Quantitative Evaluation of Scalability in Broadband Intelligent Networks

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Abstract

Scalability is the ability of a network to maintain the quality of service while increasing certain parameters relating to the size of the network, such as the number of users, the number of network nodes, the number of services provided, geographical spread, etc. In the design of a B-IN signalling system, network scalability is an important issue that must be taken into account. In this paper we use simulation to investigate scalability issues related to a Broadband Intelligent Network (B-IN), such as that being considered in the ACTS project INSIGNIA. In particular, we study the impact of processor speed and configuration (in B-IN physical entities) on signalling performance. As signalling performance measures we consider the mean call setup delay of a B-IN service request and the network throughput. For Broadband Virtual Private Network (B-VPN) service, we perform scalability experiments by increasing some of the network parameters such as the number of users and the number of nodes.

Keywords

Broadband Intelligent Networks, network scalability, performance analysis.

1 INTRODUCTION

Because of the expansive growth of the available capabilities in telecommunications it is expected that many services that today are provided by

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other media, e.g., video films, will be taken over by telecommunication networks. This imposes many requirements that must be fulfilled by these networks. To achieve this, a new approach to building, maintaining, changing and providing services is needed. A solution to fulfil these requirements is intelligent networks (see (Thorner, 1994)), a concept that was introduced in the 80's, mainly for fixed communication networks, and is now expected to be used in many other networks. The B-IN infrastructure allows the rapid and cost effective deployment of new services by separating the service control and service switching currently located in switches. Consequently, the main physical entities constituting a B-IN architecture (see Figure 1) are the Broadband Service Switching Point (B-SSP) and the Broadband Service Control Point (B-SCP). The Broadband Intelligent Peripheral (B-IP) provides the specialised resources that are required for the provision of IN broadband services, in particular multimedia user interaction. The Fixed Terminal (FT) represents the end user. Each physical entity is composed of interactive functional entities. The Signalling System 7 (Modarressi, 1990) is used to control the flow of information between the interactive network functional entities to establish, maintain and release a B-IN service request.

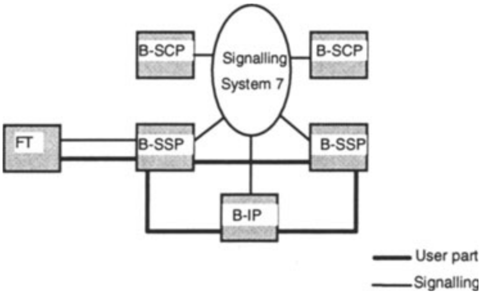


Figure 1 B-IN architecture.

Scalability (see, e.g., (Gauthier, 1996), (Lin, 1994), (Martini, 1996), (Saha, 1995)) is one of the most important factors in the design of a distributed multimedia system, such as B-IN. The system must be able to sustain a large number of users and various types of services with different traffic characteristics and Quality of Service (QoS) requirements.

Network scalability can be defined (Karagiannis, 1997) as the ability to increase the "size" of the network, in some sense, while maintaining QoS and network performance criteria. The "size" of the network may relate to one of the following:

- *the number of users that must be supported by a network node:* increasing the number of users that must be supported by a certain physical entity can cause serious performance problems because of processing capacity and memory limitations.
- *the number of network nodes and links:* the growth of number of nodes and links may cause an increase on the offered load to a given physical entity,

since the physical entity will have to manage the intercommunication with the additional nodes in a more complex topology.

- *the geographical spread covered by the network:* increasing the geographical area that is covered by a network while keeping the number of nodes constant will cause an increase of the message propagation delays since these delays are proportional to the length and number of the physical communication links.
- *number of services provided by the network:* increasing the number of services that a network provides will cause an increase in the offered load and its variability to a given physical entity, since the physical entity will have to support the additional services of different requirements.
- *the size of the data objects:* particularly in some cases like video and audio the size of transmitted files is too large, thus causing network scalability problems (e.g., I/O buffers and transmission bandwidth).
- *the amount of accessible data:* the increasing amount of accessible data makes data search, access, and management more difficult and therefore causes storage, retrieval and processing problems.

In this paper, unlike previous described work in literature, we investigate scalability issues related to the signalling system in a B-IN. Two sets of simulation experiments are performed. In the first set we investigate the ability of the B-IN to support an increasing number of users connected to the network. In the second set of experiments we investigate the network scalability when the number of B-IN nodes is increased. As test-bed we used typical network architectures specified in the ACTS/INSIGNIA (IN and B-ISDN Signalling Integration on ATM Platforms) project. The main objective of the INSIGNIA project is to define, to implement and to demonstrate an advanced architecture integrating IN and B-ISDN signalling (ACTS, 1995).

