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An Architecture of Scalable ATM Switching System and Its Call Processing Capacity Estimation

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CONTENTS

ABSTRACT

In this paper, we define the general requirements of ATM switching systems such as scalability, distributed fashion, and modularity. Also we propose a practical implementation of a scalable ATM switching system whose capacity can be easily expanded. Firstly, the architecture of the system is discussed with an emphasis on system scalability, modularity of subsystems and the simple control network of the design requirements. Secondly, we suggest the three types of distributed call/connection control schemes that are suitable for our switching system. We also estimate their call processing capacity on the average and make a comparison of them under the various system architectures. Since our scalable switching system can be constructed to perform the call processing functions on the various levels of the system capacity, it has much adaptability at the various evolution phases or regions of the network environment.

I. INTRODUCTION

B-ISDN will provide users with multimedia communications comprising voice, video, and data services in the future. ITU-T has recommended Asynchronous Transfer Mode (ATM) as the basic transport technology of the B-ISDN for various services and heterogeneous traffic. The ATM switching system, regarded as the most important element of B-ISDN, will adopt ATM technologies. It should have a structure flexible enough to handle the various services and mass traffic that B-ISDN will support. Also it must be developed so as to increase the system capacity smoothly from small to large scale. Therefore it is desirable that the ATM switching system be designed to satisfy general requirements including the above [1]-[4]. However, it is difficult to find research results about the global switching systems including switching network, control network, and call control mechanisms, etc., satisfying the general system requirements for adapting the future B-ISDN environments in the literature. Most of researches were focused on the structure of switch fabrics or the conceptual framework of call control schemes. In this paper, we aim our focus at the implementation aspects of the switching system.

In this paper we define the general requirements of ATM switching systems such as scalability, distributed fashion, and modularity. Also, we propose the practical implementation of a scalable ATM switching system whose capacity can be easily expanded. Firstly, the architecture of the system is discussed with an emphasis on system scalability, modularity of subsystems and the simple control network of the design requirement [5], [6]. Secondly, we suggest the distributed call/connection control schemes that are suitable for an ATM switching system. And we also estimate the call processing capability on the average for each call/connection control scheme.

The organization of this paper is as follows. Section II describes structural requirements for the proposed ATM switching system. In section III we propose a system architecture to satisfy the requirements. Section IV suggests three kinds of distributed call/connection control schemes. In the first schemes, overall call/connection control functions are distributed at each ATM Local Switching Subsystem (ALS) and the number translation function overlaps at all ALSs. In the second schemes, call/connection control functions are fully distributed at each ALS. In the third, overall call/connection control functions are distributed at each ALS and the number translation function is centralized at ATM Central Switching subsystem (ACS). In Section V, we compare system performance for each distributed call/connection control scheme. Finally, section VI includes conclusions.

II. REQUIREMENTS OF ATM SWITCHING SYSTEM

An ATM switching system should be designed to change smoothly the system capacity from low to large scale and also to guarantee user's QOS efficiently without system bottleneck. In this section, we define requirements of ATM switching system that considers the above:

- *Scalability* : B-ISDN developing phase through the initial stage, spreading stage, and popular stage, it is expected that the demand of B-ISDN services will increase gradually. Furthermore, an ATM switching system is necessary to provide multimedia services economically in the diverse area of widely various service demands. It is, thus, desirable that an ATM switching system has scalable structure to expand easily and efficiently from small up to large scale.

- *Distributed architecture* : The software structure of call/connection control functions has to be designed in a distributed fashion to facilitate the expansion of the system without its performance degradation. In addition, an ATM switching system is necessary in order to support distributed processing so as to make possible the flexible positioning of databases for various multimedia services in the future.

- *Modularity* : Each feature of a switching system is realized with several system functions. The system functions are implemented by using function blocks of hardware, software, or both. Sometimes the system functions and the system capacity as well are required to be changed, which causes the function blocks to be modified or added. Modularity is very important to reconstruct the system functions without difficulty and to expand the system capacity smoothly. Considering that ATM technologies are now in their initial stage and are under continuous development, the system should be built of modules for smooth evolution. New services will also be generated as B-ISDN becomes popular. So the system absolutely demands modularity for easy incorporation through adding modules.

- *Controllability* : An ATM switching system should be able to be applied for large-scale data processing as well as conventional data exchange in high-speed ATM networks. For data processing in real time, the control part of an ATM switching system must be equipped in a relatively simple scheme with powerful processors and high-bandwidth IPC (Inter-Processor Communications) channels among multiple distributed processors.

III. SCALABLE ATM SWITCHING SYSTEM STRUCTURE

The ATM switching system, regarded as the most important element of B-ISDN, will adopt ATM technologies and should have a flexible structure to handle efficiently the various services and massive traffic that B-ISDN will support [1]-[4], [8]. Also it must be developed so as to increase the system capacity smoothly from small to large scale at moderate cost. It is certain that *scalability* will provide the competitiveness. Thus we have focused our design efforts on *scalability*. In this section we describe a concept of scalable structure, system configuration, and the control network scheme of our ATM switching system.

1. Scalable Structure

The proposed scalable structure consists of ASM (Access Switch Modules) and ISM (Interconnection Switch Modules) to interconnect each switch module as shown in Fig. 1. The ASM and ISM are made by an identical ATM switch module which is a folded structure. We now define scalable depth as the degree of scalability of the system at 1:1 concentration ratio. Given that ATM switch module has bidirectional n in/out ports and the number of ISMs is k, the scalable depth m is represented as follows:

$$m = 0 \text{ if } k = 0$$

$$m = \log_2 k, \text{ where } 2 \leq \log_2 n - 1 .$$

And the number of ASMs is restricted to $2k$ because of 1:1 concentration ratio. Therefore, at the scalable depth m, the total number of links of the system is given by

$$T_{links} = 2k \times \frac{n}{2} = kn = n \cdot 2^m .$$

Under the assumption of 1:1 concentration ratio, the system size becomes $T_{links} \times T_{links}$ because our system architecture is basically a folded structure. For example, in the case of the scalable depth 0, since the number of ISM is 0, our switching system can be constructed by a single ASM. In fact a switching system which is made by a single ASM is ALS (ATM Local Switching subsystem). The detailed description about it will be appeared in section 2. In the scalable depth 1, the number of ISMs and ASMs becomes 2 and 4, respectively. Therefore, the size of the switching system can be increased gradually from $n \times n$ to $n^2/2 \times n^2/2$ by adding ASMs and ISMs. Furthermore, for adapting the users' traffic volume, we can flexibly construct the system architecture through adjusting the concentration ratio.

