ABSTRACT

The real-time environment simulator provides a model of the SPC switching system in all its complexity, using the actual processors and software. The complete switching network, all signalling and peripheral control devices and all other elements of the system are represented by memory cells in the simulator. Initially developed for software check-out in SPC systems of the Metaconta family, the environment simulator has been extended into a traffic simulation tool: ENTRASIM. This system accurately models and simulates the SPC switching machine and the external traffic environment viz. the offered calls and event sequences within each call. This new traffic simulation technique has promising applications in call handling capacity studies of SPC processors and other traffic studies where an accurate representation of the switching system and its environment is essential.

1. INTRODUCTION

A modern Stored Programme Controlled SPC switching system usually comprises a multistage switching network e.g. a space division link network, a stored programme controlled processor system concentrating most of the system's intelligence and an interface between the processors and the network; the system will normally also comprise signal receivers, senders, peripheral control devices, peripherals of the processors etc. (see fig. 1. a., the Metaconta system is taken as an example of SPC switching system).

It receives and answers stimuli emitted by the system's terminals e.g. telephone subscribers or interoffice trunks.

The throughput of such a system is determined by the real-time capacity of the processor(s) and common control as well as by the traffic capacity of the switching network.

Designers must verify the traffic and call handling capacity of the switching system and check its performance under traffic load before it is put into service.

Because of their great complexity, the SPC switching systems, and in particular their common control behaviour under traffic load, are studied at present mainly by simulation. Load testing of SPC switching machines in the field, although sometimes attractive, is not easily performed before the cut-over of the systems and has many inherent limitations.

The present paper describes the ENTRASIM: A real-time Environment Traffic Simulator of SPC switching systems.

It consists of at least two processors: the SPC system processor(s) and the simulation processor (I), see fig. 1. b. It can be used for both the network and the common control simulations.

The following sections describe how the ENTRASIM models SPC switching systems, simulates traffic and records the behaviour of the system under load. The addendum gives more details about the environment simulation technique used for programme debugging and points out the elements which led to the use of this technique for traffic simulations.

Fig. 1. b. Outline of real-time environment simulation of an SPC telephone switching system shown in fig. 1. a.

I.C. = Interrupt control
C. = Interface clock

Fig. 1. a. Metaconta switching system organization

(Additional more detail in Fig. 5)
2. MODELLING AN SPC SWITCHING SYSTEM IN TRAFFIC SIMULATION

A traffic simulation system usually consists of:
- a model, image or logical description of the simulated system; in the case of SPC switching systems, the model of a switching network, common control or both, and the software model
- a procedure of generating and offering traffic to the system or more generally a model of the traffic environment
- a procedure of extracting and recording the desired system characteristics under load conditions.

The modelling manner of an SPC system for traffic simulation and the choice of an appropriate simulation system depend on the state of development of the system studied (preliminary study, early or advanced design phases, software already structured, designed and written or not, etc.), the objectives of the study, accuracy of results required and resources available for a given project.

Due to lack of space, the present section discusses only the common control modelling and simulation. However, even when the traffic study is concentrated on the common control behaviour, the influence of the network on the control performance must be carefully considered.

One way of modelling the SPC system control and its behaviour is to reconstruct exactly in the simulation (using a general purpose computer) the structure of the common control and the logic of the systems software, substituting for instruction sequences the times needed to execute these instructions.

ENTRASIM provides an accurate model of the SPC switching system using the actual processors, memories, buffers, hoppers, etc., the operational programmes and a fully simulated switching network and its peripherals. This means that the processors and the software do not need to be modelled for the purpose of simulation. This is an important advantage of the ENTRASIM, increasing the accuracy of results and giving the certainty that nothing of the complex structure of the SPC system software has been omitted. The switching network, the signalling and peripheral control devices, indeed, virtually all hardware switching and peripheral control devices, are fully represented in the simulator memory.

Fig. 1.a and 5 show the elements of the SPC system which are simulated or that do actually exist in the simulation system. The representation of all network crosspoints, all switching devices, AC/DC bus, peripherals etc. is an inherent feature of the environment simulation technique and is necessary because the system processor(s) operate(s) in real-time and does not recognize that another processor has been substituted for part of the system (see addendum). Thus in the laboratory, we have a system very close to a real SPC switching machine on which we can perform a multitude of traffic tests.