This paper is organised as follows. Section 2 describes the network architecture and topology for the performed scalability experiments. The performance models, i.e., user workload models and network models, used for the performance evaluation are described in Section 3. The experiments and performance results obtained from the first and second sets of experiments are described in Sections 4. Finally, Section 5 concludes.

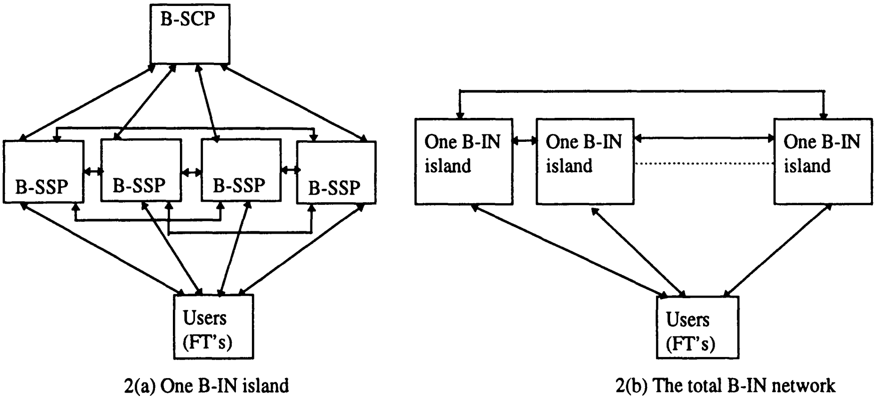
2 NETWORK ARCHITECTURE

This section briefly describes the B-IN network physical entities, B-IN network topologies and signalling information flows used in the performed scalability studies. A network topology is composed of several interacting physical entities. The signalling information flows describe the interaction among the physical entities required to establish an IN service request.

2.1 Physical Entities and Topology

The physical entities used in this work are the B-SCP, B-SSP and FT. The B-SCP is a real time, high availability system that is able to interact with other B-IN nodes and contains the logic and processing capabilities required to handle enhanced network services, such as B-VPN. The B-SSP physical entity mainly provides B-IN service switching. Additional to this functionality, the B-SSP handles the B-IN service call and connection control and it is able to modify processing functions that are required during service execution under control of the B-SCP. The B-IP physical entity provides specialised resources and functionality required for multimedia interaction between end users and B-SCP, e.g., a multimedia dialogue for selection of a Service Provider supported by interactive video. The FT physical entity is the interface of the B-IN network to the end user, e.g., a Personal Computer (PC) or a workstation.

The network topology used in the first set of experiments is depicted in Figure 2(a), and it consists of four B-SSP's and one B-SCP (B-IP is not included, since it is not required for the B-VPN service that is considered here). We call such configuration a B-IN island. In the second set of experiments we assume that there are more than one interconnected B-IN islands; this network topology is depicted in Figure 2(b). Each B-IN island is identical to the topology depicted in Figure 2(a). Note that two or more B-SSP's belonging to the same island or to different islands can intercommunicate.



2(a) One B-IN island

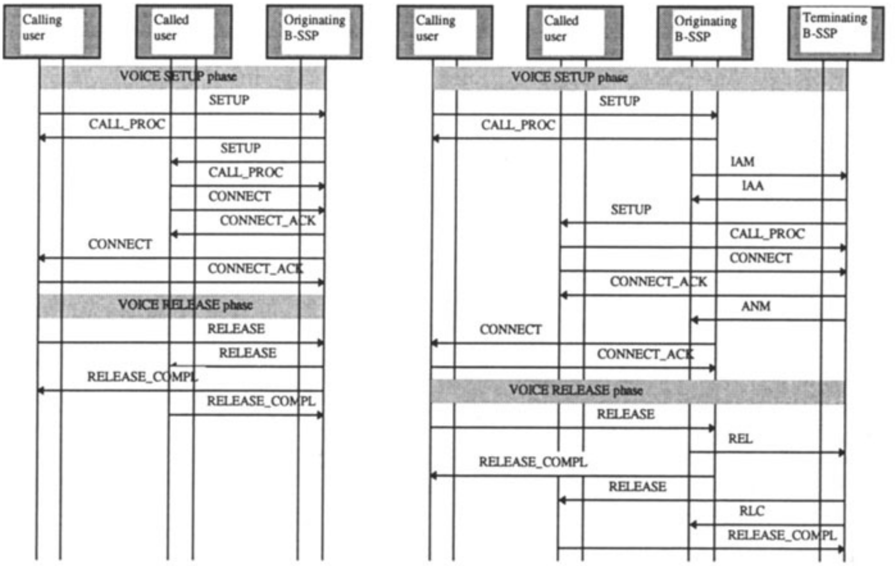
2(b) The total B-IN network

Figure 2 B-IN network topology.