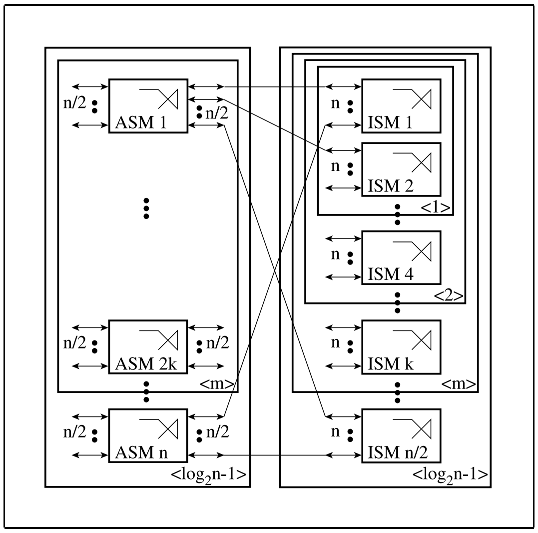


Fig. 1. Concept of the scalable structure.

2. System Configuration

An ATM switching system built with switch modules of in/out ports $n = 32$ and

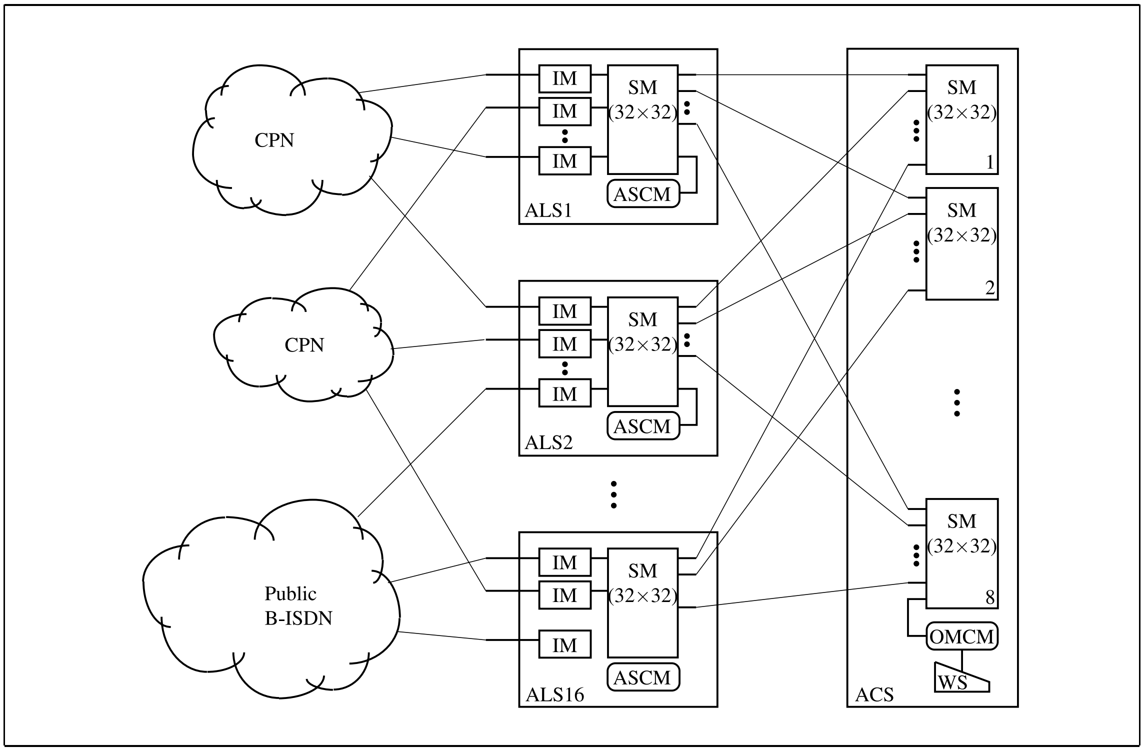


Fig. 2. ATM switching system.

scalable depth $m = 3$ is shown in Fig. 2. An ATM switching system consists of two kinds of subsystems: an ATM local switching subsystem (ALS), and an ATM central switching subsystem (ACS). The ALS has local switching and concentration functions. The ACS is a simple passive switching network for the interconnection between ALS's. Each subsystem has a modular structure interconnected with an IMI (Inter-Module Interface) protocol. Therefore, new service can be easily incorporated by adding the module that conforms to the IMI protocol. The call/connection control software is designed in a distributed fashion to facilitate the expansion of the system without performance degradation.

A. ATM Local Switching Subsystem (ALS)

The ALS is composed of a single-stage self-routing switch module and SIM (Subscriber Interface Module)/TIM (Trunk Interface Module) for UNI/NNI interface functions as shown in Fig. 3. It also has a control module for user service handling and maintenance functions. It is designed to be applicable to subscriber concentration. The concentration ratio can be adapted to traffic conditions from 1:1 to 14.5:1. The ALS can be operated as a stand-alone switching system (32 × 32).

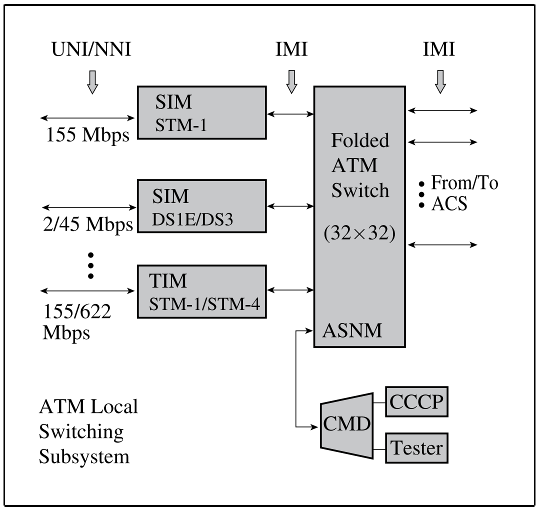


Fig. 3. ALS configuration.

A UNI/NNI interface module consists of physical layer function blocks and ATM layer function blocks. The physical layer blocks convert serial optical signals into parallel electrical signals and carry out section overhead and path overhead procedures. The ATM layer blocks perform UPC/NPC functions for input cells and handle cell routing through an input header translation table. They also convert output cells into their standard cell format by hardware. The control and the OAM part in the interface module communicate with upper-level processors for cell routing and header translation, and control ITU-T I.610 OAM functions along with upper-level processors.

