GSM mobility management using an intelligent network platform

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GSM MOBILITY MANAGEMENT USING AN INTELLIGENT NETWORK PLATFORM.

by

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to My Parents, Sinthuja, Shaki and Rajani

ABSTRACT

The principle behind Intelligent Networks (IN) is the separation of call and bearer control from service control. This enables the rapid introduction of new services, features and the ability to offer integrated service packages thereby reducing the reliance on switch manufacturers for the provision of new services.

Global System for Mobile communications (GSM) is the accepted standard for mobile communications not only in Europe, but world wide. GSM is also one of the first networks with a standardised modularised approach to its architecture.

This thesis presents an architecture to integrate GSM and IN networks enabling the provision of GSM mobility services from an IN platform. The approach is to move *mobility* provision and management functions within a GSM network to an IN platform, so providing *mobility* as an IN service rather than a GSM specific service. This proposal will enable the rapid creation of mobility based value added services. Furthermore the proposed IN - GSM integration scenario can be seen as an evolutionary step towards third generation mobile system UMTS.

The approach taken is to transform existing GSM mobility procedures such that they can fit the IN Service Independent Building blocks (SIB) architecture, thereby coexisting with IN SIBs on a Service Control Point. The GSM switching and radio access network is retained to enable the maximum reuse of the existing system.

The thesis presents results from simulation studies carried out to compare the performance of the proposed architecture against the GSM network. Signalling protocol based simulations models were developed on ‘OPNET™’ (a general purpose simulator), for both the proposed architecture and the GSM architecture. The GSM simulation model was validated using data from Cellnet’s GSM network. Results show the comparison between the two networks under different behavior conditions and the indications are that apart from the increase in signalling load on the core network, the IN approach does not significantly degrade the performance of GSM *mobility* procedures.

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GLOSSARY

Application Service Elements	ASE
Authentication Centre	AuC
Base Station Controller	BSC
Base Station Subsystem	BSS
Base Transceiver Station	BTS
Basic Call Process	BCP
Basic Call State Model	BCSM
BSS MAnagement Part	BSSMAP
Call Control Agent Function,	CCAF
Call Control Function	CCF
Common Channel Signalling System No7	SS7
Customised Application for Mobile network Enhanced Logic	CAMEL
Direct Transfer Application Part	DTAP
Distributed Service Logic	DSL
Equipment Identity Register	EIR
Fast Associated Control Channel	FACCH
Functional Entity Actions	FEA
Gateway MSC	GMSC
Global Service Logic	GSL
Global System for Mobile communications	GSM
Home Location Register	HLR
Intelligent Network Application Part	INAP
Intelligent Network Conceptual Model	INCM
Intelligent Networks	IN
International Mobile Subscriber Identity	IMSI

Link Access Protocol for Data mobile channel	LAPDm
Link Access Protocol for the ISND 'D' Channel	LAPD
Location Areas	LA
Message Transfer Part	MTP
Mobile Application Part	MAP
Mobile Service Control Point	MSCP
Mobile Service Data Point	MSDP
Mobile Service switching Centre	MSC
Mobile Service Switching Point	MSSP
Mobile Terminal	MT
Network and Switching Subsystem	NSS
Radio Interface Layer 3 - Call Control	RIL3-CC
Radio Interface Layer 3 - Mobility Management	RIL3-MM
Service Control Point	SCP
Service Creation Environment	SCE
Service Data Point	SDP
Service Independent Building Block	SIB
Service Management Functions	SMF
Service Switching Point	SSP
Signalling Connection Control Part	SCCP
Specialised Resource Function	SRF
Standalone Dedicated Control Channel	SDCCH
Subscriber Identity Module	SIM
Transaction Capabilities Application Part	TCAP
Universal Mobile Telecommunications System	UMTS
Universal Personal Telecommunications	UPT
Visitor Location Register	VLR

1. INTRODUCTION

In this thesis a new architectural approach [i, ii] based on ***Intelligent Networks*** (IN) [13-16, 18-21] is presented for the core network of a GSM [1, 2] mobile network. This approach provides a means for the evolution of the second generation mobile system GSM to ***Universal Mobile Telecommunications System*** (UMTS) [38-40], the third generation mobile communication system. The advantage of this approach over the existing GSM core network architecture is its use of IN's modular and distributed concepts. The new architecture will offer a platform for:

- The rapid and easy introduction of new services in the GSM network.
- An UMTS control platform evolving from GSM.
- Backward compatibility of the GSM radio access network in an UMTS environment.
- The integration of GSM mobility management services with fixed network IN services.

Simulation models were created to study the effect of moving GSM call control and mobility management to an IN platform on the control network and on the quality of service as seen by the user.

GSM designed in the 1980s has a modular approach to its design and encompasses features such as distributed processing and functional separation of call control from the switch. GSM is a digital feature rich network. These factors have combined to give rise to a popular standard for mobile communications which, although initially designed for Europe, has become a world standard.

GSM provides excellent voice services and supplementary features are included in its standards, but it lacks the environment for the creation of new services as offered by IN, as it predates IN standards. The ability to create and offer new services rapidly is a primary discriminator for operators and service providers. To enable rapid and easy service creation in GSM, an Intelligent Network environment needs to be introduced to the GSM network. The solution offered by the industry is the ***Customised Application for Mobile network Enhanced Logic*** (CAMEL) [11, 12], which offers GSM calls access to IN services in the users home network. CAMEL provides a bridge between two separate networks, GSM and IN. In CAMEL there is no true integration of the two networks and call processing is suspended in GSM while IN services are executed. This is adequate for the type of services defined in CS1 [22], but as the complexity of services grow a truly integrated solution is required: an integrated solution that will be of mutual benefit to both networks.

UMTS is in the process of being specified by European Telecommunication Standards Institute (ETSI). UMTS is a system capable of supporting a variety of mobile access networks sharing a common core network. Compared to today's networks, a stronger integration of mobile and fixed networks is expected of the UMTS network; it also supports access bandwidths of up to 2Mbits/s. The scale of GSM's success and the investment made in GSM has necessitated a new line of thought: it is now widely accepted that the air interface for UMTS will be (and needs to be) revolutionary while the UMTS core network will take an evolutionary path [35] from the GSM core network. Furthermore GSM is expected to provide traditional voice services into the foreseeable future, while UMTS at its inception will be used mostly for provision of multimedia and high bit rate data services. Any future third generation network must provide backward compatibility to GSM. It is envisaged that both GSM and UMTS networks will coexist, preferably sharing a common core control network and hence any new core network must offer backward compatibility with the GSM radio access network.

The UMTS core network is based on the IN concept. Mobility and service provisioning in UMTS is offered from the IN platform as added intelligence. Therefore, the GSM core network and IN networks must be integrated to form the basis for the evolution to the UMTS architecture. The requirements for such an architecture as outlined in [34] are that it must:

- encompass the existing GSM and IN architectures;
- reduce the time and effort needed to enhance these standards, by focusing available expertise / resources onto a common framework, thus avoiding replication and minimising cost.
- protect investment to date.

- provide a modular structure so that operators / manufactures can pick and choose what they implement.
- provide a ubiquitous, standard platform, but with interfaces, such that operators and manufacturers may compete by offering proprietary and differentiating features.
- provide a "single track" approach for evolving towards UMTS.

The key drivers for the integration of GSM and IN from the GSM perspective are, therefore, the need for GSM evolution to UMTS while maintaining backward compatibility with the GSM access network and the need for a service provision environment in GSM.

The principle argument in favour of IN is its four-layered model[18], which enables a modular approach to network design, distribution of intelligence and technology independence. Furthermore IN is an 'overlay' network, which is independent of the access network and this is exploited in UMTS to bring about the closer integration of mobile and fixed networks and manage multiple access networks from a single control platform. It is essential to note the difference between the IN concept and the IN implementation today. The IN conceptual model is expected to remain constant and provide an uniform approach to IN implementations, which will evolve with the technology of the day to meet increasing service and performance requirements. IN is restricted to some extent today by the lack of technology to support it, rather than being limited by the concept itself.

The key to IN lies in the ***Service Independent Building Block*** (SIBs) [13, 19, 23]: these are reusable network-wide units from which services are composed. New services are implemented using the SIBs from the existing library of SIBs and new SIBS are only introduced as and when required. This technique results in a fast and efficient method of service implementation.

In this thesis, GSM call and mobility functionality are defined in terms of SIBs, which will enable the close integration of these functionalities with supplementary service SIBs. The result is the ability to use GSM functionality in any other fixed or wireless networks based on IN for mobility management, security and call control. Hence service such as *Universal Personal Telecommunications* (UPT)[70,71] can be provided using GSM SIBs.

The main hindrance to GSM-IN integration is signalling. GSM uses the ***Mobile Application Part*** (MAP) [2, 6, 9], specifically designed for signalling in the GSM core network. Intelligent networks use the ***Intelligent Network Application Part*** (INAP) [17, 73-75] developed with services and applications in mind [33]. Both protocols are based on the ITU *Common Channel Signalling System No7* (SS7) [64-67] and use the Transaction Capabilities [69] offered by SS7. Although they are both similar in principle, the packaging used is different. Due to the limitations of processing speed and network capabilities at the time GSM standards were defined, GSM procedures were 'hard-wired' for optimisation by offering it as one package; IN procedures are modular in definition. The distinction between the two protocols is made at the beginning of a signalling transaction when protocol identifiers are used to distinguish between INAP and MAP. From then onwards, protocol identifiers are not used and only message numbers are used. Both MAP and INAP messages share the same range of message identity numbers, so that simply integrating both protocols would result in contention

A standardised approach is required for integrating the two protocols. The UMTS protocol will contain elements of both the INAP and MAP. The current trend is that IN is being expanded to include mobility and GSM to include IN functionality, resulting in two sets of super-standards[34]. In this thesis a 'pre-UMTS' protocol focusing on mobility management is presented, by retaining the modularity and reusability of IN and by including GSM's tried and tested mobility functionality. This brings together the best of both worlds and prevents the wheel from being reinvented. There is no benefit in either of the protocols inventing functionality found in the other. If the functionality required is not sufficiently supported by the existing protocols, then the existing protocols could be extend to support the requirements. The benefit is that both networks will mutually benefit from the extensions. The architecture presented in this thesis enables the evolution of the GSM core network to support UMTS and retain the capability to continue to support the GSM radio access network from the evolved core network.

MAP was designed and developed with the specific aim of achieving speed and optimisation for the GSM network. To date no publication has investigated the performance issues related to moving GSM mobility management and call control to a more generic architecture and platform. This thesis presents results on the effect of the control network and quality of service (as perceived by the user) as a result of providing GSM functionality from an IN platform. Furthermore, the use of an IN architecture can result in the distribution of GSM functionality which may not be optimum for a mobile network. Therefore the simulation models investigate the effect the various physical IN architectures will have on the signalling network and on the GSM procedures.

There are two obvious paths for integration and evolution, GSM into IN or *vice versa*. This thesis argues that mobility, in principle, is independent of the access network and by no means restricted to the cellular networks. Intelligent Networks on the other hand are access network independent and offer the same range of services across the multitude of access networks, therefore absorption of GSM into IN is supported here.

This thesis describes in detail a 'pre-UMTS' architecture based on the integration of the GSM and IN networks. The focus of the contribution is on the provision of GSM call control and mobility management from the pre-UMTS IN platform and the related performance issues. This introductory chapter has served to summarise the contribution of this thesis in the context of GSM migration to UMTS.

Chapter 2 serves as a brief introduction to the GSM network covering elements of both the radio access network and the core network. Signalling in the various parts of the GSM network is described with emphasis on the core network signalling protocol, the *mobile application part*. The signalling procedures for GSM mobility management and call control in the core network are discussed.

Chapter 3 introduces the concepts behind Intelligent Networks and its role in supplementary service provision today. The IN conceptual model which describes the various levels from service description to service execution across the physical entities is given. A detailed description of the signalling protocols used within the IN framework is provided, as signalling is central to the research presented in this thesis.

The integrated GSM / IN architecture proposed by the author is described in Chapter 4. The working of GSM mobility management and call control from an IN platform and the resulting signalling procedures are also described and the modifications necessary to the existing GSM network are identified.

The simulation models developed by the author to investigate the performance of the architecture presented in Chapter 4 is described in Chapter 5. This chapter details the modelling of the various parts of the network, the assumptions made for the simulation study and modelling user mobility. The verification and validation of the models are discussed.

In chapter 6, the various physical architectures that could result from GSM - IN integrated case are presented. Simulation models for these architectures are discussed and the results of the simulation are studied to determine the most suited physical architecture.

In chapter 7 the approach taken in this thesis is validated and verified. A comparison with other approaches tackling the integration of GSM and IN is made. Finally, Chapter 8 concludes with the merits of this approach highlighted and its limitations identified. Areas for further work are also given.

2. THE GSM NETWORK

2.1 AN INTRODUCTION

Global System for Mobile communications (GSM) was born from the need by several European countries to introduce a common mobile communication network and overcome the limitations of the existing analogue system. The analogue system was limited in several ways, including its inability to cope with the unprecedented growth in the demand for mobile communications, the use of open channels allowing for easy 'eavesdropping' and 'cloning', the inflexibility in the introduction of value added services and the lack of a common network across Europe, among others.

In 1982 the Conférence Européenne des Postes et Télécommunications (CEPT) formed the "Groupe Spécial Mobile" (GSM) (later to be called Global System for Mobile communications) to define the standards for a new mobile communications system. Although GSM was introduced as an European specific standard, it has been adopted by several countries world wide. The system was required to allow roaming in participating countries, offer services and facilities found in other public networks and use an internationally standardised signalling system for interconnection of mobile switching centres and location registers.

In the late 1980s it was realised, the specification and implementation of GSM could not be achieved in a single instance. A limited GSM roll-out (phase 1) was effected in 1991, offering basic voice telephony only. The specifications for phase 2, an 'enhancement' to phase 1, includes new supplementary services and the introduction of half rate speech channels. GSM as a standard has been in a constant state of evolution since its inception and will continue to do so into the foreseeable future.

GSM as a network is not defined by a set of rigid and stagnant standards. It is a network not only willing to evolve, but by the very nature of its specifications it needs to evolve. These qualities embodied within GSM make the results described in this thesis feasible and a practical reality.

"A platform [GSM] which is full of hooks, mechanisms and not at least potential to continue to build on and provide mobile communications in all its possible forms and varieties. Even before Phase 2 standard has been completed, GSM has grown far beyond its original geographical "limitations" and the Global System for Mobile communication really starts to deserve its name. With Phase 2, and in particular Phase 2+, GSM will also expand far beyond its originally intended functional boundaries and open up for new applications, new access methods, new technologies and thus altogether for new categories of market, needs and users. It looks promising." Jonas Twingler, GSM co-ordinator of ETSI. [1]

GSM is one of the first 'intelligent' networks with distributed processing, clear separation between the switch and bearer control and to use *Common Channel Signalling System No.7*. This provides GSM the hooks, mechanism and the potential to evolve and grow. This potential combined with the similarities between Intelligent Networks and GSM network architectures will be exploited will in this thesis to present an evolutionary path to a 3rd generation of mobile communication network.

Although GSM has been thoroughly covered in [1, 2], a brief overview of GSM is given in this chapter, with the aim of highlighting the clear separation between GSM's radio access and core networks. The clear separation of core and access networks are vital to the evolution of any network to ensure that one is not restricted by the other and changes to one does not necessarily result in the replacement of the complete network. The evolutionary path presented in this thesis relies on this separation.

The following sections will highlight the separation between the core and access networks and will show that the key to call, service and mobility management lies in the core network and not the radio access network. For our purposes, a detailed explanation on the workings of the radio access network is not necessary and therefore will not be presented.

2.2 GSM SUB SYSTEMS

GSM architecture [1-3] is composed of two main parts;

- The radio access network or the *Base Station Subsystem*.
- The switching, call handling and mobility management network, referred to as the *Network and Switching Subsystem* in [2] and referred to as the GSM '***core'*** network in this thesis.

The primary object of this research will involve the core network and this chapter will reflect this, but to present a complete picture elements of the radio access network are introduced.

Human interaction with the GSM network is via the *Mobile Station*, which consists of the ***Mobile Terminal*** (MT) and the *Subscriber Identity Module*. The mobile terminal provides the user interface and the radio connectivity to the network. The *subscriber identity module* is a smart card with information pertaining to the customer, security parameters and the ability for the network to identify the user. The separation of the mobile station into two entities allows the GSM network to cater for both terminal mobility and personal mobility. Unlike the analogue systems where a user is tied to the terminal, in GSM two users A and B can share terminal X and maintain individual billing as well. Hence *subscriber identity module* roaming (i.e. personal mobility) is catered for in GSM.

The ***Base Transceiver Station*** (BTS) or '***cell***' provides the means for two way radio communications with the mobile terminal. Any signal processing specific to the radio interface is handled by the cell. A user must keep the network informed of his whereabouts i.e. update his location, so that the network can direct calls to the users current location. The mobile terminal monitors the signal strength from the surrounding cell sites and reports the identity of the cell site with the strongest signal to the network. The cell identity is associated with the user and when the user needs to be contacted, the cell site is paged. Cell sizes vary in size from a few meters to a few kilometres in radius. In areas where the cell sizes are small, a user on the move will generate a large volume of signalling traffic in location update procedures as a result of the frequent cell boundary crossings. In order to minimise the volume of signalling traffic, cells are grouped into ***Location Areas*** (LA) and the user reports the location area currently being roamed rather than the cell identity. Now the user need only update the network when a *location area* boundary is crossed.

Several cells are managed by the ***Base Station Controller*** (BSC), which is responsible for the allocation, release and management of radio channels. The BSC is a small switch linking the several cells under its control to the ***Mobile Service switching Centre*** (MSC). The radio access network includes the mobile terminal, BTS and the BSC as illustrated in Figure 2-1.

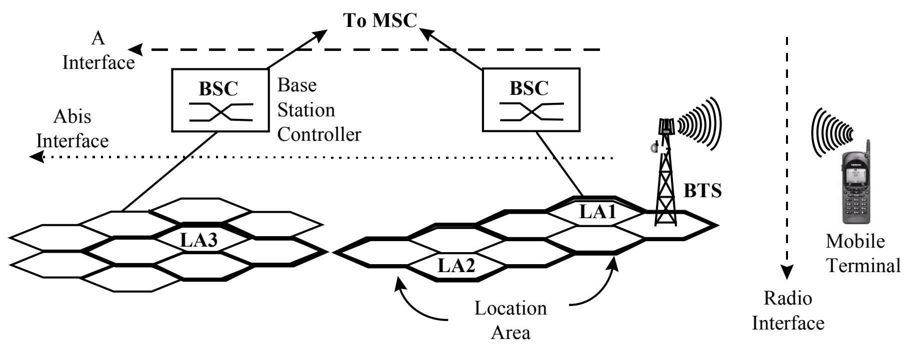

Figure 2-1 : GSM Base Station Subsystems.

The MSC is primarily a large switching centre providing connectivity between mobile stations within it's area of coverage and the outside world. A MSC's coverage is a geographical area, determined by the network operator. The mobility management functions catered for by the MSC include setting up of mobile-originating and mobile-terminating calls, inter-BSC, intra-MSC and inter-MSC handovers, and location updating.

Once a mobile station comes into the coverage of a MSC, it becomes the responsibility of the ***Visitor Location Register*** (VLR) attached to the MSC. VLRs are temporary databases containing data necessary to setup calls to and from the mobile station by the MSC. Information contained within the VLR includes the *location area* being roamed, the mobile stations roaming number, the *International Mobile Subscriber Identity* and *Mobile Station ISDN Number*. The VLR keeps the ***Home Location Register*** (HLR) updated on the location of the user. The VLR's functionality is in two parts: a database for temporary storage of user data as described above and (the second part) mobility management and call handling control functionality, which includes procedures such as registration of users, call setups, authentication, location updating, among others. Although the standards draw a clear distinction between the MSC and the VLR, in practice they are implemented as one entity.

All mobile networks need to maintain a record of a user's present whereabouts in a permanent centralised location, the HLR. The HLR contains user subscription information in addition to the present location of the user. The user's subscription parameters include roaming limitations, supplementary services subscribed to, charging information, etc. A user's HLR can be identified from the user's phone number as a GSM network has several HLRs. The HLR also houses the *Authentication Centre* and the *Equipment Identity Register*. In addition, the HLR offers mobility management and database management functionality.

Upon interrogation, the HLR provides routing information to the user's present or last known location in terms of address of the roaming MSC, local mobile terminal identity and the VLR address.

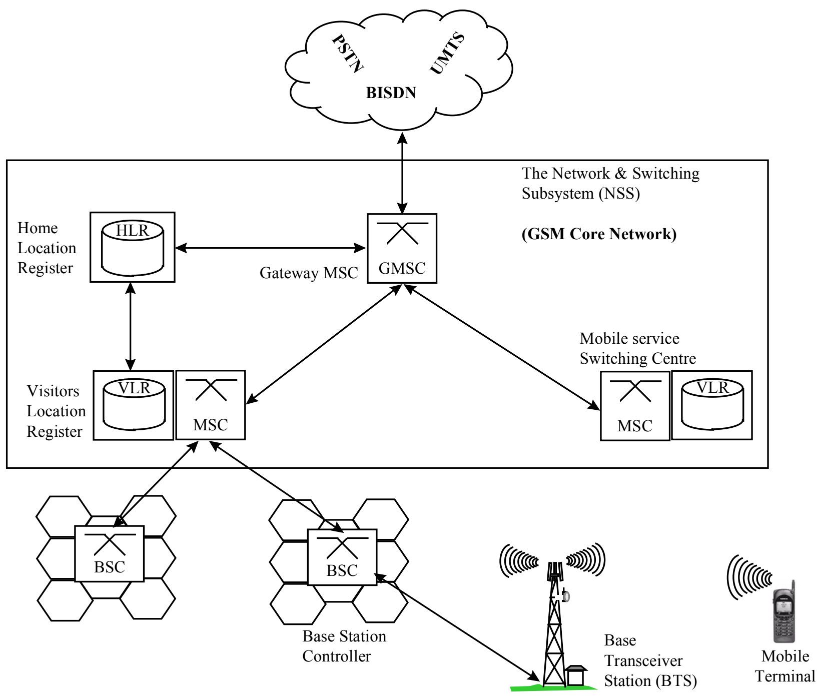

Figure 2-2 : The complete GSM architecture.

For a call destined for the GSM network where the originating network cannot directly interrogate the users HLR, the call is routed to a ***Gateway MSC*** (GMSC) by the originating network. The GMSC interrogates the HLR and routes the call to the subsequent MSC. The MSC, HLR, VLR and GMSC make up the core network as illustrated in Figure 2-2.

2.3 SIGNALLING IN GSM

For a network to function successfully, it must have the ability communicate within the network and with entities outside its boundaries. The GSM network is no exception, but uses a larger variety of signalling protocols [1,2,4,7,9,10] and different transport mechanisms compared to other networks. The transportation mechanisms [1,2] used by GSM signalling protocols are;

1. ***Link Access Protocol for Data mobile channel*** (LAPDm) is used between the mobile terminal and cell (i.e. the radio interface); this is a GSM specific signalling standard. LAPDm makes uses of the dedicated ***Standalone Dedicated Control CHannel*** (SDCCH) as its carrier over the radio interface. The data rate over the SDCCH channel is very slow (≅ 1Kbps) and it is only used for signalling outside a call.

   Once a call has been setup and a voice/data channel is available, signalling messages are transmitted over the voice channel by 'stealing' a burst, i.e. the voice channel is used as a carrier for signalling data. This is referred to as the ***Fast Associated Control CHannel*** (FACCH). The faster data rate of FACCH is useful when time critical procedures such as handovers need to be conducted.
2. The Abis interface between the cell sites and the BSC makes use of a derivative of NISDN signalling, ***Link Access Protocol for the ISND 'D' Channel*** (LAPD), this is a 64 Kbits/s signalling.
3. For the 'A' interface and for interfaces between the various core network entities (such as VLR, HLR, MSC, GMSC), 64Kbits/s SS7 channels are used.

The signalling protocols that use the various transport mechanisms are:

1. *Radio Interface Layer 3 - Mobility Management* (RIL3-MM) - between the mobile terminal and the MSC/VLR for user location and security management.

2. *Radio Interface Layer 3 - Call Control* (RIL3-CC) - between the mobile terminal and the MSC/HLR for call control management.

3. *BSS MAnagement Part* (BSSMAP) - between the MSC and the BSC for messages specific to a connection.

4. *Mobile Application Part* (MAP) - between the various core network entities for non-call related signalling.

5. *ISDN User Part* (ISUP) or *Telephone User Part* (TUP) - between core network switches for call related signalling.

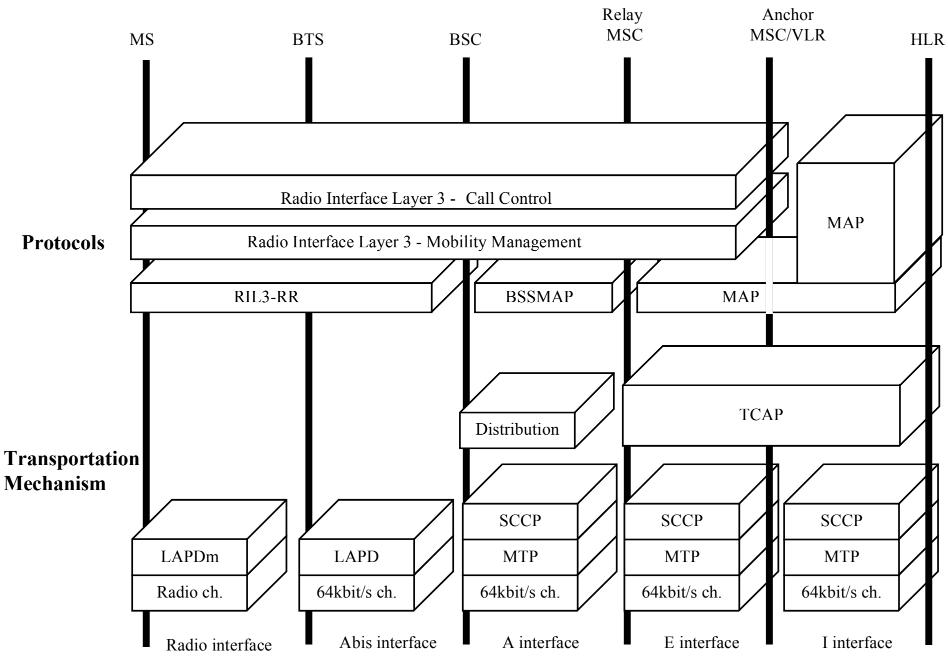

Figure 2-3 : GSM signalling architecture[1].

Between the MSC and the mobile terminal, the *Protocol Discriminator* (Eg. Call Control (CC), Radio Resource(RR), Mobility Management(MM)) is used as a means of addressing signalling messages. The nodes use the protocol discriminator in deciding if the message is destined for that node or if the node needs to act as a transparent relay. Once at the appropriate node, the protocol discriminator is used to decide on the type of processing required. For example, in the case of a message with the protocol discriminator CC, the BSC and BTS act as relay points. Over the A interface, the SS7 ***Signalling Connection Control Part*** (SCCP) basic connection oriented service (virtual connection) is used for messages to the BSC belonging to a particular mobile terminal, where each mobile terminal has an independent connection. A distribution layer is added on top of the SCCP layer to add a header to messages on the A interface. The header distinguishes between *Direct Transfer Application Part* and BSSMAP messages. The BSC depending on the header, either relays the message to the mobile terminal or processes the message.

2.4 MOBILE APPLICATION PART

It is worth taking a diversion to look at how GSM and Signalling System No. 7 (SS7) interact. SS7 is the signalling system used within the GSM core network and for signalling exchanges with external networks. Most of the signalling in mobile networks results from tracking users and, therefore, is non-call-related signalling. GSM has defined a signalling protocol, the *Mobile Application Part* (MAP) which uses SS7 for non-call-related and call-related signalling within the GSM core network. For call-related signalling between GSM switches (MSCs) and the external network, SS7's *Telephone User Part* and *ISDN User Part* are used.

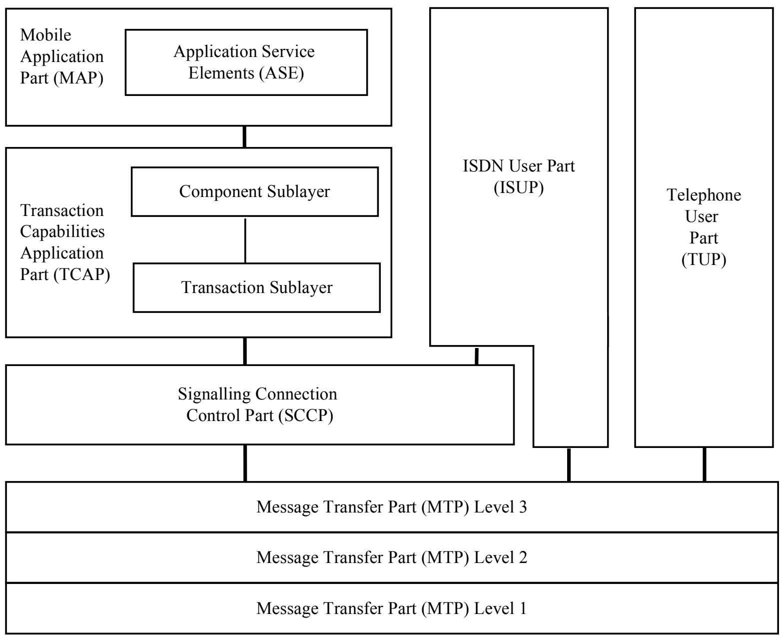

Figure 2-4 : SS7 and GSM.

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[1] Illustration based on Figure 2.20 in [2].