2.2 Signalling Information Flows

The signalling information flows (message sequence charts) define the spanning and routing of signalling messages among the different entities in the network on behalf of a service request. For each service that is supported by a network topology a specific signalling information flow scenario is required. The services considered in this paper are VOICE and B-VPN. The VOICE service is a normal plain telephony service, while the B-VPN service (INSIGNIA, 1996a) realises a logical sub-network of a B-ISDN which appears to a specific group of users as a private broadband network, for voice, video or data communication.

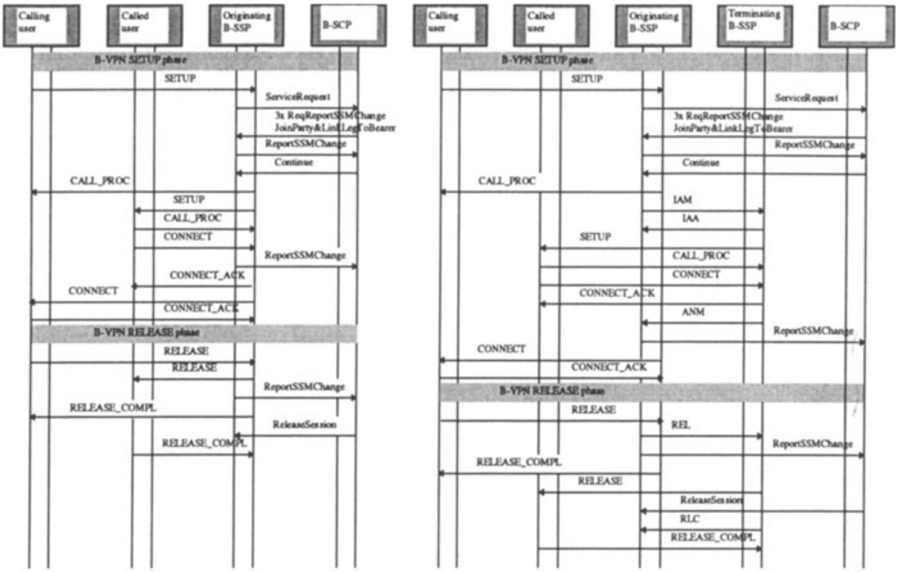
The VOICE message sequence charts (see (INSIGNIA, 1996b)) are given in Figure 3(a) and Figure 3(b) for the cases where a called user is connected to the originating B-SSP and the terminating B-SSP, respectively. Note that the originating B-SSP is always able to communicate directly with the calling user, while the terminating B-SSP is always able to communicate directly with the called user. The used signalling messages are standardised Q.2931 (ITU-T Q.2931) and B-ISUP (ITU-T Q.2761) messages.



3(a) VOICE MSC 3(b) VOICE MSC (different originating and terminating SSPs)

Figure 3 VOICE message sequence chart (MSC).

The B-VPN (see (INSIGNIA, 1997b)) message sequence charts are given in Figure 4(a) and Figure 4(b) for the cases where the called user is connected to the originating B-SSP and the terminating B-SSP, respectively. Note that the interface between users and a B-SSP is called User to Network Interface (UNI), the interface between different B-SSP's is called Node to Node Interface (NNI) and in this paper, the interface between a B-SSP and B-SCP is called Intelligent Network Interface (INI), whose signalling messages are described in (INSIGNIA, 1996b).



4(a) B-VPN MSC

4(b) B-VPN MSC (different originating and terminating SSPs)

Figure 4 B-VPN message sequence chart (MSC).

3 PERFORMANCE MODELS

This section describes the performance models, i.e., user workload model and network model, used to accomplish the scalability experiments. The user workload model describes the user calling pattern and intensity that has to be supported by the B-IN network, while the network models represent the flow and processing of messages through the network on behalf of user requests. Two performance measures are used to assess the network scalability; namely the network throughput and the B-VPN mean setup delay. Network throughput is defined as the total number of calls (VOICE and B-VPN) per time unit that the network can support at a given utilisation. The B-VPN setup delay is defined as the time duration from the instant when the user starts the B-VPN call set-up procedure (i.e., by sending a SETUP message to a B-SSP) until the call set-up procedure is completed (i.e., a CONNECT message is received by the initiating B-VPN user), excluding any user response times.

