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A TELETRAFFIC SIMULATOR FOR CIRCUIT SWITCHED AND SIGNALING INTELLIGENT NETWORK WITH SS7

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ABSTRACT

CCITT Signaling System Number 7 (SS7) and Intelligent Networks have just been fully or partially implemented by many telecommunica-tions companies in the past few years. Their impact on the performance of the entire network has been incredible, however room for improvement still remains through thorough study and careful planning. A CSIM-based teletraffic simulator originally designed for a circuit switched network, was further expanded to simulate SS7 and intelligent networks. This paper illustrates the design paradigm of the simulator and how it achieves the performance measurement of and planning for hybrid networks.

1 INTRODUCTION

The variety of customer oriented communication services enhances the telecommunications industry's profitabilities by cutting the operating and administrative costs, effectively utilizing resources and increasing customers' satisfaction. The market for additional and more complex communication services is expected to grow. Examples of intelligent network services include Alternate Billing Service, Free phone or Toll free and Private Virtual Network Service. These services are made possible by an intelligent network with the CCITT Signaling System Number 7 (SS7). SS7 provides reliable information transfer for call control, remote control, network database access, and management and maintenance signaling. SS7 has very high performance, that is characterized by short transfer delay, no loss of messages, high availability, etc (Worrall 1987).

The CCITT SS7 protocols provide the fundamental structure and performance constraints for a signaling network. However, there are many issues left to the implementers. For example, the Service Switching Point (SSP) may or may not combine with the circuit switching box at the End Office (EO); and there are many architectural options and congestion control mechanisms. The processing time in each vendor's SS7 components may be different, therefore, resulting in different packet delays. Also, each service provided by an intelligent network has a different size and number of packets generated, and may result in different database access performance (delay, number of successful and failed queries etc.). Therefore, research continues on the performance of SS7 and intelligent networks since there is still room for improvement.

For a signaling network where the SSP is separated from the circuit switching box, the performance impacts on the signaling network and the circuit switched network requires investigation. Since SS7 provides very high reliability and efficiency, it is more likely that the architecture of the circuit switched network will have overflow and congestion. Through simulation, network planners will be able to optimize the architectures of the circuit switched network and the signaling network, the congestion control mechanisms (Brown, Chemouil and Delosm 1985) and the criteria of the intelligent network services, and enhance network planning.

A teletraffic simulator was designed to study the performance of many telecommunications networks. In the first phase, the base simulator only simulated a circuit switched network (Scoggins 1991a and 1991b). In the second phase, the signaling network functions were added on. Finally, many customer oriented services were added for an intelligent network. Depending on the purpose of the simulator, the validity of the simulation can be maintained even though certain functions of each network are not simulated, and other functions are represented in a way different from the real world. For example, while SS7 has several levels of protocols the simulator will not simulate all the levels. Instead, it focuses only on the Signaling Network Level for the signaling network, and on the Signaling Network Level for the Signaling Connection Control Part (SCCP) and the Transaction Capability Application Part (TCAP) of the intelligent network.

This simulator is built on top of the simulation package CSIM, which is a product of Microelectronics and Computer Technology Corporation (MCTC). CSIM is a collection of C routines. These routines allow the users to create processes in a multitasking environment, to allocate resources, to schedule events, to pass messages, to manage queues, and to collect statistics. CSIM provides the basic functions for any type of simulation; it can be either procedure oriented or event driven, either discrete or continuous, and has free format. These advantages give CSIM a great deal of flexibility and power in building a simulator. As with any C-based simulation package CSIM also provides the flexibility of adding customer oriented functions, which is a very important capability. Modularity is another advantage gleaned from using C. Regardless of the number of functions provided by a general purpose simulation language, it is almost always insufficient for simulating all kinds of systems. New network features can be easily added on or removed from the simulator without affecting other functions. Once the base simulator is built, it is easy to add on additional functions.

In the second section, we will introduce the hybrid network which is composed of a circuit switched network, and a signaling intelligent network (Baldasaro and Kaschube 1990, Willmann and Kuhn 1990, Worrall 1987, Brown 1985). This will provide the necessary background for readers who are not familiar with the terminology used in and the features of the telecommunications industry, to be able to understand the design of the simulator. The third section describes the design paradigm of the hybrid network. The modeling techniques for the circuit switched network, the signaling network, and the intelligent network are discussed separately. The fourth section outlines the performance measurements, this includes the performance objectives of SS7 (Baldasaro and Kaschube 1990) and the intelligent network (Worrall 1987), the performance of the simulator and the statistics that allow the network planners to study the hybrid network. In the last section, some conclusions are made.