The breakdown of call attempts with respect to the degree of completion of the calls is necessary for traffic studies of common control in SPC systems. The call pattern concept permits the representation of all kinds of incomplete calls, such as calls with incomplete dialling, called subscriber busy, no-answer, etc. Calls from and to special lines like PBX, lines with push-button.

The concept of describing the traffic environment of an SPC switching system by writing in detail the event sequences for all call types used in a simulation, will be named "the call pattern concept". The call (or event) patterns are written in a symbolic form and are translated by the simulation event compiler. The way of generating traffic by repeating and modifying the events specified in the call pattern is discussed in para. 3.a. An example of a call pattern is shown in fig. 2.

**Fig. 2. Example of a call pattern, toll call with MFC-MFC signalling**

<table>
<thead>
<tr>
<th>IDEN</th>
<th>EXAMPLE TOLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>1 0 0 0 , 2 0 0</td>
</tr>
<tr>
<td>CALL</td>
<td>X'13F', 5 0 0</td>
</tr>
<tr>
<td>MOD</td>
<td>1 , 1 , 1 0 0 , X'3FF'</td>
</tr>
<tr>
<td>MFC, CG</td>
<td>A 1 , 0 , B 1 , 2 0 , 2 0</td>
</tr>
<tr>
<td>MFC, CG</td>
<td>A 1 , 2 0 , 2 0 , 2</td>
</tr>
<tr>
<td>MFC, CG</td>
<td>A 1 , B 3 , 2 0 , 2 0</td>
</tr>
<tr>
<td>LOP, CG</td>
<td>1 , 1 , 1 0 , 9</td>
</tr>
<tr>
<td>LOP, C D</td>
<td>2 0 0 0</td>
</tr>
<tr>
<td>SEND DIGITS</td>
<td>MFC SIGNALLING AND MODIFY EACH TIME THE LAST DIGIT AT RANDOM BETWEEN 0 AND 9</td>
</tr>
<tr>
<td>CALLED PARTY HOOKS OFF</td>
<td>AFTER 2000 MILLISECONDS</td>
</tr>
<tr>
<td>CALLING PARTY CLEARS</td>
<td>AFTER A RANDOM TIME WITH A MEAN OF 10000 MILLISECONDS</td>
</tr>
<tr>
<td>CALLED PARTY HOOKS</td>
<td>ON 2000 MILLISECONDS LATER</td>
</tr>
</tbody>
</table>

By describing the external events in the form of a call pattern we can take practically all the real call details into account. For example, call phases such as off-hook by subscribers, calls on i/c trunks, waiting for dial tone, dialling, signalling, selection, ringing, answer, release, etc. can be easily represented and simulated with the present model. Going further into detail we will mention that, e.g. in a dialling phase, digits will be formed by pulses of an assumed duration. The interpulse and interdigital times will follow an assumed distribution.

The modelling manner of an SPC system for traffic simulation and the choice of an appropriate simulation system depend on the state of development of the system studied (preliminary study, early or advanced design phases, software already structured, designed and written or not, etc.), the objectives of the study, accuracy of results required and resources available for a given project.

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3. MODEL OF TRAFFIC ENVIRONMENT CALL PAT- TERN CONCEPT

ENTRASIM uses a specific way of simulating the traffic environment of switching systems.

The concept of describing the traffic environment of an SPC switching system by writing in detail the event sequences for all call types used in a simulation, will be named "the call pattern concept". The call (or event) patterns are written in a symbolic form and are translated by the simulation event compiler. The way of generating traffic by repeating and modifying the events specified in the call pattern is discussed in para. 3.a. An example of a call pattern is shown in fig. 2.
sets, abbreviated dialling, transfer and other facilities provided by an SPC switching system can also be simulated.

It is to be noted that the call pattern concept not only permits the full representation of elementary events but also the preservation of correlation between these events and their correct timing. These features are of great interest when studying the call handling capacity of SPC switching systems.

The interarrival times between events for each type of call, can be chosen in accordance with specific distribution laws assumed for a given environment. The choice of these distributions is based on observation and analysis of the traffic environment (4).

a. Traffic generation procedures

There are several possibilities of offering traffic to the environment simulation system. One of them is discussed here:

Pattern of basic calls

The list of all call types used in a simulation, including the sequences of events for these calls when they appear for the first time, is termed "the basic call pattern". A sequence of events for one of such calls has been shown in fig. 2 (example a toll call). The pattern will consist of several basic calls so that all types of calls used in the simulation are represented in the pattern.

