}\}$ and

$$a_{ij} = \begin{cases} 1, & \text{if there is a link between node } i \text{ and } j, \\ 0, & \text{otherwise.} \end{cases}$$

h : a logical calculation symbol which represents any available routing strategy.

Q_{pijq} can be obtained using the routing strategy P. During the optimization process, network structure keeps changing. It is also different in different state. Because our target is to reach minimum total cost, we can finally find a satisfactory network structure.

Similar to a physical annealing process, we use "temperature" to control the process of system optimization. It starts from a high temperature T_0 and then to some lower temperatures T_1, T_2, $\cdots$, T_i, $\cdots$ When a pre-defined temperature T_E is reached, we can say that "stop condition" is satisfied. We can define a function $T_i = f(T_{i-1})$ to control the cooling process. This is called the "Cooling schedule". For each temperature, several iterations should be done to reach a local optimum state, say, "Heat balance" is reached. "Metropolis principle" is used to control the system to transfer to a new "better" state. Although we cannot obtain the optimum solution, SA algorithm gives good solutions that are useful in planning network architecture.

6.2 Forecasting the Demand of the Multimedia Communication Systems

Today network environments of universities for education and training are growing, fueled by extensive enhancements of computer hardware and software as well as the rapid growth of the Internet, World-Wide Web (WWW or Web) and Wireless Local Area Networks (WLAN). To use limited network resources effectively, network managers need to obtain accurate and reliable information from these networks, such as how much traffic is every day, how high the peak traffic is and when peak comes, etc. and to know how to forecast traffic in the future. In the subsystem of the network planning, we use a forecast method for forecasting the demand of the multimedia communications networks with exponential smoothing method. Forecasting with exponential smoothing and deleted method works with a few parameters inputted by the users and gives a tendency of development of network traffic. Here we first use a sort of linear regression analysis with traffic time series to represent the service quantitatively and to construct the traffic characteristics model. Then we analyze the traffic characteristics using coefficient of variation and apply exponential smoothing and deleted method to forecast the traffic volume. Numerical results using practical observation data show that the proposed method produces an effective forecast and is thus effective for use.

6.3 Analysis of Web-Based Network (Internet/Intranet) Traffic

Considering development of the Internet traffic in a campus network, we may find out in historical data collected that total traffic volume in the Internet related with time to forecast the future traffic demand for the multimedia information in the network.

(1) Internet Traffic Load Statistics

Figure 6 shows traffic load statistics of historical traffic for the Internet of a university campus for a 24-hr period (midnight to midnight) on a day by digitizing statistics of the traffic volume per 10 minutes in a day. The statistics of historical Internet traffic volumes were from April 1, 2000 to July 31, 2000.

During ordinary day period, the students are most active on the network, the web traffic grows substantially, and since the daytime limits are relaxed. Observe also, from Figure 6, that the Internet traffic is lower in Saturdays and the Internet traffic is the lowest in Sundays

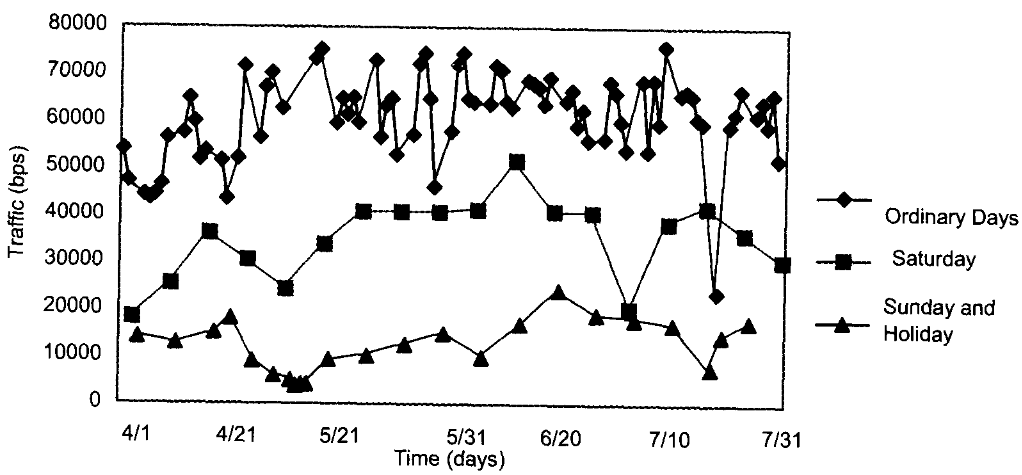

Figure 6 Traffic of the Internet of a university network

and holidays including holidays of the university.

(2) Periodical Element

We calculate the autocorrelation coefficient by following equation to analyze the periodicity of the traffic load:

$$\rho_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (5)$$

where x_i and y_i represent time (ith day) and traffic load of ith day, respectively, $\bar{x}$ and $\bar{y}$ are their average values.