2 FEATURES of the HYBRID NETWORK

In a circuit switched network, switches are responsible for finding and maintaining a time slot, or DS0 port, in each trunk link for each call connection. The time slot won't be released until either end user hangs up the phone. For the synchronization purposes, some time slots are reserved for signaling. Signals can be in-band (using the same bandwidth as the voice traffic does), or out-of-band (using a different bandwidth from the voice traffic). Common Channel Signaling (CCS), is where all signals are carried in the same channel. Since the CCITT recommendation for **Signaling System Number 7 (SS7)** was introduced in 1980 (in the Yellow Book), there have been more and more telecommunications companies using SS7 as their signaling network. SS7 meets the requirements of reliable information transfer for interprocessor transactions within a network for call control, remote control, network database access, management, and maintenance signaling. SS7 is the backbone of the intelligent network. Mobile telecommunication switching offices and broadband ISDN are other important areas of SS7 applications.

SS7 has several levels of protocols. Level 1, the **Signaling Data Link Level**, defines a 56/64 kbps (USA/Europe) bidirectional link that is switchable as semi-permanent channels in the exchange. Level 2, the **Signaling Link Level**, defines the functions and procedures for and relating to the transfer of signaling messages over one individual signaling data link. Level 3, the **Signaling Network Level**, defines the protocols for reliable transfer of signaling messages between the nodes of the signaling network. In the case of failure and congestion, level 3 provides the necessary management actions and procedures to reconfigure the routing of messages through the signaling network These functions are referred to as signaling message handling functions and signaling network management. Signaling message handling functions include message routing, message distribution and message discrimination. Signaling network management is comprised of signaling traffic management, signaling link management and signaling route management. The combination of levels 1 through 3 is called the **Message Transfer Part (MTP)**. The **Signaling Connection Control Part (SCCP)**, level 3.5, provides additional functions to the MTP which cater to both connectionless and connection oriented network services for the transfer of circuit related and noncircuit related signaling information and other types of information between exchanges and specialized centers in telecommunication networks. The **User Part (UP)** includes the Integrated Services Digital Network-User Part (ISDN-UP), Telephone User Part (TUP), Data User Part (DUP), Operation Maintenance and Administration Part (OMAP), Transaction Capabilities Application Part (TCAP), and others which are the user parts actually related to the individual user call control functions.

A signaling network contains two components: **Signaling Points (SPs)** and **Signal Links (SLs)**. Examples of SPs are SSPs, STPs and SCPs. SPs are the SS7 network end nodes that originate, terminate or route the signaling messages. **Service Switching Points (SSPs)** are exchange offices and are associated with call processing and communicating with application databases. **Signal Transfer Points (STPs)** serve as intermediate signaling message transport switches, and can provide level 3 and above functions such as SCCP, ISDN-UP, and stand-alone functions. **Service Control Points (SCPs)** enhance the intelligence of the network by their database control. SLs are used to provide communication paths among SSPs, STPs, and SCPs.

The fundamental intelligent network architecture consists of SSPs, SCPs, and an interconnecting common channel signaling network (assumed to be SS7) which consists of STPs and SLs. The intelligent network also contains Service Management Systems (SMSs), Intelligent Peripherals (IPs), and Feature Nodes (FNs). Elements are connected via transport channels and signaling channels. An intelligent network is service oriented. A wide variety of network based services exist today. Each service may be used separately and represents a decision based on a set of conditions. These decisions