3.1 User Workload Model

In all experiments we have used a traffic mix of telephony (VOICE) and B-VPN. The inter-arrival time of all user call requests at each node (i.e., B-SSP) is modelled as a Poisson process. The percentage of VOICE calls is equal to 85% of the total load, while the percentage of B-VPN calls is 15% of the total load. Therefore, a user call request is VOICE with a probability of 0.85 and B-VPN with probability of 0.15. It is assumed that the VOICE and B-VPN call duration distributions are identical and follow a mixture of two normal distributions as described below:

$$F(t) = aF_1(t) + (1-a)F_2(t), \quad t \geq 0,$$

with,

$$F_i(t) = \frac{1}{\sigma_i\sqrt{2\pi}} e^{-\frac{(t-\mu_i)^2}{2\sigma_i^2}}, \qquad t \geq 0, \qquad i = 1, 2.$$

The values for the parameters of the above distribution are: $a = 0.4$, $\mu 1 = 0.655$, $\sigma 1 = 0.165$, $\mu 2 = 1.055$, $\sigma 2 = 0.25$. It is assumed that the call rate per user is fixed, and that the called user is connected to any B-SSP in the B-IN network with equal probability. Note that the load per network node can be varied by varying the number of users per node.

3.2 Network Models

In order to perform the planned experiments, we must fully characterise the network model and its parameters. In this section we give the queuing models used for performance evaluation. The routing of messages through this queuing model is determined by message sequence charts of Section 2.2. The scheduling of user requests and signalling messages at the physical entities is also characterised. Finally, model parameters, such as message processing times are given.

3.2.1 Queuing models

Queuing network models are used to represent the processing and flow of signalling messages through the B-IN network. Each physical entity (i.e., B-SSP, B-SCP) is modelled by a single server queue with an infinite buffer. As an example, Figure 5 depicts the queuing model used to represent the B-IN island viewed in Figure 2(a). The network topology viewed in Figure 2(b) could also be easily represented in a similar way by extending the queuing network model.

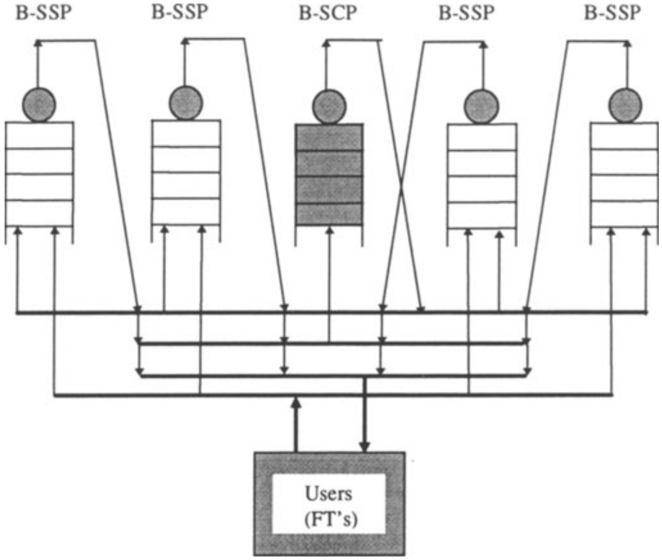


Figure 5 Queuing model for one B-IN island.

3.2.2 *Message routing*

The spanning and routing through the queuing network model on behalf of a user request is defined by the signalling information flows. This means that the behaviour of the queuing models is different for each service that the network provides. When the VOICE service is used, then the message routing provided by the queuing models is defined by the signalling information flows depicted in Figure 3(a) and Figure 3(b). For the B-VPN service the routing is provided by the flows depicted in Figure 4(a) and Figure 4(b).