From the time series data as shown in Figure 6, we can obtain the autocorrelation coefficient as shown in Figure 7, where the higher autocorrelation coefficient values are for ordinary days, the lower autocorrelation coefficient values are for Sundays and holidays, others are for Saturdays. It is clear that the periodicity is 7 days (one week) taking out the period of holidays including holidays of the university.

(3) Trend Element

We calculate liner regression relationship between traffic and time (days) by following equation to draw the trend element of the traffic load and study a general underlying pattern connecting these two variables:

$$y' = a + bx, \quad (6)$$

$$a = \bar{y} - b\bar{x}, \quad (7)$$

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (8)$$

where x_i and y_i represent time (ith day) and traffic load of ith day, respectively, $\bar{x}$ and $\bar{y}$ are their average values. y' denotes the ordinate of any point on the least squares regression line and y_i' denotes the ordinate of the point on the regression line corresponding to x_i. a is the height of the line at the point x = 0. The quantity b is the slope of the line. when x increases by one day, the height of the line changes by b units.

Figure 8 shows the liner regression relationship between traffic and time (days). The plot shows the average increase rate per month is 7.5%. It means that the Internet traffic volume of the campus is in a growth period.

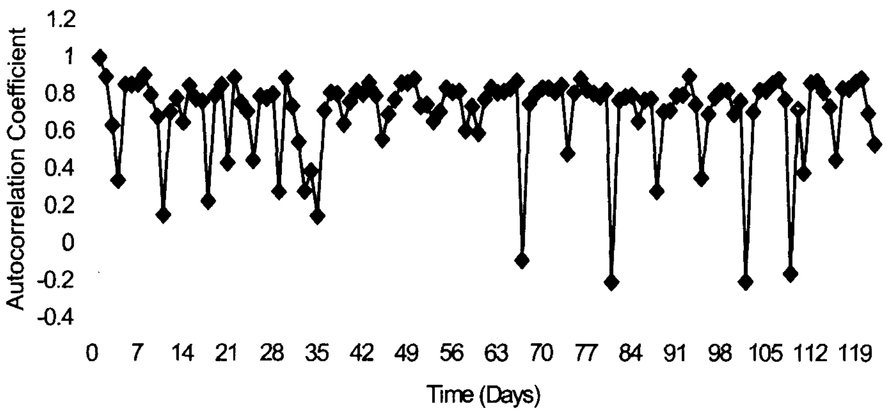

Figure 7 Traffic autocorrelation coefficient versus time (days)

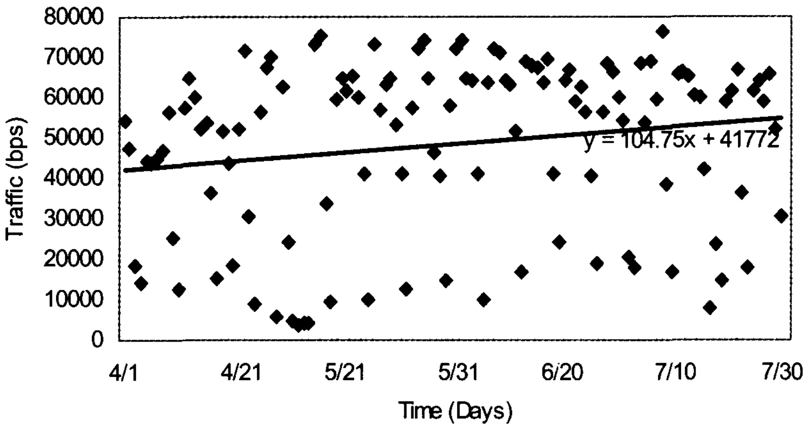

Figure 8 Linear regression relationship of traffic and days

6.4 Exponential Smoothing Method

We use a forecast method called exponential smoothing method for analysis and forecast of the traffic demands on multimedia communication systems. Forecasting with exponential smoothing method can execute its task by a few parameters inputted by the users and gives a tendency of development of network traffic. First, we give two definitions as follows:

(1) Average traffic W_i of one week before ith day that is given by

$$W_i = \sum_{i=1}^{7} x_i / 7 \qquad (9)$$

where x_i is traffic of ith day.

(2) Coefficient of variation C_{di} of days that is given by

C_{di} = traffic load of dth day of ith week / average traffic load W of ith week.

We need to forecast the average traffic volume W_{i+n} and the coefficient of variation C_{di+n} of N weeks after ith week. Using the above definitions, forecasting with exponential smoothing method can be presented as follows:

[Step 1] To forecast the average traffic W_{i+n} of N weeks after ith week by

$$W_{i+n} = Y_i + T_{i+n}, \qquad (10)$$

$$T_i = B_{i-1}, \qquad (11)$$

$$B_i = (Y_i - Y_{i-1}) + (1-\alpha)(T - (Y_i - Y_{i-1})) \qquad (12)$$

where Y_i is the average of actual traffic volumes of i weeks. For example, we can give traffic volume of a week by adding traffic volumes of 7 days measuring traffic volume per 10 minutes in a day. T_i is the forecasted trend value of ith week. α is a smoothing constant.