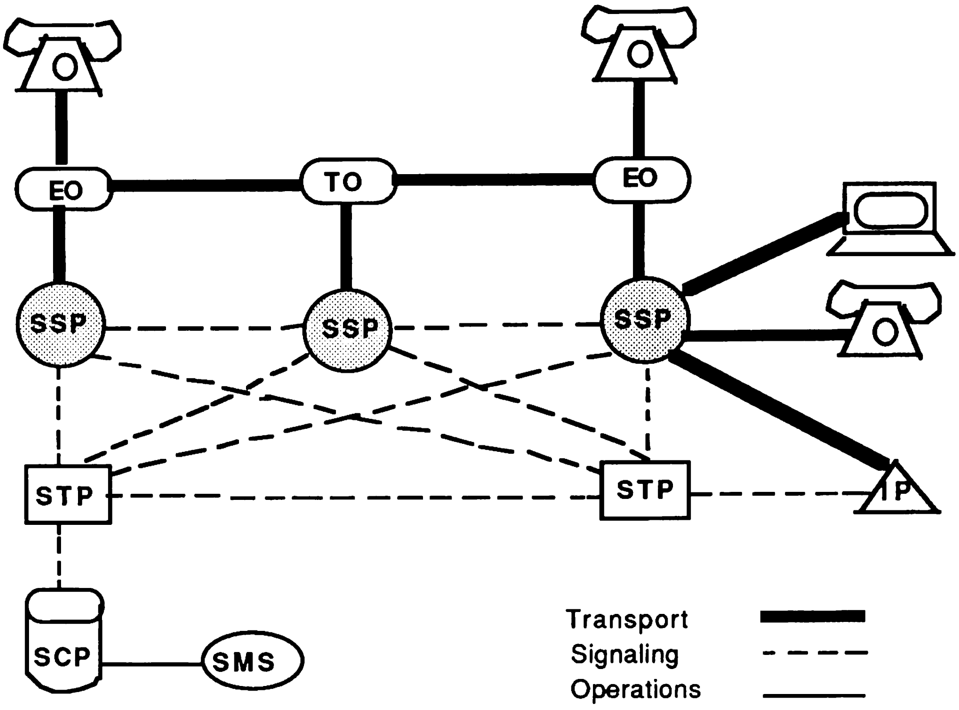

Figure 1: The Architecture of a Hybrid Network

may be linked together in a tree like fashion to construct very complex services.

In telecommunication networks, a circuit switched network and a signaling network work closely together. Figure 1 shows the architecture of such a hybrid network. Subscribers are connected to the End Office (EO). The EOs are connected to other EOs or Toll Offices (TOs). A TO can only transfer calls and is not connected to any end users. The trunks between EOs or between EOs and TOs are called Inter-Machine Trunks (IMTs). The EOs, TOs, and IMTs form the circuit switched network. This part of the hybrid network uses time division switching techniques. A trunk that consists of 24 time slots (DS0 ports), it is called a DS1-trunk. A DS3-trunk is a trunk group which consists of 3 DS1-trunks. Trunks can be either unidirectional or bidirectional. For unidirectional trunks, each call connection occupies two DS0 ports. For bidirectional trunks, each call connection occupies one DS0 port. Once the connection is setup, the DS0 port will not be released until either end user hangs up the phone. When the EO switch detects dialing from the calling party, it communicates with the local SSP. The SSP may or may not reside in the same physical unit as the circuit switched box at the EO. If there is a direct connection between the local SSP and the remote SSP, then the local SSP sends connection establishment packets (which are called the Signaling Units or SUs) to the SSP. Otherwise, the packets may go through at most two STPs before reaching the remote SSP. Some of the calls may require access to the SCP database to validate the authorization for using the services and retrievial of information for processing the call. Depending on the intelligent network architecture, some networks may have SSPs directly connected to a SCP, while others may have only STPs connected to a SCP. The connections between the SSPs, STPs, and SCPs use SLs and comprise the signaling network, portion of the hybrid network, SS7 protocols are used. The SSPs and STPs check on the availability of the remote EO circuit switching box andthe IMTs. If other intermediate switches (called via switches, which can be either EOs or TOs) are required, then the SSPs and STPs will send the connection establishment signaling packets to the via switches' SSPs and check the availability of the via switches.

To disconnect the line, either end user may initiate the tear down process, which is similar to the call setup process. However, the number of packets generated may differ depending on which end user initiates the tear down process. Also, different services such as 800 numbers, 900 numbers, or calling cards may generate different numbers of packets.