The MAP functionality makes use of SS7's ***Transaction Capabilities Application Part*** (TCAP). Transaction capabilities in turn uses the *Signalling Connection Control Part* (SCCP) [68]. SCCP provides the upper layers with connectionless virtual path type signalling capabilities using SS7's *Message Transfer Part*. The workings of the message transfer part are not directly relevant to the discussion here and it can be safely assumed that SS7 messages will get to the correct destination. At each node there may be several users of SS7 and the message needs to be passed on to the correct user. The introduction of connectionless services has made the addressing capabilities of the message transfer part inadequate for identifying the user.

The SCCP overcomes this by the addition of *Sub-System Numbers* which identifies the users of the SCCP functionality, like GSM MAP, intelligent network's INAP and ISUP. The sub-system number is a 8 bit code and the number allocated to MAP is 00000101(05 hex). In addition, further sub-system numbers are allocated to individual entities in GSM as shown in Table 2.1.

User	SSN	Comments
Whole of MAP	00000101 (05 hex)	Reserved for possible future use
HLR	00000110 (06 hex)	
VLR	00000111 (07 hex)	
MSC	00001000 (08 hex)	
EIR	00001001 (09 hex)	
Allocated for Evolution	00001010 (0A hex)	Possible Authentication Centre

Table 2.1 : Sub-system codes for MAP

By specifying the originating SSN and the destination SSN, the MAP interface is identified. Hence MAP can be seen as a collection of sub-protocols based on the interfaces shown in Figure 2-5.

The introduction of networks such as GSM and IN have led to the need for non circuit related signalling and remote operations. In a mobile network location registering is a procedure that occurs outside a call where the network database is informed periodically on the whereabouts of the user; thus will need to make use of connection-less signalling. To accommodate these requirements, the transaction capabilities layer was introduced to SS7. This is a protocol offering connection-less traffic based services. Transaction capabilities supports both real time and off line (non time critical) based services; for instance, the translation of an freephone number is a real time service and the retrieval of statistical information on a exchange is not time critical (off line).

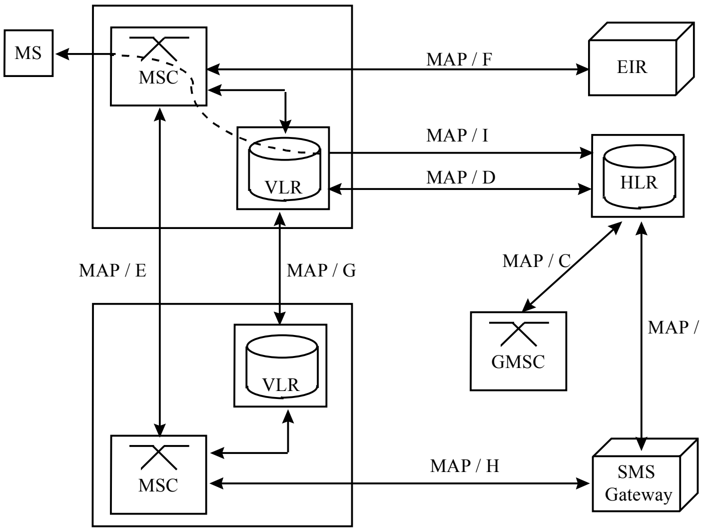

Figure 2-5 : MAP interfaces between core network entities[2].

Transaction capabilities is a flexible transfer mechanism which offers the tools necessary for a user to carry out remote operations on other nodes and obtain the results of the operation in information elements termed *components*. It has two parts: the component sub-layer and the transactions sub-layer.

The component layer manages the relationship between individual remote commands and their responses within a dialogue. This transaction capability functionality means that MAP does not need to correlate commands with the appropriate responses. Often replies to remote invocations are contained in the ‘Return Result’ or ‘Return Error’ components associated with the ‘Invoke’ component. Although the reply messages have message names specified in the recommendations, the actual reply may not specify a name and is only meaningful in the context of the invoking message.

The transaction layer manages the end-to-end exchange of components, i.e. it manages the dialogue. Two types of services are offered by the transaction layer: the

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[2] Illustration based on Figure 2.22 in [2].

unstructured dialogue where a response is not expected and a structured dialogue for two way communications. For bi-directional dialogues a unique ID is allocated, which allows the remote entity to co-ordinate the components.

Above the transaction capabilities is MAP. MAP communications are defined by a collection of *Application Service Elements* (ASEs) which contain the operations, errors and parameters invoked and sent to the communicating entity. Examples of ASEs include location registering, handovers, authentication, etc. Each entity involved in the procedure will have an ASE for the procedure. For an example, both the MSC and VLR are involved in issuing a new TMSI and therefore both have the 'reallocation of TMSI' ASE. To execute a procedure, ASE from one entity will communicate with ASE from the other entity.

2.5 MOBILITY PROCEDURES IN GSM

What are mobility procedures? For the purpose of this study, mobility procedures will be defined as the functionality required to offer and maintain communications with a mobile user at any given time and any functionality resulting as a consequence. Within GSM, authentication, ciphering and security are a integral part of the network and are intertwined with mobility functionalities.

The aim of the study is to model mobility functionalities independent of the access network used. As such GSM radio access functionality is not covered here. The emphasis, as the reader will discover is, on the exchange of messages by mobility functions within the core network. The negative outcomes of mobility procedures are not discussed unless deemed significant.

2.5.1 LOCATION UPDATING PROCEDURE

For a mobile network to offer connectivity to a mobile user, the location of the user must be known. The procedure of a mobile terminal informing the network of its whereabouts is referred to as location updating[2,5,6,9]. The request by a mobile terminal for location updating upon entry into every new cell (which may be as small as 100 meters in radius), will place undue stain on the network in terms of excessive signalling traffic. To optimise network performance and reduce signalling load, cells are grouped into *location areas*. With *location areas*, the mobile terminal is only required to update its location when it enters a new *location area*. In addition, the network requires the mobile terminal to carry out periodic location updating. The time between periodic location updates is set by the network operators and can vary from 6 minutes to a little more than a day. There are other situations (such as a VLR failure) where location updating procedure is initiated; these situations are rare compared to others and are not described here.

A user's location is stored in three different locations in the GSM network; the *subscriber identity module*, the VLR attached to the roaming MSC and the HLR. For the purposes of routing a mobile terminating call, the HLR only stores the destination of the MSC being roamed, it being the VLR that stores the *location area* the mobile terminal is currently in. This leads to two variations in the location updating procedure (illustrated in Figure 2-6):

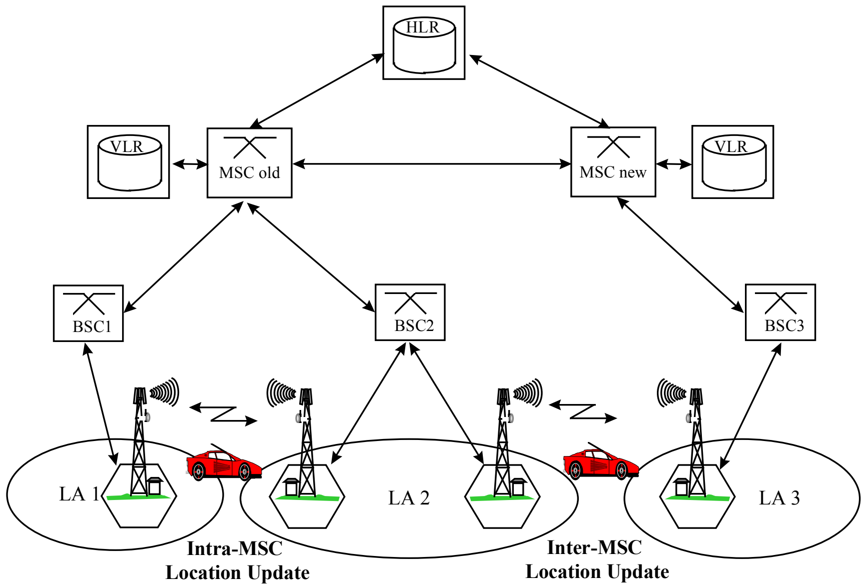

Figure 2-6 : Two location updating scenarios in GSM

- **Intra-MSC location update** : The mobile terminal moves into a new *location area* within the same MSC. In this case only the VLR needs to be informed and the HLR need not be informed as the MSC roamed is unchanged.

- **Inter-MSC location update** : The mobile terminal comes into the coverage of a new *location area* controlled by a different MSC to the one being roamed. In this case the VLR associated with the new MSC needs to be informed. The new VLR will then have to update the HLR with the new MSC's address and the old VLR will have to delete the user from its records.

Other cases where location updating may be initiated are not discussed here.

2.5.1.1 INTRA-MSC LOCATION UPDATE PROCEDURE

The procedure for a intra-MSC location update is given using pseudo code to describe it:

MT	{Detects that coverage is provided by a new location area} **Initiate a location update procedure** {Transmit a LOCATION UPDATING REQUEST message over the standalone dedicated control channel. The message contains the *International Mobile Subscriber Identity* (IMSI)[3] or the *Temporary Mobile Subscriber Identity* (TMSI)[4] and the new location area identity}
MSC	**Forward LOCATION UPDATING REQUEST to the VLR.**
VLR	{Before the users records are updated with the new location, the user needs to be authenticated[5].} **Initiate authentication procedure** {The VLR will make an authentication request to the mobile terminal}
MT	{Respond to authentication request} **Send AUTHENTICATION RESPONSE message**
VLR	**IF (Authentication outcome = success)** **Begin**

---

[3] The IMSI is the unique number associated with a mobile user. A GSM node is able to derive the user's country of origin, the ***Public Land Mobile Network*** (PLMN) within the country and the HLR associated with the user from the IMSI. The SS7 address of the HLR can be derived using translation tables and hence the routing information. The IMSI comprises of the ***Mobile Country Code*** (MCC), ***Mobile Network Code*** (MNC) (eg. Vodafone, Cellnet) and the ***Mobile Subscriber Identification Number*** (MSIN). Usually the most significant digits of the MSIN will resolve the identity of the HLR.

[4] When a user registers on a VLR, the VLR allocates a TMSI to the user. This avoids the IMSI being used over an insecure radio channel. The TMSI is half the size of IMSI, hence it improves radio channel usage. A TMSI is associated with a LA within each MSC/VLR. When the user moves on to a new LA, a new TMSI is allocated. The TMSI contains adequate information for a GSM node to identify the issuing VLR.

[5] The authentication functions in GSM serves to prevent unauthorised access to the network. Each user is assigned a secret key called *Ki*, which is stored in the SIM and the user has no access to it. The *Ki* assigned to a user is also stored in the HLR. Running *Ki* and RAND (a random number varying from 0 to $2^{128} - 1$) through an algorithm known as A3, produces a ***Signed RESult*** (SRES). So when a request for authentication is made only the RAND is transmitted to the mobile terminal. Both the mobile terminal and the network posses the same A3 algorithm, hence they should produce identical SRESs. The SRES is transmitted back to the network and compared with the SRES produced by the network, if they are identical the user is authenticated. The possibility of identifying the Ki from the SRES and RAND depends on the complexity of the A3 algorithm.

Request ciphering of radio channel.
Issue a new TMSI { in FORWARD NEW TMSI message}
End

MT **Acknowledge receipt of TMSI.**

VLR **Update local record**.
Forward LOCATION UPDATE ACCEPTED message to mobile terminal
{Location update procedure is complete}

The signalling exchange is shown in Figure 2-7.

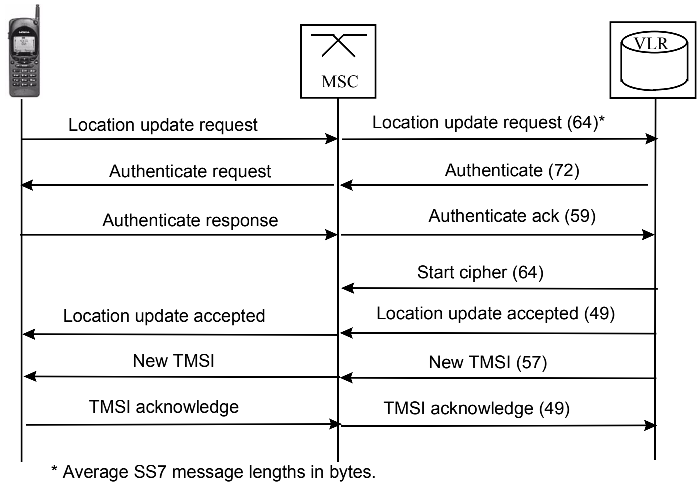

Figure 2-7 : GSM signalling messages for location updating procedure for MS within the same MSC (Values within brackets are the average SS7 message lengths[6] in bytes.).

2.5.1.2 INTER-MSC LOCATION UPDATE PROCEDURE

The procedure for inter-MSC location updates is as follows:

MT {Detects that coverage is provided by a new location area}
Initiate a location update procedure

~ As in the intra-MSC case ~

VLR **IF (TMSI sent by mobile terminal ≠ TMSI from current VLR)**
Request user parameters from old VLR
{From the TMSI the VLR recognises that the mobile terminal is registered on a different VLR. The VLR will request the old VLR to forward the users authentication and subscription parameters}

IF (Mobile station identities itself with IMSI instead of the TMSI)
Request user parameters from HLR
{Request for the users authentication and subscription parameters is made to the users HLR, which can be identified from the IMSI}

VLR **IF (Received user data = TRUE)**
{Once the new VLR has the information on the user, the procedure is as the intra-MSC case}

~ procedure as in intra-MSC case ~

VLR **IF (Location update procedure = successful)**
Inform HLR of new MSC
{Sends a LOCATION UPDATE REQUEST message to the users HLR with the identity of the new MSC being roamed}

HLR **IF (LOCATION UPDATE REQUEST is received)**
Acknowledge new VLR
{The HLR replies with the LOCATION UPDATE ACCEPTED message and forwards the user s subscription and authentication parameters (if requested)}
Delete old VLR record
{The HLR will request the old VLR to delete the user from the VLR's records}

The exchange of signalling messages is shown in Figure 2-8.

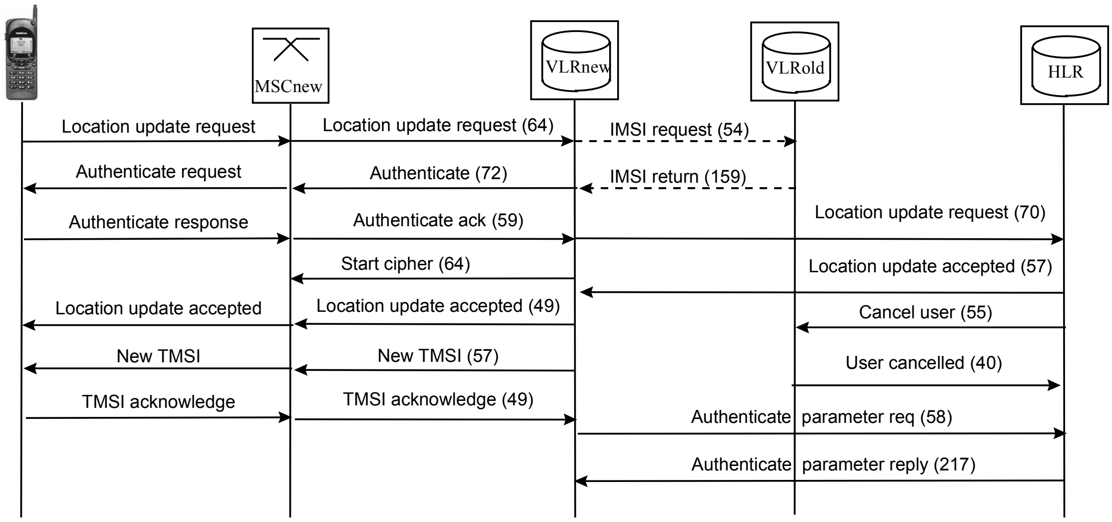

Figure 2-8 : GSM signalling messages for location updating procedure for MS register onto a new MSC (The continuos lines show message exchanges common to both scenarios.)

2.5.2 MOBILE ORIGINATING CALLS

Here the signalling procedure for a mobile originating call[1,2,6,7,9,10] is described; it is shown in Figure 2-9. A GSM caller wishing to make a call does not receive a line to the exchange as in fixed networks. The number being called is entered on the terminal and the 'send' button is pressed.

MT IF (SEND button pressed = TRUE)
Initiate outgoing call setup
{The mobile terminal sends a SERVICE REQUEST message to the MSC. The SERVICE REQUEST message does not contain any confidential information as its transmitted over a clear channel. Only the TMSI and the service identity are included.}

MSC Forward SERVICE REQUEST to the VLR.
{As a PROCESS ACCESS REQUEST message.}

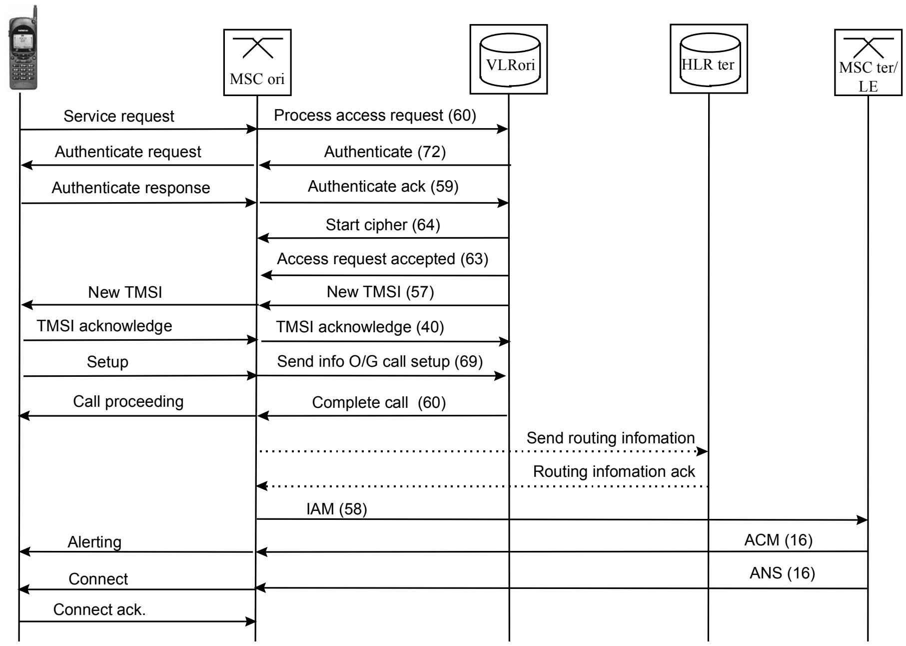

Figure 2-9 : GSM signalling procedure for a mobile originating call.

VLR **IF (User registered in VLR = TRUE)**
Initiate authentication procedure
{As described in the location updating procedure}

VLR **IF (Authentication = Success)**
Begin
Issue TMSI
Cipher radio channel
Send ACCESS REQUEST ACCEPTED to MSC
{In reply to the request for service by the MSC on behalf of the mobile terminal.}
End

MT **Acknowledge TMSI**
Send information for outgoing call
{With a secure channel in place, the mobile terminal sends called party's address to the VLR in a SEND INFO. FOR O/G CALL SETUP message.}

VLR **IF (Number called not barred)**
{The VLR checks the number and type of service against the user subscription parameters.}
Send COMPLETE CALL

MSC **Inform the mobile terminal that the call is proceeding**.
IF (Called party = Mobile User)
Get routing information from HLR
{The called party's HLR is interrogated for routing information to the mobile's current location.}
IF (Called party = Fixed network user)
Determine routing information from number supplied.
Being call establishment to the destination
{Send IAM message to called party}
Inform mobile terminal of called party status
{Send a CALLED PARTY ALERTING or CALLED PARTY BUSY message to the mobile terminal. }
IF (Call is answered)
Send CONNECT message to mobile terminal

MT IF (CONNECT message received)
Send CONNECT ACKNOWLEDGE message to the MSC.

2.5.3 MOBILE TERMINATING CALL

For a call terminating at a mobile terminal [2,4,6,9], two scenarios need to be considered. First, the calling party is a mobile user (i.e. belongs to the PLMN), in which case the calling party's MSC has the ability to interrogate the called party's HLR as described in section 2.5.2. Once the HLR is interrogated, the call is routed to the roaming MSC. Once at the MSC, the call setup procedure to the mobile terminal is independent of the origin of the call.

Not all callers have the ability to interrogate the HLR directly (e.g. calls from the fixed network); this is the second scenario. In such circumstances the call is routed to a ***Gateway MSC*** (GMSC). The GMSC extracts the called mobile's MSISDN number from the incoming ISUP INITIAL ADDRESS message. The address of the mobile's HLR is derived from the MSISDN number and the GMSC sends a request to the HLR for routing information to the mobile. Once the GMSC receives routing information to the MSC being roamed, the GMSC sets up a connection to the MSC. The procedure from the MSC onwards to setup a connection to a mobile terminal is as follows:

MSC **Request for information from VLR for incoming call setup.**

VLR **IF (Mobile terminal status receive = Enabled)**
{VLR checks the if the caller can receive calls (ie. the terminal is not switched off, or call forwarding has not been activated) and the service requested can be accommodated by the user.}
Page mobile terminal
{VLR will request the MSC to page the mobile terminal in the location area associated with the mobile terminal.}

MSC **Page location area.**
{The mobile terminal is paged over the paging channel.}

MT **Respond to page.**

MSC **IF (MT respond = True)**
Request VLR to process an access request.

VLR **Authenticate User**
IF (Authentication = Success)
Begin
    Cipher radio channel
    Issue TMSI
    Forward COMPLETE CALL message to the MSC.
End

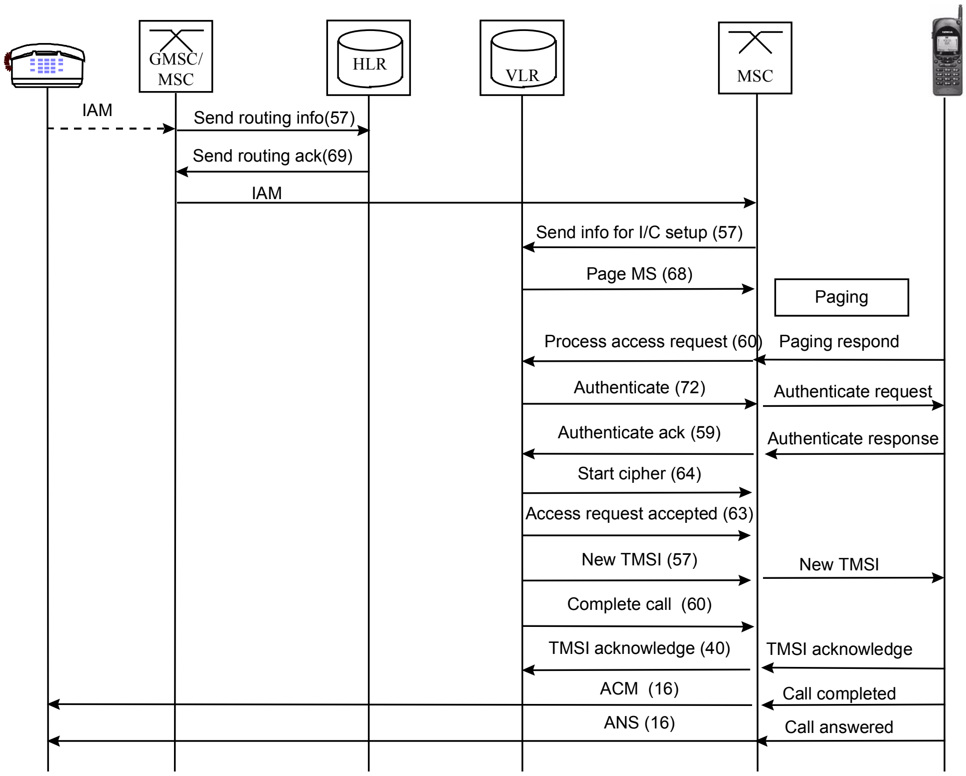

Figure 2-10 : GSM signalling procedure for a mobile terminating call.

Once the mobile terminal tunes to the allocated radio channel, an address complete message is sent to the caller and the call is connected through when the mobile terminal answers.

2.5.4 HANDOVERS IN GSM

The procedure where a radio path to a mobile user is switched during an active call, without significant degradation in the quality of service is termed a handover. Various factors contribute to the decision to execute a handover procedure [2,6,8,9]:

- Mobile station moving out of radio coverage of the current cell.
- Deterioration in the radio signal strength.
- Improve global interference levels (confinement handovers).
- Traffic management (traffic handovers).

Handovers carried out to prevent a call being lost are termed a rescue handovers. Confinement and traffic handovers are used to improve the performance of the network and are initiated for the benefit of the network.

In GSM the decision to initiate rescue handovers is made by the network. This is because global interference level calculations are made in the network and the cell plan is only known to the network. The data on which the network makes its decisions and calculations are supplied by the various mobile terminals. Mobile terminals make measurements of the radio reception levels for the current and neighbouring cells, and report this information to the network. The usual reporting rate is once a minute. Based on these measurements the serving BSC makes the decision to execute a handover. Only rescue handovers are described here and the various types are listed;

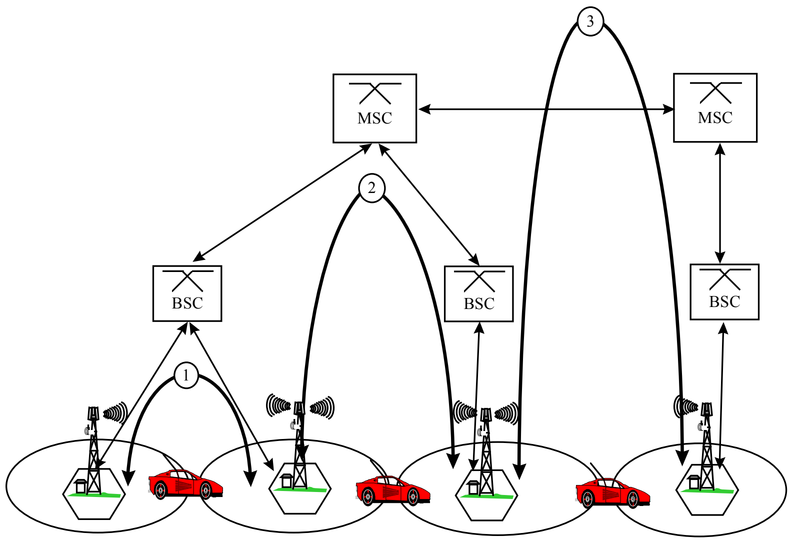

Figure 2-11 : Various scenarios for handovers.

1. ***Inter-BTS*** handovers, handover between two cells connected to the same BSC, executed internally by the BSC without the MSC's knowledge.

2. ***Inter-BSC*** handovers, between cells covered by the different BSCs, where both the BSCs are controlled by one MSC. BSC_{old} (BSC currently serving the mobile terminal requiring a handover) sends a message to the MSC with a list of target cells for handover. MSC establishes a SCCP virtual connection to BSC_{new} (BSC serving target cells), where a new radio channel is allocated and activated. BSC_{old} is informed and will instruct the mobile terminal to execute a handover to the

appropriate cell. Once the mobile terminal has access to the new radio path, the old path is cleared.

3. ***Inter MSC*** handovers, between cells covered by separate MSCs. Inter MSC handovers are explained in detail below.

The following is a description of the inter-MSC handover procedure.

BSCold **Compose and send a HANDOVER REQUIRED message to MSCold**
{The message will contain a list of target cells for the handover.}

MSCold **Send a PERFORM HANDOVER message to MSCnew**
{Message will contain the list of target cells and all the parameters BSCnew will require to allocate a radio channel.}

MSCnew **Send a HANDOVER REQUEST message to BSCnew**
{Message will include the list of target cells, transmission mode, cipher mode (existing) and the terrestrial channel reference between MSCnew and BSCold.}

BSCnew **IF (radio channel status = Ready)**
Send a HANDOVER REQUEST ACKNOWLEDGE message to MSCnew.
{Which has encapsulated in it the HANDOVER COMMAND message.}

MSCnew **Request for a handover number from VLRnew.**
{This is done with the ALLOCATE HANDOVER NUMBER message. The handover number is used by MSCold to set up a circuit to MSCnew through TUP or ISUP.}

VLRnew **Issue Handover number**.

MSCnew **Return HANDOVER COMMAND and handover number to MSCold**.

MSCold **Setup connection to MSCnew**
IF (ACM is received from MSCnew = True)
Forward HANDOVER COMMAND to mobile terminal.

MT **Switch radio channel**.

Once the handover takes place, old connections are released and a HANDOVER REPORT is sent to VLR_{new}. Subsequent inter MSC handovers are possible and are treated in the same manner described above, apart from MSC_{old}(in the previous case) becomes the anchor MSC, i.e. it remains the switching point. All messages between the two MSCs involved in subsequent handovers are passed through the anchor MSC. A new connection is required from the anchor MSC to MSC_{new}.

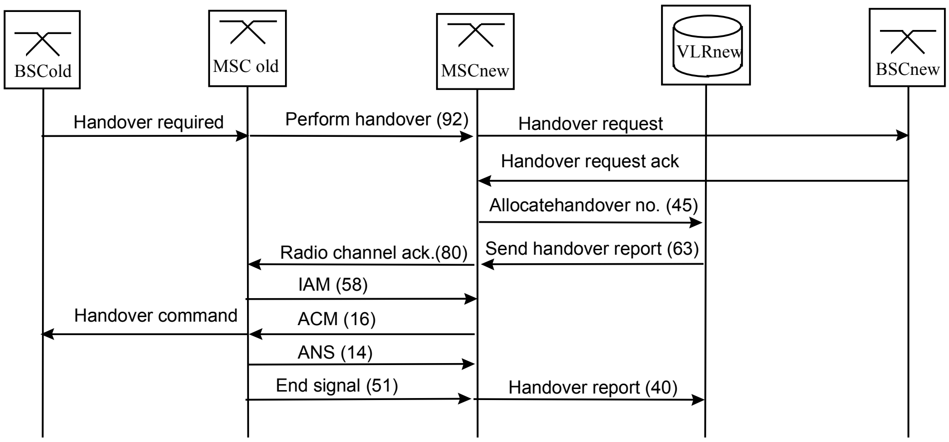

Figure 2-12 : GSM signalling procedure for inter MSC handovers.