3.2.3 *Priority scheduling of signalling messages*

An important characteristic of the network model is the priority scheduling scheme used to serve the user requests and the subsequent signalling messages. In our performance experiments, the so called Time-Based priority scheduling discipline is used. By using this priority scheduling, new and cycled messages belonging to the same IN request get the same priority, which is assigned based on the arrival time of the IN request. Earlier IN requests and their messages are assigned higher priorities than those assigned to later IN requests and their messages. The priority assignment to a user request (and its messages) that arrives to the B-IN network can be described as follows. Let user requests be ordered according to their arrival times to the network. Then the m-th request and all its messages are assigned priority $P(m) = P(m-1) - 1$, if $m > 0$; $P(m) = MAXIMUM$, if $m > 0$, where

MAXIMUM is the highest possible priority. For example, suppose that a request message *m1* arrives at the B-SSP at time step *t1* and it gets a priority P_1. This message will be served by the B-SSP and then sent to the B-SCP. Now suppose that a new request message *m2* arrive at the B-SSP at time step *t2* (*t2* > *t1*). This request message will get the priority P_2 ($P_2 < P_1$). The message *m2* waits to be served by the B-SSP. Before this message is processed, message *m1* comes back to the B-SSP. The message *m1* will be queued before *m2* at the B-SSP queue since it has a higher priority. After the *m1* departs from the B-SSP, the message *m2* will proceed with its requested service at the B- SSP. In (INSIGNIA, 1997a) it has been shown by performance evaluation experiments that the Time-Based scheduling performs better than other disciplines, such as FIFO. Therefore, this priority scheduling has been used in the performed studies.

3.2.4 Model parameters

Model parameters, such as message processing times at physical entities have been obtained experimentally from the prototype platform used in the INSIGNIA project. Due to confidentiality reasons, the absolute measured values can not be disclosed. Therefore, the processing time Service Request message (see Section 2.2) is used in the experimental studies as a "Time Unit" (TU). The measurements have been performed for a B-VPN and plain telephony (VOICE) services. The NNI (B-ISUP) message processing times (in TUs) are estimated from measurements on the UNI (Q.2931). The distribution of all message processing times is assumed to be deterministic. The ratios of the measured message processing times relative to the Service Request message processing time appearing in Table 1 to Table 3, have been used in the performed studies.

4 EXPERIMENTAL RESULTS

Once the network model has been constructed, and fully characterised, it can be used to evaluate performance measures of interest. In the experimental studies of the next sections the simulation technique is used to evaluate the queuing model of the B-IN network. To provide independent observations the method of batch means is used; thus making it possible to provide confidence intervals associated with estimates of the performance measures.

Two sets of experiments are performed. The ability of a B-IN to support an increasing number of users connected to the network is investigated in the first set of experiments. In the second set of experiments we investigate the network scalability when the number of B-IN nodes is increased.

For confidentiality reasons, the absolute estimated values of performance measures could not be disclosed. Instead, all processing times and estimated delays are normalised to the value of the Service Request message processing time, which we denote in this paper as TU (Time Unit).

Table 1 The service time ratios of the INI messages for a B-VPN service

Entity	Incoming Message	Outgoing Message	Service time (TU)
B-SSP	3*RequestReportSSMChange + JoinPartyToSession&LinkLeg	ReportSSMChange	0.29381
	Continue	CALL_PROC	0.13745
	Continue	SETUP	0.22164
	ReleaseSession	OUT(end)	0.13745
B-SCP	ServiceRequest	3*RequestReportSSM	1
	ReportSSMChange	Continue	0.27319
	ReportSSMChange	ReleaseSession	0.39003
	ReportSSMChange	OUT(end)	0.27319

Table 2 The service time ratios of the UNI and NNI messages for a B-VPN service

Entity	Incoming Message	Outgoing Message	Service time (TU)
B-SSP	SETUP	ServiceRequest	0.40034
	CONNECT	ReportSSMChange	0.39690
	CONNECT	CONNECT_ACK	0.44158
	CONNECT	CONNECT	0.45704
	CALL_PROC	OUT(end)	0.04467
	ANM	CONNECT	0.31958
	IAM	IAA	0.20790
	IAM	IAM	0.29037
	IAM	SETUP	0.29037
	CONNECT	CONNECT_ACK (in this case ReportSSMChange is not created)	0.30584
	CONNECT	CONNECT (in this case ReportSSMChange is not created)	0.31958
	IAA	OUT(end)	0.07560
	RELEASE	RELEASE	0.02920
	RELEASE	ReportSSMChange	0.20790
	RELEASE	RELEASE_COMPL	0.30068
	REL	REL	0.02920
	REL	RELEASE	0.02920
	REL	RLC	0.30068
	RELEASE_COMPL	OUT(end)	0.02920
User	SETUP	CALL_PROC	0.11168
	SETUP	CONNECT	0.89347
	CONNECT	CONNECT_ACK	0.07560
	RELEASE	RELEASE_COMPL	0.86254