During the setup and tear down stages if the signaling packets are not received by the associated SSP due to link failure or congestion then processing cannot proceed until these signaling packets are received, even though the circuit switching box can set up a cross connection for the call. Similarly, if the signaling packets have been received by the associated SSP, but the circuit switching box cannot find a cross connection for the call, the connection establishment cannot be completed. Therefore, when simulating only one of the two networks traffic engineers and network planners may simplify some issues and make inaccurate observations about the performance of the of the hybrid telecommunications network. Thus, statistics should be collected for both the circuit switched network and the signaling network in order to measure the overall network performance and plan for the entire telecommunications system.

Since SS7 is the backbone of an intelligent network, the requirement for simulating an intelligent network on top of the SS7 is to add on the services. Important statistics to the network planners are the relationship between services and database access (such as packet sizes and number of queries, etc), and the relationship between services and signaling transfer (such as packet transfer delay and queueing delay, etc).

3 DESIGN PARADIGM for the HYBRID NETWORK

Many options can be incorporated into the simulator, among these are the input traffic types, traffic units, routing schemes, lost call policies, etc. As more options are included, the amount code grows and simulator efficiency decreases. One method of minimizing the size of the simulator is to make each option a module, then when the simulator is linked only the modules necessary for a particular simulation are included.

Time granularity is the trade off between the computational effort and run time, and the precision of the computations. Since switch processing time ranges from 4.5 to 6.7 milliseconds for setup, is 0.13 milliseconds for tear down, and the SSP processing time is about 10 milliseconds it is convenient to have a time unit based on 1 millisecond. CSIM uses double precision floating point numbers for the timer. Time increments can be in any fraction of 1 millisecond.

A user interface module handles all the displays. These displays include input displays, statistic displays, and simulation status displays. The user may choose to stop simulation at certain break points to examine intermediate simulation results, and then resume simulation. By supplying different simulation attributes through inputs, network planners can study the performance impacts of different setups. The present version of the simulator, requires that changes of simulation attributes be done statically prior to simulation execution. However, future simulator versions will allow dynamic changes to be made, which will enhance the study of network survivability.

Objects in the system are treated as either dynamic factors or static factors. Dynamic factors are represented by entities (or processes), which can be created, executed, and terminated during the simulation. Static factors are typically system resources such as facilities or storage, and must be declared with types and amounts at the beginning of a simulation and hence are represented by global variables. The number of resources can either be increased or decreased. Each resource is in either a busy or an idle state.

3.1 Modeling the Circuit Switched Network

Feature groups are used to distinguish the types of customer services required for the processing of calls. Each trunk may have a certain number of DS0 ports reserved for certain types of features. Each feature group in an Originating and Destination (O-D) Local Access and Transport Area (LATA) may have its own arrival distribution and mean call holding time. This makes routing in the circuit switched network and statistical analysis more complicated. However, it is important to analyze the impact of (service) types of calls on the traffic flow, delay, and blocking.

Each call is treated as a process, the **Call_Process**. There are several ways to generate Call_Processes, depending on the type of traffic input. Either traffic matrices or Call Detailed Records (CDRs) can be supplied as input to generate traffic. CDRs are taken directly from the switches database, while traffic matrices are aggregated from the CDRs during preprocessing. The arrival distribution can be of many types and is configurable prior to simulation. The traffic unit can be either in Erlangs (number of call attempts multiplied by the call holding time in an hour), or in CCS (number of call attempts multiplied by the call holding time in hundreds per second).

Not every field in a CDR is useful to the simulator. Of the 850 to 1200 bytes of data in most CDRs, only 55 bytes are used by the simulator. This data includes the source and destination LATAs, originating and terminating switches, calling number (which is used to distinguish between regular calls, 800 calls, 900 calls, calling card calls, and where applicable service types), arrival time, call holding time, feature group, answer code, termination code, and treatment code. So, preprocessing of the CDRs to reduce their size can improve simulator efficiency .

If traffic matrices are used, then many of the fields mentioned above will not be available, unless further tabular information are provided. Usually, this tabular information is given in the form of probablities for the occurrence of events. For example, between LATA-A and LATA-B the probability of a call with feature A is 0.2, with feature B is 0.1, with feature D is 0.4, and with feature P is 0.3.