2.6 SUMMERY

This chapter has served as a brief introduction to GSM. Only the aspects of GSM that are central to this thesis (mainly signalling procedures) have been presented here. There are several aspects of GSM that have not been covered and are beyond the scope of this thesis.

3. INTELLIGENT NETWORKS

3.1 'INTELLIGENT' NETWORKS?

The most intelligent switches in the history of telecommunication were perhaps the first human operated telephone exchanges. The problem was, they were a little too intelligent and hence Strowger invented the first mechanical automatic switch. From the first mechanical switches, telecommunication switches, exchanges and networks have grown in size to become one of the most complex large systems in the world; in terms of complexity and in 'intelligence'.

Is the aim in telecommunications to develop a network which would have a similar level of intelligence as pre-Strowger days without the human element? The trend in telecommunications technology would suggest that. The Strowger exchange was certainly a giant step forward for automation, but an even greater step backwards for intelligence. Intelligence in the network has grown since the Strowger days, with the stored program control exchanges of the 1970s which offered supplementary services on PABXs. The 1980s saw the introduction of ISDN and the provision of supplementary services in the public networks, with the service code embedded in switches. It would appear that 'intelligence' has been available in networks for sometime, so why did we have to wait until the 1990s for Intelligent Networks?

Intelligent Networks (IN) is a misleading term; it is not as it may suggest the first introduction of intelligence to the network. IN is a concept that was introduced to solve some of the problems associated with large telecommunication systems. The problem was that all telecommunication networks needed to evolve and keep up with current technology to offer an acceptable level of service. But the telecommunication networks of the 1980s faced the following difficulties:

- Switches were at the heart of telecommunication systems, with intelligence hard coded in the switch software. Hence the network was expensive to improve or evolve and invariably the network was heavily dependent on the switch manufacturers. As a result, the introduction of new services and features were excessively time consuming.

- The unprecedented growth in telecommunication networks in recent years has seen the introduction of a large numbers of switches into the network. If the trend of intelligence in switches continued the previous problem would be made worse.
- The interval between the emergence of new technology is ever decreasing. Therefore the switches need to be updated more often. In practice, switches were updated infrequently and as a result new technology was introduced in leaps rather than in a gradual and continuous fashion.
- Network evolution was often restricted by the lack of backward compatibility and incompatibility between different manufactures.

The solution came in the form of IN, where the network was compartmentalised to allow the separate evolution of the individual components. Intelligence was distributed away from the switches such that several switches could share 'intelligence resources'. Finally bearer and service control was separated.

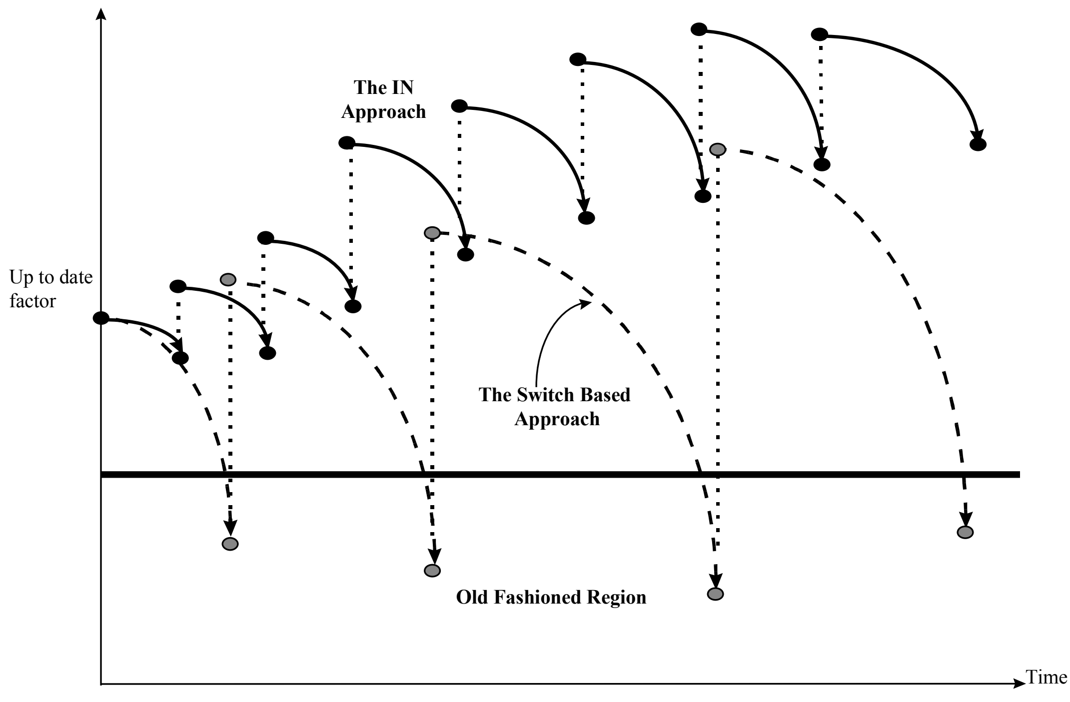

Figure 3-1 : A comparison of the 'up to date factor' for the two approaches. **[Source : Figure 8.1 of [13]].**

The Intelligent Network is not a self contained network, but is a concept that could be applied to any communications network. With IN;

- Introduction times for new services are drastically reduced.

- The reliance on the switch manufacturers for the provision of new service has been reduced, enabling the provision of a broader range of services by multiple vendors in a competitive environment.
- Through distribution and compartmentalisation, the network can be brought up to date, without the need for expensive modernisation of the whole network, but by updating only the necessary elements. The IN concept is such that it maintains backward compatibility.

Intelligent networks has enabled the introduction of services such as 'call waiting', 'call forwarding', 'freephone' services among others.

The principle behind rapid service creation in intelligent networks is the construction of services from ***Service Independent Building Blocks*** (SIBs). SIBs are reuseable components that implement a network function. In an IN there is a library of SIBs: a new service is constructed from existing SIBs and new SIBs are only added to the library when the functionality required by the service does not exist. SIBs are resident in the ***Service Control Point*** (SCP)[20,21,24] (the term '*control point*' is also used in this thesis to refer to the SCP) , the nerve centre of the intelligent network platform. For a service to be executed, the request for it needs to be detected and processed. The request for services are detected at the switch and the appropriate service logic is invoked at the *service control point*. The functionality within the control point is supported by the ***Service Data Point*** (SDP) [20,21,24], providing data essential to the provision of IN services and the ***Specialised Resource Function*** (SRF) [20,21], for interfacing with the user (for such things as voice prompts) or data collection functionality.

Figure 3-2 illustrates the operation of intelligent networks by way of example: the provision of freephone services. The local exchange recognises from the dialled digits, that a freephone number is being called and routes the call through to a exchange with a ***Service Switching Point*** (SSP) [13,20,21,24]. At the exchange, call processing is suspended while the *service switching point* invokes the "translate service" in the control point; that translates the called number to the destination number, which is forwarded to the *service switching point*. With the receipt of the destination number, call processing is recommenced towards the destination and the caller is connected through.

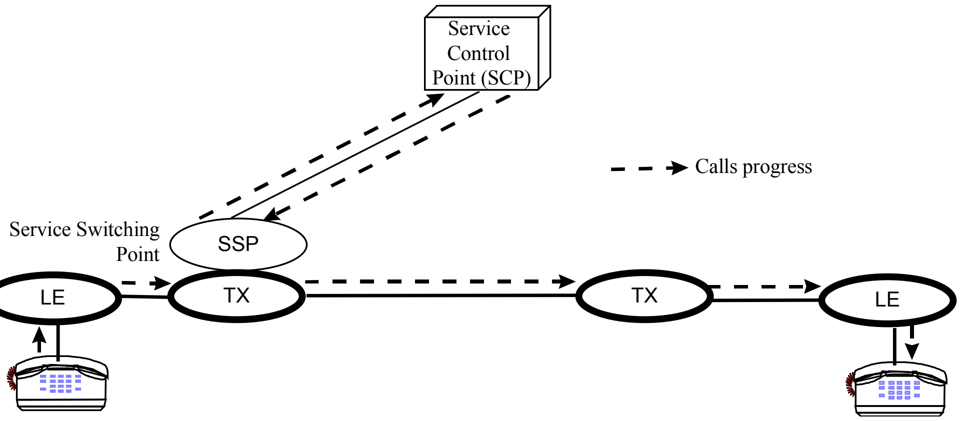

Figure 3-2 : Example of a freephone call processing and switching.

The ultimate goal of intelligent networks is to provide services to a wide variety of access networks through a common platform, so giving them all the same range of services. The re-use of services by several access networks increases network efficiency and will mean that fixed networks and mobile networks will offer the same range of services[78,79].

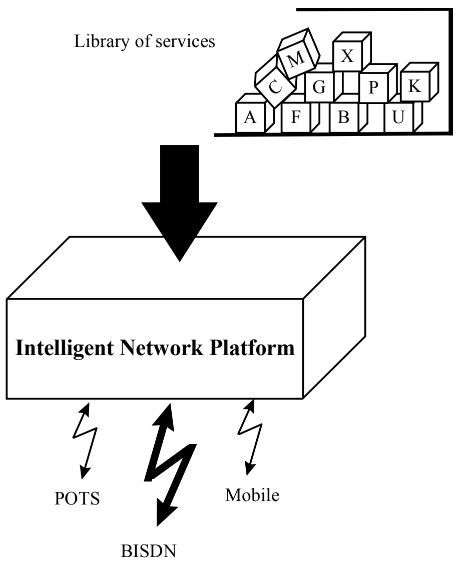

Figure 3-3 : A common platform offering services to the various access networks.

Since the inception of GSM, no modifications have been made to the *mobile application part* of the signalling. This is because any future mobility protocols will be addressed as a part of intelligent networks[17]. This thesis addresses the issues of migration of the GSM network to an intelligent network and thereby implementing

GSM mobility procedures from an IN platform. This will be in line with UMTS, where mobility will be offered as added intelligence from an intelligent network platform. This chapter will serve as an introduction to elements and signalling in Intelligent Networks.

3.2 INTELLIGENT NETWORK CONCEPTUAL MODEL

Intelligent networks should be seen as a concept, rather than a specific architecture for the implementation of certain technologies. To preserve the IN concept, assimilate future evolution of technology and architectures, and provide a better understanding of the concept, ITU has defined the ***IN conceptual model*** (INCM) [13-16,18]. This is a formal framework within which the purpose of IN concepts are defined and the interworking of such concepts and their relations are identified within the limitations of the concept. The IN conceptual model is a four-layer abstract model, where each layer (or plane) represents the capabilities of an IN network. The four planes of the model are:

- The ***service plane***[80] offers a users perspective to a service's functionality and capability. The implementation of the service is not indicated in this plane. Services are formed from one or more *service features* and the interaction between services and service features are considered at this level. As an example, consider two services A and B composed of service features (a1, a2) and (b1, b2) respectively. The interaction between services A and B is considered as well as the interaction of service features a1 and a2. A service feature may be used by more than one service.
- ***Global Functional Plane*** [13,19] incorporates service independent building blocks (SIBs). SIBs are standard reusable service independent network wide capabilities; these are the smallest components in intelligent networks, the atoms of IN that make IN possible. A service feature consists of one or more SIBs and a service is implemented by the use of *Global Service Logic*, which defines the logical order of execution of SIBs, potential branching and information flow between SIBs. A SIB has no knowledge of other SIBs in the *Global Service Logic*. Hence the *Global Service Logic* is the only component in the *Global Functional Plane* that is service dependent. A normal call is handled by the *Basic Call Process* SIB.

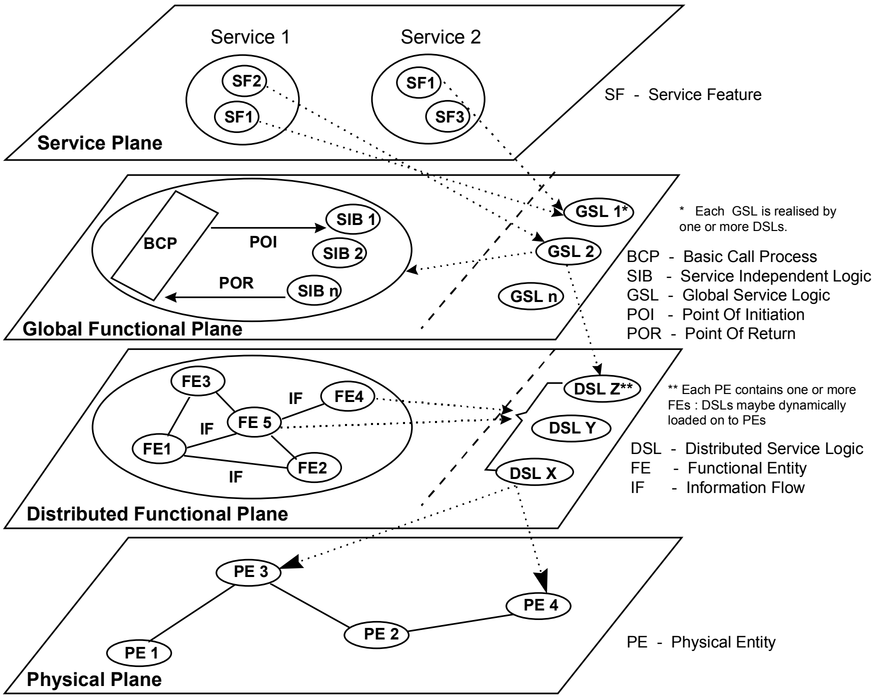

Figure 3-4: IN Conceptual Model with service logic **[Source : Figure Based on Figure 21 of [18]]**

- The ***Distributed Functional Plane*** [13,20,24] contains *functional entities,* which are a specific group of functions required to implement the IN concept. The distributed functional plane defines the relationships between functional entities in terms of *information flows*. The main functional entities are:
    - *Call Control Agent Function:* the interface between the user and the network call control functions.
    - *Call Control Function;* which provides call / connection processing and control as requested by the call control agent function; it acts as the trigger mechanism for IN services.
    - *Service Switching Function*; which in association with the call control function, provides the functionality required for interaction between the ***Service Control Function*** (SCF) and the *call control function*.
    - The *service control function* is at the heart of intelligent networks. It contains all the functionality necessary to implement, manage and control services as well as communicate with and control the *service data function*, *special resource function* and *service switching function* and interact with other service control functions.

- The *Service Data Function* provides the data needed for the execution of services.
- Other functions include the *Service Creation Environment Function* and the *Service Management Functions*.

Figure 3-5 shows the interaction of the functional entities.

- Finally the ***physical plane*** [21] is the entity where the functional entities are implemented. A *physical entity* may contain one or more functional entities, but a functional entity can only be mapped onto one physical entity; the same instances of the functional entity may be mapped onto other physical entities.

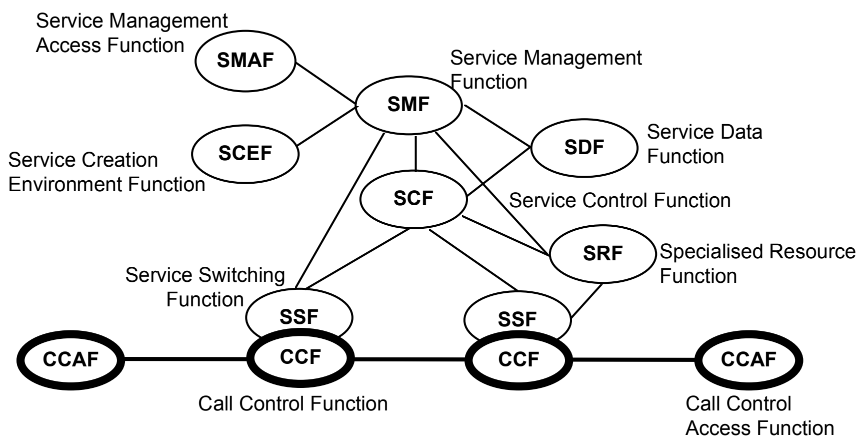

Figure 3-5 : IN Distributed Functional Plane model **[Source : Figure 2.1 of [20]].**

3.3 SERVICE PLANE

The IN concept is service independent, but to illustrate the workings of the IN conceptual model, ITU capability set 1 (CS-1)[22] is used as an example. Two types of service features have been defined for CS-1, type A and B. 'Single ended', 'single point of control' services are referred to as type A. With this type, a caller on one end may only be controlled by the control point associated with that caller and cannot be controlled as part of services being provided to any other callers on that call. Furthermore other parties in the call may invoke and run services independently as long as so doing does not interact adversely with any other service in progress.

All other services are referred to as type B. For reasons discussed later, CS-1 supports only type A services. Example of services defined in CS-1 are;

- Abbreviated dialling
- Account card calling
- Call forwarding
- Follow me diversion
- Freephone
- Televoting
- Universal Personal Telecommunications
- Virtual private networks.

These services are composed from service features and service independent building blocks. Examples of service features are;

- Authentication
- Call queuing
- Call forwarding
- Mass calling
- Personal numbering
- Time dependent routing

An example of a type B service is a conference call, where a caller may be added or dropped at anytime during the call. This would require control at both ends of the call. The complexities associated with type B services are far greater that those offered for type A services and as such not considered in CS-1.

3.4 GLOBAL FUNCTIONAL PLANE

Service independent building blocks (SIB) are at the heart of the IN concept. Not only are SIBs service independent, but also they are reusable in different services without the need for modification. These reusable entities allow intelligent networks to construct, test and offer new services rapidly. Most services can be constructed from the library of existing SIBs, but if a functionality is unavailable, then it is only that functionality that needs to be added to the library as a SIB or a combination of SIBs. The *global functional plane* views the IN structure as a single entity. It describes a service or service feature and their inter-working with the basic call process using *global service logic*. The *global service logic* can be seen as the glue that holds the chain of SIBs within a service, hence it is the only service dependent entity in the *global functional plane*. Furthermore, it provides all the data needed by the various SIBs, defines the logical connectivity between SIBs, and the logical commencement and termination of services.

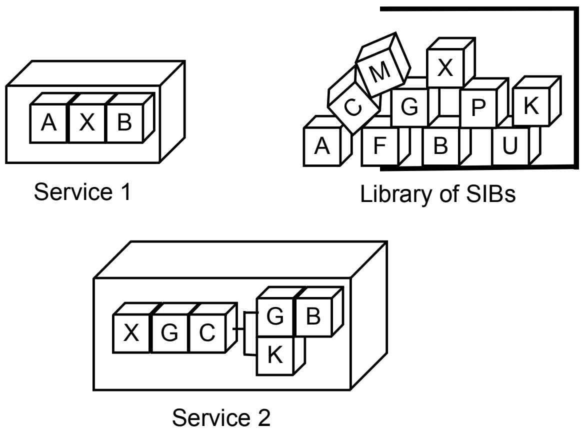

Figure 3-6 : The IN concept.

Although, by definition, SIBs are service independent, some form of service dependence has to be implemented and that is achieved by the use of data parameters. Data parameters are made available to SIBs by the *global service logic*. These parameters include, dynamic and static parameters. Dynamic parameters are referred to as *Call Instance Data* (CID)**,** which vary with each execution of a SIB. Examples of call instance data are;

- calling line identification as supplied by the basic call process SIB
- a translated number generated by a previous SIB in the chain of execution
- information collected from the user, such as the dialled number.

Each call instance data value has a logical name associated to it, namely the call instance data field pointer.

SIBs also make use of static data parameters referred to as *Service Support Data* (SSD) which are service specific and are specified by the global service logic. In the case of the translation SIB, the location of the translation data file is fixed for all call instances, and hence the 'file indicator' *service support data* value is fixed. A graphical description for a general SIB and for a translation SIB[23] are given in Figure 3-7.

SIBs are realised using one or more functional entities. The interaction between functional entities in the *distributed functional plane* is not known to SIBs in the *global functional plane*. A SIB must have a unified and stable interface allowing multivendor IN products to support them identically.

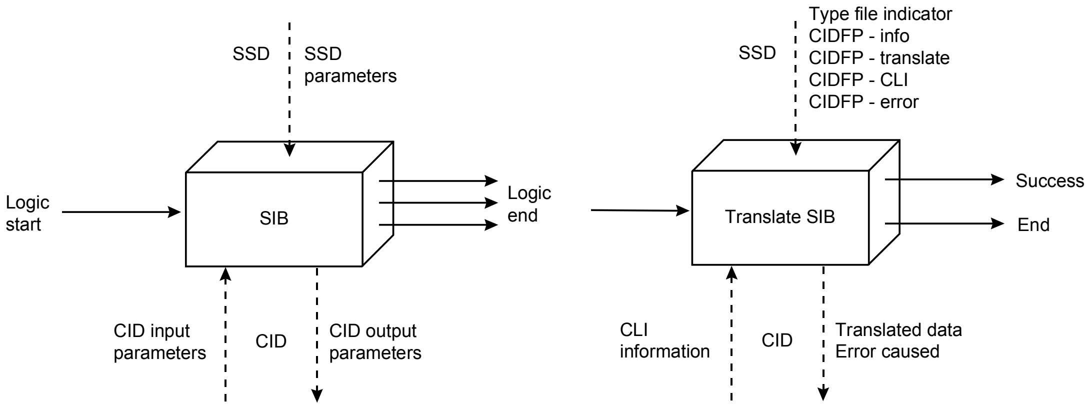

Figure 3-7 : Graphical representation of SIBs. [Based on Figure 13 of [23]].

3.4.1 Basic Call Process SIB

The *Basic Call Process* SIB is a specialised SIB responsible for providing 'normal' call services, such as the connection and termination of calls and retaining the call instance data for that call instance. The invocation of IN services is possible from a *Basic Call Process*, where the point of invocation is termed the *Point Of Initiation*. The invocation of an IN service can occur at any point during a call, therefore several points of initiation have been identified by CS-1[13,14,19,23]. For example, 'busy' *Point Of Initiation* identifies the called number as being busy and the 'call originated' *Point Of Initiation* identifies the user has made a service request prior to specifying a destination address. A 'service' will have different implications based on the *point of initiation*.

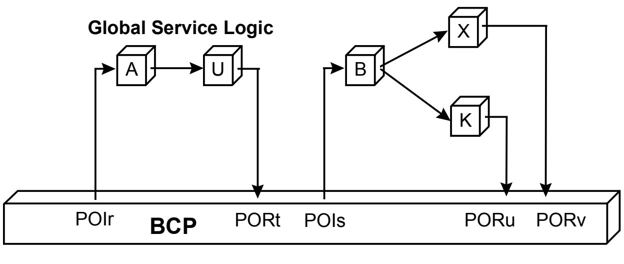

Figure 3-8 : The relationship between the basic call process (BCP) and the global service logic (GSL)

Similarly the *Point Of Return* identifies the point in the basic call process where the SIB chain (or *global service logic*) terminates. As with the point of initiation, different points of return exist (for example, continue with existing data, clear call, initiate call, etc.). Different points of return for the same chain of SIBs will have different implications on the service.

3.5 DISTRIBUTED FUNCTIONAL PLANE

The global functional plane views the IN network as an unified entity and views the *Distributed Functional Plane* [24] as one entity, although in reality it is more likely to be a distributed architecture. Services via SIBs are realised on *functional entities*, the distributed elements that make up the IN network. Each *functional entity* provides functionality necessary for the provision of services, such as the *service switching function* (responsible for the detection and invocation of services), the *service data function* (for the provision and maintenance of service data) and the *service control function* (which provides the *service logic execution environment)*.

The tasks performed by functional entities are composed of *functional entity actions*, which are self-contained units performing specific actions. As the global service logic describes the logical order of execution for SIBs for a realisation of services, the *Distributed Service Logic* defines the logical order of execution of functional entity actions for the realisation of SIBs. The transfer of information between functional entities is termed *information flow* and IN uses ITU SS7 TCAP for this purpose, resulting in the ***IN Application Part*** (INAP)[17,73-75]

3.6 PHYSICAL PLANE

A functional entity needs to be mapped onto a single physical entity [76] on the physical layer in the IN conceptual model. Duplicate functional entities can be mounted on different physical entities, but not on the same physical entity. The physical layer describes the realisation of functional entities as network elements. Once a functional entity is mapped onto a physical entity, the function mapped is termed a point, the ***Service Control Point*** (SCP) instead of service control function.

Of the several functional entities identified for intelligent networks, only the service control function and service switching function are described in detailed here, as they are the most relevant to this study.

3.7 SERVICE SWITCHING FUNCTION / POINT

The ***Service Switching Point*** (SSP) consists of the *Call Control Function* for supporting non IN calls and ***Service Switching Function***(SSF) for the detection, invocation, interaction and release of IN services. In order to support IN calls, the *service switching point* must provide interfaces to other IN entities such as the *service control point* and *intelligent peripherals*. The request for an IN service is detected when pre-set conditions (know as triggers) are encountered (for example; dialling a freephone number or pressing the '#' button). When a trigger is detected, normal call processing is suspended and the appropriate IN service logic is invoked. An IN service can be requested at any point during a call, so that the state and the progress of the call needs to be monitored to allow for the appropriate processing of the requested service. This is achieved by using an IN call model.

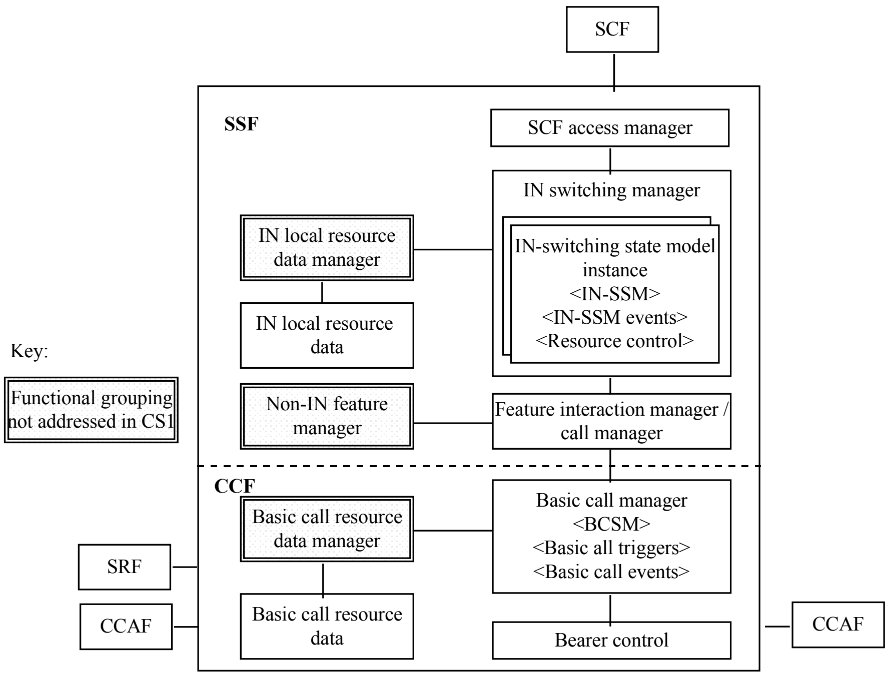

Figure 3-9 : Call Control Function / Service Switching Function. [Source : Figure 4.1a of [24]].

3.7.1 BASIC CALL STATE MODEL

The IN call model is based on the ***Basic Call State Model*** (BCSM)[13,16,20], which is a finite state model description of *call control function's* call processing activities, where the progress of the call is monitored in terms of *Points In Call*, *Detection Points*, transitions and events.

The *basic call state model* presents the IN service logic with a view of the *call control function's* workings, not all aspects of which need to be known to the service logic. It is the *basic call state model* that determines the amount of detail with which a view of the *call control function* is presented to the service logic. The level of abstraction and granularity with which the *basic call state model* presents information varies from service to service, if any is presented at all. The points during the call when IN service logic is allowed to interact with the basic call processing is identified by *points in calls*. The transfer of control to IN service logic takes place at detection points. The normal flow of call processing between points in calls is termed transitions and events trigger transitions.

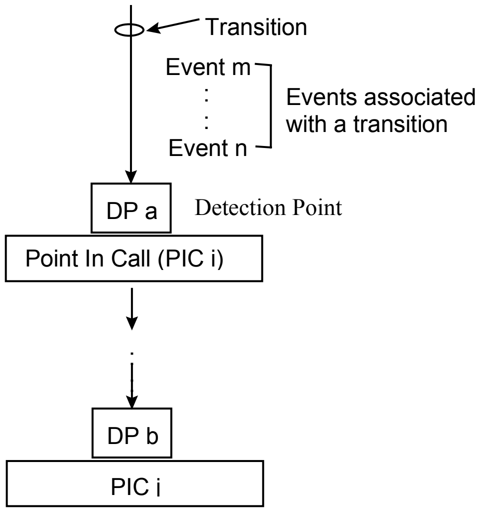

Figure 3-10 : Components of the BCSM. [Source : Figure 4.2 of [24]].

3.7.1.1 DETECTION POINTS

Detection points are points in the basic call and connection processing at which the invocation of IN service logic, or the notification of service logic, or the transfer of control can occur. A detection point must be "armed" for the service logic to be notified that a detection point has been encountered. Once a detection point is armed and the criteria met, the service switching function provides information flow to the *service control function* to influence call processing (control relationship) or to monitor call processing (monitor relationship). For a control relationship, the *service switching function* suspends call processing, notifies the control function and awaits instructions. Instructions from the control function may influence further call processing. In the case of monitor relationship, the control function is notified, but call processing is not suspended neither is a reply from the control function expected.