Table 3 The service time ratios of the UNI and NNI messages for a VOICE service

Entity	Incoming Message	Outgoing Message	Service time (TUs)
B-SSP	SETUP	CALL_PROC	0.20790
	SETUP	SETUP	0.29037
	CONNECT	CONNECT_ACK	0.30584
	CONNECT	CONNECT	0.31958
	CALL_PROC	OUT(end)	0.01374
	IAM	IAA	0.20790
	IAM	IAM	0.29037
	IAM	SETUP	0.29037
	IAM	ANM	0.29037
	IAA	OUT(end)	0.07560
	RELEASE	RELEASE	0.02920
	RELEASE	RELEASE_COMPL	0.19759
	REL	REL	0.02920
	REL	RELEASE	0.02920
	REL	RLC	0.19759
	RELEASE_COMPL	OUT(end)	0.02920
User	SETUP	CALL_PROC	0.11340
	SETUP	CONNECT	0.92611
	CONNECT	CONNECT_ACK	0.04982
	RELEASE	RELEASE_COMPL	0.75429

4.1 Increasing the Number of Users per Node

In this set of experiments the number of nodes is fixed while the number of users connected to a B-SSP node is increased. The B-IN network topology and network model used in this set of experiments are depicted in Figure 2(a) and Figure 5, respectively. It is assumed that the total load on the B-IN network is equally divided among the four B-SSP's. The experiments are accomplished in the following way: First the bottleneck of the network is found by increasing the load (e.g., increasing the number of users per B-SSP). In order to maximise the network throughput for a given utilisation, this bottleneck is removed by balancing the processing speed of all B-IN network physical entities, such that the utilisations ρ_{SCP}, ρ_{SSP}, of the B-SCP and each B-SSP, respectively, are approximately equal. The balanced network is then used to accomplish the actual scalability experiments. These experiments were performed in a number of steps, during which the processing speeds/capacities of all physical entities are multiplied by a factor α. The initial value of the factor α is set to 1, and the maximum value of α was set to 100. For each step the throughput for a network utilisation of 0.9 (i.e., throughput for which one or more of the utilisations ρ_{SCP}, ρ_{SSP} reach the value 0.9) and the normalised B-VPN mean setup delay (i.e., in TUs) are estimated. Note that reaching full utilisation for one or more entities implies simulating unstable system, i.e., unbounded delays.).

The estimates (with their 95% confidence intervals) indicating the bottleneck of the B-IN network are listed in Table 4. Figure 6 depicts the normalised B-VPN mean setup delay (i.e., in TUs) when the total load is varied. It is found that (for the used performance and workload parameter values) initially the B-SSP is the bottleneck. To balance the network the processing speed of each B-SSP is multiplied by the factor 1.4684 such that the load on all B-IN network physical entities is balanced (the utilisations ρ_{SCP} and ρ_{SSP}, of the B-SCP and each B-SSP, respectively, are approximately equal).

Table 4 Utilisations and normalised B-VPN mean setup delays

Load (Calls/TU)	0.213768	0.427985	1.069948	1.713408	1.979207	2.139955
B-VPN mean setup delay (TU)	3.304123 ±0.01273	3.458762 ±0.01164	4.190721 ±0.02776	5.922680 ±0.09144	8.144329 ±0.50584	11.864261 ±0.680068
ρ_{SCP}	0.06	0.12	0.32	0.51	0.59	0.64
ρ_{SSP}	0.09	0.18	0.45	0.73	0.84	0.91

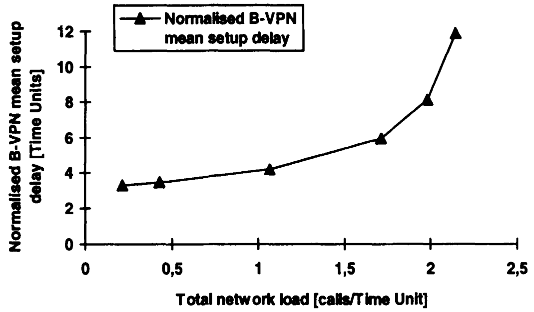


Figure 6 Normalised B-VPN mean setup delay as function of the total load.

After balancing the network we accomplished the actual scalability experiments. The obtained estimates (with their 95% confidence intervals) are listed in Table 5. In Figure 7 the results are illustrated in graphs having as X-axis the factor α and as Y-axis the corresponding throughput at the given network utilisation (i.e., 0.9). Figure 8 has as Y-axis the corresponding normalised B-VPN mean setup delay at the given network utilisation (i.e., 0.9). In order to estimate the normalised B-VPN mean setup delay when the B-IN network load (i.e., number of users per B-SSP) is varied, the speed factor α is set to 10. These estimates (with their 95% confidence intervals) are listed in Table 6. Figure 9 depicts the normalised B-VPN mean setup delay as function of the total load.