An Access Switching Network Module (ASNM) is a self-routing switching network for high-speed cell switching. The module is of 32 × 32 size and is composed of two stages of 16 × 16 switching elements. The switching element is a limited shared memory switch (LSMS) with an address FIFO for each output port. It also is designed to maintain fairness for hot-spot traffic.

B. ATM Central Switching Subsystem (ACS)

A block diagram of the ACS is shown in Fig. 4. It consists of several 32 × 32 self-routing switch modules, which are identical to the switch modules in the ALS, as well as the control module for operations and maintenance functions at the overall system level.

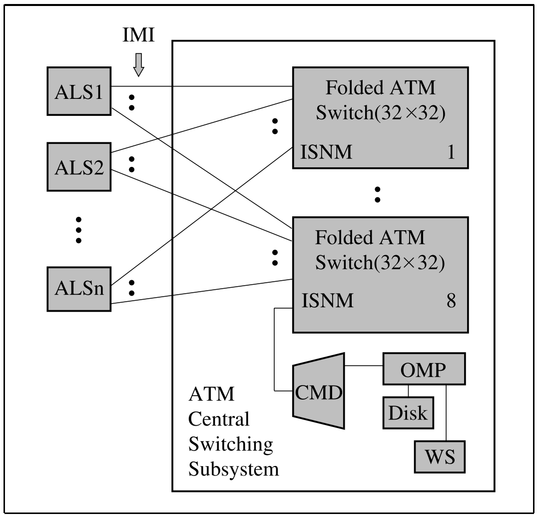


Fig. 4. ACS configuration.

The switching network is used for the interconnection of ALS's and can be expanded up to 8 × (32 × 32) with appropriate system configurations. The ACS control part performs the control of graphic input/output functions as well as the overall system-level functions for maintenance, testing, measurements, and data analysis.

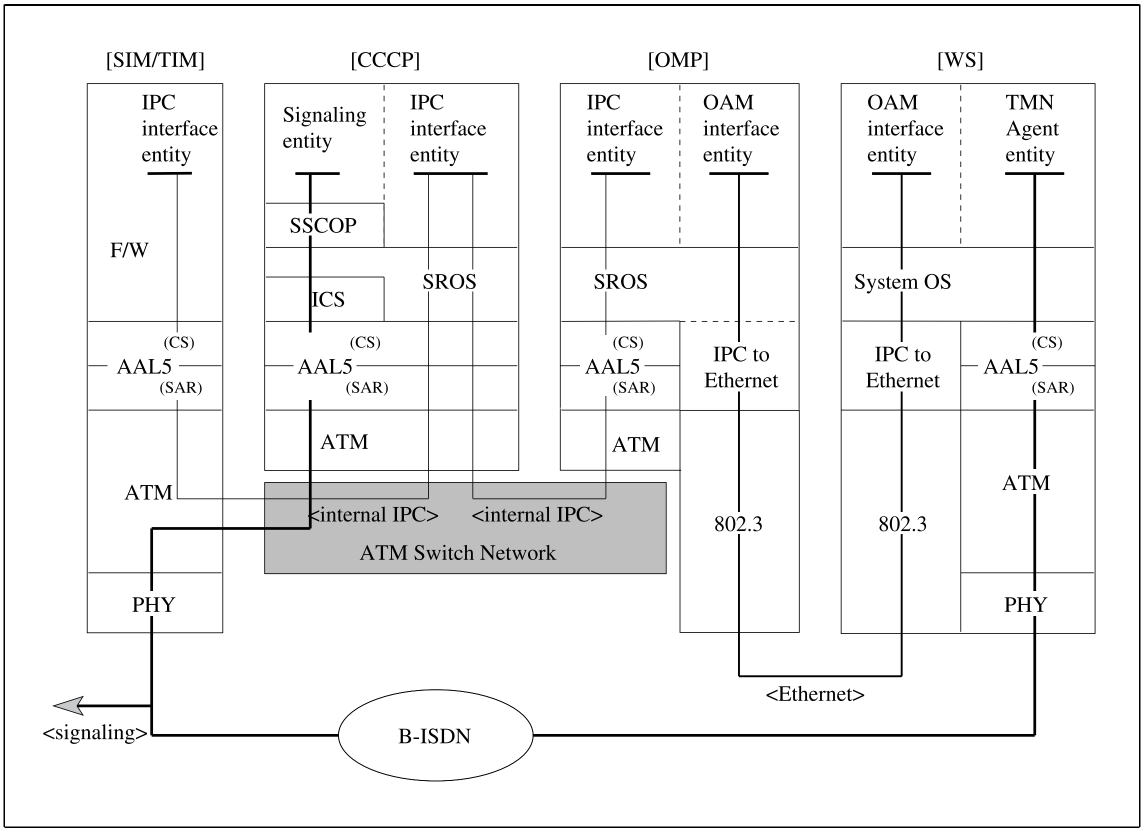


Fig. 5. Protocol stack of control entities.

3. Control Network Scheme

A control part has a distributed structure and modularity such that it makes provision for an increment of system capacity, deals with fault status without hitch, and provides flexibility for the addition of new functions. It consists of upper-level processors, controllers to control each device, and IPC (Inter-Processor Communication) network to communicate with each control entity. All the routes for communication use semi-permanent virtual channels to interconnect each other through the switch network as shown in Fig. 5. Thus all the control entities perform ATM layer functions and AAL layer or similar functions. Protocol stacks in each control entity are shown in Fig. 5. UNI/NNI signaling virtual connection is terminated by the signaling entity of the CCCP (Call Connection Control Processor). The signaling entity converts the signaling information into internal IPC messages as shown in Fig. 6, and these are transferred to appropriate processors. SAR and CPCS sublayers in the AAL layer are type 5 of ITU-T AAL layers. The signaling cells