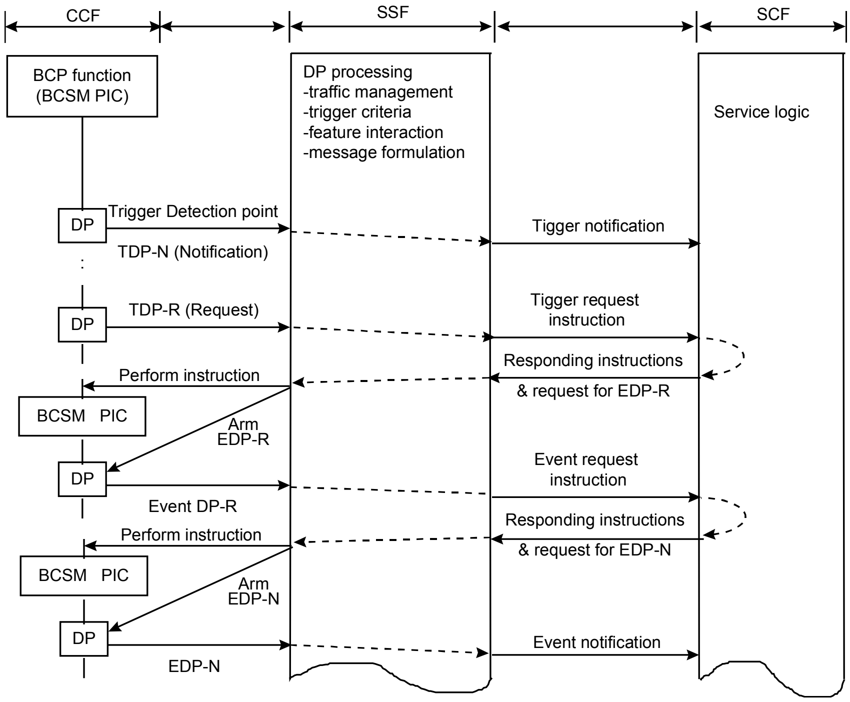

Figure 3-11 : DP processing for each DP type. [Source : Figure 4.5 of [24]].

3.7.2 IN-SWITCHING MANAGER

The *IN-switching manager* is the functionality within the *service switching function* which interacts with the *service control point*, providing it with an observable view of *service switching function* call processing activities and access to *service switching function* /*Call Control Function* (SSF/CCF) resources and capabilities. Call processing events related to IN services are detected and reported to the appropriate IN service logic instance by the IN-switching manager.

IN call / connection processing within the SSF/CCF is described by the *IN-Switching State Model*, in terms of IN call connection states. The amount of control the *service control function* has over the SSF/CCF IN call/connection processing is set within the IN-switching state model. Several types of IN-switching state models may exist, where each is defined by the objects that constitute it. For example, the 'connection control' IN- switching state model contains objects that are abstractions of switching and transmission resources as shown in Figure 3-12.

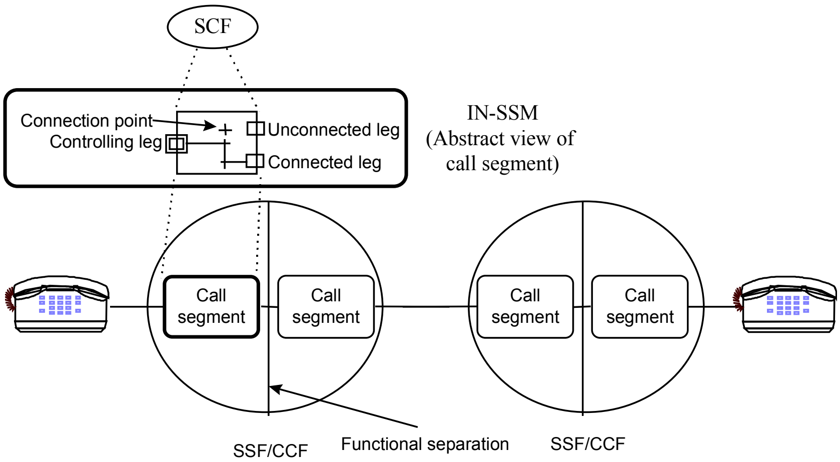

Figure 3-12 : Call segments in a two party inter CCF/SSF call and abstract SCF view of IN-SSM [Source : Figure 4.12 of [24]].

3.7.3 FEATURE INTERACTION MANAGER

A mechanism is necessary for the invocation of the appropriate service, once a trigger is encountered and to manage possible interactions with IN services and non-IN services that are already active. The mechanism is provided by the *Feature Interaction Manager*. If a user is using service A and invokes service B that is mutually incompatible with service A, then the request for service B needs to be rejected. The feature interaction manager manages both compatible and incompatible interactions. Two suggestions have been made in ITU Q1214[24] for the management of service interactions. The first makes a decision on service compatibility and service priority prior to invoking a service; the second approach makes a decision once the service is invoked but is beyond the scope of CS-1. At present, every possible interaction between every possible combination of service features is stored on the SSF/CCF and as the number of services grows this becomes an inefficient method of solving interaction problems. Q1214 itself recognises the short comings of this approach and has identified a need for a more efficient approach using a database or a knowledge based technique.

3.8 SERVICE CONTROL FUNCTION

The ***service control function*** (SCF) is the brain of the IN architecture. Within it lies the functionality to provide and sustain services. Services are composed of SIBs and *Service Logic processing Programs*, which governs the logical order of execution of

SIBs and the flow of information between SIBs. The functionality that makes up a *service control function* is shown in Figure 3-13.

The *service logic execution environment* invokes, runs and controls *service logic processing programs*, as well as managing simultaneous invocation and execution of multiple *service logic processing programs*. Within the execution environment is the *service logic execution manager*, which provides the functionality to handle and control the total service logic execution. The execution of a *service logic processing programs* is known as a *SLP instance*. The execution manager executes *SLP instances*, maintains data associated with the *SLP instance* for the duration of execution, manages *SLP instance* access to data within the SCF and external functions via the SCF data access manager and manages the exchange of information between *SLP instances*. In addition to interacting with the SCF data access manager, it also interacts with the *functional entity access manager* to support *SLP instance* executions.

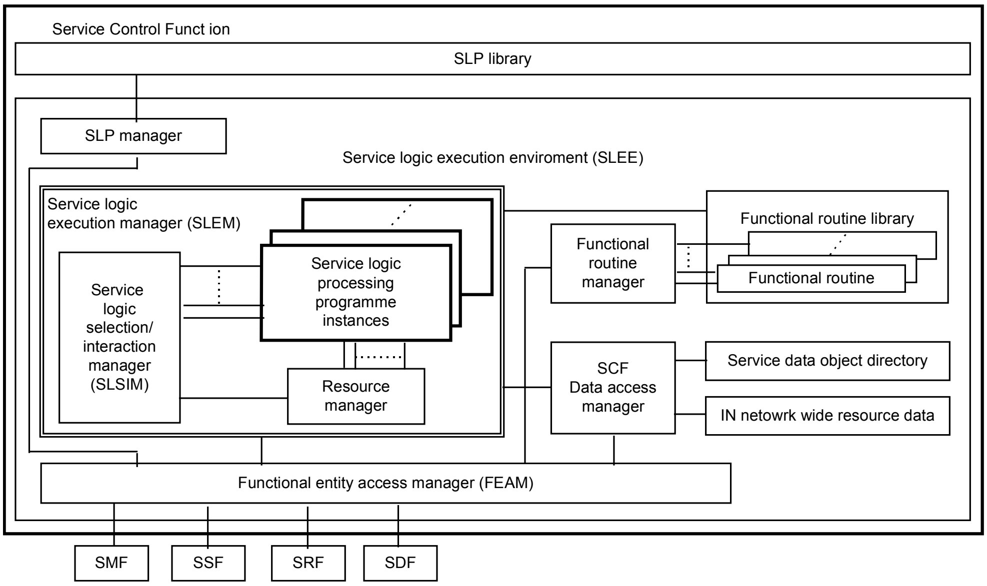

Figure 3-13 : SCF functionality. **[Source : Figure 4.19 of [24]].**

The *Service logic selection / interaction manager* selects a *service logic processing programs* for execution in response to either an event from another functional entity or to an internally set trigger or to the request for a *service logic processing programs* from a *SLP instance*. The selection / interaction manager also manages multiple executions of *service logic processing programs* within a SCF. With multiple simultaneous executions, there is the need to control *service logic processing programs* interactions and the selection / interaction manager provides for mutual exclusion to prevent the execution of a *service logic processing program* incompatible with a SLP instance currently active. The precedence for the selection of a *service logic processing program* from a group of *service logic processing programs* that meet the same selection criteria is also provided by the *service logic selection / interaction manager*. Local and network resources needed to support *SLP instance* executions are identified, located and provided by the resource manager.

The interaction between *service logic execution manager* and other functional entities via the transfer of information using messages, is managed by the *functional entity access manager*. This is required to provide a mechanism transparent to SLP instances, correlate request and response messages, associate multiple messages with each other, comply with OSI structures and principles and offer reliable message transfer.

The management, storage and access to shared and permanent information in the SCF is provided by the data access manager, which also provides functionality to access remote information in service data functions.

The maintenance of functional routines within the functional routine library is managed by the functional routine manager, including the addition, deletion and suspension of functional routines.

The level of discussion here has to been introduce the reader to IN principles, functionality and operations. Detailed operations are not discussed as the implementation of these functions are vendor. It is felt that, this level of abstraction is sufficient for the proposals made in this thesis and the models constructed.

3.9 INTELLIGENT NETWORK APPLICATION PART

Intelligent networks make use of SS7 signalling capabilities just as GSM MAP does. Like MAP, intelligent networks need to cater for both call-related, out-of-call signalling and require a signalling mechanism logically separated from the bearer channel. The *Intelligent Network Application Protocol* which handles all of INs signalling needs is a user of SS7 transaction capabilities. Therefore most operations are similar to GSM MAP. INAP was introduced after GSM MAP and hence it includes more functionality.

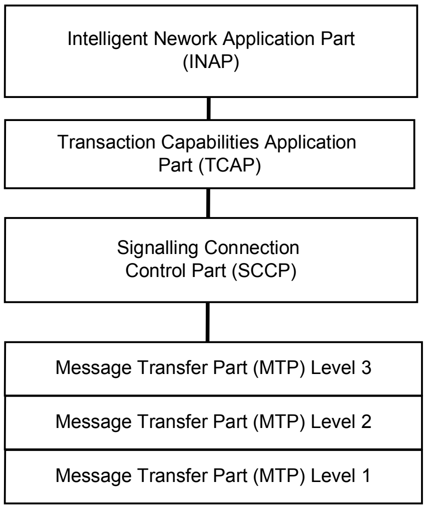

Figure 3-14 : INAP and SS7

SIBs need to be broken down into operations performed by the physical nodes involved in the SIB and the information flow between the nodes. For example, the service data management SIB is used to retrieve or update records in the service data function. The nodes involved in this SIB are the *service control point* and the *service data point*. These nodes are referred to as the application process. Each application process will contain the protocol and mechanisms relating to information flows to and from other application processes in *application entities*. As such each application process may contain more than one application entity. An instance of a application entity being used is termed an *application entity invocation*.

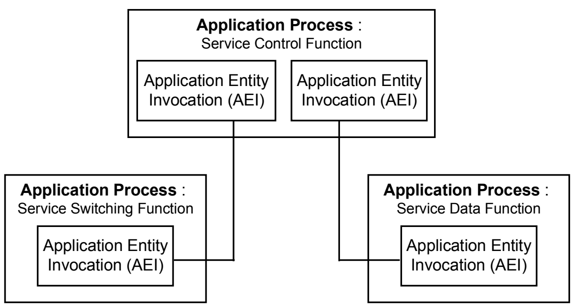

Figure 3-15 : Relationship between application processes and their application entities.

Functional relationships between two application processes are termed application associations. Since an application entity defines all the functional exchanges between two application process, it will contain several application associations. Each application association has a *single association object* which contains all the communications capabilities needed by that application association. These communication capabilities are defined in terms of *application service elements.* Each single association object may contain several *application service elements*, therefore the ordering and co-ordination of *application service elements* is carried out by the *single association control function*.

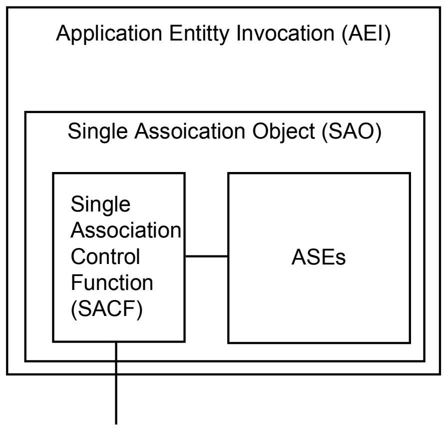

Figure 3-16 : Relationship between AEIs and *application service elements*

In INAP, SIBs are realised using *application service elements*, where the protocol elements needed for a SIB could be realised as a single or a collection of *application service elements*. The mapping of SIBs to *application service elements* may be one to one, one to many or many to one. This is the relationship between SIBs and *application service elements* with respect to signalling.

In GSM each entity is allocated a *sub-systems number* for the routing of signalling messages from the *signalling connection control part* to the appropriate user. In intelligent networks its left to the discretion of the network operator to decide which sub-system numbers are routed to the intelligent network application part.

3.10 THE FUTURE - IN?

Is IN the answer to all our problems? Certainly not. The concept is sound but it still has several shortcomings. If IN is to become a common platform from which all access networks can access services, the single point of control will need to be modified to cater for type B services. Type A services catered for in CS-1 are a severe limitation on the variety of services offered. Type A services may be adequate for the POTS access network, but it will not be adequate for the provision of complex services in either BISDN or mobile networks which may require multiple points of control. It is hoped that CS-3 will rectify this short coming and will cater for interaction between service control points.

The approach for the invocation of services using a state model will become restrictive as the complexity of services increase and so will the use of a hardwired solution for service interaction. A knowledge based flexible approach is required. Another restricting factor is the user interface. The instruments used today were not designed for accessing IN services and as such the use of the '*' and the '#' keys on the instrument for invoking services is not user friendly. Therefore a more user friendly interface is required to exploit the full potential of IN services.
These are problems that will be solved with evolution. IN is a sound, tried and tested concept that will (hopefully) withstand the test of time. Today it would appear as the path forward.

4. GSM / IN - AN INTEGRATION APPROACH

4.1 MOTIVATION FOR INTEGRATION

The two previous chapters served as an introduction to GSM and IN. It is the purpose of this chapter to describe in detail the author's methodology for integrating the GSM and IN networks and the resulting GSM-IN architecture. The integrated architecture was first published in [i] and the associated performance issues in [ii]. The integrated architecture is described in detail in section 4.3. This thesis is the first work to use the concept of IN SIBs in offering GSM mobility and hence the use of an IN platform for GSM mobility, with INAP as the signalling protocol for the control network. In references [26-28, 30, 32, 36, 37] the inclusion of IN elements in mobile networks have been investigated, but none have adopted the IN concept wholly or, more importantly, considered the use of an IN platform as the control platform for GSM; they have been at a conceptual level.

The primary objective of GSM is the provision of mobility and, originally the provision of supplementary services was not a key objective. As GSM is a digital network, facilities were made for the provision of a limited number of supplementary services internally. GSM failed to provide a dedicated environment for the development and provision of supplementary services. As the importance of supplementary services to network operators became apparent, GSM operator's developed a solution for service creation and provision in GSM networks, CAMEL. CAMEL is based on IN principles, which enables call processing to be suspended while a request for information on the completion of the call is made to the home network. The problem with CAMEL is the lack of interaction or interworking between INAP used for service provision and MAP for mobility management. The local processing of services is also not possible with CAMEL. In the short term CAMEL is a solution to service provision in the home and roamed networks. However it is not a long term solution that would truly integrate GSM and IN. Before the integrated architecture is presented, the need for such an architecture must be justified.

The justification is found by looking to the future. GSM is a second generation mobile network standard that has out-performed all expectations to become a world standard and ***Universal Mobile Telecommunications System*** (UMTS) is the next generation mobile network system that is being standardised by ETSI. Intelligent networks (which separate service control from bearer control) will form the platform that will be used for control of mobility in UMTS. The nature of UMTS is such that from a single control platform it will offer coverage to several radio access technologies while sharing a common backbone network with the fixed network. For GSM to be one of the access networks covered by UMTS, GSM will need to migrate to UMTS. For the migration to take place, GSM mobility management needs to be transferred to an IN platform away from the existing GSM switches, VLRs and HLRs. The contribution of this thesis is a pre-UMTS architecture in which GSM's mobility management functionality is transferred to an IN platform.

Once again the need for a pre-UMTS architecture needs to be justified against a direct step from GSM to UMTS. The step from second generation mobile telephony (GSM) to third generation mobile telephony (UMTS) will be an evolution rather than a revolution[32]. There will be several aspects of UMTS that will be revolutionary, such as the new radio access networks offering high bandwidth radio interfaces, but these new radio access networks will coexist with existing technology. Furthermore, GSM operators view the GSM / IN integrated pre-UMTS architecture as the launching pad for UMTS[43]. This would enable the reuse of existing infrastructure and allow for a fast track approach to UMTS leading to the gradual introduction of the UMTS network sooner rather than introducing a completely new system later.

In the GSM-IN pre-UMTS architecture described here, mobility management functionality is separated from the GSM access network and is offered as a service from the IN platform. This results in both mobility services and supplementary services existing on a single platform. This single IN platform will allow new supplementary services based on mobility or otherwise to be developed rapidly and with ease for the GSM network. Furthermore, this proposal offers a single unified platform for service creation and evolution. The structure also eliminates today's problems of having to develop services excluding GSM mobility functionality, coping with the incompatibilities between the service domain and the mobility management domain and reverting to the home network for service provision. Having eliminated the dependence of mobility management on the radio access network, it now becomes possible to offer mobility based supplementary services such *Universal Personal Telecommunications* (UPT) services using mobility procedures based on GSM.

Standardisation bodies are currently working on introducing mobility procedures to intelligent networks. This thesis proposes the use of the tried and tested GSM mobility procedures as the basis for mobility in IN, instead of redefining mobility procedures for IN and reinventing the wheel. However IN mobility procedures will need to address different access networks (such as DECT) and although GSM mobility procedures may not be suitable for all these new access technologies, they can be used as the basis on which other mobility services are built. The principal behind IN is the reuse of existing functionality as much as possible and the addition of new functionality only as and when it is needed. So IN only needs to add to the GSM mobility functionality when it cannot cater for mobility management in another access network by reusing GSM mobility functionality. If GSM and IN are not merged now to form a unified standard there is the danger of two sets of standards being produced, each duplicating the other's functionality[33]. This is a situation that must surely be avoided.

The aim of this thesis is not to reinvent GSM or dispose of the existing GSM system, but to reuse as much of the existing system as possible with the minimum of change. To this effect the following aims have been identified for the integrated architecture (GSM-IN) :

- Separate the radio access elements and the mobility management elements of the GSM network.
- Retain the radio access network with minimal change.
- Transform the mobility management and call handling network architecture to an IN architecture, as mobility will be offered from an IN platform.

This chapter will discuss the GSM-IN architecture, the entities used in the architecture and identifies the changes to current entities, if any. The later part of the chapter will detail the GSM mobility procedures implemented from an IN platform as envisaged by the author and hence identify the mobile SIBs necessary for GSM mobility services.

4.2 GSM / IN INTEGRATED ARCHITECTURE

The integrated network (GSM-IN) proposed here will be GSM in the radio access network with IN dominance over the control (core) network. The point of interaction between the radio access network and control network (IN) will continue to be the MSC. The MSC will include elements of both IN and GSM. The MSC will have to be equipped with functionality to recognise and manage IN service requests, i.e. with ***Service Switching Functionality*** (SSF). The MSC is the logical point for mounting the *service switching functionality*, as all mobility management messages and service messages from and to the mobile terminal are aimed at the MSC for forwarding or processing in the GSM network. The switching point between the radio access network and the outside world will remain the MSC, as there is no reason to change this. The physical node with both MSC and *service switching functionality* will be referred to as the ***Mobile Service Switching Point*** (MSSP).

The mobility functionality from the MSC, VLR and HLR will be mounted on the ***Mobile Service Control Point***[6] (MSCP). Service and mobility data stored on the HLR in GSM network will be moved to the ***Mobile Service Data Point*** (MSDP) and integrated with IN service data and user data. Hence a service data point with mobility data will be referred to as *mobile service data point*. Once this is achieved, the HLR will no longer be required.

The VLR in GSM serves two purposes: it provides mobility control functionality and serves as a temporary database where user information is stored when the user is roaming the MSC it serves. Caching user information on the VLR reduces the number of occasions on which it needs to be retrieved from the HLR, thereby reducing the total signalling traffic on the network. Once the information on the user is downloaded by the VLR, no further request for information from the HLR is necessary. With the

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[6] The term '**mobile'** is used to distinguish IN entities with mobility functions. This is not to infer that the functionality of an entity with the 'mobile' prefix is different to an entity without the prefix. For an

mobility control functions moved to the MSCP, the VLR now serves only as a temporary database. In GSM-IN the temporary database attached to a MSSP will contain both IN and GSM user data and hence is referred to as $MSDP_{temp}$. It is possible to offer mobility services without the temporary database. A comparison of a 'pseudo' GSM implementation of GSM-IN with $MSDP_{temp}$ will be compared to a 'classical' IN implementation without a temporary database in Chapter 6. As a result two variations of GSM-IN arise, the first with a $MSDP_{temp}$ attached to the *mobile service switching point* as shown in Figure 4-1 and the alternative without a $MSDP_{temp}$.

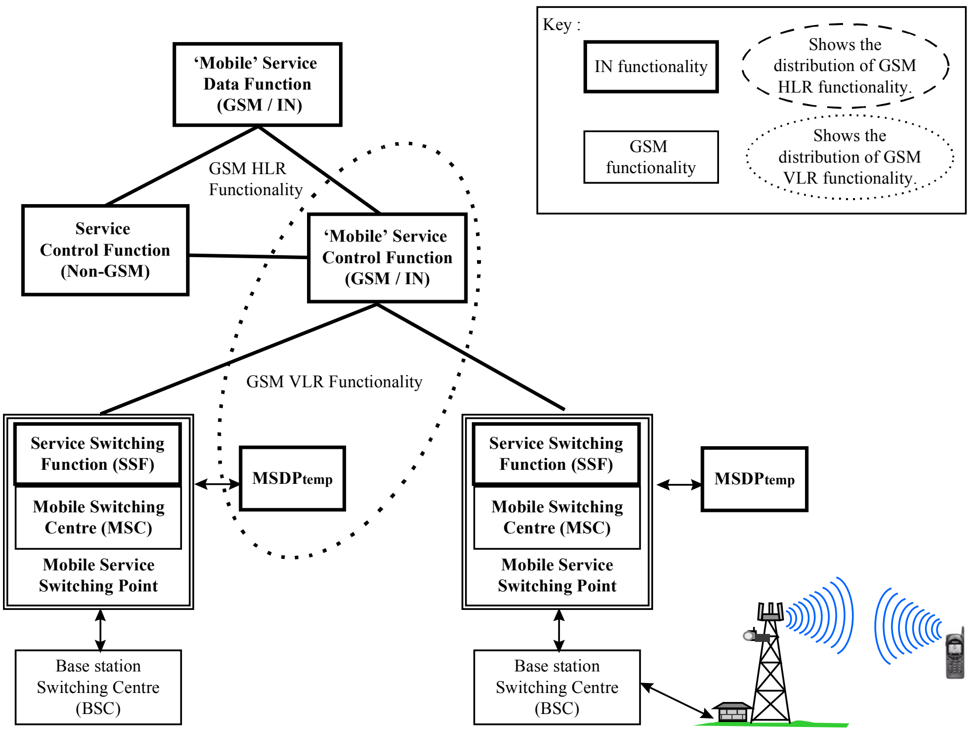

Figure 4-1 : GSM / IN integrated architecture functionality, illustrating the distribution of GSM functionality.

example, MSCP refers to a SCP with SIBs to provide mobile services, whereas a SCP does not have SIBs to provide mobile services.

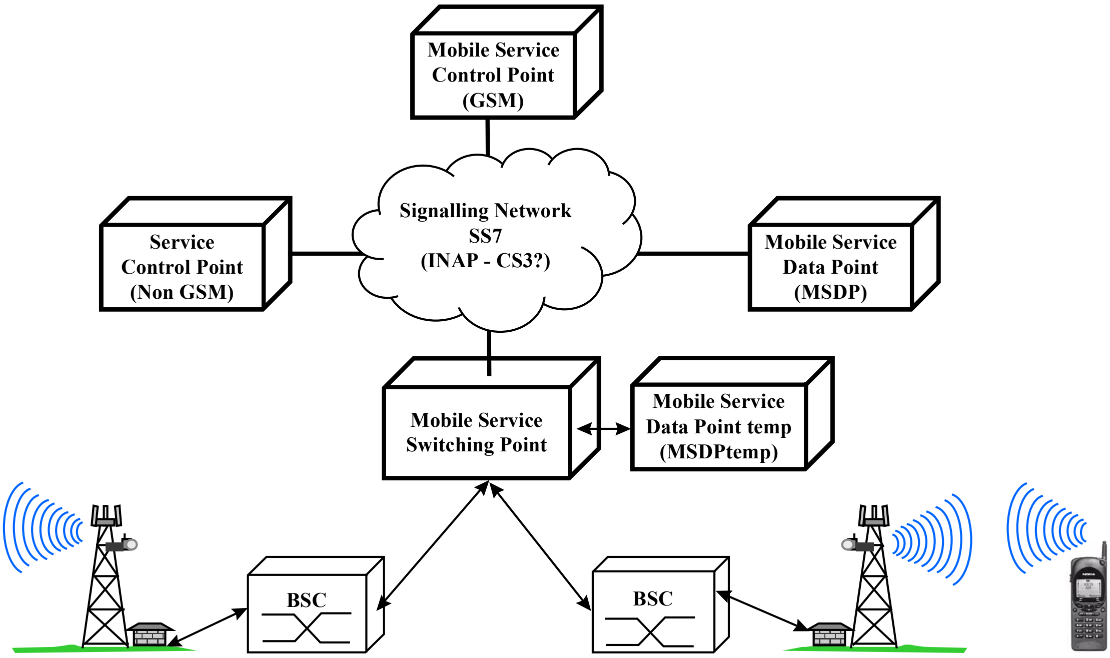

Figure 4-2 : A physical implementation of GSM-IN.

Once on the IN platform each GSM mobility service will be offered as a combination of SIBs. SIBs will be determined by decomposing GSM mobility functionality to 'atomic' elements. It will then be possible to identify common elements among the various mobility procedures. In the case of common elements, a single SIB will be reused. For an example, the authentication procedure is used in more than one GSM mobility procedure (such as call setup, location updating), so the 'authentication SIB' can be reused in several mobility services. The following sections look at the integrated architecture in detail.

4.3 SIGNALLING IN THE INTEGRATED ARCHITECTURE

Having proposed an integrated architecture it is necessary to consider a signalling system to make the architecture functional. An initial approach might have been to use existing MAP protocols from IN platforms. This would have been the simplest solution available, and from the routing point of view there are no conflicts at the SCCP between MAP and INAP. MAP is identified by subsystem numbers from 5 to 10, while INAP subsystem numbers are defined by the operator. Since routing of messages to the application is flexible, it will be possible to route both INAP and MAP messages to the same user part. Hence there is no conflict, and messages can be routed correctly.

The problem arises at the transaction capabilities layer. If mobility services (i.e. MAP) are to be combined with supplementary services (i.e. INAP) then it will be necessary to mix messages from both protocols during a dialogue. The problem in SS7 is that the application context (i.e. MAP or INAP) needs to be agreed on prior to the start of any communications [73]. Defining a new MAP / INAP combined application context and using that for signalling in the integrated architecture would lead to conflicts between INAP and MAP operations; these conflicts arise as a result of both MAP and INAP using the same local values for operation, hence the local values are not unique. For example, in GSM local operation value 26 is used for the 'page' message while in IN 'EventNotificationCharging' message has the same value. This is not the only example. Hence MAP operations cannot co-exist with INAP operations without modifications. A solution to this problem is to renumber the MAP operation local values (also suggested by [33], where the suggestion was made to add a prefix to all MAP local values). Another suggestion in [33] was the use of object identifier values for each operation, making them unique, but this will add an enormous price in message length and processing overheads. The problem with these suggestion is, effectively, there will still be two protocols; also by retaining MAP, it will be necessary to retain the HLR and the VLR for carrying out some of the MAP operations.

Having considered these options and other possibilities such as (a) different encoding schemes or (b) the use of flags and tagging, the result is that a considerable effort needs to be expended in making INAP and MAP co-exist. What is suggested here is to take the process a step further and absorb MAP into INAP, eliminating MAP completely. The advantage of the absorption is that INAP does not yet cater for mobility but in the future, it will. If MAP is absorbed into INAP now, then INAP does not have to reinvent the wheel on mobility and the possibility of conflict between MAP procedures and INAP mobility procedures is also eliminated.

A problem posed by the definition of MAP is the need for a node involved in a MAP transaction to contain the complete set of MAP *application service elements*. By moving MAP to INAP not only is MAP broken up into smaller and more efficient components, but MAP operations are defined as INAP operations with unique operation codes eliminating conflicts with INAP. Furthermore if MAP procedures are defined in INAP generically then they can be reused to support mobility in other access networks as well.

4.4 MOBILE SERVICE SWITCHING POINT

The previous sections have described the GSM-IN architecture and the associated signalling. In this and the next two sections the functional and physical entities in GSM-IN are described in detail, starting with the *mobile service switching point.* There are two aspects to a *mobile service switching point*; the *service switching function* and the *call control function*. The *service switching function* is part of intelligent networks and is standardised under IN, while the *call control functionality* is a part of the local access network. Although both functionalities are mounted on a same physical node they are independent functional entities. The interface between the functionalities is internal; it is therefore not subject to standardisation and is left to the discretion of the manufacturer.

Recapping, the *call control function* manages normal call processing (i.e. switching), provides a trigger mechanism for accessing IN functionality and monitors the progress of calls. The *service switching functionality* extends the logic needed to process requests for IN services, manages the signalling between the *call control function* and the *service control function* and controls the switch at the request of the *service control function*.

There are two possible locations for the placement of the *service switching function*: the MSC or the BSC as they are both call control functions. The MSC is chosen for the following reasons:

- All mobility management messages and service messages from and to the mobile terminal are aimed at the MSC for forwarding or processing in the GSM network. Therefore it is in the ideal location to detect and process messages both from the mobile terminal and *service control points*. In addition, the MSC already has mechanisms to detect service requests and a call state model.