From this evaluation we conclude that (see Figure 6 to Figure 9, and Table 4 to Table 6): For a load mix of 85% VOICE and 15% B-VPN, the bottleneck of an B-IN island is initially (i.e., before balancing) the B-SSP. To balance the network the processing speed of each B-SSP is increased by a factor 1.4684. The total network throughput increases linearly with the processing speed. The normalised B-VPN mean setup delay decreases when the processing speed is increased. We have set α = 10 in order to estimate the B-VPN mean setup delay when the B-IN network load (i.e., number of users per B-SSP) is varied. From Figure 9 it can be seen that the B-VPN mean setup delay exhibits a typical delay vs. load characteristic, i.e., the mean delays increase sharply beyond a certain limit.

Table 5 Throughput and normalised B-VPN mean setup delays

α	1	5	10	20	50	100
B-VPN mean setup delay (TU)	13.432989 ±0.480068	2.737113 ±0.125567	1.522852 ±0.060137	0.739862 ±0.037731	0.340378 ±0.013934	0.215807 ±0.015716
Throughput (calls/TU)	3.101478	15.50448	31.01478	62.02956	154.32312	310.15944

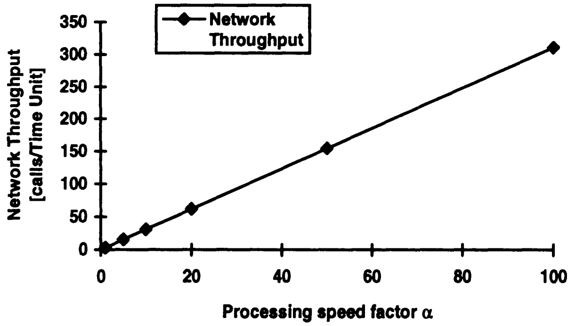


Figure 7 Total network throughput as function of the processing speed factor α.

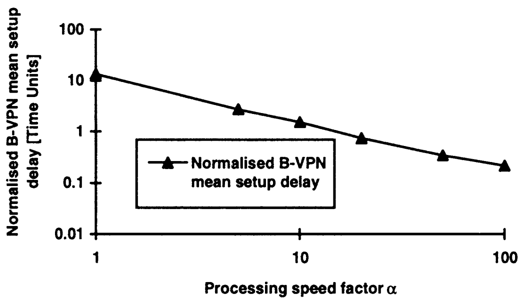


Figure 8 Normalised B-VPN mean setup delay as function of α (log scale).

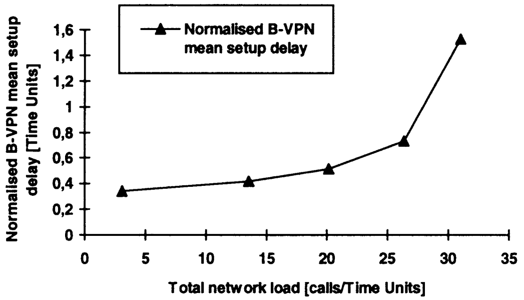


Figure 9 Normalised B-VPN mean setup delay as function of the total load.

Table 6 Normalised B-VPN mean setup delays

Load (calls/TU)	3.101478	13.55478	20.16048	26.37624	31.01478
B-VPN mean setup delay (TU)	0.341065 ±0.000568	0.417353 ±0.002348	0.515292 ±0.006219	0.730927 ±0.013113	1.522852 ±0.060154

4.2 Increasing the Number of Nodes

In this set of experiments we consider a network with more than one interconnected B-IN islands. The used network topology is given in Figure 2(b). It is assumed that the processing speed factor α = 10, and that the total load on the B-IN network is equally divided among all islands. The experiments were performed for an increasing number of islands N. Note that initially a fixed number of users is connected to each island. This number of users may change slightly in order to adjust the network utilisation to the chosen value of 0.9. The initial value of N is one and the maximum value of N is 10. For each value of N, the throughput for a given network utilisation (0.9) and the corresponding normalised B-VPN mean setup delay (i.e., in TUs) are estimated. The obtained estimates (with their 95% confidence intervals) are listed in Table 7. In Figure 10 the results are illustrated in graphs having as X-axis the number of islands N and as Y-axis the corresponding throughput at the given network utilisation (i.e., 0.9). Figure 11 has as Y-axis the corresponding normalised B-VPN mean setup delay at the given network utilisation (i.e., 0.9).