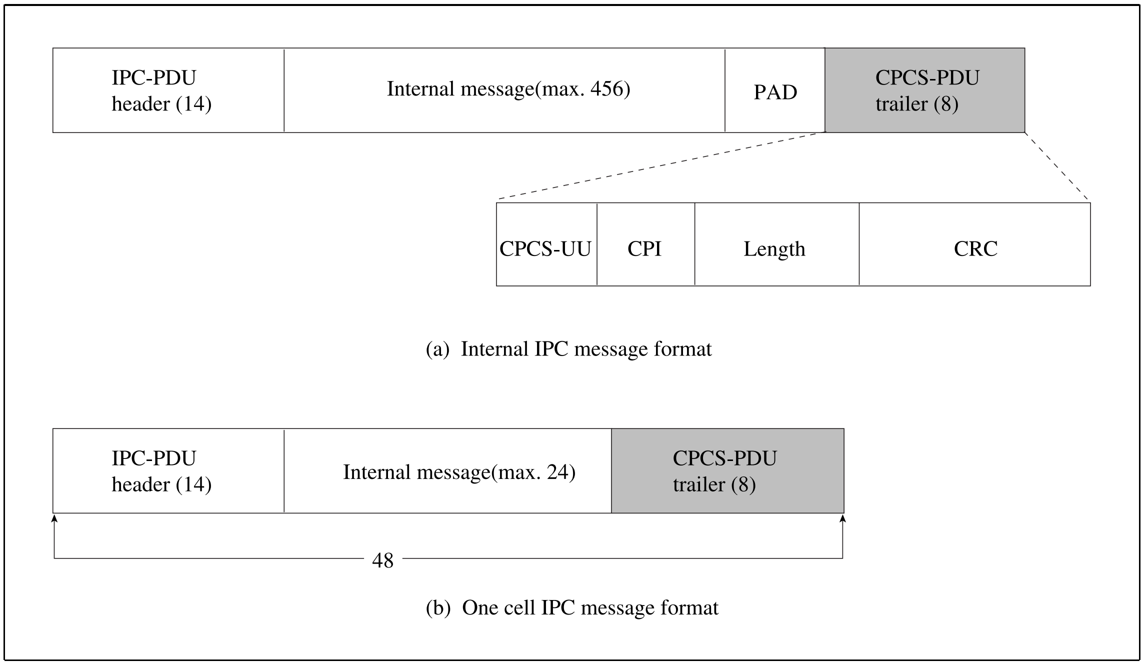


Fig. 6. IPC message format.

from user/network are reassembled to the AAL type 5 message [7], the ICS (IPC conversion sublayer) inserts IPC header of SROS (Scalable Real-time Operating System) layer and then transfers it to application software block by means of the SROS. The IPC messages in the controller that dose not adopt SROS are one cell format of Fig. 6(b). The operational terminal (WS) and the Operation and Maintenance Processor (OMP) are connected to each other by the ethernet bus. The operation terminal provides operator various graphics input/output functions. The WS contains a TMN (Telecommunication Maintenance Network) agent entity and connects to the TMN interface entity via a semi-permanent ATM connection.

IV. CALL/CONNECTION CONTROL SCHEMES

In this section we describe the call/connection control schemes for our ATM switching system. As mentioned in the previous representation of the switching system, our switching systems are multi-module structures. This makes it possible to implement various schemes of call/connection control, according to how to design the number translation functions, call/connection admission control functions, and resource management functions. We consider three types of control schemes: Fully-distributed, Partially-distributed, and Partially-centralized schemes. The characteristics of these schemes are described in detail in the following sections and their capacities of call processing are also estimated in section V. In addition, each processor manager subordinates only resources that are physically linked to its ALS. Thus, for determining the internal path of an incoming call after the completion of the number translation, each processor performs CAC (Call Admission Control) for a subordinate line and then communicates with the other processor through the switching network, regardless of call processing schemes. However, in the partially-centralized scheme, since the information of routes is managed in the OMP, the OMP performs CAC for the routes.

1. Partially-Distributed (PD) Schemes

In this scheme, each ALS has all the information about the subscriber numbers that are connected to the switching system. This implies that the number translation function can be performed only at the originating call processor. Thus, this storing method makes it easy to find the destination call processor for the incoming set-up signal messages in the types of internal or incoming call processing. In transit or outgoing call processing, each CCCP has a *route selection table*, which is a priority information, for the selection of an optimal route based on the states of trunks. Each CCCP is able to update dynamically this priority information according to the states of the trunks. The OMP, which is located in the ACS, is used to monitor periodically the states of the trunks and then to send it to the CCCPs. In this scheme, the procedure of number translation function is as follows: When an originating processor receives a call set-up message, it performs the prefix number translation for the incoming setup message. If the incoming message is for an internal or incoming call, then the originating processor performs the subscriber number translation and finds the terminating processor (or destination CCCP). If the incoming message is an outgoing or transit call, the originating CCCP refers to the *route selection table* to find the terminating processor, and sends to set-up message to the terminating processor which is indicated by the *route selection table*. If the bandwidth of the route is not available for connecting that call, the terminating processor returns the set-up message to the originating processor. When the originating processor receives the returned set-up message, referring to the table to search the other off-spring-route, it sends the set-up message to the new terminating processor and continues in this manner until the incoming call is connected or blocked. The procedure of internal call in the partially-distributed scheme is depicted in Fig. 7. Fig. 8 shows transit call procedure in this scheme.

In this method, the number of IPC messages among the processors for outgoing or transit call processing may increase when the available bandwidth is not enough. Another disadvantage is the problem of the consistency