- The present GSM architecture will enable several BSCs to access a single *service switching function* attached to a MSC. In terms of network efficiency and network evolution, mounting the *service switching functionality* on the MSC is much more efficent than having *service switching functionality* on every BSC.
- By not introducing IN elements to the radio access network, it will be possible in the future for the radio access network to evolve independently of the intelligent network and visa versa. This would be an advantage during the evolution of the GSM network to UMTS.

How will the MSC need to be changed to accommodate the *service switching function* and hence transform to the *mobile service switching point*? There are two aspects to the MSC: management of the radio network and mobility management. In the proposal here the MSC will retain all of its radio channel and radio network control / management functionality, but all mobility procedures will be moved to the *service control point,* with the exception of inter cell and inter BSC handovers. Although handovers are defined as mobility procedures there are different levels of handovers. Inter-cell handovers are managed by the BSC and the MSC only receives an acknowledgement once the handover is complete; inter-BSC and inter-MSC handovers are managed by the MSC because the MSC is the switching point for these handovers. The *service control point* sees the MSC and the radio access network below it as one entity. Therefore, any internal switching of paths need not be visible to the *service control point*. Both inter-cell and inter-BSC handovers are in effect switching in the radio access network and the *service control point* need not be aware of these procedures. Furthermore not involving the *service control point* improves the speed of handovers. But the control of inter-MSC handovers will be controlled by the *service control point*. The reasons for implementing inter-MSC handovers as an IN service are;

- If the IN network sees the MSC and the radio network below it as one entity, then an inter-MSC handover involves two entities from the IN viewpoint. Furthermore the point of service interaction changes to the new MSC (i.e. the MSSP) and the *service control point* needs to be aware of the change.

- Inter-MSC handovers are defined as part of the *mobile application part* (MAP) protocol and keeping in line with the proposal to eliminate the use of MAP and transfer all MAP functionality to INAP.
- In GSM the first MSC involved in the call remains a stable switching point from which all subsequent inter-MSC handovers are executed (i.e. the anchor MSC). With the control of inter-MSC handovers transferred to the *service control point*, it will be possible to switch the call to the new MSC via the shortest path and not via the anchor MSC as illustrated in Figure 4-3.
- Finally, with the possibility of multimode terminals in the future, there will be a need for handovers between different types of mobile networks (Eg. between GSM and DECT). These handovers will need to be carried out at the MSC level. So by moving the control of inter-MSC handovers to the *service control point*, handovers between MSCs from different networks can be catered for by adding intelligence to the basic handover service.

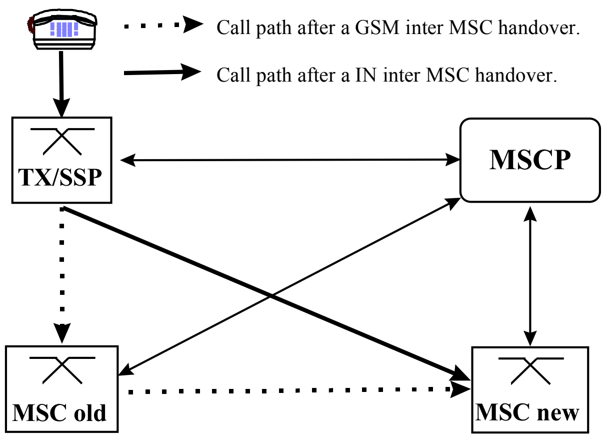

Figure 4-3 : A comparison of call paths after inter-MSC handovers.

The MSC will require functionality to detect requests for IN services (i.e. mobility and supplementary services). In GSM there are two scenarios where IN services are requested: the first is during a call when services such as call waiting, conference call and handovers can be requested; the second is in the absence of a call, when services such as location updating and Short Messaging Service (SMS) are requested.

In IN CS-1, services are triggered by arming detection points in the *basic call state model*, but if no call is present, a call state model will not exist and therefore requests for services such as location updating cannot be processed. Remember that the call state model is controlled by the *call control function* and not by the *service switching function*. Hence IN networks are not involved in detecting requests for IN services and so a GSM specific triggering mechanism can be used in the GSM-IN integrated network and this will not conflict with IN standards. The functionality to detect mobility management requests already exists in GSM: when a location update request is made in GSM it is detected and the associated processing is initiated. So the existing mechanism can be used for detecting and triggering IN services outside a call.

The call state model used in GSM is not in line with the basic call state models recommended for the *call control function* by IN, (the GSM's model is tailored for mobility management) so the GSM model needs to be enhanced to meet IN requirements. At the same time, the GSM model cannot simply be replaced by the IN *basic call state model*. The sequential nature of the *basic call state model* used in fixed networks places severe limitations on the call processing ability of mobile networks and there will be times when parallel processing of services will be required in the IN environment. For an example, when a user is using the call waiting service and a handover request is made. Both services are time critical and will need to be processed simultaneously. Unlike the situation in the *basic call state model*, the handover request processing cannot wait until processing of the existing service is complete as the call may be lost. Neither is the IN *point in call* concept applicable here because handovers must be capable of taking place at any time. The GSM mechanism for detecting call and mobility service requests will have to be used to detect and trigger IN services in the presence or absence of a call. This functionality needs to be enhanced to be able to inform the *service switching function* that a request for a service has been made and forward the appropriate parameters necessary for the service to the *service switching function*.

When a call is present, its state needs to be monitored as most services need to know the state of a call and / or are dependent on the state of the call. Therefore, a call monitoring function will need to be added if one does not already exist. The same function will need to monitor the progress of service executions in the absence of a call. The feasibility of this approach is yet to be verified and as such marked for further study.

In the proposal here, all GSM mobility control procedures will be transferred to a common IN platform (MSCP) from the various GSM nodes (HLR, MSC, VLR), but none of the procedures are modified. To the radio access network and the GSM user the change in the control point is transparent. The mobile terminal does not see any changes in the network and, the mobile terminal still functions as if it were communicating with the MSC and is unaware of any IN components. As IN mobility control functionality imitates GSM functionality there is no need to suspend call processing as in POTS to conduct IN processing. This is only true for GSM mobility procedures offered as IN services. When GSM mobility procedures offered as IN services are combined with other IN supplementary services it may become necessary to suspend call processing and transfer control to the *service control point*.

For the execution of mobility services outside a call, knowledge about the state of the switch is not required by the *service control point* and there is adequate information within the GSM message to provide the service. If a request for an inter MSC handover is made, then knowledge of the switch state must be made known to the *service control point* and the *service control point* will need control over the switch. At present the capabilities offered by CS-1 IN-*switch state model* would seem adequate to meet these requirements.

Services may be invoked in the absence of a call, during a call and in parallel with the execution of a current service. As such the question of compatibility and interaction between services becomes complex. The approach in the IN CS-1 *features interaction manager* for solving interaction and compatibility issues between services by maintaining a look up table of all possible interactions for all possible combination of services is not viable. What is required is a knowledge based approach combined with a database approach. In Figure 4-4 modifications to CS-1 *service switching function* and the MSC functions are shown.

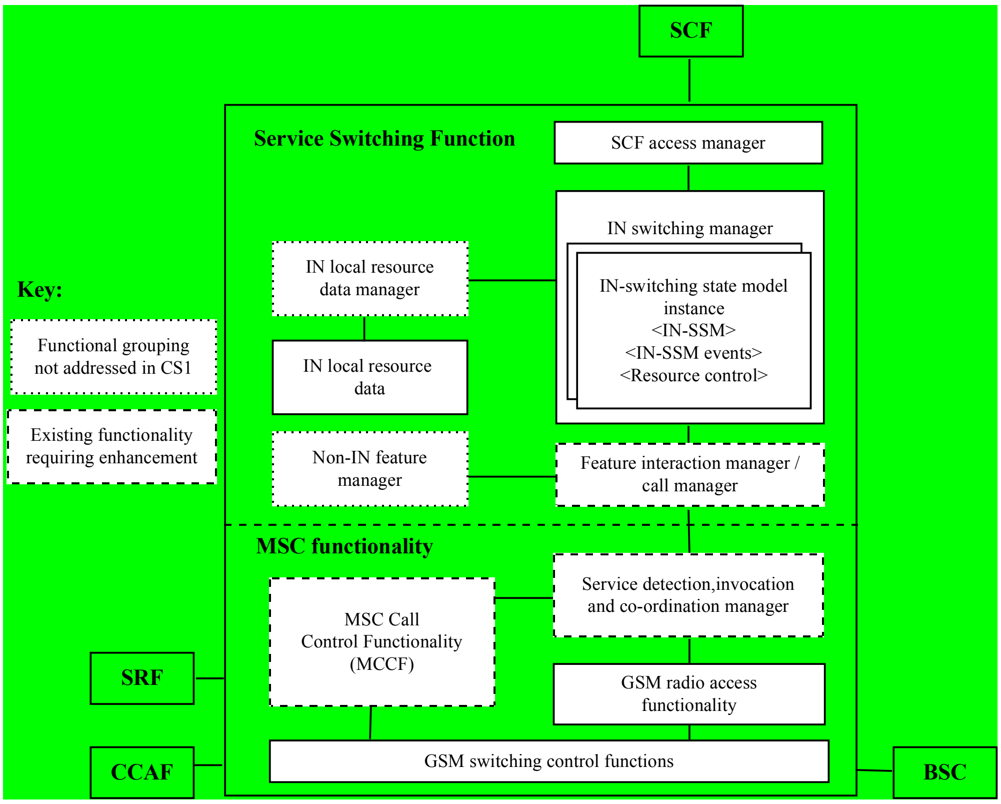

Figure 4-4 : Mobile service switching point (MSSP) functionality identifying the MSC and SSF functionality and the elements that require enhancement .

Having discussed the functionality of the *mobile service switching point* (MSC+MSSF) the signalling perspective on the *mobile service switching point* is now discussed. The *mobile service switching point* will need to be implemented with a new functionality which is referred to as the '*translation function'* (Figure 4-5) for interworking between GSM and IN. The translation function will be responsible for interpreting the signalling messages between the mobile terminal and the radio access network, and the IN control network. GSM messages to and from the mobile terminal and the radio network will be translated by this function to INAP messages and visa versa. This functionality is restricted to translating signalling messages where the MSC acts as a relay between the mobile terminal and the *service control point* because message number used by INAP will not necessarily be the same as those used by messages in the radio access network.

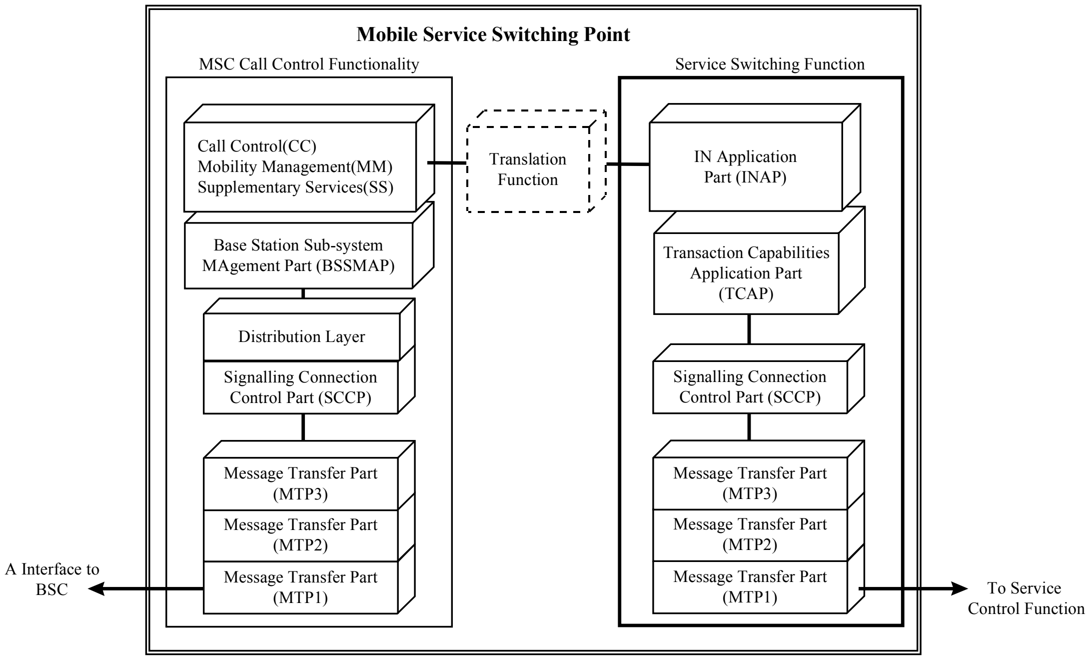

Figure 4-5 : The signalling protocol stack for the mobile service switching point illustrating the interworking between the service switching function and the MSC.

4.5 MOBILE SERVICE CONTROL POINT

The term ***Mobile Service Control Point*** (MSCP), will be used to identify a *service control point* that has the functionality to cater for mobility services. Hence within *mobile service control points* must reside ***Mobile SIBs*** (MSIBs), which are dedicated mobility functions. This is the only difference between *mobile service control points* and *service control points*.

In IN CS-1, *service control points* cannot interact to share, negotiate or handover control between *service control points*; CS-3 will provide this functionality, which will be of benefit for the efficient provision of GSM services from an IN platform. CS-3 also introduces multiple points of control which again will be of benefit.

4.5.1 MOBILE SERVICE INDEPENDENT BUILDING BLOCKS

By modularising [32,51] the GSM mobility procedures (location updating, handovers, call set up, etc.) described in Chapter 2, it is possible to identify commonality within the various procedures. Examples of common sub-procedures are authentication, issuing a new TMSI, paging, database enquiry and database updating among others. These sub-procedures are self contained and identical irrespective of the mobility procedure using it. Each of these sub procedures will need to be converted to a SIB, i.e. Authentication SIB, Paging SIB and TMSI SIB. For database enquiry and database updating a modified version of the IN CS-1 *service data management* (SDM) SIB can be used and this will be referred to as *mobile service data management* (MSDM) SIB. The complete list of SIBs necessary to offer GSM mobility functionality is listed below.

- Authentication SIB - Calculates RAND and forwards it to the mobile terminal and checks the calculated value against the returned value.
- Cipher SIB - Instructs the radio access network to cipher a channel to mobile terminal.
- TMSI SIB - Issues a new TMSI to the mobile terminal.
- MSDM SIB - Used for creating, updating and deleting records on databases.
- Paging SIB - Instructs the radio access network to page a mobile terminal in a specified area.
- Location_Update SIB - If the location update procedure was successful then the user is informed accordingly or else the SIB is used to process any errors that may have occurred during the procedure and forward the appropriate error message to the user (Eg. Roaming not allowed).
- Call_Setup_Incoming SIB - Instructs the *mobile service switching point* to check compatibility of incoming call with the mobile terminal and capture a radio channel to the mobile terminal. This SIB also process any error that arise during the service and generates the necessary response.
- Call_Setup_Outgoing SIB - Checks the compatibility of the service requested by the user with the subscription for the user. Instructs the MSC capture a radio channel to the mobile terminal and forwards instruction on call completion to the *mobile service switching point*. Errors arising are also processed generating the appropriate response.
- GSM_GSM_Handover SIB - Dedicated to handling GSM inter-MSC handovers, it instructs the new MSC to allocate a radio channel for the user. The user is informed when a new radio channel is available and instructed to handover. This SIB also handles all error processing.

4.6 MOBILE SERVICE DATA POINT

A **Mobile Service Data Point** (MSDP) is a *service data function,* where users service data and mobility data are stored. A users 'character set' will contain users mobility data (such as the location of MSC being roamed and roaming limitations) and supplementary service data (such as supplementary services subscribed). The advantage of a combined 'character set' is the availability of complete user information locally. The location of the *mobile service data point* will be identified from the users telephone number just as the address of the HLR is derived from the users number in GSM.

4.6.1 MOBILE SERVICE DATA POINT TEMPORARY

The temporary databases functionality is identical to the *mobile service data point*. The temporary database is used by a user only when roaming an associated MSC. The *service control point* will use the MSC - *mobile service data point temporary* association to find location of the *mobile service data point temporary.*

4.7 IN / GSM MOBILITY PROCEDURES

This section describes GSM mobility procedures offered from an IN platform as envisaged by the author. The SIBs required to offer these services and their functionalities are identified. The estimates of the signalling messages sizes are based on corresponding messages for GSM procedures. As mentioned earlier, the IN procedures will mimic GSM procedures, the difference will be the network entities involved in the transactions.

4.7.1 LOCATION UPDATING PROCEDURE

There are two types of location updating procedures that will need to be defined. Intra-MSC and inter-MSC (the procedure for intra-MSC and periodic location updates are the same). Also two variations on the GSM-IN architecture have been identified: with $MSDP_{temp}$ and without $MSDP_{temp.}$ This results in four possible procedures for location updating.

4.7.1.1 LOCATION UPDATE PROCEDURES WITH A $MSDP_{TEMP.}$

MT {Detects that coverage is provided by a new location area}
Initiate location update procedure
{Transmit a LOCATION UPDATE REQUEST message over the standalone dedicated control channel. The message contains the *International Mobile Subscriber Identity* or the *Temporary Mobile Subscriber Identity* and the new location area identity}

MSSP {Treat message from MT as a service trigger.}
Compose INAP message and forward message to *service control point*
{LOCATION UPDATE REQUEST}

MSCP **Invoke (Location update service logic program)**
if (old MSC = new MSC) {i.e. intra MSC location update}
Begin(1)
Invoke (*Mobile service data management* SIB) {to request authentication data on user from $MSDP_{temp}$}

$MSDP_{temp}$ **Return (Authentication data for user**)

MSCP **Invoke (*Authentication* SIB)**
***Authentication* SIB forward RAND to mobile terminal.**

MSSP **Translate and compose GSM message and forward message to mobile terminal**
{AUTHENTICATE REQUEST message forwarded to mobile terminal}
{All messages between the MT & SCP go through a translate and compose at the MSSP}

MT **Calculate SRES and return SRES.**

MSCP **if (Authentication outcome == success) proceed**
else exit (invoke *Location Update* SIB(Authentication failed, Error))
End(1)

MSCP **if (old MSC != new MSC)** {i.e. inter MSC location update}
Begin(2)

Invoke (*mobile service data management* SIB) {to request user data from old $MSDP_{temp}$}

$MSDP_{temp}$(old) **Return user record**.

MSCP ~ Authentication using *authentication* SIB as in previous case. ~

Invoke (*mobile service data management* SIB) {to update user record on mobile *service data point* (MSDP) (i.e. users home database) with new MSC location.}
Invoke *mobile service data management* SIB {to create new user record on $MSDP_{temp.}$}
Invoke *mobile service data management* SIB {to delete user record on old $MSDP_{temp.}$}
End(2)

Invoke (Cipher SIB) {to cipher channel to mobile terminal}

BSC **Cipher channel and acknowledge.**

MSCP **Invoke (TMSI SIB)** {to issue new TMSI to mobile terminal}

MT **Acknowledge TMSI.**

MSCP **Invoke (Location update SIB (location update accepted))**
{*Location update* SIB inform mobile terminal : LOCATION UPDATE ACCEPTED message.}

The same service is used in both cases and the *global service logic* for 'location update' service shown in Figure 4-6.

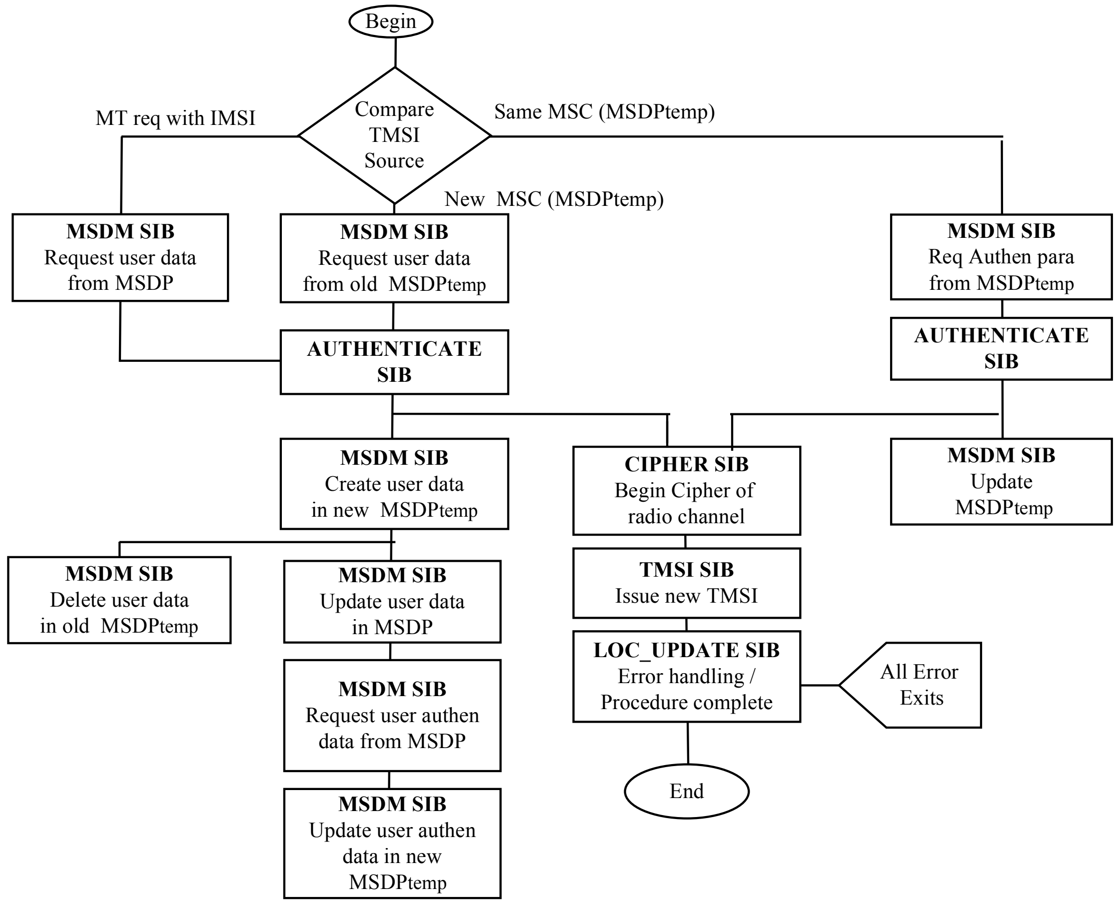

Figure 4-6 : Global service logic for 'Location Update' service when $MSDP_{temp}$ is present.

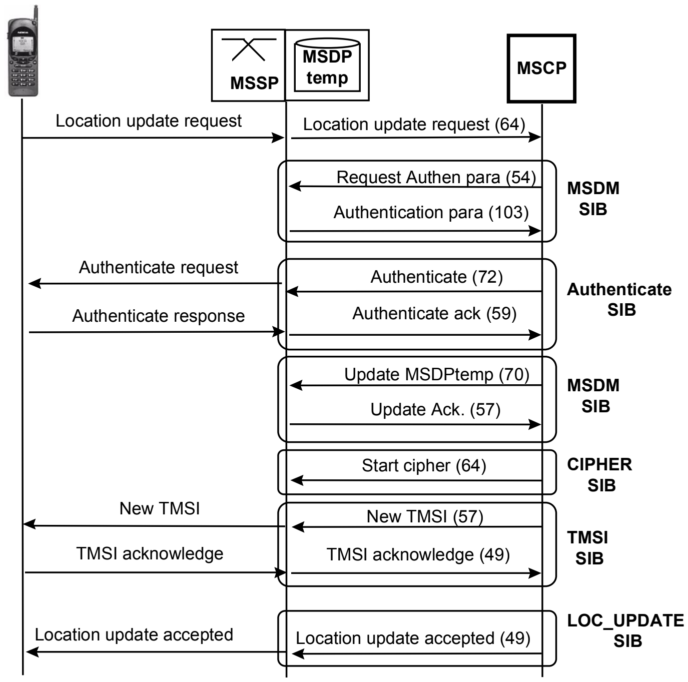

Figure 4-7 : Intra-MSC location updating signalling procedure with a $MSDP_{temp}$ present.

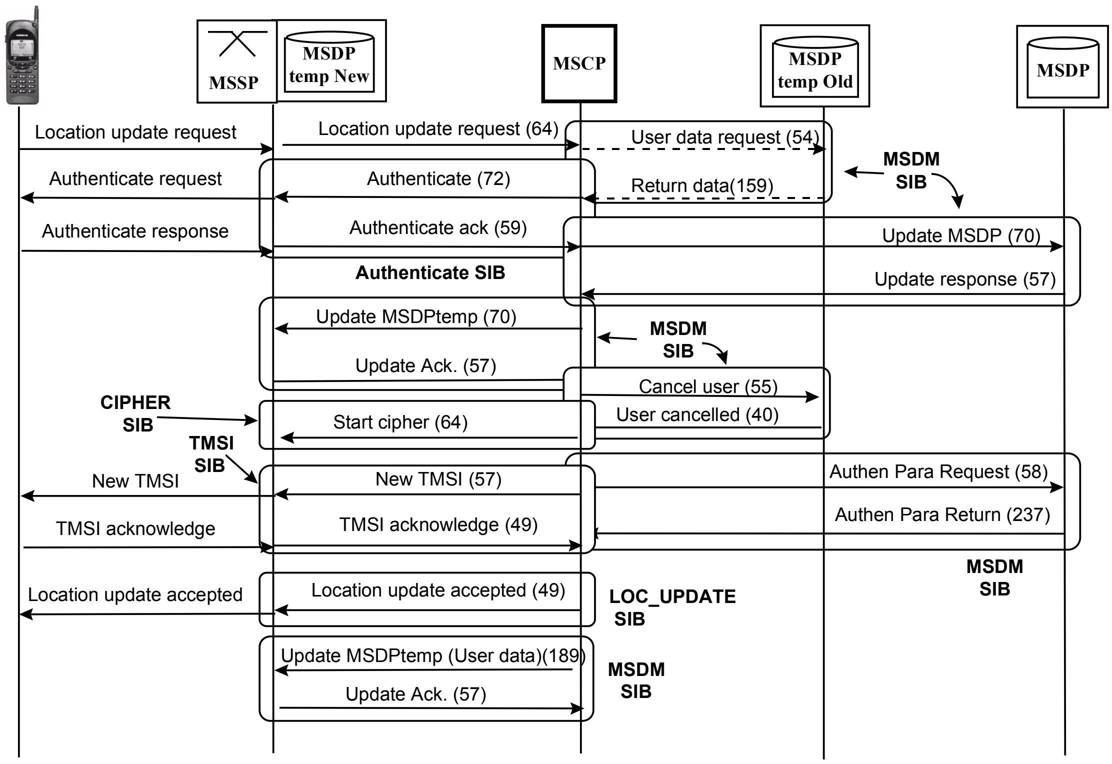

Figure 4-8 : Inter-MSC location updating signalling procedure with a $MSDP_{temp}$ present.

4.7.1.2 LOCATION UPDATE PROCEDURES WITHOUT A $MSDP_{TEMP}$.

The global service logic for location updating service when $MSDP_{temp}$ is not present is shown in Figure 4-9. In the absence of $MSDP_{temp}$ the same procedure is used for intra-MSC and inter-MSC location updates.

MT	{Detects that coverage is provided by a new location area} **Initiate location update procedure** {Transmit a LOCATION UPDATE REQUEST message over the standalone dedicated control channel. The message contains the *International Mobile Subscriber Identity* or the *Temporary Mobile Subscriber Identity* and the new location area identity}
MSSP	{Treat message as a service trigger.} **Compose INAP message, and forward message to *service control point*** {LOCATION UPDATE REQUEST message is forwarded.}
MSCP	**Invoke (Location update service logic program)** {Since no temp databases exist, both intra and inter MSC location updates are handled in an identical fashion.} **Invoke (*Mobile service data management* SIB)** {to request authentication data on user from MSDP}
MSDP	**Return authentication data for user**.
MSCP	**Invoke (*Authentication* SIB)** ***Authentication* SIB forward RAND to mobile terminal**
MT	**Calculate SRES and return SRES.**
MSCP	**if (Authentication outcome = success) proceed** **else exit (invoke (*Location Update* SIB(Authentication failed, Error)))** **Invoke (*Mobile service data management* SIB)** {to update user record on MSDP} {Users home database updated with new MSC location and / or new location area identity.} **Invoke (Cipher SIB)** {to cipher channel to mobile terminal}
BSC	**Cipher channel and acknowledge.**
MSCP	**Invoke (TMSI SIB)** {issue new TMSI to mobile terminal}
MT	**Acknowledge TMSI.**
MSCP	**Invoke (Location update SIB (location update accepted))** {*Location update* SIB inform mobile terminal : LOCATION UPDATE ACCEPTED message.}

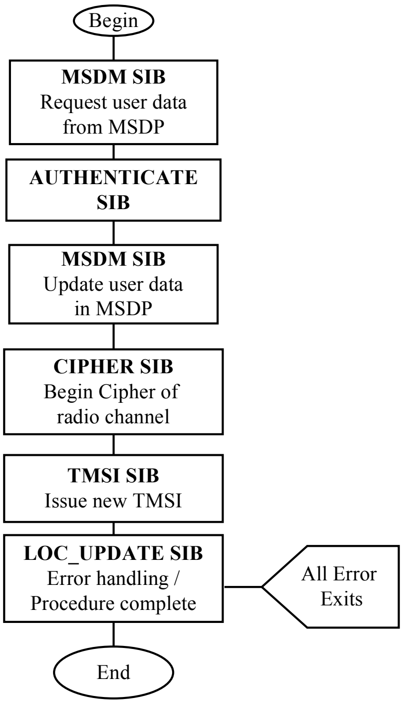

Figure 4-9 : Global service logic for location updating service in the absence of $MSDP_{temp}$.