The common **routing schemes** for circuit switched networks are Fixed Hierarchical Routing (FHR), Dynamic Non-Hierarchical Routing (DNHR), Dynamic Control Routing (DCR), and Adaptive Routing (AR). This simulator provides both FHR and DCR. There is a **routing table** for the circuit switched network. It specifies the direct and alternate paths between each pair of originating switch and terminating switch/LATA. **Lost call policies** include Lost-Calls-Cleared (LCC), Lost-Calls-Delayed (LCD), and Lost-Calls-Held (LCH). This simulator provides only LCC.

Switches and trunks are treated as static factors and are declared as facilities. A Call_Process will reserve switches for the duration of the call setup process or tear down process, and then release the switches. The Call_Process will reserve the trunks for the duration of the call holding time and the tear down process. If a switch is busy, a Call_Process may enter the switch queue unless the switch is in a high level of congestion (level 2 or 3). However if a trunk has no idle DS0 port, then the Call_Process will try all possible paths and then terminate.

When the total load is above 78% of the maximum switch cpu capacity, the switch is in **level 1 congestion** it then starts to refuse originating calls. This allows calls which have already entered the system to be completed before the switch accepts any more calls. If the total load is above 81% of the maximum switch cpu capacity, then the switch is in **level 2 congestion**, and it will remove calls which have been waiting in the switch cpu queue for more than three minutes in addition to refusing originating calls. If the total load is above 83% of the maximum switch cpu capacity, then the switch is in **level 3 congestion**, and it will terminate all calls which have not been processed in addition to all the procedures for level 2 congestion.

3.2 Modeling the Signaling Network

SS7 has several levels of protocols. The simulator does not simulate all the levels, instead, it focuses only on the Signaling Network Level, SCCP, and TCAP. The reasons for this are that the functions in level 1 are more mechanical; while level 2 mainly deals with data framing; and the application services and functions in level 4 and above provide interfaces to user applications. In contrast, the purpose of the simulator is to simulate the packet switching functions and certain customer services, particularly those from TCAP. However, even when the simulator does not simulate certain levels, some information from these different levels are useful for calculating the total packet delay in SS7. For example, the channel rate, 56 kbps, from the Signaling Data Link Level is used to compute the propagation delay. The flow control mechanism from the Signaling Link Level is also important to know, so that when there are no signaling packets transferred among SPs, a Fill-In Signaling Unit (FISU) will be sent to keep synchronization among the SPs. In case of an overload, a switch will send a busy Link Status Signal Unit (LSSU) to stop incoming transmissions. If the switch does not send any signal for 200 milliseconds or it continues sending busy LSSUs for 10 seconds, then it is reported as out of service.

In the **Message Handling** function of level 3, Message Discrimination and Message Distribution are not really issues for the simulator since all the packets will be delivered to the proper SPs. **Message Routing** uses a Signal Link Status (SLS) field to balance the load between a pair of SSPs. This mechanism is included in the simulator.

Part of the **Signaling Network Management** functions of level 3 are implemented in the simulator. In changeover processing, forced rerouting and controlled rerouting procedures of the **Signaling Traffic Management** function will be executed when a SL or SSP fails. The Signaling Route Management functions of the Signaling Network Management are used by SSPs to inform other SPs about the status of congestion, restrictions, and prohibitions. Since the status of SPs are global information, in the simulator, there is no need to exchange information about the status of SPs and SLs. However, the status of SPs, SLs, and the routing table for the signaling network should be updated promptly so that the other nodes can look up the information and make proper routing decisions.

The Signaling Link Management functions of the Signaling Network Management are used to restore failed SLs, activate idle links, and deactivate aligned SLs. Since the simulator does not currently support survivability modeling, these functions are not incorporated in it.

Since **SCCP** and **TCAP** are important in providing customer oriented services for an intelligent network, both are included in the simulator.

Some of the fields of Signal Units (SUs) are recorded by the simulator. They are: Length Indicator (LI, which is used to distinguish the type of SU), service indicator bits and subservice bits of the Signaling Information Octet (SIO), Destination Point Code (DPC), Origination Point Code (OPC), and the SLS of the routing label (which is in the beginning) of the Signaling Information Field (SIF). Different network management messages have different lengths and subservice codes in the SIO, which are recorded. The SS7 numbering plan is used to first find the network cluster and then the cluster number.