For example, when simulating a combined local and transit SPC telephone exchange, the basic call pattern may comprise local, incoming, outgoing and transit call types split into:

- attempt without dialling
- attempt with partial dialling
- called subscriber no-answer
- called subscriber (in distant exchange) busy, blocking condition in distant exchange
- call with conversation.

Blocking condition in own exchange appears as a response of the system to the traffic offered and thus does not need to be specified in the pattern.

Once the pattern of basic calls has been prepared, the automatic generation of calls is achieved by repeating the basic calls and by modifying their parameters. The mean interarrival time of each type of call will be chosen separately in accordance with the traffic of each type and the call mix. Each time a call is taken for handling, it is replaced in the pattern by a call of the same type but with other calling and called numbers, the originating time and the times of other events being modified according to specific probability laws. In this way calls are generated and placed in a list of calls to be handled. This list corresponds to the original pattern but its parameters are modified according to generated random numbers as the simulation progresses.

The simulator scans the list at regular intervals (e.g. 1 ms), finds calls having their origination time and updates the map of subscribers or incoming lines kept in the simulator. The system processors detect the status change of the (simulated) lines and take the call(s) for treatment.

The first call of each type has predetermined parameters. Except for the first call of each type, events of all other calls are generated on-line in accordance with distribution laws assigned for each type and generated random numbers.

The above mechanism for creating calls and modelling traffic environment is very flexible and can be used to realize a variety of traffic conditions.

As already explained, each type of call is independent of other types.

The distribution laws for interarrival times of calls, duration of all call phases, interdigital, pulse and interpulse times will usually be the same for several call types (with different mean values for each type).

In the above example of a combined local and transit telephone exchange, all types of incoming calls will use:

- an exponentially distributed (Poisson) process for call arrivals
- exponentially distributed service times for all call phases
- distribution law for signalling phase will be chosen depending on the type of signalling used (e.g. for MFC signalling, duration of and times between signals will be constant).

The call pattern concept can be used to simulate many interesting features, e.g.

- short term traffic peaks can be created by introducing additional call types starting and terminating at specific times in the simulation run. If required, the peaks can be repeated following an assumed distribution law
- overflow traffic can be simulated using interrupted Poisson process (5) for some or all call types.

The above method of generating traffic resembles the method used in the classical time-true traffic simulation models. The fidelity of representation of the real call details and possibility of using many call types increases the accuracy of the traffic environment simulation.

b. Artificial loading

The switching system simulated by ENTRASIM can also be artificially loaded. As explained above, the investigated switching system is replaced in the simulator by a memory map, each crosspoint, junctor, receiver etc. being represented by a memory cell. The simulation processor can access the memory map and the system processor(s) memory at any time during the simulation run; the memory map can therefore be filled-in with zeroes and ones according to predetermined probability distribution laws and required loadings at different stages of the network. This method of loading is somewhat similar to the NEASIM simulation of the network graph (6). In this case, however, we have the complete switching system (not only the network graph) which is artificially loaded, and we can investigate various blocking situations in the network, peripheral control devices, processor(s) and software.

Another possibility of artificial loading, is to establish permanently a certain number of connections without their release (3). In both cases, the artificial load of the network will be combined with a load created by real calls. The processor(s) are loaded by real calls.

Artificial loading is mentioned here only to illustrate the possibilities of ENTRASIM. An example of application is given in para. 6.b. (study of processing times for path and table search).

4. APPLICATION RANGE

The ENTRASIM provides a tool for the study of an already developed, fully structured SPC system with already written operational programmes. The hardware must be fully structured but it is not necessary for it
to exist actually (except the processors). If the operational programmes exist already and if the environment simulator has been developed and is used anyway for the check-out of these programmes (its original application), only a relatively small additional programming and engineering effort is required to use it for traffic studies. In this case, the environment simulator can be used for traffic and call handling capacity studies, study of the software efficiency under load conditions, verification of overload control strategies, performance of the processor(s) during short-term load peaks, transitions, etc.