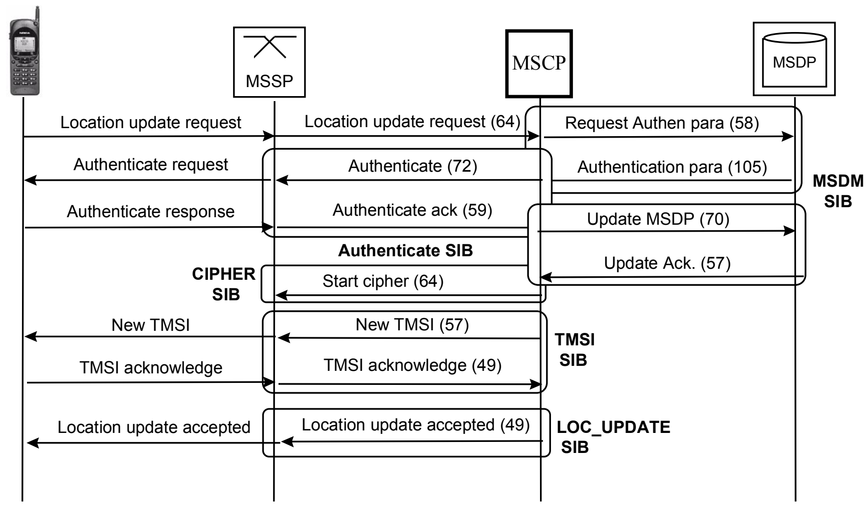

Figure 4-10 : Signalling procedure for the location updating procedure in the absence of $MSDP_{temp}$.

4.7.2 Gateway MSC Functionality and Mobile Call Termination

In GSM mobile terminating call from the fixed network are directed to a *gateway MSC* when the fixed network is unable to interrogate the HLR directly. *The gateway MSC* provides the routing information for roamed MSC by interrogating the HLR. HLR interrogation is just a database look up function. In the GSM-IN integrated architecture, this function translates to the *mobile service database management* SIB.

As in other MSCs the *gateway* MSC will have a *service switching function* attached to it, hence it will be referred to as the *gateway mobile service switching point*.

A call arriving from the fixed network at the *gateway mobile service switching point* will trigger a *routing service* with the mobile users number. The local *service control point* will then interrogate the *mobile service data point* for the user and receive routing information to the roamed MSC. The result of which is forwarded to the *gateway mobile service switching point* and the call is routed to the roamed MSC.

Once the call arrives at the roamed *mobile service switching point* (i.e. the roamed MSC), the CALL_SETUP_INCOMING service is triggered. The procedure for the service is described here.

MSSP {Receives a initial address message to setup a call to a user roaming the MSC, identified by roaming number.}
Compose INAP message to initiate CALL_SETUP_INCOMING service

MSCP **Invoke (CALL_SETUP_INCOMING service logic program)**
Begin {CALL_SETUP_INCOMING service}
Invoke (*Mobile service management* SIB) {To request authentication and location data from $MSDP_{temp}$. For the architecture where $MSDP_{temp}$ is absent, this data is retrieved from MSDP}

$MSDP_{temp}$ **Return (authentication data, TMSI and location area info. for user)**

MSCP **Invoke (*Page* SIB)** {Page user in location area being roamed}

MSSP **Translate and forward page request to BSC** {All further communications between the MSCP and the radio access network is translated by the MSSP}

MT **Acknowledge paging request.**

MSCP **Invoke *(Authentication* SIB)**
***Authentication* SIB forward RAND to mobile terminal.**

MT **Calculate SRES and return SRES.**

MSCP **if (Authentication outcome == success) proceed**
else exit (invoke (*call_setup_incoming* SIB (Authentication failed, Error)))
Invoke (*Cipher* SIB) {to cipher channel to mobile terminal}

BSC **Cipher channel and acknowledge.**

MSCP **Invoke (*TMSI* SIB)** {to issue new TMSI to mobile terminal.}

MT **Acknowledge TMSI.**

MSCP **Invoke (*Call_setup_incoming* SIB).**
***Call_setup_incoming* SIB forward call complete message to MSSP.**

End {CALL_SETUP_INCOMING service}

MSSP **Forward *SETUP* message to MT** {This message will begin call establishment with the MT}

MT **Acknowledge with *Call Confirmed* message** {Having checked compatibility with incoming call}

MSSP **Instruct radio network to assign a radio channel to the MT**

MT **Send Alerting message**

MSSP **Send Address Complete Message to call originating party.**

Figure 4-11 is a *global service logic* for the CALL_SETUP_INCOMING service. Figure 4-12 shows the signalling exchanges for setting up a mobile terminating call with the estimated signalling message sizes used for simulation purposes.

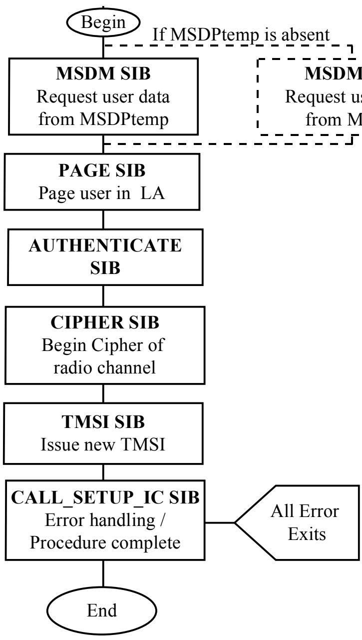

Figure 4-11 : Global service logic for mobile terminating calls.

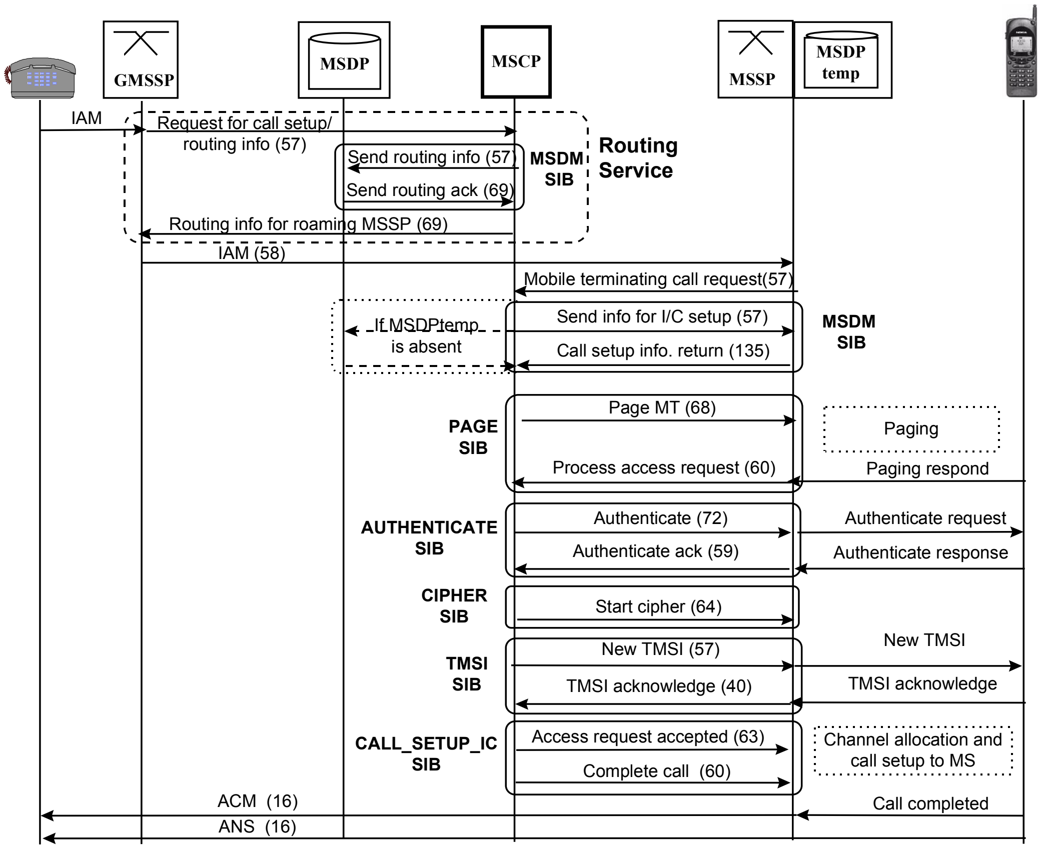

Figure 4-12 : Signalling procedure for a mobile terminating call.

4.7.3 MOBILE ORIGINATING CALL

The procedure for a mobile originating call is described here.

MT {When the send button is pressed on the mobile terminal}
Send *service request* message to network.

MSSP {Detects that a request for a outgoing call setup has been made}
Forward service request to MSCP.

MSCP **Invoke (CALL_SETUP_OUTGOING service logic program)**
Begin { CALL_SETUP_OUTGOING service }
Invoke *(Authentication* SIB)
***Authentication* SIB forward RAND to mobile terminal.**

MT **Calculate SRES and return SRES.**

MSCP **if (Authentication outcome == success) proceed**
else exit (invoke (*Call_setup_outgoing* SIB(Authentication failed, Error)))
Invoke (*Cipher* SIB) {to cipher channel to mobile terminal.}

BSC **Cipher channel and acknowledge.**

MSCP **Invoke (*TMSI* SIB)** {to issue new TMSI to mobile terminal.}

MT **Acknowledge TMSI**
Send *Setup* message info for outgoing call.

MSCP **Invoke (*Call_setup_outgoing SIB)***
Begin { *Call_setup_outgoing SIB* }
Check outgoing call info. against user subscription parameters.
If (Requested call is allowed) proceed
else exit (Unsubscribed service error)
If (called number == mobile number) Initiate (Routing_Info service) {If its a mobile terminating call then use routing service to find roaming MSC for terminating call. This is also true for 'freephone' call etc.}
Inform MSSP to complete call.
End { *Call_setup_outgoing SIB* }

End { CALL_SETUP_OUTGOING service }

MSSP **Inform MT call is proceeding.**
~ Assign radio channel to mobile terminal ~
Send initial address message to called party.

The call is connected through when the calling party answers.

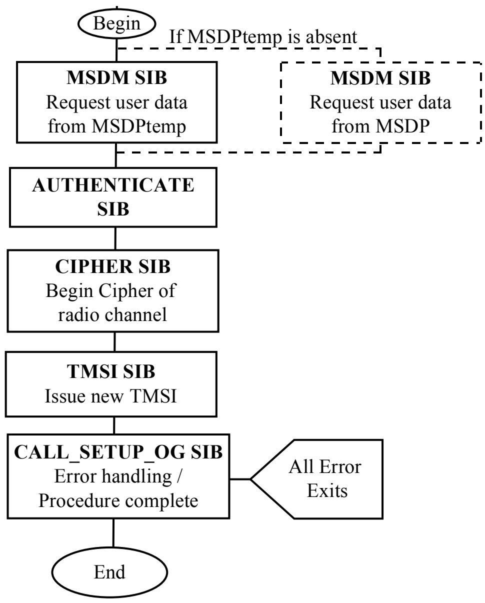

Figure 4-13 : Global service logic for mobile originating calls.

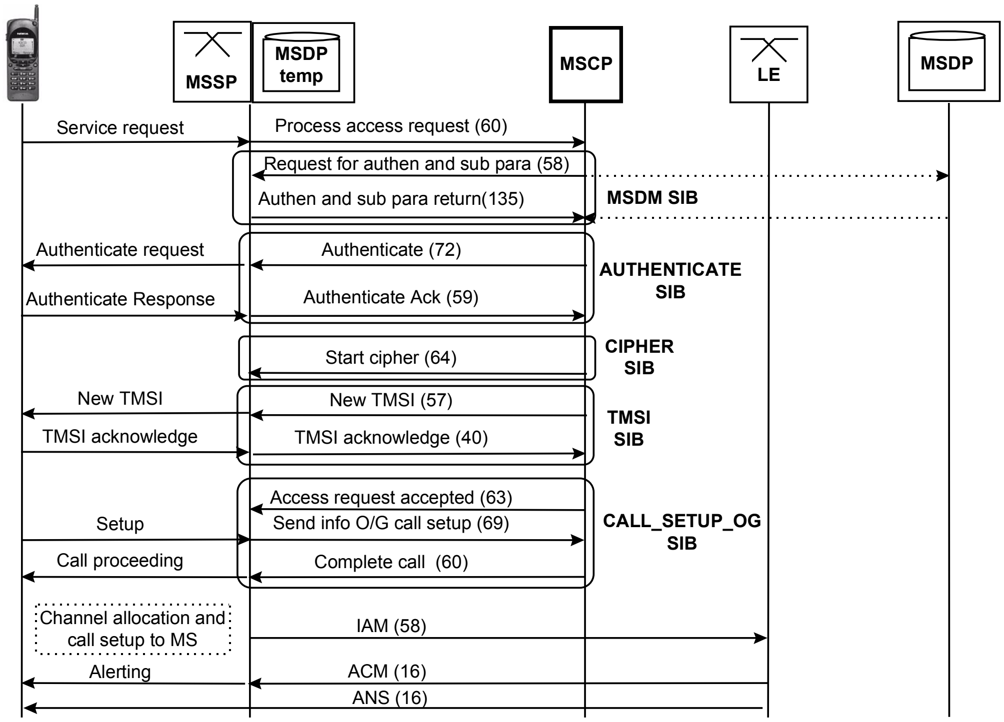

Figure 4-14 : Signalling procedure for a mobile originating call.

4.7.4 INTER MSC HANDOVERS

Earlier in this chapter the reasons for only conducting inter-MSC handovers from the IN platform were given. The procedure for inter-MSC handovers is described here is limited in one respect, the lack of interworking between *service control points*. The interworking between *service control points* is yet to be defined by IN CS-3. If in the physical implementation of GSM-IN architecture, a *service control point* is associated with each MSC, then service control for the user needs to be handed over to the new *service control point* to enable efficient handling of services at local level. Unfortunately this is not possible at the moment, and will not be until IN CS-3 define inter-SCP control handovers.

The second limitation is the shortest path to the new MSC cannot be routed directly to new MSC due to buffering at MSC old.

BSCold {Decides a handover is required and forwards the list of target cells to MSC (i.e. MSSP)}
Send *handover required* message to MSC.

MSSPold {Detects that a handover is required and forwards message to MSCP}
Forward service request to MSCP as *perform handover* message

MSCP **Invoke (HANDOVER service logic program)**
Begin {HANDOVER service}

if (Handover == GSM to GSM) { Decide on handover type}
Begin {GSM to GSM handover}
if (roaming limitation violated == TRUE) exit(error)
Invoke (*GSM_GSM_Handover* SIB)
Begin (*GSM_GSM_Handover* SIB)
Send *allocate radio channel* message {Instructs MSSPnew to allocate a radio channel in the desired cell site with parameters in message}

MSSPnew **Instructs cell site to allocate a radio channel.**
If (radio channel allocation == success) return *allocate radio channel ack* message {This message also contains a reference number used in setting up the land line to the MSSPnew }

MSCP **Instructs MSSPold to setup a connection to MSSPnew.**
Forwards new radio channel details to MSSPold.
Send *perform handover ack* message to MSSPold. {Both the previous instructions are carried in this single message}
End (*GSM_GSM_Handover* SIB)

MSSPold **Send IAM to MSSPnew**

MSSPnew **Reply with ACM.**

MSSPold **If (ACM == received) send *handover command* message to mobile terminal.**

MT **Perform handover.**

MSSPnew **Forward end signal message to MSCP.**

MSCP **End** {GSM to GSM handover}
End {HANDOVER service}

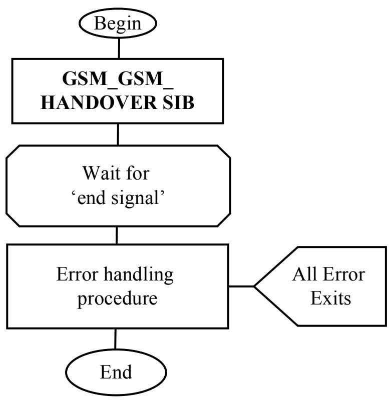

Figure 4-15 : The global service logic for inter-MSC GSM handovers.

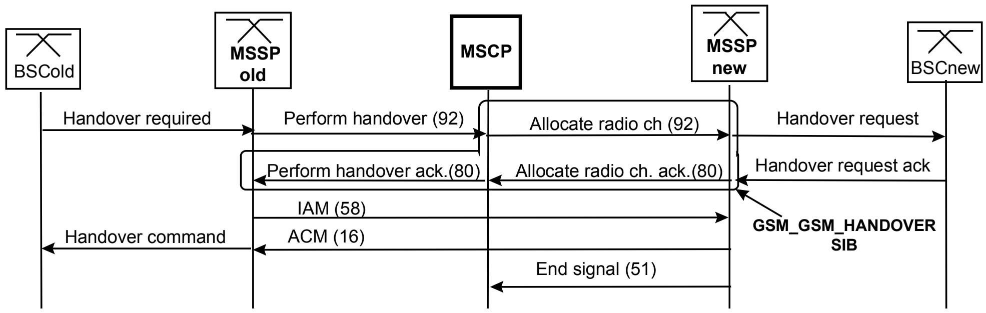

Figure 4-16 : Signalling procedure for inter-MSC handovers.

4.8 INTEGRATION SCENARIOS

The advantage of an IN approach to the provision of mobility is the availability of IN platforms on most networks today and the next generation of mobile networks will be built around the IN concept. With the transformation of GSM mobility functions into IN services, the provision of GSM mobility services is no longer restricted to the GSM network; with the lifting of this restriction, several implementation scenarios become possible, some of which are outlined here.

4.8.1 GSM - IN: INTEGRATED APPROACH EXAMPLE

An example of a mobile originating call is used to illustrate (Figure 4-17) the workings of the GSM-IN architecture. The mobile terminal informs the network of the need for service and a signalling channel is allocated to the mobile terminal over the radio interface. The mobile terminal passes the type of service required to the MSC (i.e. the *mobile service switching point*) as a call set-up request message (1). The *mobile service switching point* treats this message as a trigger for the 'call_setup_outgoing' service and composes a INAP message with a request for the service which is then sent to the *mobile service control point* (2). The 'call_setup_outgoing' service will require information on the user and this is obtained from the *mobile service data point* or *mobile service data point temp* using the *mobile service database management* SIB (3)(4). The *mobile service control point* will send an authenticate request to the user via the *mobile service switching point*, which now acts as a translation function for messages between the control point and the mobile terminal (5). Once authentication is successfully completed (6), a channel is ciphered and a new TMSI is issued by the *mobile service control point* (7)(8)(9). The number of the called party and the type of service is now sent by the mobile terminal to the *mobile service control point* (10). The control point checks the requested service type against the users subscription parameters and instructs the *mobile service switching point* to setup up a path to the called party with the necessary bearer capabilities and to allocate a radio channel to the mobile terminal(11). The call is connected through when answered.

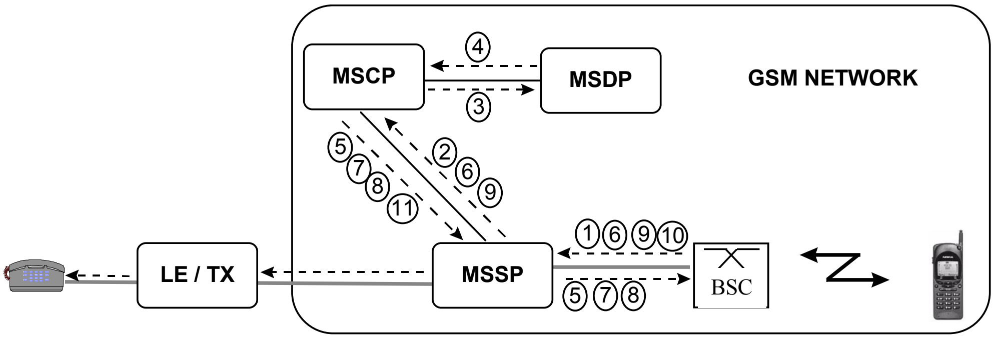

Figure 4-17 : Example of a IN / GSM call.

4.8.2 THIRD GENERATION MOBILE NETWORKS - UMTS

UMTS is a mobile network system planned to succeed GSM, offering broadband services up to 2Mbits/s and an enhanced range of services based on the IN concept. It is widely accepted that the step between GSM and UMTS will be evolutionary rather than revolutionary, because of the financial constraints and the widespread use of GSM by the time UMTS is introduced. What is ideally required is a set of stepping stones for GSM to evolve to UMTS.The integrated architecture and GSM / IN mobility procedures presented in this thesis provide those stepping stones.

UMTS architecture (Figure 4-18) is based on IN architecture, so as to allow easy integration with the fixed network and therefore shares a common core network (BISDN). UMTS is intended to be the umbrella from which a wide variety of mobile services (such as paging, domestic cordless telephony, wireless PBXs, radio LANs, PMR and public cellular services) are offered. The provision of mobility in UMTS is from *mobility and service control points* rather than from mobile switches as in GSM. Therefore by transferring mobility control procedures to a *mobile service control point* it will be possible to modify the GSM network to be ready for UMTS as soon as UMTS is introduced. Then radio access network GSM will become one of the many radio access networks within UMTS.

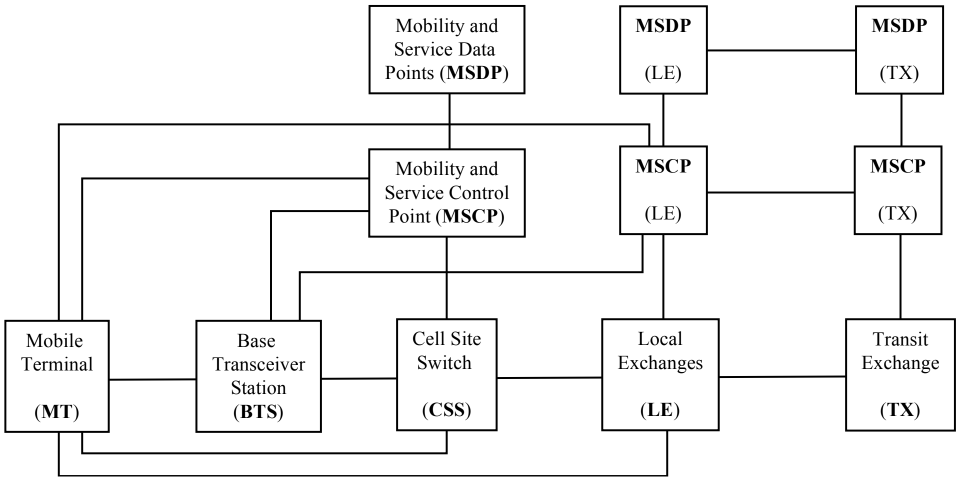

Figure 4-18 : UMTS functional architecture.

4.8.3 MOBILE SIBS ON FIXED NETWORKS

GSM mobility defined in terms of IN SIBs allows the provision of a GSM network as an 'access network' for a fixed network operator; obviously this may cause regulatory problems. By mounting the GSM mobility SIBs on a *service control point* in the fixed network, it will be possible to access the GSM radio access network directly from the fixed network without requiring a gateway MSC. When a GSM number is called from a fixed network phone, the *service switching point* at the local or trunk exchange will recognise it as a trigger for the IN service, just as dialling a freephone number. The *service switching function* will recognise the number dialled as a GSM number and invoke the GSM CALL_SETUP_INCOMING (described in Section 4.7.2). The call setup procedure is identical to one carried out by a mobile service control point in the GSM network, except here its controlled by a *service control point* in the fixed network. The process is depicted in Figure 4-19.

The advantages of this approach are that the user location is determined and the mobile terminal is paged prior to making a connection to the GSM network. Therefore route duplication does not take place and network resources are utilised only if the mobile terminal is available. Obviously a conscious decision has to be made to decide when a originating network conducts the GSM mobile terminating call service otherwise excessive signalling delays may be experienced.

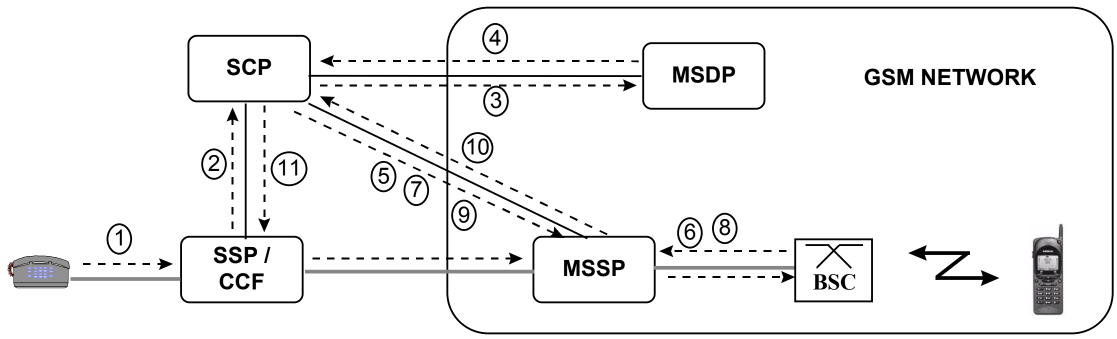

Figure 4-19 : A GSM call, setup from outside the GSM network.

5. SIMULATION MODELLING

In the previous chapter a new integrated architecture for GSM and IN networks was proposed and the signalling exchanges in the core network for the various mobility functionalities were described. Having identified the functional architecture for the GSM-IN network it is necessary to investigate using simulations [47, 49, 50, 52-57, 81, 82] the effect of different physical implementations of the functional architecture on the performance of mobility procedures.

Having proposed the signalling exchanges between the network nodes and identified message sizes, the volume of signalling traffic through the core network can be calculated theoretically. This is also true for various degrees of mobility, as mobility can be modelled using a simple equation[60, 61]. But the nature of networks is such that the estimation of mobility procedure performance becomes too complex for mathematical analysis. Neither will the results produced by mathematical analysis be a true representation of the system because the signalling messages pass through several interfaces of differing transmission rates, because packet sizes in the SS7 network are variable and because the signalling message sizes are different over the radio interface and the fixed interfaces. Therefore simulation models are required to calculate the completion times for the various mobility procedures.

At the outset there were two options: either to develop a simulator specifically for this problem or to use a commercial simulator. A purpose-built simulator will certainly be faster in terms of execution time, but the savings made on the execution time are likely to be more than offset for by the development time. Preliminary tests showed that the purpose-built simulator would not be much faster than current commercial tools. Furthermore the benefit of a commercial simulator is the availability of existing library models and the ability to plug in the models developed by the author for further work.

The commercial simulator used was OPNET™, a general purpose telecommunications network simulation tool. OPNET is a discrete event simulator: the discrete event in models described here will be the signalling packets. OPNET uses a graphical interface where simulation models are defined at four levels. The top level is the network level, where the topology of the simulated network model is defined; the interconnection of networks (e.g. ATM links, BISDN, radio interfaces.) are also identified at this level. At the second level (the node level) the elements that make up the network nodes and their interconnections within the networks are defined; these elements include queues, processes, sources, receivers and transmitters. The functionality of each process or queue element is defined in terms of a finite state diagram and the transitions between states; this is the third level. The fourth and final level is where the processing in each of the states in the finite state diagram is defined in C code.

Firstly an account of the models developed is given. These will include the assumptions made, the techniques used and the incorporation of measurements from the GSM network in the models. Finally a section on verification and validation is presented.

The results from the GSM-IN simulation model will need to be compared against the GSM network. For this comparison a model of GSM network is required as well as the GSM-IN model. The results from the two models will be used for comparison of performance. To add validity to the comparison, the GSM model will be calibrated against data [58, 59] from Cellnet's GSM network and the assumptions used in the calibration of the GSM model will be implemented in the GSM-IN model, in order to increase the accuracy of this model.

The performance of networks will be analysed by comparing the signalling load on networks, signalling network dimensions and completion times for mobility procedures.

5.1 SIMULATION MODEL OF THE GSM AND GSM-IN ARCHITECTURES

Both the GSM and GSM-IN architectures makes use of three types of transmission mechanisms for signalling. The radio interface is used between the mobile terminal and the cell, LAPD (a derivative of NISDN signalling) for the Abis interface and SS7 message transfer part between all other network nodes. The modelling of the radio access network is first discussed.

5.1.1 RADIO ACCESS NETWORK

The radio network is not simulated in any great detail, because:

- its complexities will degrade the performance of the simulator;
- the radio access network will is the same in both networks.

A simplified model has been built, using data from the GSM radio network for fine tuning. However each component of the radio access network is modelled in a simple manner: this will facilitate detailed modelling of the radio access network if the need were to arise in the future.

5.1.1.1 GSM RADIO INTERFACE

The GSM radio interface is a mixture of FDMA and TDMA. Each FDMA channel is 200kHz wide, with 0.577ms wide TDMA slots.

For time critical signalling during an active call, the ***Fast Associated Control CHannel*** (FACCH) is used for signalling. This channel 'steals' a data slot from the channel being used for voice or data. This allows for higher transmission rates over the radio link for time critical signalling, such as handovers. With the *fast associated control channel*, a slot is available every 8 slots, i.e. 0.577ms slot every 4.615ms. This channel is used for handovers and signalling associated with an active call. LAPDm frames are used to transmit signalling messages over the *fast associated control channel*, with a LAPDm frame of 23 bytes. The frame uses a control byte and an address byte, leaving 21 bytes for information. Each frame is interleaved over 4 full bursts, for improving transmission quality. Therefore, the effective transmission rate is 21 bytes every 18.46ms (4 x 4.65ms). Hence the effective bit rate for the *fast associated control channel* is 9.1Kbits/s (21 x 8bits / 18.46ms).

For signalling outside a call, the ***Stand-alone Dedicated Control CHannel*** (SDCCH) is used for procedures such as location updating. This channel is given a slot for every 8 slots a *fast associated control channel* receives, hence the transmission rate is 1.138Kbits/s .

Propagation delay will depend on the position of the mobile station relative to the cell site. In reality, the delay will vary as the user moves and different delays will be experienced by different users. To simplify the simulation model, a constant propagation delay is used for all mobile terminals. Assuming the average distance between a cell and mobile terminal is 1000m, the one way propagation delay will be 3.3μs at the speed of light. Due to the very low transmission rates over the radio channel, propagation delays are negligible compared to the delays in transmission. For a signalling message of 20 bytes, the transmission delay will be approximately 150ms. Although the propagation delay is negligible it has been included in the model.