Similar to the circuit switched network, the SPs and SLs are treated as facilities. The difference between SLs and trunks is that SLs are only occupied for the duration of packet transfers rather than for the call holding time. There should be a **routing table** for the signaling network, which specifies the routing choice between every pair of source and destination SSPs. Another table allows the user to enter the number and length of packets generated for each type of messages. The types of messages can be IMT call setup messages, call terminating messages, calling card messages, 800 number service messages, 900 number service messages, etc.

3.3 Modeling the Intelligent Network

An Intelligent network (IN) uses SS7 as the backbone. The SSP recognizes IN call handling requirements through its trigger table. SSP capabilities are typically quoted in terms of Busy Hour Call Attempts (BHCAs) where a call is considered to be a normal and simple call. SSP uses distributed processing, an attempted but failed call requires virtually the same processing time as a completed call, and the time is largely unaffected by the application of any features.

4 PERFORMANCE MEASUREMENT

CCITT has several requirements for the performance of SS7. For network down time,

- Each user interface segment should be down no more than 3 minutes per year.
- Each network access segment should be down no more than 2 minutes per year.
- The backbone network segment should be down only a negligible amount of time.

For end-to-end signaling delay:

- The mean office delay is 75 milliseconds.
- The mean cross office message transfer time is 150 milliseconds.
- The data channel propagation time is 2 milliseconds.
- The end-to-end signaling delay per message is 392 milliseconds, where 75 + 45 + 150 + 45 + 75 + 2 = 392.

EO	STP	TO	STP	EO
75	45	150	45	75

This simulator provides many statistics for each network and the hybrid network performance analysis.

- For the circuit switched network, statistics are grouped into 3 categories:

. In the routine category, the statistics include the total number of calls arrived, completed, and blocked due to no DS0 port in the trunks or due to switch congestion. These statistics are further broken down based on use of direct paths and alternate paths.

. In the trunk category, the statistics include the total number of calls arrived, completed and blocked, the utilization rate, and the throughput and service rate. These statistics are further itemized by direct trunk and alternate trunk usage.

. In the switch category, the statistics include the total number of calls arrived, completed and blocked, the utilization rate, and the throughput and service rate. These statistics are further broken down based on originating switches, via switches, and terminating switches.

- For the signaling network and the intelligent network, statistics are classified into 5 groups:

. The signaling routing statistics include the total number of packets arrived, completed and blocked due to no queue space. These statistics are further classified depending on whether a direct path or an alternate path was used.

. For each of the SSP, STP, SCP, and SL categories the statistics include the total number of packets arrived, completed and failed, the utilization rate, throughput, average, maximum and minimum queueing delay. For the SCP category, each item is further itemized by packet types. Also for this category the average number of query tries is recorded.

- For the overall network performance, the statistics include the total number of calls arrived, completed, blocked due to no DS0 ports or switch congestion, lost due to miss-dial, no answer or other errors, and the total number of packets generated for each type of packets, and the number of packets processed and blocked. The average time, the maximum time and the minimum time that a call or a packet stays in the system or in a queue are also recorded.

This simulator can run in either an interactive mode or a batch processing mode. In the interactive mode, the overall statistics are constantly updated and displayed in a window. The user can interrupt simulation during the break points (which are user configurable) and examine the statistics. Therefore, the execution time may take two days to finish two hours of busy traffic. However, in the batch processing mode, this simulator only requires about 780 seconds of cpu time to complete two hours of busy traffic. The compression rate of simulation time to the real time is about 10%, for the batch mode.

5 CONCLUSIONS

Any improvement in the perform-ance of a hybrid network results in increased customer satisfaction, and costs savings or additional revenue for the telecommunication companies. The implementation of SS7 and intelligent networks has only a few years of history, so there are still many issues to be studied and improvements that can be made to the hybrid network. Through simulation network planners can not only study historical performance, but they can also better plan for the future. This simulator achieves a simulation time compression rate of 10%, when simulating the multiple processes that are occurring in a telecommunications system during busy hour traffic while providing the statistics required for hybrid network performance analysis! Modular design allows the simulator to only be linked with the optional modules required for each specific simulation run. The addition of new modules to the simulator is easily accomplished. Thus, this simulator is a powerful and flexible tool for simulating the hybrid networks that make up telecommunications systems.

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