5. SYSTEM PERFORMANCE EVALUATION UNDER TRAFFIC LOAD

The traffic performance evaluation of an SPC switching system implies offering loads near or exceeding the nominal load of the system and measuring the response of the system to these traffic loads. The measurement programmes provided in the system processor(s) will follow the specifications of the Administration who will use the system, and will usually comprise a wide range of measurements needed for correct management of the system in the field, traffic forecast, measurement of the grade of service given to subscribers, etc. The measurement programmes provided in the simulator allow us to make all kinds of additional measurements required for processor observation and a particular traffic study. All time measurements use a clock located in the simulation interface, for example a nanosecond clock. This is facilitated by the fact that the simulator can access the memory of the system processor(s) at any time during the run. The measurements performed in the simulator do not add to the load of system processors, a feature which is important when the load is close to the maximum value.

6. EXAMPLES

a. Simulation of a Metaconta 10C Toll Exchange

Fig. 3. is a schematic representation of a Metaconta 10C toll office.

The real structure of the switching network is fully represented in the memory of the simulator in a manner described in the preceding paragraphs. The number of switching modules, peripheral control devices and signalling devices is taken from a practical application.

Following types of signalling are used: MFC, decimal and CCITT N°6 signalling. The 2000 incoming and 2000 outgoing junctions are split into 32 directions on the i/c and o/g side. The operational programmes in the system processor(s) remain unchanged. The largest part of a simulation package for programme testing is also used for traffic simulation. Some new programmes have been added:

- automatic call generator (see para. 3. a)
- measurement programmes.

The preparation of input data consists in writing a basic pattern according to a given call mix and traffic intensity for each type of call. The preparation of the basic pattern is facilitated by the use of an automatic (basic call) pattern generator.

The information concerning the prefixes and number-lengths for each direction, classes and signalling types of incoming and outgoing junctions, etc., is contained in the memory of system processor(s). The simulator has access to this memory and can simulate the automatic pattern generation. The output gives statistics obtained from measurements in both the system processor(s) and the simulator.

The main statistics recorded are the following:

- statistics on calls started (per call type and direction, with breakdown according to the degree of completion)
- average time and distribution time for each call phase (e.g. preselection, signalling, conversation and supervision phases)
- average processor(s) occupancy
- number of markings, occupancy, average and distribution of operation time per marker-driver
- for about ten programmes in the system computer: number of times the programme has run, average execution time and distribution of this time.

Two ITT 3200 computers are used with a memory of 112 kwords (of 32 bits) for the system computer and 64 kwords for the simulation computer. The simulation time/real time ratio in this example is of the order of 10:1 to 30:1 depending on the traffic load.

b. Evaluation of processing times and occupancy

Elementary processing times:

The knowledge of elementary processing times is essential to optimize the programme and sometimes for a rough estimation of processor occupancy.

As it is programmed to record the real time at chosen addresses, the simulator permits measurements of processing times of given programmes with an accuracy of nanoseconds (elementary time of the hardware clock in the simulation interface which is accessible to the simulation computer).

Path search and table search times:

The path search and in some cases the table search times strongly depend on the loading of the network. When the network is loaded, for example in a way explained in para. 3. b., it is possible to measure the path and table search times by reading the times at the start and end addresses of the programmes performing the search. Making a large number of calls permits to obtain distributions and mean search times.

c. Instruction count

Once the system has been loaded realistically, a full trace can be made of each instruction executed by the system software during a simulation run. Frequency of instruction usage can be obtained for different loadings and traffic conditions in the switching system. Analysis
of instruction frequency is useful to optimize programmes and for performance prediction of new generations of processors, software and system configurations.

7. CONCLUSION

The choice of an appropriate technique among several existing traffic simulation techniques depends on the state of development of the system studied, the objectives of the study, accuracy of results required and resources available for a given project. The ENTRASIM technique can be used after programmes for an SPC system have been structured, designed and written. If the environment simulator is available for the software check-out, it can be adapted for traffic studies and used for call handling capacity verification, improving software efficiency, testing overload control strategies and other traffic simulation studies requiring high fidelity modelling of the investigated SPC switching systems.

The main advantages of the ENTRASIM technique are:
- it uses the actual processor(s), memories and software
- all other devices of the SPC switching system are simulated without simplifications
- traffic environment is modelled accurately using detailed event and call patterns.