5.1.1.2 ABIS INTERFACE

The *LAPD* is used over the Abis interface. The cell site and the BSC are connected via a 64kbits/s link and again a constant propagation delay for the link between cell sites and the BSC is assumed. The average distance between cell sties and BSCs is assumed to be 5km, giving a delay of 33.3μs (assuming half the speed of light).

Total delay (Abis) = Transmission delay + Propagation delay

5.1.2 MODELLING OF RADIO ACCESS NETWORK

The simulation model of the radio access network (shown in Figure 5-1) is modelled as a single network module. Several of these radio access network modules are connected to a single MSC, each with a single a 64kbits/s link.

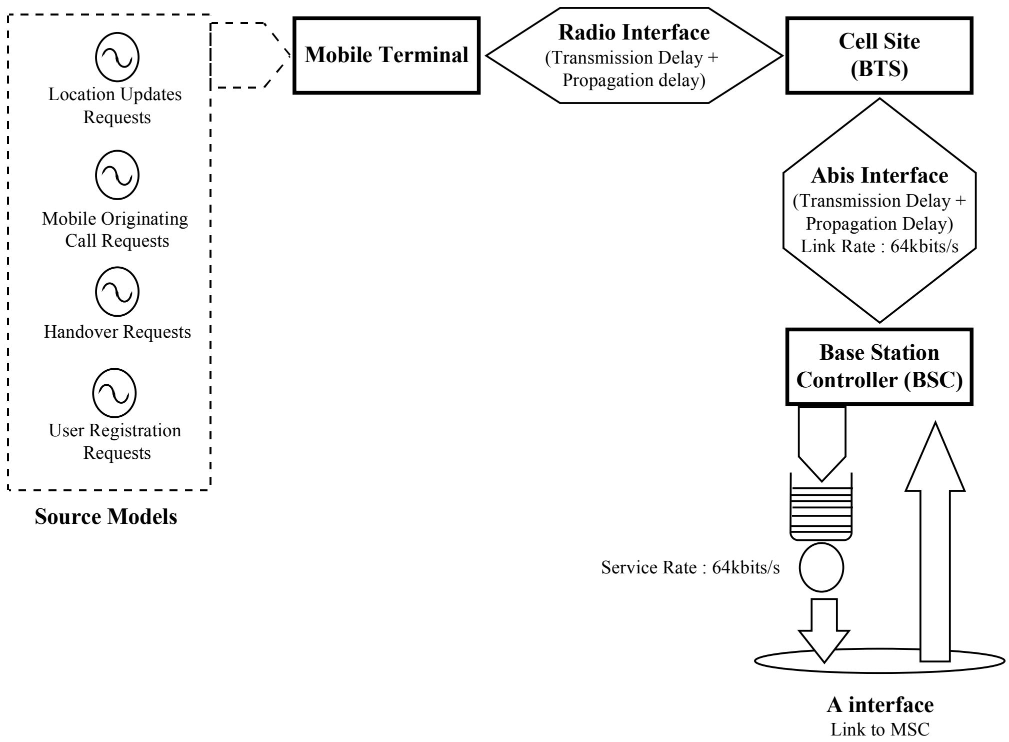

Figure 5-1 : Simulation model of the radio access network.

Delay processing within the BSC is modelled as shown Figure 5-2; the processing is identical for packets from the cell site. The message transfer part (MTP) processing delay is set 1ms and the message transfer delay is set to 400μs [58]. Packets to the MSC from the BSC are sent to a queue which places the packet on to a 64kbits/s link to the MSC.

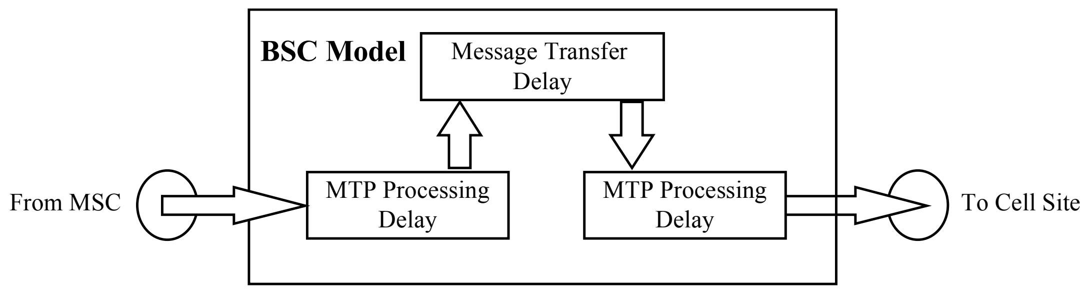

Figure 5-2 : Delay processing in the BSC module.

The Abis interface module calculates the transmission delay at 64kbps transmission rate and adds the fixed propagation delay. The cell site will add a further 400μs delay to all packets crossing its path, i.e. the local transfer delay.

The radio interface module will calculate the delay for a packet on the radio interface depending on the nature of the signalling packet. If the signalling message occurs outside a call then the transmission delay is calculated at the *stand-alone dedicated control channel* rate and at the *fast associated control channel* rate for signalling during a call. The propagation delay across the radio interface is fixed for all packets. Error free transmission is assumed on all interfaces within the radio access network.

In Figure 5-1, the reader will notice the only queue module in the radio access network is on the link to the MSC. The radio access network model does not contain any other queues because:

- a single cell site is used to model all cell sites in the network, so there is no multiplexing of traffic from the various cell sites at the BSC;
- instantaneous access to the radio interface by the signalling packets is assumed;
- multiple radio channels are not modelled so there is no multiplexing of traffic from the various radio channels at the cell site.

The modelling of the mobile terminal is described in detail in the next section.

Requests for mobility services will be generated by the source models. In this simulation study, individual users are not modelled, although each request is modelled on an individual basis. As the interest is in the aggregated behaviour of users, the aim is to model the inter-arrival time between requests for services as seen by the network. The source models are as follows;

1. **Location Update Requests** : The rate of location updates (λ_{lu}) is determined by the mobility model described further on in this chapter. Location updates are Poissonian in nature [elec-letter] and therefore the inter-arrival time between location updates is determined by an exponential distribution.
2. **Handover Requests** : Handover rates (λ_{ho}) will be determined by the mobility model and by the probability of a user being engaged in a call (P_{call}). As with location updates, handovers are Poissonian in nature.
3. **Mobile Originating Call Requests** : The rate of call requests (λ_{mo}) will be determined using data from Cellnet's network. Once again the Poisson distribution is used.

5.1.3 MOBILE TERMINAL

The mobile terminal module has the capability either to initiate a service or to respond to a signalling request from the control network for mobility procedures. Only the positive outcomes for the mobility procedures are modelled. The module will generate the appropriate signalling messages, set the appropriate parameters and set the size of the signalling message[6].

For the purpose of analysis and tracking of procedures, each service request is assigned a unique ID. This ID is included in all signalling messages associated with that instance of the service.

The mobile terminal module is developed as a finite state machine. Once initialisation of the module is complete at the beginning of the simulation, the module goes to the 'idle' state. It remains in the 'idle' state until it receives a request from one of the sources or a signalling message from the network. The transition to the next state is determined by the nature of the request or signalling message. Once at the new state, the processing for that state is carried out. This will usually involve composing a signalling message and transmitting the message to the network with a composing delay. The composing delay is set to 800μs. Once the processing is complete the transition is either back to the 'idle' state or to a new state. The state diagram for the mobile terminal module is shown in Figure 5-3.

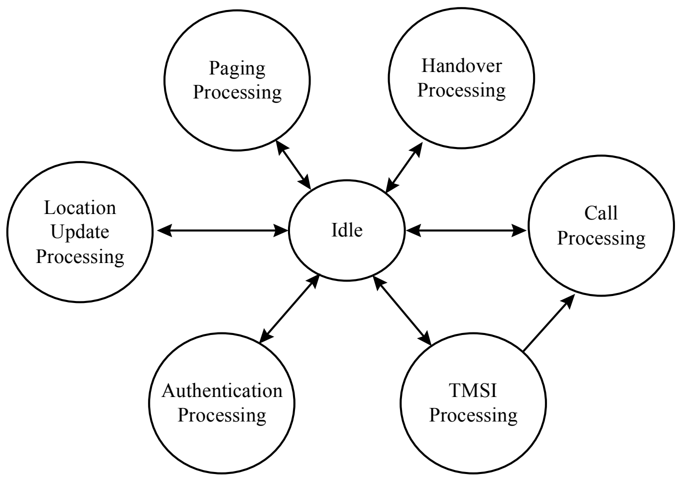

Figure 5-3 : Mobile Terminal module processing states.

Data was obtained from Cellent's GSM network on the time taken by mobile terminals to respond to paging messages during call setup to a mobile terminal. From the data a best fit distribution [63, 81] for the data was found to be a log-normal distribution. When responding to page requests from the network, the mobile terminal module responds with a random delay generated from this distribution. The raw paging data and the best fit probability distribution are shown in Figure 5-4.

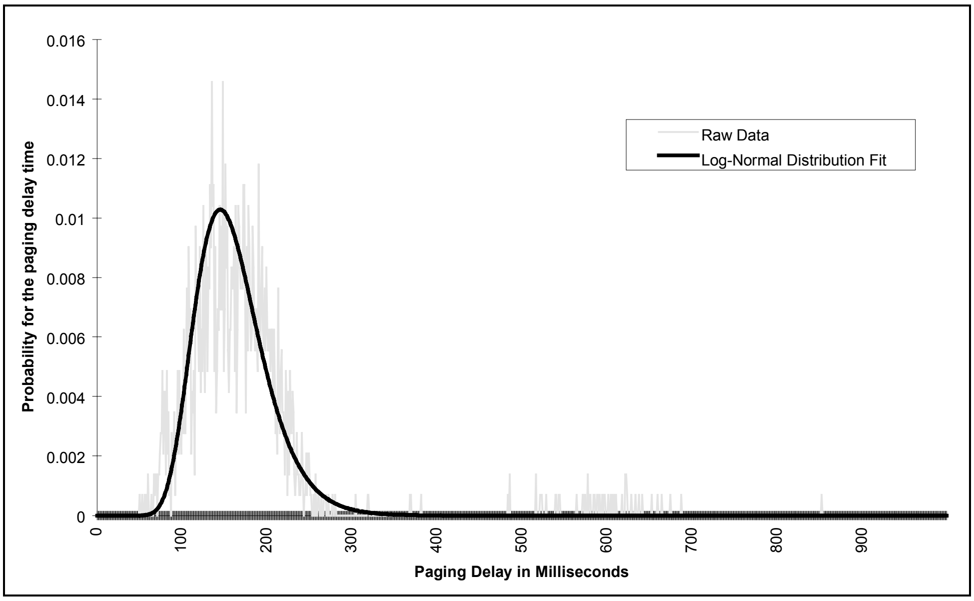

Figure 5-4 : Graph illustrating the raw paging data and the theoretical fit.

The mobile terminal needs to determine whether the call setup requested is a land (fixed) terminating call or mobile terminating call. Using data from Cellnet's network the ratio of mobile to land, termination was found to be approximately 0.1(Table 5.1).

Calls per Hour	Mobile to Land	Mobile to Mobile	Land to Mobile
Answered	184619	13559	141623
Not Answered	36478	3602	35423

Table 5.1 : Data on the number of calls made in and out of Cellnet's TACS network per hour.

The mean call holding times were also determined using data from Cellnet's network (Table 5.2). Call holding times are assumed to be exponentially distributed. Once a call has been setup, the mobile terminal will generate a random time for the duration of the call based on the given data. A call terminate message is sent after the random delay.

Type of call	Mobile to Land	Mobile to Mobile	Land to Mobile
Mean holding time(Sec)	111	126	126

Table 5.2 : Mean Call Holding Times for the Holborn area of London.

5.2 MSC AND MSCP NODE MODELS

This simulation model is a signalling protocol based model so that it is necessary to generate the appropriate signalling messages in the correct sequence. To achieve this, every request for a service must be processed on an individual basis and the progress of each service request must be tracked.

This is achieved using the dynamic processes capabilities in OPNET. It was found that the best way to model a services was to use the IN principal of service built using SIBs. This is an object-oriented approach that allows for the reuse of functionality. The service (e.g. location updating, handovers, mobile originating call, mobile terminating call) is a process defined in terms of a finite state diagram which defines the path followed by each service. Each state may carry out processing by itself or request a SIB (e.g. authentication function, TMSI function, database management function, paging function) to carry out the processing. If a SIB is request and the result of the SIB processing is sequential to the service processing it will remain in the same state until the outcome of the SIB process is known. If the SIB processing can be done in parallel with the service, then the service will move to the next state. SIBs are also processes defined in terms of finite state diagrams. Processing within a SIB is fixed; only the parameters for the processing can be changed.

The node (the MSC or the MSCP) is the parent process. This is a static process that will last throughout the simulation. The primary functions of the parent process are described below.

- Initialisation of the simulation environment is done by reading in data from initiation files and gathering the necessary routing information for the duration of the simulation.

- The node will be in receipt of two types of signalling packets: the packets making the initial request for service and packets in return for requests made by the node in reply to a service process.
- The parent process will need to invoke the correct service based on the initial service request, place the service process on a list of service and pass the appropriate parameters to the service process.
- Each service process or SIB process has a unique process ID. All signalling packets generated by a service or SIB will contain this ID; the reply to signalling messages will also contain this ID. The parent process maintains the list of service and SIB processes and their corresponding IDs. The parent process will forward the signalling message to either the service process or SIB with that ID.
- Each service process is assigned a timer. Each service has a maximum completion time and if the time taken to complete a service overruns this value, the node process will abandon the service, kill the service process and all associated SIB processes.
- The node process also maintains a data collection functionality to collect data on service processing.

The node or 'parent' process can have any number (limited only by the limitations of the machine) of processes running under it.

For each service request, the node process will create a child process, that is the process for the service requested. The service process will create SIB processes or 'grandchild' processes. The service process will pass all the necessary parameters to the SIB process and the SIB process will identify the service process using the parent (service process) child (SIB process) relationship. Figure 5-5 illustrates this.

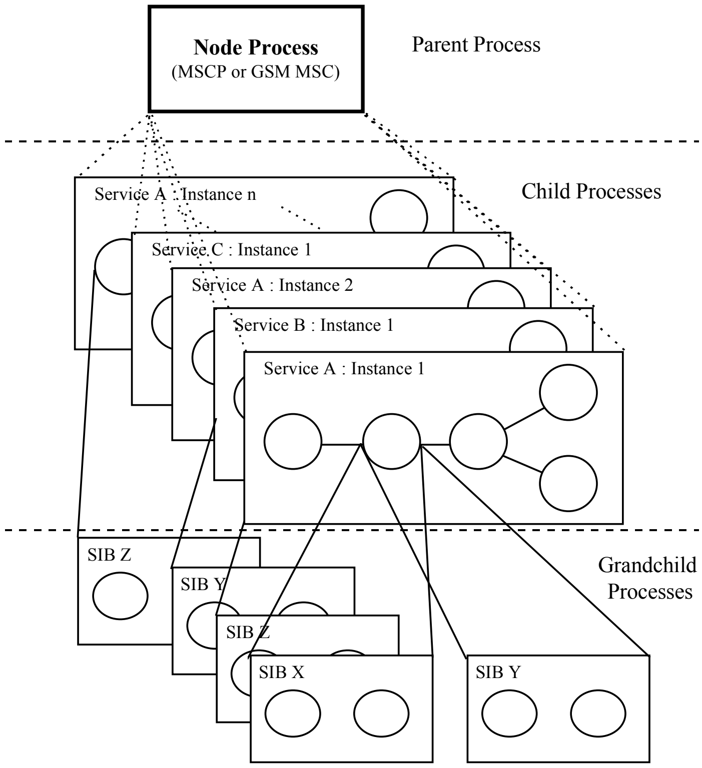

Figure 5-5 : MSCP and GSM MSC node process relationship with service and SIB processes.

5.2.1 DATABASE PROCESSING

In order to simplify the database model, packets sent to databases contain the size of the packet to be returned. The database functionality will compose a reply to the request and set the size of the reply to the specified packet size. Depending on the nature of the request, the database process will send the packet with a delay: read from database requests is 3ms, write to a database is 6ms and delete a record from the database is 10ms.

5.2.2 MODELLING THE SS7 SIGNALLING LINK

A SS7 link consists of the three layers of the message transfer part. A simplified model of the SS7 link is used in the study here with a fixed delay of 1ms [66] assumed for processing at layers 2 and 3. Functionality to monitor the nature of signalling traffic is installed in layers 2 and 3. These include the monitoring of link utilisation, packet loss, arrival rates, interarrival times for signalling packets and packet sizes.

The physical layer may have more than one link, each with a fixed buffer set at the beginning of the simulation. Signalling packets from layer 2 are sent to the link with the most free space in its buffer. Packet loss occurs when the size of the signalling packet exceeds the biggest available free buffer space. The link transmission rate is 64kbits/s and queue service [62, 63] is first in first out. The delays in buffers and in transmission are added to the total delay experienced by the packet. Propagation delay on the link is determined by the length of the link using a value of half the speed of light for propagation over the link. Figure 5-6 illustrates SS7 message transfer part models in GSM and GSM-IN nodes.

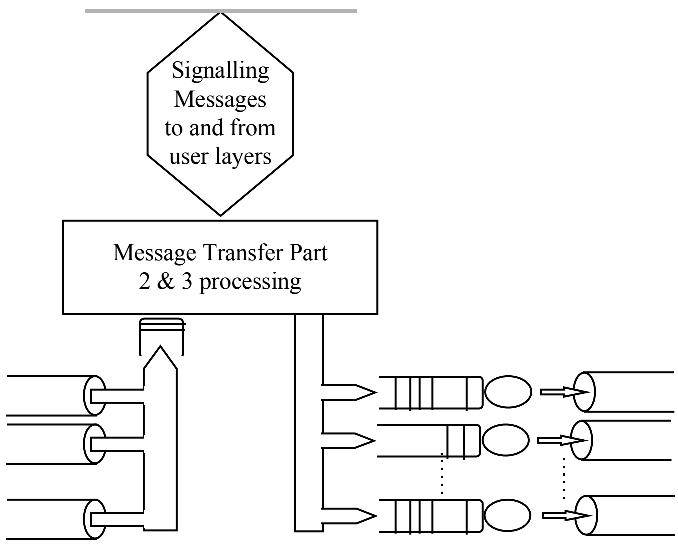

Figure 5-6 : SS7 message transfer part model.

The other part of the SS7 signalling network is the signalling transfer point, responsible for routing and switching of signalling messages. All routing functionality is carried out at layer 3. Furthermore the data is collected on the behaviour of each link into the signalling transfer point.

At the beginning of a simulation, the signalling transfer point will initialise its routing table using routing packets set by nodes attached to it. These packets are then sent to all other nodes attached to the signalling transfer point. As the packets propagate a routing plan of the network is built.

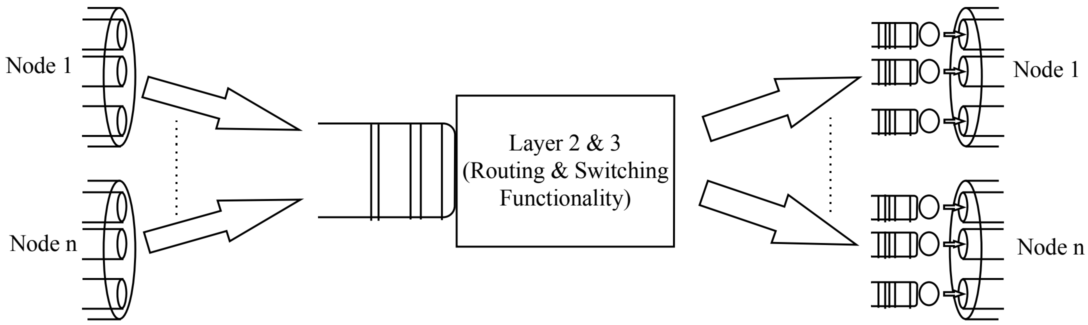

Figure 5-7 : Signalling transfer point model

5.3 MOBILITY BEHAVIOUR

User mobility is modelled using a fluid flow model [60] which derives the rate of user-crossings from an area. This model assumes that the movement of users are not correlated, the direction of movement is uniformly distributed between 0 and 2π and the user density is evenly distributed in the area of interest.

Users are assumed to have a velocity magnitude of v, with f being the probability density function of v. The number of users in an area is given by ρs, where ρ is the user density and s the surface area.

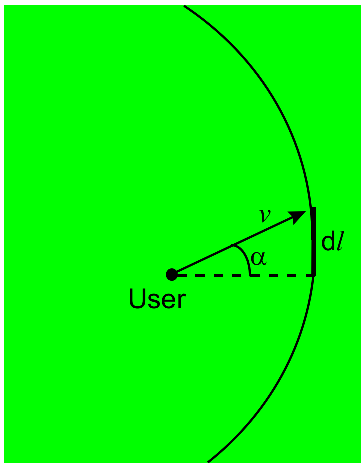

Figure 5-8 : A user with velocity *v*.

Consider a small section of the boundary dl (boundary element) of an area as shown in Figure 5-8. It is now possible to calculate the number of users leaving the area via this boundary element in time dt.

Consider a user with velocity magnitude of v, where the velocity vector forms an angle α with the perpendicular to the boundary element dl. The users crosses the boundary if located in the rectangle of sides dl and v cosα dt.

Therefore the number of users crossing the boundary element is distributed according to the following density,

$$\mathrm{dM}(\mathrm{d}\alpha, \mathrm{d}v, \mathrm{d}l,\ \mathrm{dt}) = \mathrm{f}(v)\,\mathrm{d}v\,\frac{\mathrm{d}\alpha}{2\pi}\,\rho\, v\cos\alpha\ \mathrm{dt\,dl} \qquad (1)$$

$$\mathrm{dM}(\mathrm{d}l,\ \mathrm{dt}) = \frac{\rho}{2\pi}\int_{-\pi/2}^{\pi/2}\int_{0}^{+\infty}\mathrm{f}(v)\, v\cos(\alpha)\,\mathrm{d}v\,\mathrm{d}\alpha\,\mathrm{dt}\,\mathrm{d}l \qquad (2)$$

f(v) is a probability density function, therefore by definition

$$\int_{0}^{+\infty}\mathrm{f}(v)\, v = \mathrm{V} \qquad (3)$$

where V is the mean velocity.

Therefore

$$\mathrm{dM}\ (\mathrm{dl},\ \mathrm{dt}) = \frac{\rho \mathrm{V}}{\pi}\int\int \mathrm{dl\ dt} \qquad (4)$$

Integrating with respect dl for the boundary of a circle will give the circumference L. Therefore rate of crossing out a circular area is given by

$$\frac{\mathrm{dM}}{\mathrm{dt}} = \frac{\mathrm{V}\rho\mathrm{L}}{\pi} \qquad (5)$$

This equation is used for calculating user mobility rates in this study.

5.4 VERIFICATION AND VALIDATION

Having developed a simulation model, the mode needs to be verified and validated. Verification determines whether the model does indeed perform as intended and validation shows whether the model is a true and accurate representation of the system modelled [82]. This needs to be carried out at two levels, the first on a fine scale by looking at individual objects that make up the network and then at the whole network.

The simulation model used some library models supplied with OPNET: the receiver, transmitter and physical link models. In addition to which node processes were developed to model GSM and IN functionality. All library function were verified and tested using purpose built test models.

Although various queueing models were provided within OPNET, these were found to be inadequate to model multiple server queues with individual buffers serving packets from a single source. A queue module [62, 63] was developed that would receive packets from a single source and place the packet into the queue with the largest free buffer for service. This single queue module is capable of modelling 'n' buffers and servers serving a single source. The reason for using a single module is that a single queue module serves a single logical link, even if the link has n x 64kbits/s SS7 channels. This simplified data collection on link behaviour between two nodes.

A modular approach was used. This allowed for each functionality within the queue module to be tested individually and independently. Once it was established that each functionality operated as intended, the complete module was verified using single stepping techniques and recording the state of the system. This showed that the module operated as expected. Furthermore the module was tested against known simplistic mathematical models such as a M/D/1 queue [62, 63, 81], some of the results of which are shown in Figure 5-9 and Figure 5-10.

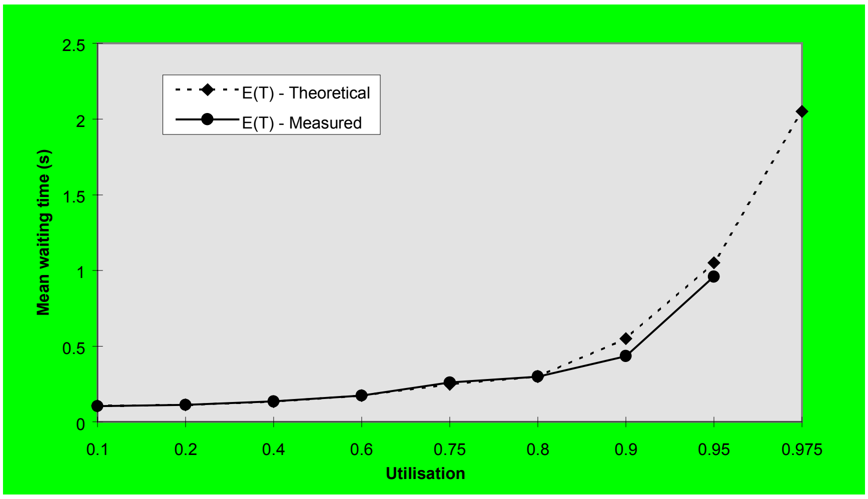

Figure 5-9 : Comparison of simulated and theoretical mean waiting times for a M/D/1 queue.

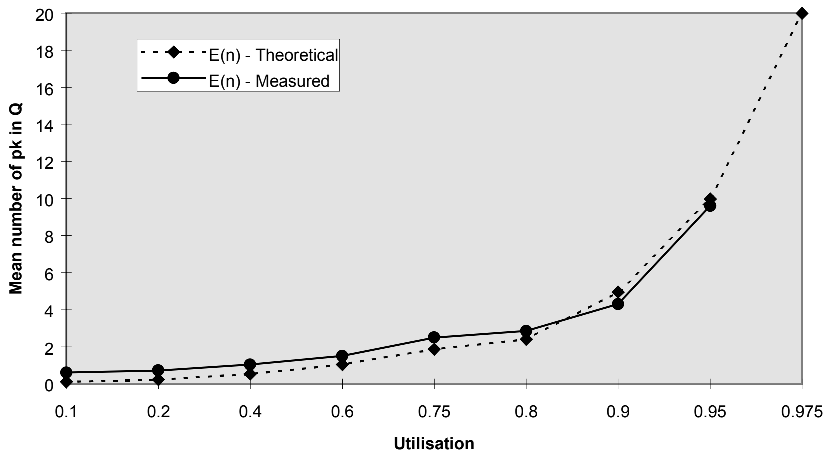

Figure 5-10 : Comparison between the mean number of packets for a M/D/1 theoretical queue and simulated case.

The node processes for GSM and IN functionality was developed in a similar fashion. These were again verified using single step techniques and tested using test modules. Service dependent processing was verified against GSM recommendations to ascertain that the operations and the resulting signalling messages generated were in accordance with the recommendation and so was the sequence in which they occurred.

The next step was the validation of the complete GSM simulation model. This was carried out using measurements made on the GSM network. Ideally the measurements available would have been segmented providing a view of various parts of the GSM network, i.e. data over the radio interface, data over the A and Abis interface. However the data available was taken by driving around London in a car and attempting call setups. The holding times for the SDCCH were noted for call setups. One hundred samples of SDCCH holding times were made and a distribution was found to fit the data. The best fit distribution was a log-normal curve.

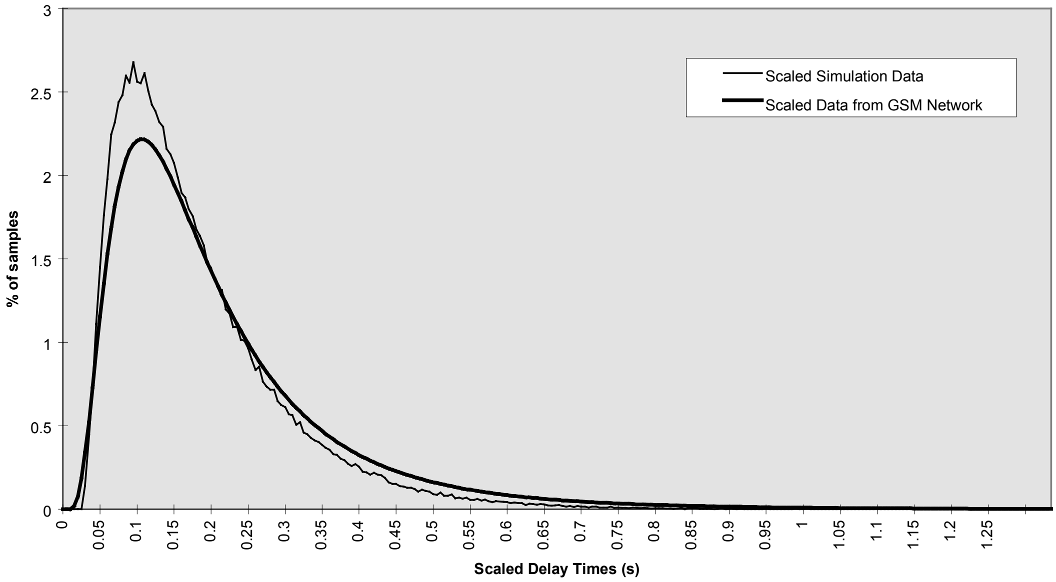

Figure 5-11 : Graph showing the normalised simulation and GSM data for the distribution of SDCCH holding times for mobile originating calls.