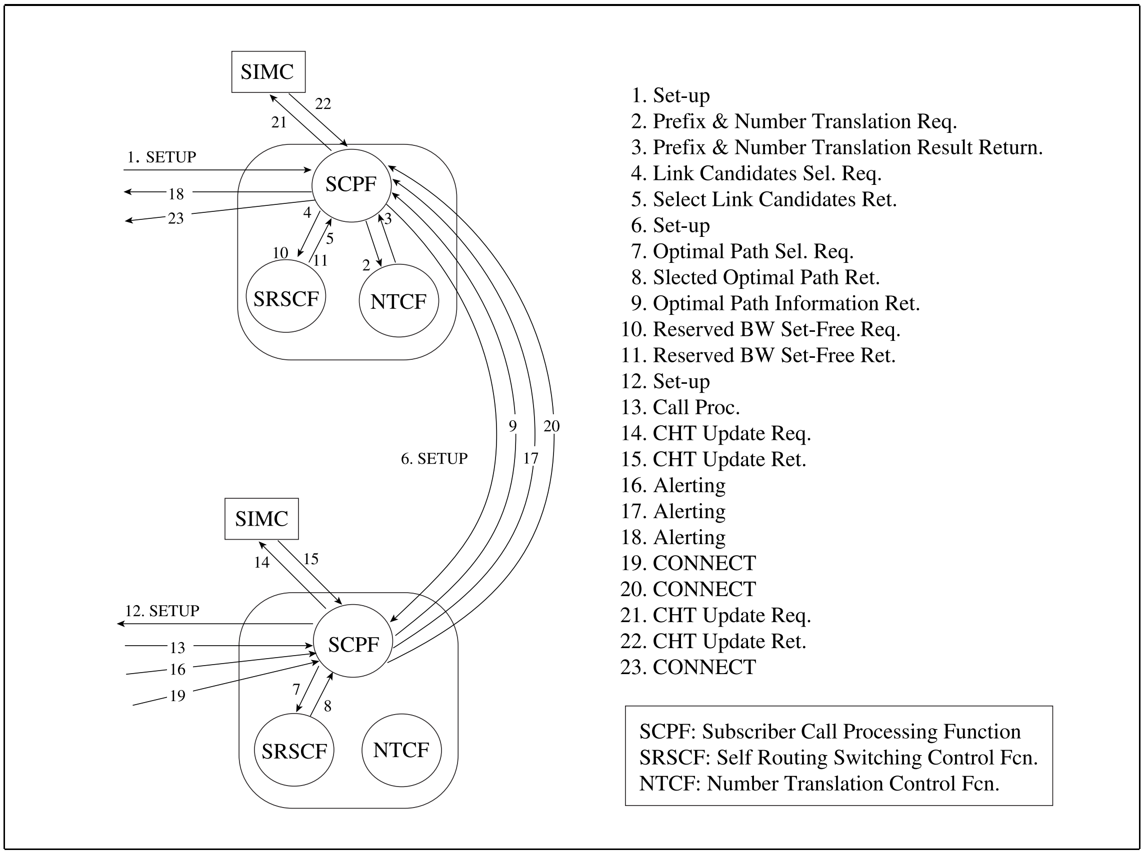


Fig. 7. Internal call procedure for the partially-distributed scheme.

of data, such as the information of the states of the trunks, prefix numbers, and subscriber numbers among the call processors.

2. Fully-Distributed (FD) Scheme

In this scheme each ALS has only the information of subordinate prefix and subscriber number. Thus each call processor in an ALS has both prefix and subscriber number translation functions, regardless of types of calls, unlike the partially-distributed scheme. In this scheme the call procedure is as follows: When a call processor receives a call set-up message, it performs the number translation. If the set-up message is for a subordinate line unit, it goes to the next step for establishing the call. Otherwise, the set-up message is transferred to the next processor by IPC until the relevant processor is found. In this scheme there is no longer the disadvantage of data consistency that occurs in the partially-distributed schemes. However, the problem of the additional IPC messages required in the switching

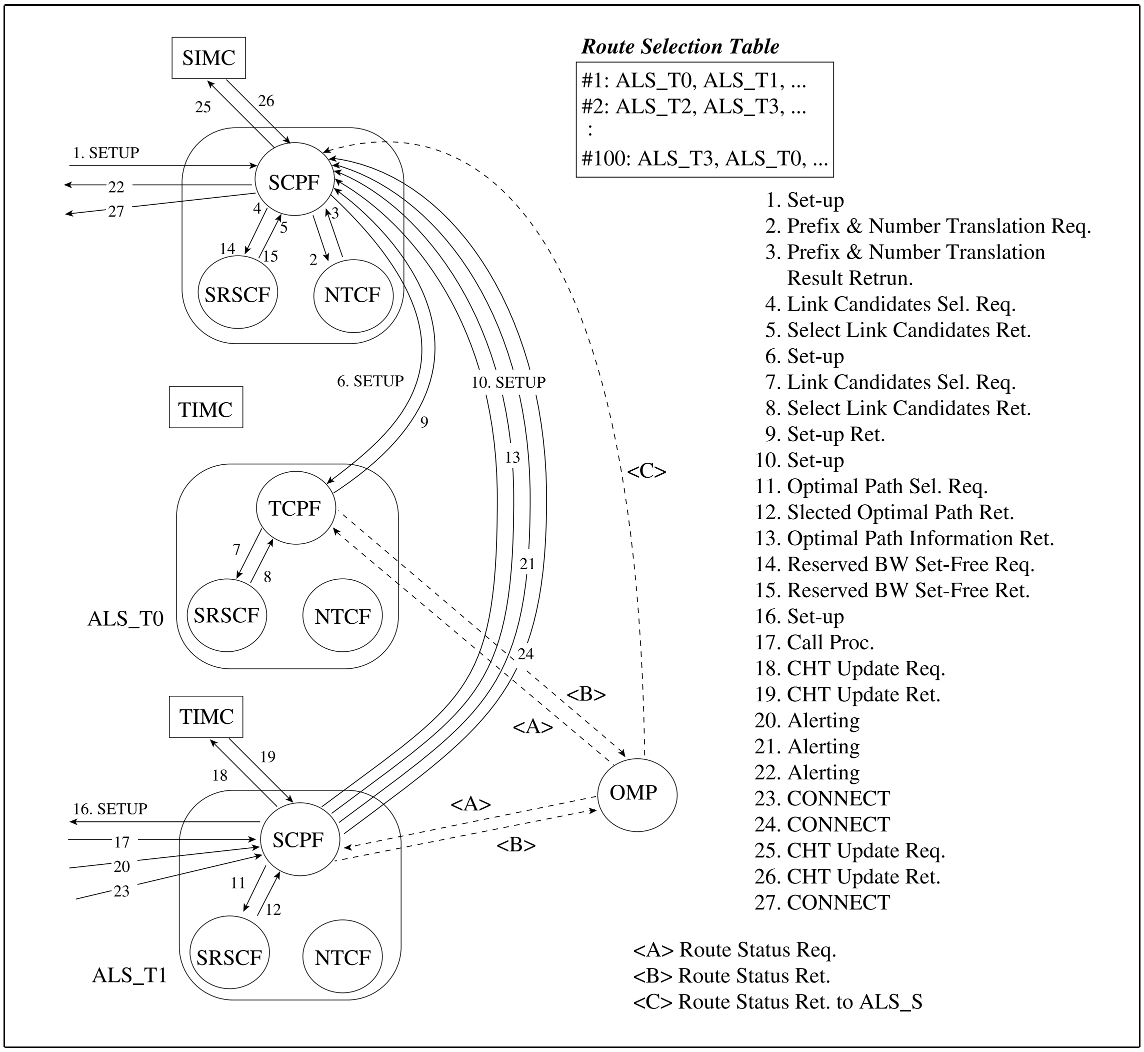
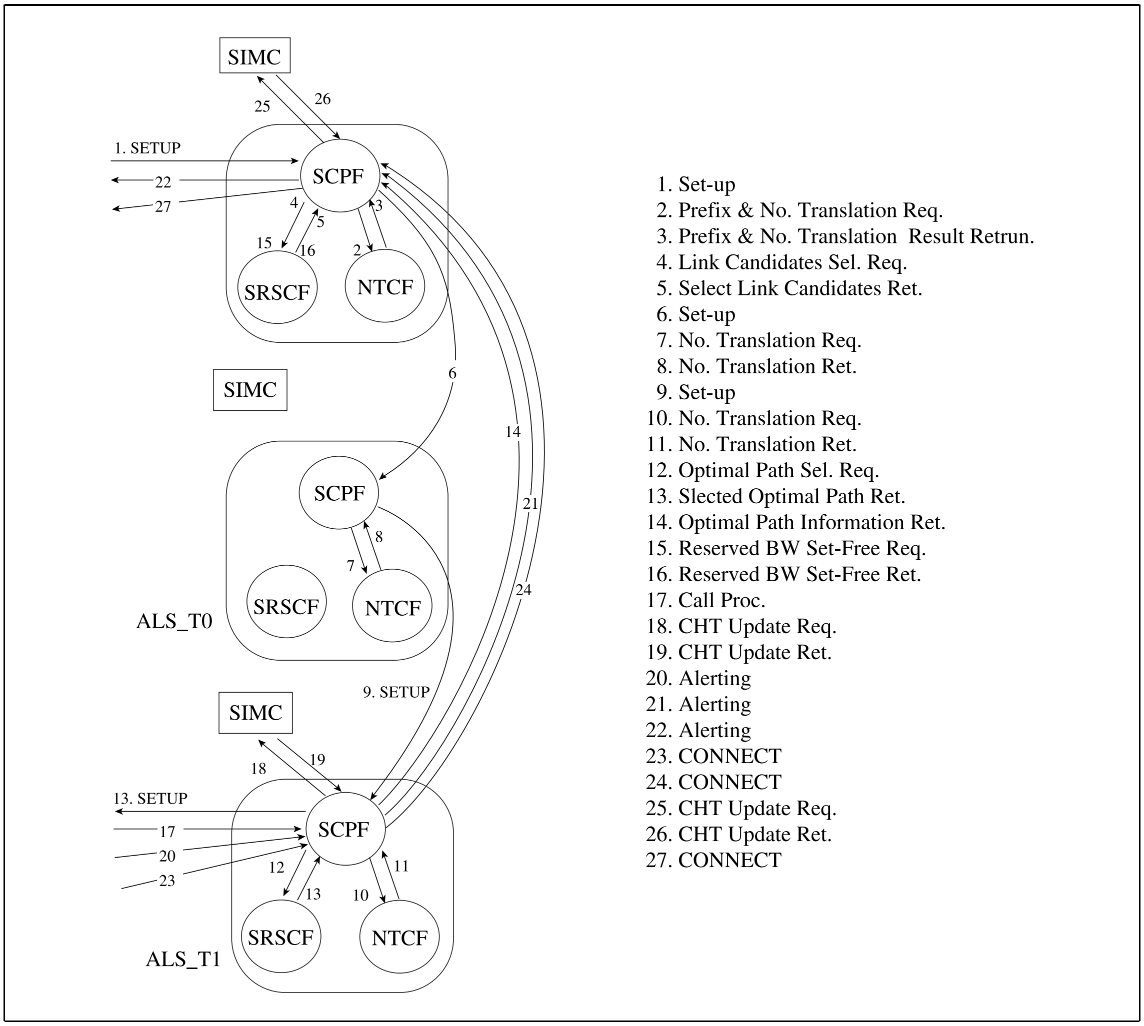