Therefore, the results which can be obtained with this tool are precise and reliable. However, it can only be used in advanced system development phases and its application must be closely linked to the overall system engineering effort.

Acknowledgement

The author wishes to express his appreciation to G. Adams who adapted and developed the simulator described in para. 6. a., to F. Cornelis who introduced the author to the environment simulation technique and to E. Szybicki for many stimulating discussions and for suggesting the acronym ENTRASIM.

8. REFERENCES


2) G. Dietrich and R. Salade: Subcall-type Control Simulation of SPC Switching Systems. 8th ITC, Melbourne, 1976


ENVIRONMENT SIMULATION TECHNIQUE

The environment simulation technique was introduced in 1966 by Bell Telephone Mfg Co as a method of programme check-out for the Metaconta 10C stored programme controlled switching system (7).

Since then, the environment simulations have been successfully implemented and used for checking the programmes of all SPC switching systems of the ITT Metaconta family, as well as for the SPC call charging centres, signalling systems, etc.

The main objective of environment simulations is to check programmes of the SPC systems before the actual hardware (except the processor(s)) is available. It uses the actual system processor(s) including its (their) memories and the actual software, but the entire environment of the processor(s) is substituted by a separate processor connected via the simulation interface (see fig. 1. b.).

The environment (which is simulated) consists of:
- the switching network including all its crosspoints, juncitors, trunks, receivers, senders, etc.
- all network access and peripheral control devices like scanners, testers, markers, drivers, etc.
- all real-time clocks which may generate interrupts in the system processor(s)
- all asynchronous peripheral devices and input/output media of the processor(s) like teleprinters used for man/machine communication, line-printers, paper tape readers, random access rotating memories, sequential access memories etc. Actual processor(s) peripherals can also be used.
- the external environment of the SPC system e. g. telephone subscribers, interoffice trunks, other exchanges, including the stimuli created by these subscribers, exchanges etc., and offered to the SPC switching system. For the traffic environment simulations, the meaning of the "external (or traffic) environment" is extended and receives the significance of a very general traffic model.

Real-time operation

The real-time operation is achieved by running the operational programmes and alternately stopping the system processor(s) or the simulation computer whenever they receive or output information from or to the interface.

The interface comprises a real-time counter which counts the control clock pulses (located in the interface) and dispatches interrupts to the simulation computer. These interrupts are used by the simulation programme to measure the real-time, update external events and provide clock interrupts to the system processor(s). They are also used to return interrupts (at precise time instances) when the system processor(s) should receive information from the hardware e. g. "end of job" signals of markings/drivings etc. Various "delay cells" are kept in the simulator to ensure correct timing and caddening of interrupts.

ADDENDUM

The environment simulation technique has been initially developed for the Metaconta SPC switching systems working with two or more processors sharing the load. The simulations can be performed with the system processor(s) working in simplex or duplex operation mode (or multiprocessing where applicable).

While the principles of the environment simulation technique are described in the present addendum in connection with SPC telephone switching systems, it can also be used for other SPC systems such as telex, call charging centres, data switching, signalling systems, etc.

Simulation of external events

The external events such as calls on subscriber or incoming lines, dialling, answer of the called subscriber, release etc. are simulated in the system by event lists called "event patterns" or "call patterns". Some of the internal events, e. g. sending of backward multifrequency signals, can also be specified in the event patterns. These patterns specifying the sequence of events and the times at which these events must occur are written in a symbolic form (a programming language developed specially for this purpose, use of macro and micro instructions) and are translated by the simulation event compiler.

This procedure may be facilitated by using programmes for the automatic preparation of patterns and the generation of events from a short basic pattern (see section on traffic generation).

The simulator scans the compiled lists of events at regular intervals, finds which event has its origination time and updates the map of subscribers, trunks or test points in accordance with the event processed. The way of describing the external environment in form of event patterns is an important element of the environment simulation technique. It permits to take into account all the real call details and its extension (e. g. use of automatic generation of events, introduction of certain distribution laws for interarrival times of events, repetition of events following certain functions etc.) leads to the traffic environment simulation technique. The event patterns use self-defining terms and commands. The number of commands is relatively small and a few hours will suffice to learn them.

The writing of a short pattern, e. g. a pattern of events for one complete call, is easy and can be done quickly.