Table 7 Throughput and normalised B-VPN mean setup delays, as functions of N

N	1	2	5	7	10
Load/ island (calls/TU)	31.01478	29.46084	28.1688	27.7614	27.44712
Throughput (calls/TU)	31.01478	58.9275	141.0768	194.3298	274.4886
B-VPN mean setup delay (TU)	1.522852 ±0.060154	1.371993 ±0.072027	1.209622 ±0.031597	1.146219 ±0.054415	1.113402 ±0.048178

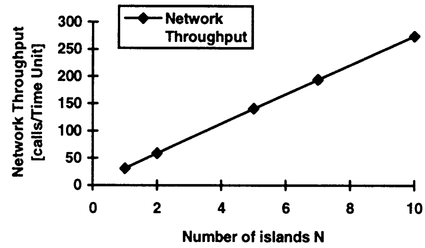


Figure 10 Total network throughput as function of the number of islands N.

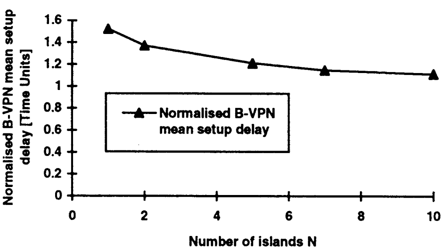


Figure 11 Normalised B-VPN mean setup delay as function of N.

For a fixed number of islands (N=10) the normalised B-VPN mean setup delay is estimated for a varying network load (i.e., a varying number of users per B-SSP). These estimates (with their 95% confidence intervals) are listed in Table 8. Figure 12 depicts the normalised B-VPN mean setup delay as a function of the load per island. From this evaluation we conclude that (see Figure 10 to Figure 12, and Table 7 and Table 8): The total network throughput increases linearly with the number of islands. The normalised B-VPN mean setup delay (i.e., in TUs) decreases by increasing the number of islands. The main reason for this is that (see Table 7) the input load on each island has to be slightly decreased (in order to adjust the network utilisation to 0.9) when the number of islands *N* is increased, hence the slightly lower delays. For *N* = 10 we have performed experiments on the normalised B-VPN mean setup delay by varying the load per each B-IN island. From Figure 12 it can be seen that the normalised B-VPN mean setup delay increases by increasing the network load per island (or the total network load).

Table 8 Normalised B-VPN mean setup delays, for N = 10

Load/island (calls/TU)	3.101478	13.55478	20.16048	26.37624	27.44712
B-VPN mean setup delay (TU)	0.350859 ±0.001654	0.438144 ±0.002841	0.556529 ±0.020859	0.931958 ±0.048694	1.113402 ±0.048178

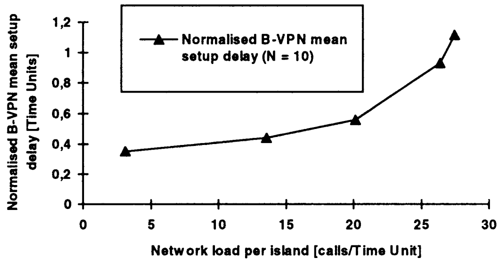


Figure 12 Normalised B-VPN mean setup delay as function of the load per island.

5 CONCLUSIONS

This paper investigates some scalability issues related to a Broadband Intelligent Network (B-IN). In particular we have considered the B-IN signalling system being developed in the INSIGNIA project. The experiments are accomplished in several steps. First the bottleneck of the network is found by increasing the load (e.g., increasing the number of users per B-SSP). Then this bottleneck is removed by balancing the processing speed of all B-IN network physical entities (i.e., B-SSP and B-SCP), such that their utilisations are approximately equal. The balanced network is then used to accomplish two sets of scalability experiments. In the first set we investigated the ability of a B-IN to support an increasing number of users connected to the network. From this set of experiments we conclude that the total network throughput increases linearly with the processing speed, and that the B-VPN mean setup delay decreases by increasing the processing speed. In the second set of experiments we have investigated the scalability when the number of B-IN nodes is increased, and we concluded that the total network throughput increases linearly with the number of B-IN nodes, while the B-VPN mean setup delay remains almost unchanged. A future target for B-IN is to provide advanced services to fixed and mobile users; the scalability of such a network is an important issue which is currently being investigated.

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8 BIOGRAPHY

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