Fig. 8. Transit call procedure for the partially-distributed scheme.

network remains.

3. Partially-Centralized (PC) Scheme

In this scheme, each ALS has all the information of the prefix numbers. However, the information for subscribers and routes is centralized in the OMP. Thus, when a set-up message arrives at the originating processor, the terminating processor can be found, only one at a time, by the number translation function of the OMP. It is well known that centralization makes it simple to control call connection. However, this scheme has a critical disadvantage that the OMP may become a bottleneck processor. Thus, it is not suitable for the high-



1. Set-up
2. Prefix & No. Translation Req.
3. Prefix & No. Translation Result Retrun.
4. Link Candidates Sel. Req.
5. Select Link Candidates Ret.
6. Set-up
7. No. Translation Req.
8. No. Translation Ret.
9. Set-up
10. No. Translation Req.
11. No. Translation Ret.
12. Optimal Path Sel. Req.
13. Slected Optimal Path Ret.
14. Optimal Path Information Ret.
15. Reserved BW Set-Free Req.
16. Reserved BW Set-Free Ret.
17. Call Proc.
18. CHT Update Req.
19. CHT Update Ret.
20. Alerting
21. Alerting
22. Alerting
23. CONNECT
24. CONNECT
25. CHT Update Req.
26. CHT Update Ret.
27. CONNECT

Fig. 9. Internal call procedure for the fully-distributed scheme.

volume call connections.

V. CALL PROCESSING CAPABILITY

In this section we analyze the performance of the call processing capability of the control network under point-to-point call connections. As the measurement of call processing capability, BHCA (Busy Hour Call Attempts) is used. To determine the call processing capability on the average of the switching system, we employed the Bellcore method to evaluate the processor capacity (calls/hr) and applied ITU-T methodology [9].