[Step 2] To forecast the coefficient of variation C_{di} of dth day of ith week by

$$C_{di} = B_{di-1}, \qquad (13)$$

$$B_{di} = Y_{di} + (1-\alpha_n)(C_{di} - Y_{di}) \qquad (14)$$

where $B_{d0} = Y_{d1}$ and Y_{di} is actual value of the coefficient of variation of dth day in ith week. Y_{di} is given as follows:

Y_{di} = actual traffic volume of dth day in ith week / average actual traffic volume of 7 days before dth day of ith week.

C_{di} is the forecasting value of coefficient of variation of dth day in ith week (i=1, 2, …).

α_n is a smoothing constant.

[Step 3] To forecast traffic S_{di+n} of dth day of N weeks after ith week. S_{di+n} is given by

$$S_{di+n} = C_{di+1} + W_{i+n} \, . \qquad (15)$$

6.5 Forecasting Traffic Volumes of Campus Internet

With the exponential smoothing method presented in 6.4, we forecast traffic volume of the Internet for the days from April 1 to July 31 and from October 1 to December 31, 2000, and compare the traffic volumes between the surveyed traffic volume and the forecast traffic volume, where, the period from August 1 to September 30 is that of the summer vacation. It should be noted here that holidays of universities are different and longer than holiday of other organizations.

The forecast error e is given by e = (actual values - forecast values) / actual values. The forecast errors are shown in Figure 9.

Though some values of the error may have large differences between actual and forecast values, from the network management view point, the forecasting traffic volume is important to estimate the traffic volume on the safe side which takes into account the prediction distribution. Numerical results plotted in Figure 9 show that the exponential smoothing method is an effective method that produces a well forecast and is thus an effective method for practical use.

We can conclude that the exponential smoothing method is an effective method to forecast the demand of traffic volumes, but it is not the best method. For more accurate forecasting of the growth traffic model, we

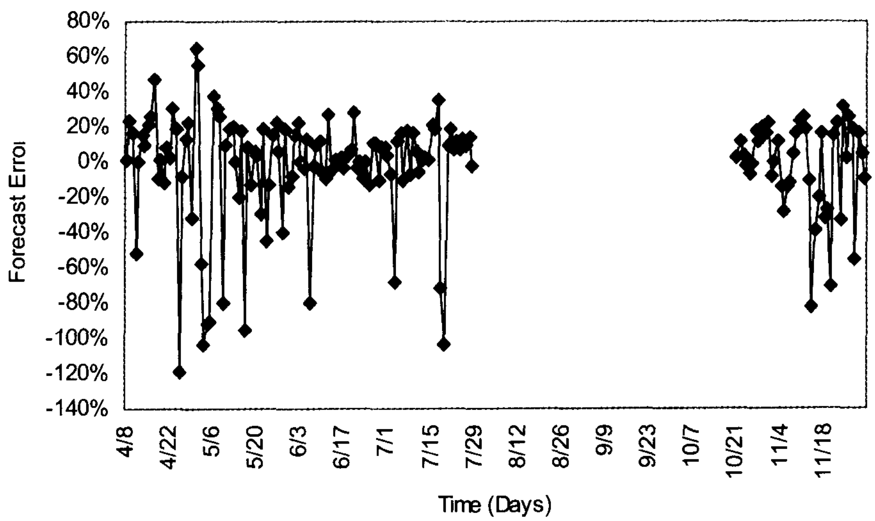

Figure 9 Forecast error of the growth model using exponential smoothing method

need to improve the exponential smoothing method with other support methods, since many factors affect traffic volume of the network.

7. Conclusions

This paper presented a new index system for the performance evaluation and network planning of multimedia communication systems using measurement on actual systems to support several different traffic types. In this index system, we developed an expert system to evaluate the performance of such multimedia communication networks including channel utilization and call blocking probability and packet delay, and applied the network planning methods to optimize the networks and forecast the demand of the growing multimedia communications systems. We first discussed analysis methods, performance measures for the multimedia communication system. Then, we described network planning methods for the multimedia communication systems and gave some efficiency network planning methods. Finally, we presented some results studied in traffic forecast for a campus network and showed the effectiveness of these methods.

The main aim of our research is to put forward the index system for the evaluation, select appropriate indices or methods from index system and comprehensive evaluation methods, operate the real data from some multimedia communication networks and establish the computer evaluation support system. The index system will be widely used, not only during design and development, but also for configuration, tuning, and capacity planning purposes. We have surveyed our researches on the multimedia communication network planning and economic engineering in recent years. Some of the models, methods and tools are proven to be useful in performance evaluation and planning practice. Efficient performance planning supports are urgently required. And new methods, technologies, models and practical tools are to be discovered in the future from the growing multimedia communication systems for education (virtual universities and distance learning), information dissemination (virtual libraries and virtual museums), and information aquarium (content-based retrieval of images and video), and so on.

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