In general, to evaluate the call process-

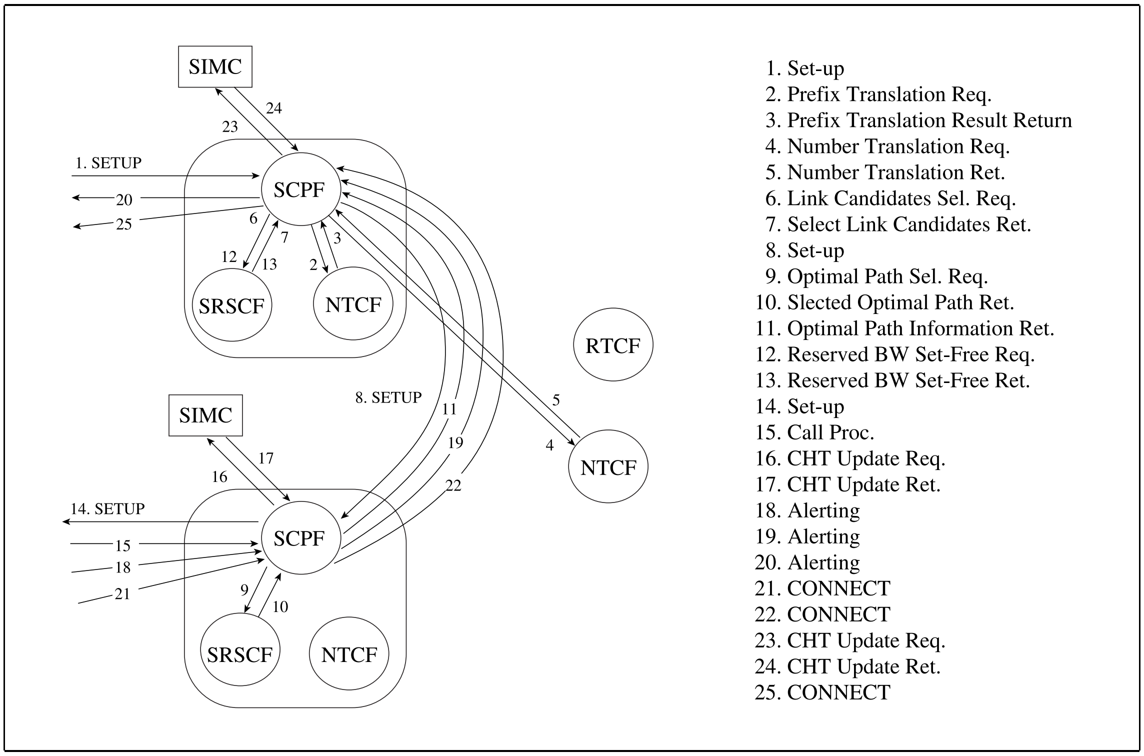


Fig. 10. Internal call procedure for the partially-centralized scheme.

ing capability of the distribution-structured switching systems, we first have to classify the calls, for example originating calls, incoming calls, half calls, and full calls, etc. Second, the reference capacity unit must be determined in order to estimate the capacity of each processor. Third, the capacity of each processor such as the central processors and peripheral processors should be estimated in the control system within the switching system. Finally the global capability of the switching system must be evaluated, based on the bottleneck processor.

Assumptions :

- We consider only point-to-point call connection.
- A processor only performs functions associated with the call connection.
- We do not consider bandwidth insufficiency in the switching network.
- The limiting call processor occupancy is 90 percent.
- The input pattern of the messages into each processor is the Poisson.
- We assume the following call-mix:
- In general, as for the call attempts spectrum, there are called subscriber busy, no answer from called subscriber, and complete call. In

this paper we consider only complete calls.

- In transit or outgoing calls the number of offspring for a route is three.

Type	Attempt ratio
Internal Call	0.20
Outgoing Call	0.40
Incoming Call	0.35
Transit	0.05

Classification of Calls : In our switching system, there are structured SCP (Subscriber Call Processor) and TCP (Trunk Call Processor) to control the call/connection handling at UNI and NNI, respectively, and OMP to manage the operations and the system maintenance of the switching system. Thus, our call processing scheme is basically a distributed scheme with exception of some particular functions, such as number translation and call admission control functions. In this distributed scheme, two or three processors are needed to connect a complete call, according to the implementation method of the call processing. To evaluate the capacity of processors in our system, we use two types of classification methods: One is for estimating the capacity of half-call processing of a SCP or a TCP, the other is for estimating of the capacity of full-call OMP processing.

- Types of half-call: It is used to estimate the capacity of call processors
  - i) Originating half-call from the subscribers
  - ii) Terminating half-call to the subscribers
  - iii) Originating half-call from the trunks
  - iv) Terminating half-call to the trunks

In the above classification, the first type includes the originating parts of internal calls and outgoing calls. In the second, there are the terminating parts of internal calls and incoming calls. The third are the originating parts of transit calls and incoming calls. The last type includes the terminating parts of transit calls and outgoing calls.

- Types of full-call: used to estimate the OMP capacity.
  - i) Internal calls
  - ii) Outgoing calls
  - iii) Incoming calls
  - iv) Transit calls

We use the above “originating half-call from the subscribers” and “internal call” as our reference capacity unit for each classification of calls.

Processor Capacity : As a definition [9], Processor capacity is the maximum number of calls per hour that a processor can carry while still satisfying service standards[1]. We can calculate the processor capacity using the following equation:

$$\text{Processor Capacity} = \frac{(3.6 \times 10^6 \text{ ms/hr})}{\text{Average Real Time per Call (ms/call)}}$$

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[1] The service standards are not yet specified. However, in this paper, we assume that it should be met under 90 percent of the limiting call processor occupancy.

$$\times \frac{\text{Limiting Call Processing Occupancy}(\%) \times 100}{\text{Average Real Time per Call (ms/call)}}$$

In the above equation, “Limiting Call Processing Occupancy” means the maximum processor occupancy available for call processing with all service objectives met, and it can be specified by the vendors. We assume 90 percent as the value of the limiting call processing occupancy. “Average Real Time per Call” is calculated as the weighted average of processor real time for each attempt type. This average real time per call depends not only on the processor real time for each attempt type, but also on the call-mix defined in the above assumptions.

<Processing Capacity Computation>

Let P_i be the fraction of call attempts expected to be type i of call ($\sum_i P_i = 1$)
F_i be the weighting factor for type i of call.

Step 1) Calculate the RUPC (Reference Unit Processing Capacity) by using the “Processor Capacity” equation.

Step 2) Calculate the processor capacities of each type of call.

Step 3) Calculate the weighting factors for each type of call.

$$F_i = \frac{\text{RUPC}}{\text{processing capacity for type } i \text{ call}}$$

Step 4) If the estimating processor is a call processor, we calculate the attempt rate in terms of busy hour half-units:

$$R = \frac{\text{RUPC}}{\sum_i P_i F_i}$$

If it is OMP, go to the next step.

Step 5) Calculate the call processing capability of each processor.
If it is a call processor, $BHCA = R/2$.
If it is OMP, $BHCA = \frac{\text{RUPC}}{\sum_i P_i F_i}$.

System Call Processing Capacity : The call processing capacity of a switching system depends on the capacity of the bottleneck processor in each scheme. Thus, to estimate the capacity of the system, the first work is to find the bottleneck processor through evaluating the capacity of the processors. The capacity of the system in the distributed scheme, then, equals the number of call processors × its processing capacity. In the partially-centralized scheme, the capacity is the minimum value between the number of call processors × its processing capacity and the one of the centralized processor.

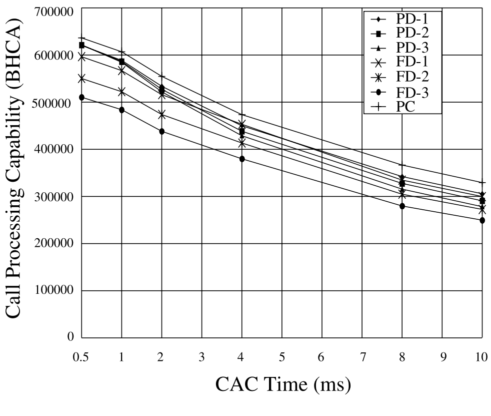

Fig. 11. Call processing capacity of 64 × 64 switching system with 1:1 concentration ratio.

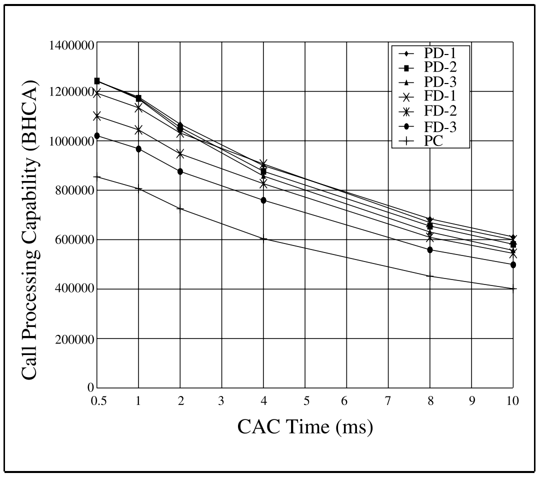

Fig. 12. Call processing capacity of 64 × 64 switching system with 14.5:1 concentration ratio.

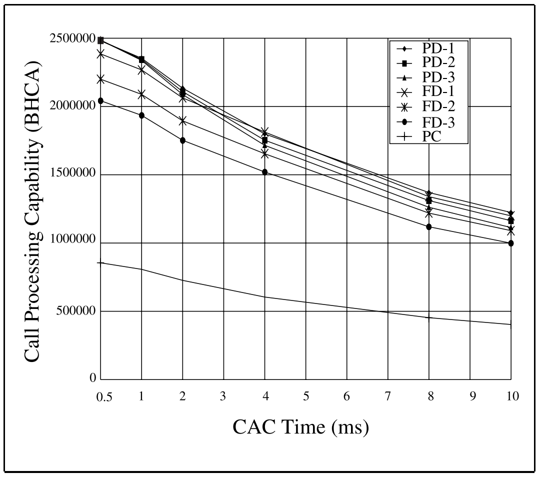

Fig. 13. Call processing capacity of 256 × 256 switching system with 1:1 concentration ratio.

The comparison of the capacity for four types of switching system is shown in Fig. 11-14. Fig. 11 shows capacity for 64 × 64 switching system with 1:1 concentration ratio. Fig. 12 is for 64 × 64 switching system with 14.5:1 concentration ratio. Fig. 13 is for 256 × 256 switching system with 1:1 concentration ratio. Fig. 14 is for 256 × 256 switching system with 2.875:1 concentration ratio. In the evaluation of the call processing capability, it is assumed that the CAC (Connection Admission Control) times, in each processor, are 0.5, 1, 2, 4, 8, 10 (mili-seconds). In this paper, CAC time means the execution time of bandwidth allocation for the requested call in the switching system. In fact there is no statistical bandwidth allocation algorithm to guarantee the QOS requirements of individual connections. Thus, we estimated the call capacity under the average CAC time assumption. If a certain statistical bandwidth allocation algorithm is developed, we can easily obtain the call capacity from the average execution time, that is, CAC time, of it. In legends of the figures, *n*, for example, “PD-n”, “FD-n”, means the number of searches for the relevant termi-

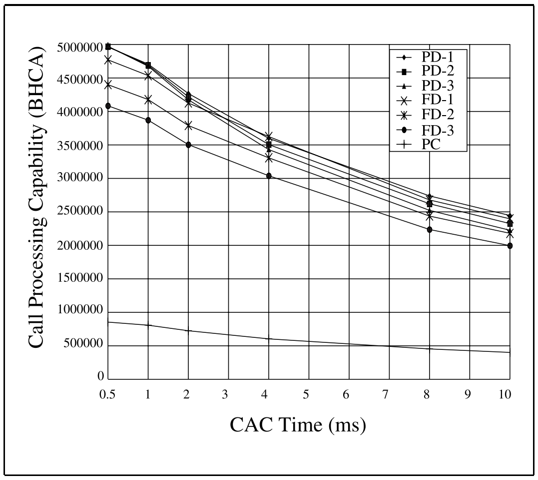

Fig. 14. Call processing capacity of 256 × 256 switching system with 2.875:1 concentration ratio.

nating processor. We assumed that it needs trials for searching the relevant terminating processor in the distribution schemes, regardless of the type of calls. In the figures, note that the concentration ratio depends on only the number of call processors. Thus, in 64×64 switching system, the system with 1:1 concentration ratio has 4 call processors and 1 OMP. And the one with 14.5:1 ratio has 8 call processors and 1 OMP. As we pointed out before, the capacity of the distributed schemes should be determined by the number of call processors and its processing capacity. In these schemes, thus, the capacity of the system can be increased by adding the call processor as long as the switch link capacity is available.

However, the one of the partially-centralized scheme is the minimum value between OMP's capacity and the number of call processor $\times$ its processing capacity. Thus, PC has the highest capacity in Fig. 11 but it has the lowest one due to the fact that OMP is the bottleneck processor in Fig. 12.

For 256×256 systems, we can interpret in the similar aspects. In addition, since the difference between PD and FD seems to be negligible, we have to consider another aspect such as data consistency, implementation, etc., in the selection between PC and FD.

From the above results, the distribution schemes are expected to be better than the centralization schemes for a large-scale switching system although the distribution scheme is more complex than the centralization schemes.

VI. CONCLUSION

In the future it is expected that the demand of B-ISDN services will increase gradually. Therefore it is desirable that a switching system has a scalable structure in order to expand its capacity from small to large scale, easily and efficiently. In this paper, a scalable switching system architecture and its practical implementation have been proposed. This scalable architecture makes it possible to implement various call/connection control schemes in distribution fashion to eliminate system bottlenecks. From this point of view, we proposed the three kinds of call/connection control schemes, according to the design of the number translation function and the call/connection control function. Detailed descriptions of the concepts for these schemes have been also represented. Next, the capacity of call processing of the switching system for three kinds of call/connection control schemes has been estimated. From the results, we can expect that our scalable switching system will be well accommodated to future uncertain behavior of B-ISDN services. In general, before the discussion of the system performance, the following problems are the first considered; 1) B-ISDN Traffic Reference Model, and 2) Objective Utilization of Links. The further research will be focused on the above considerations.

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