The data from simulation and GSM network were shifted (normalised) to the origin to carry out a comparison of results. Figure 5-11 illustrates the good fit between the two data sets, the main difference being the higher peak experienced by the simulation data. The simulation data shown here is for one simulation scenario, in which case the network conditions over the course of the simulation will remain static, so that a clustering of SDCCH holding times would be expected. The real data shows measurements made at various points in the network at various times in the day: therefore, the longer tail and shallower peak are to be expected. If compensation is made for errors induced by the simplicity of the radio access model, the simulated model is a good representation of the actual network.

There is a difference in the mean values obtained from the simulation results and data from the GSM network. Therefore all results need to be scaled by this factor to make then more realistic in terms of delays. The difference in the mean values are: 0.3s for mobile originating calls; 0.24s for location updates; 0.18s for mobile terminating calls.

As a means of secondary validation, the signalling link behaviour was considered. It is well know that signalling traffic in mobile networks is very bursty. On all signalling links in the model, link utilisation measurements were taken every second. The Figure 5-12 illustrates the bursty nature of signalling traffic that was observed.

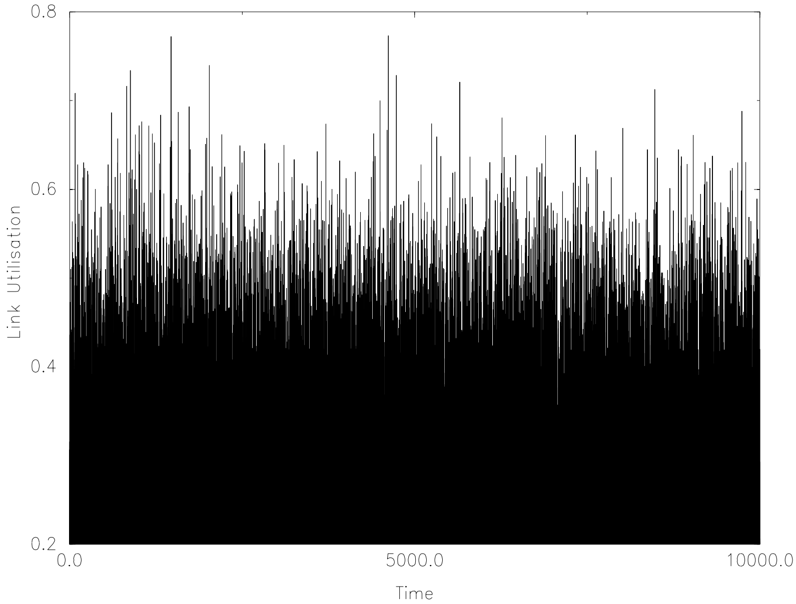

Figure 5-12 : Link utilisation over 10000 seconds

6. ANALYSIS & SIMULATION RESULTS

In the previous chapter simulation models produced as part of this research to investigate the performance of the GSM-IN architecture were described. The focus of the simulations is to investigate the influence of IN architecture on mobility service performance. Mobility performance in GSM will be used as the benchmark.

Several physical architectures are possible for the GSM-IN integrated architecture present in Chapter 4. These variations need to be investigated as different operators will chose the most suitable architectures for their requirements. Each of these physical architectures will generate a different amount of signalling traffic in the core network and hence influence the performance of mobility procedures. The two principal philosophies influencing the physical architectures are oriented towards mobility or intelligent networks. A GSM operator will be likely to tailor the GSM-IN architecture to a mobile environment resulting in the traditional mobile architecture, where the *mobile service control point,* the *mobile service switching point* and the temporary database (MSDPtemp) are co-located on a single platform. If a single control point supports more than one *mobile service switching points*, then the control point is located away from the *mobile service switching points* resulting in a physical architecture more in keeping with the IN philosophy.

A result of combining mobile and IN architecture philosophies is the resulting pseudo architectures, where one has elements of the other. The temporary database (MSDPtemp or VLR) is a mobile network concept aimed at reducing signalling traffic in the core network and improving service provision times. A mobile network architecture without the temporary database is referred to as a pseudo mobile architecture and an IN architecture with a temporary database will be referred to as a pseudo IN architecture. Figure 6-1 outlines the different physical implementations used in the simulation study. An architecture not considered here is when the control point is separated from the *mobile service switching point* but has a temporary database attached to the control point. This architecture may cause contention and future evolutionary problems because an element of an access network (the temporary database) is introduced into the control architecture. For these reason this architecture is avoided.

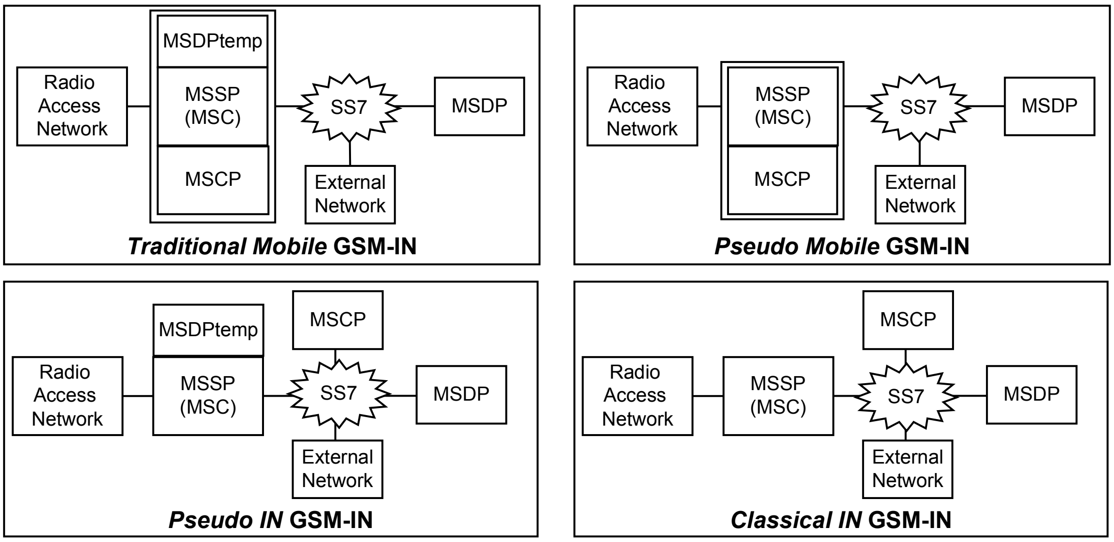

Figure 6-1 : Physical implementations for the GSM-IN integrated architecture.

The results presented in the following sections will be from two sources; an analytical approach to calculating signalling load and the use of simulations for performance measures of mobility services and signalling network.

6.1 SIGNALLING LOAD ANALYSIS

The GSM-IN architecture implements no changes to the radio access network and as such the signalling volume in the radio access network is unchanged for any physical implementation of the GSM-IN architecture. It is the signalling volume in the core network that varies for different physical implementations and hence determines the difference in the quality of service. Any future reference to signalling volume or signalling traffic refers, thereafter, to that in the core network unless specifically stated otherwise. This section will analyse the effect various physical implementations of the GSM-IN architecture will have on the volume of signalling traffic.

The analysis [50, 52, 56] will first involve calculating the signalling load generated by each mobility procedure for different physical implementations using the signalling transactions identified in Chapters 2 and 4. Secondly, the rates at which the procedures are invoked will be identified and finally the total signalling load is calculated.

The signalling volume generated by each procedure is given in Figure 6-2 for the different physical architectures. The signalling analysis in this section is for a network covered by a single MSC and the parameters [47, 48, 58, 59] for which are given in Table 6.1. The variable rates are calculated using the fluid flow technique given in Chapter 5.

Parameter	Value
Area covered by MSC (Circular radius of 30miles)	2826 sq. miles
Number of Location Areas in MSC	Variable
Size of Location Areas	Variable
Number of mobile users covered by MSC (C_{users})	500,000
Average speed of mobile users	5 miles / hour
Average number of Calls to and from a user (C_{call})	1 call / hour
Rate of calls to and from MSC (λ_{call})	139 / second
Ratio of mobile originating calls to mobile terminating calls (P_{mo}:P_{mt})	0.56 : 0.44
Mean call holding time for User(C_{ht})	120 seconds
Average number of Power Ups for User (C_{pu})	2 / day / user
Rate of Power Ups in MSC(λ_{pu})	11.6 / second
Rate of Inter-MSC crossing ($\lambda_{lu\_inter\_MSC}$)	14.74 / second
Rate of Intra-MSC crossing ($\lambda_{lu\_intra\_MSC}$)	Variable
Rate of Inter-MSC handovers ($\lambda_{ho\text{-}inter\_MSC}$)	0.05 / second

Table 6.1: MSC parameters for signalling load analysis

For the GSM network used as the benchmark, the MSC and the VLR are assumed to be co-located keeping with the standard GSM architecture. For entities that are co-located, a internal interface is used and as such signalling between co-located entities will not appear in the calculations. This assumption is used for the GSM-IN architectures and when the temporary *mobile service data point* in the GSM-IN architecture is co-located with the *mobile service switching point*.

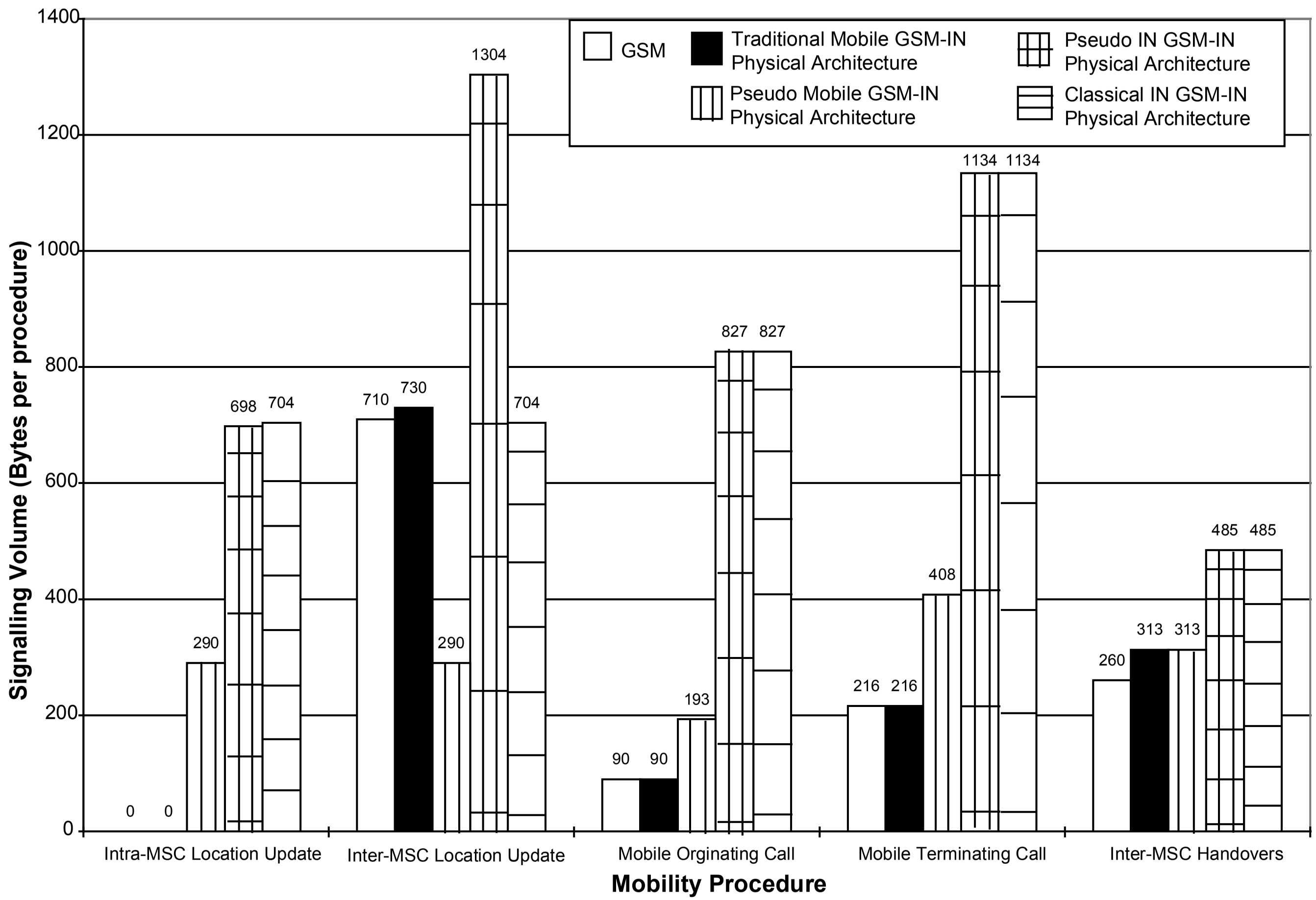

Figure 6-2 Signalling volume generated by different mobility procedures in the core network for GSM and the various physical implementations of GSM-IN.

The total signalling load [54] on the core network (σ_{total}) (per second) is given by

$$\sigma_{total} = (L_{lu\_inter\_MSC} \times \lambda_{lu\_inter\_MSC})(1- P_{in\_call}) + (L_{lu\_intra\_MSC} \times \lambda_{lu\_intra\_MSC})(1- P_{in\_call})$$
$$+ ((L_{ho\_inter\_MSC} \times \lambda_{ho\_inter\_MSC}) + (L_{pu} \times \lambda_{pu})$$
$$+ (L_{mo\_call})(\lambda_{call} \times P_{mo\_call}) + (L_{mo\_call})(\lambda_{call} \times P_{mo\_call}) \quad \ldots\ldots\ldots(1)$$

where P denotes the probability of the event. The signalling volume generated by a user (σ_{user}) per hour on the core network is given by

$$\sigma_{user} = (L_{lu\_inter\_MSC} \times P_{lu\_inter\_MSC})(1- P_{in\_call}) + (L_{lu\_intra\_MSC} \times P_{lu\_intra\_MSC})(1- P_{in\_call})$$
$$+ (L_{ho\_inter\_MSC} \times P_{ho\_inter\_MSC}) + (C_{pu} / 24) L_{pu}$$
$$+ (L_{mo\_call})(C_{call} \times P_{mo\_call}) + (L_{mo\_call})(C_{call} \times P_{mo\_call}) \quad \ldots\ldots\ldots\ldots.(2)$$

Figure 6-3 illustrate the total signalling load generated based on the above assumptions, parameters in Table 6.1 and messages sizes in Figure 6-2, as a function of the number of *location areas* in the switch (i.e. MSC). Similarly Figure 6-4 shows the volume of signalling generated per user per hour.

Increasing the number of location areas within a switch reduces the size of location areas. Hence increasing the number of crossings of location areas boundaries by users. Varying the number of location areas within a MSC does not affect the rate of inter-MSC location updates and handovers as the size covered by the MSC remains constant; only the rate of intra-MSC location updates and handovers will increase. The increase is reflected in both the graphs (Figure 6-3 and Figure 6-4), where the volume of signalling increases with the number of locations areas for all but the traditional mobile architectures (GSM and GSM-IN). For these two architectures intra-MSC location update and handover signalling is contained within the access networks and hence an increase in mobility is not reflected by increased signalling in the core network. The *traditional mobile* GSM-IN architecture generates 1% higher signalling volume than the GSM architecture, as the GSM-IN architecture transfers users supplementary services and mobility data across the network as opposed to just mobility data in GSM.

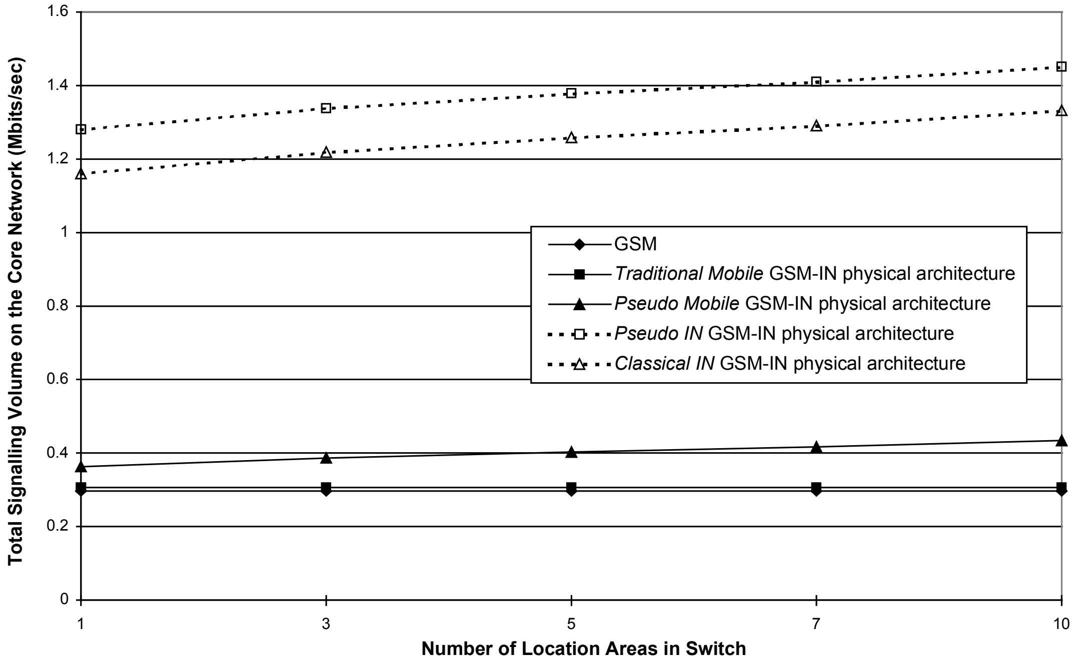

Figure 6-3 : Signalling load on the core network per second for the various physical implementations.

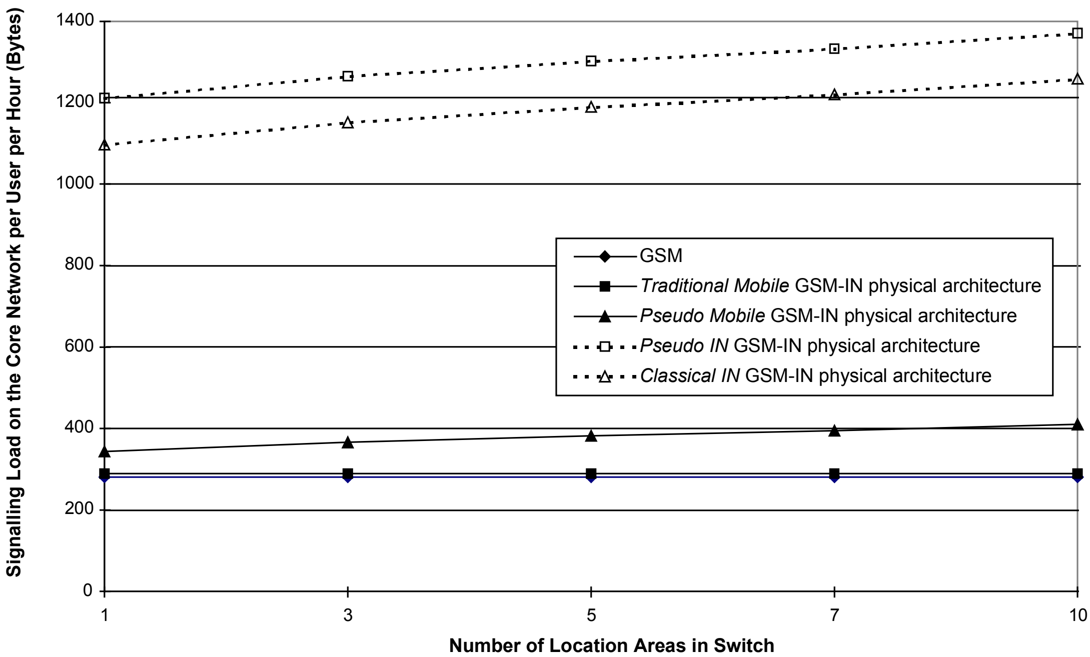

Figure 6-4 : The signalling load generated per user per hour for the various physical implementations.

The lack of a temporary database in the *pseudo mobile* GSM-IN architecture means the permanent database needs to be accessed for intra-MSC location updates. Therefore an increase in intra-MSC location updates will be reflected in the signalling volume. For a single location area the *pseudo mobile* GSM-IN architecture generates 22% more core network signalling than a GSM network and 46% for 10 location areas in a switch. As the number of location areas within a switch is increased, the resulting increase in signalling load is not linear. The rate of increase flattens out as the number of location areas increase. The is to be expected as the user density is assumed to remain constant even when the size of location areas decreases.

Although the increase in signalling in the core network for the pseudo mobile architecture is small, the disadvantage is the greater number of transactions to the users permanent database as shown in Figure 6-5.

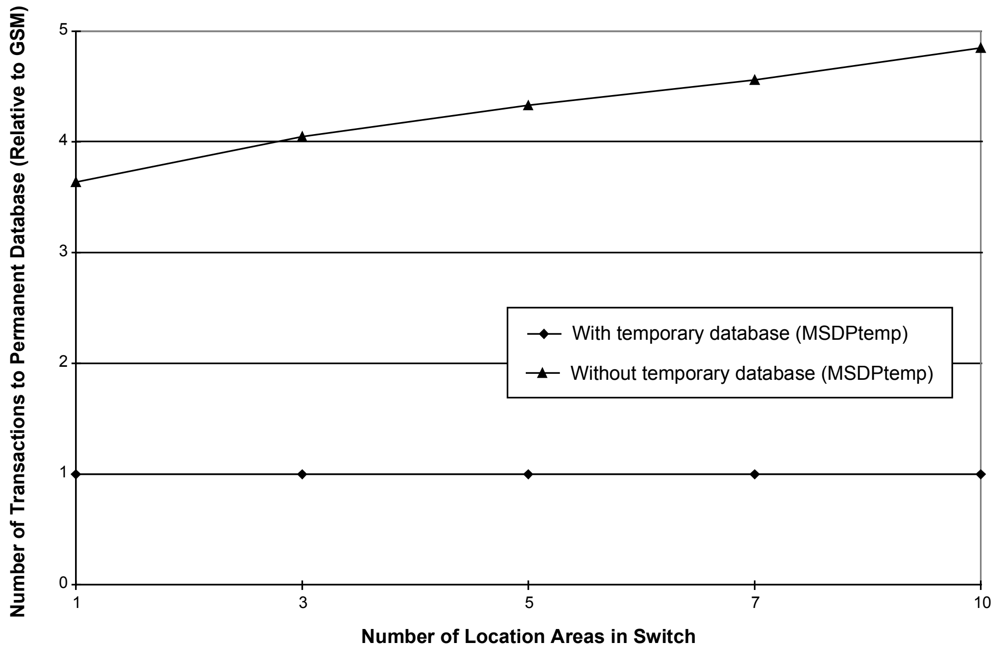

Figure 6-5 : Comparison of transaction to the permanent database per user per hour relative to GSM.

For the *classical IN* and *pseudo IN* GSM-IN architectures signalling volume increases by a factor of 3.9 and 4.3 respectively for 1 location area compared to GSM. For 10 location areas the increase is by a factor of 4.5 and 4.9. The separation of the *mobile service switching point* and the *mobile service control point* in these two architectures accounts for the higher volume of signalling traffic. This is a result of having to transmit each and every control message through the core signalling network. The separation produces a steeper gradient in the rise in signalling volume with increasing number of location areas compared to the *pseudo mobile* architecture. As with the *pseudo mobile* GSM-IN architecture, the rate of increase tails off for the *classical IN* and *pseudo IN* GSM-IN architectures. The *pseudo IN* GSM-IN architecture generates more signalling traffic than the *classical IN* architecture which does not have a the temporary database. This is a result of having to update three databases for an inter-MSC location update when a temporary database is present as opposed to only the permanent database (one) when the temporary database is absent from the architecture. This results from separating the temporary database from the control point, even though the aim behind the temporary database is to reduce the signalling in the core network. It is interesting to note that when the control point and the mobile service switching point are separated, network efficiency in terms of signalling load is superior without a temporary database.

Summarising, the *traditional mobile* GSM-IN architecture generates the same level of signalling as the GSM network, both in total signalling volume and per user. Therefore a *traditional mobile* GSM-IN physical implementation will not detract from the performance of a GSM network. The *pseudo mobile* GSM-IN architecture generates a 35% increase signalling volume on average and only a 46% increase for 10 location areas. Considering the architecture is not fully oriented towards mobility the increase is acceptable.

Both the *classical IN* and *pseudo IN* GSM-IN physical architectures on average generate in excess of a four fold increase in signalling volume compared to GSM. Merely considering the signalling load would suggest that the performance obtained from these two network architectures would be severely impaired. Although the number of signalling links needed to accommodate the *classical IN* and *pseudo IN* architectures will be approximately 5 times greater, this need not detract from the service performance as shown in the next section.

6.2 SIMULATION RESULTS

The simulation models described in Chapter 5 were used to model the GSM network and the four different physical architectures for the GSM-IN architecture (Figure 6-1). The results from these simulation models are presented in this section; these results include the time taken to complete mobility services and the probability of losing a service because of packet loss in the network or because of expired timers as a result of excessive delays in the network. The timers were set at 5 seconds for all services, a realistic figure.

6.2.1 SCENARIO 1

This scenario will serve as a one-to-one comparison between the different implementations of GSM-IN physical architectures. Some of the results will not be 'realistic', because real networks will not operate with such poor quality of service, but this comparison helps illustrate the relative performance of the different physical architectures under similar network loads.

The GSM network is used as the benchmark. The core signalling network was dimensioned for the GSM network to achieve a near loss less network with minimal delays in queues by maintaining link utilisation levels at 30%. The corresponding loads were then applied to all similarly dimensioned GSM-IN networks to analyse their relative performance. The parameters for this scenario are as given in Table 6.1 with the exception of the number of calls to / from a user set at 0.3 calls/ hour. Each node was connected to the signalling transfer point (STP) using 3 x 64kbits/s links each with 16kbit buffers. The GSM and GSM-IN simulation model configurations for this scenario are shown in Figure 6-6.

6.2.1.1 RESULTS FOR SCENARIO 1

A comparison of intra-MSC location update service completion times against the number of location areas in the switch is given in Figure 6-7. These times are relative to the mean intra-MSC location update time for the GSM network with 3 location areas (1.31seconds), as intra-MSC location update procedures occur in GSM only when more than one location areas exists within a MSC. The *traditional mobile* GSM-IN physical architecture takes on average 1% longer than GSM to complete the intra-

MSC location update procedure. As both have identical physical architectures, performance similar to that for GSM is expected. The involvement of the service control point in the GSM-IN architecture and the resulting processing time will account for the 1%.

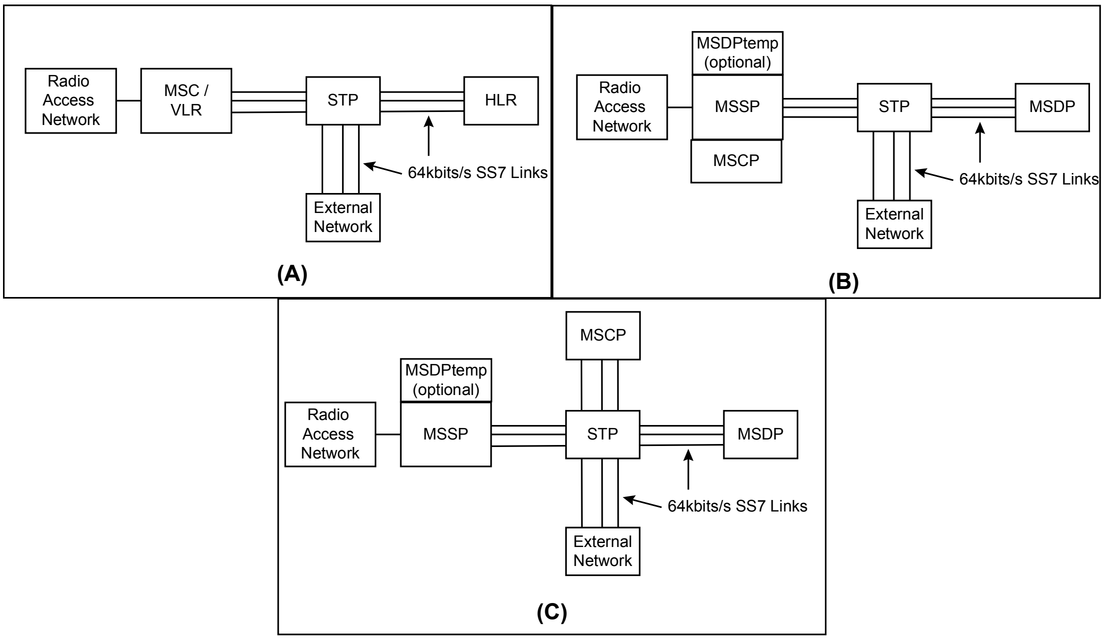

Figure 6-6 : Simulation network configuration for a) The GSM architecture, b) the *traditional mobile* and *pseudo mobile* GSM-IN physical architectures and c) the *classical IN* and *pseudo IN* GSM-IN physical architectures.

Due to the absence of the temporary database in the *pseudo mobile* GSM-IN physical architecture, every intra-MSC location update involves querying the permanent database (MSDP). Hence intra-MSC location update procedures take 14% longer than GSM in the *pseudo mobile* GSM-IN physical architecture. The signalling traffic for the *pseudo mobile* architecture increase with the number of location areas (Figure 6-3) as a result of the increasing number of intra-MSC location updates. The *pseudo mobile* architecture absorbs the increase in signalling traffic without degradation in the quality of service. This can be seen in Figure 6-7, as the delay for intra-MSC location updates remain at 14% for increasing number of location areas. A 14% increase for the intra-MSC location update completion time is quite acceptable, especially since that service is not real-time.

For the *classical IN* and *pseudo IN* GSM-IN physical architectures a degradation in the quality of service was expected, due to the distributed nature of the architecture and the resulting increase in signalling load (Figure 6-2and Figure 6-3). The intra-MSC location update times for the *classical IN* physical architecture show an increase of 155% for 3 location areas and 180% for 10 location areas. For the *pseudo IN* architecture, increases of 125% through to 150% were recorded. These large service completion times are due to the signalling traffic generated by these two architectures (Figure 6-3) exceeding the signalling capacity of the network. As a result, the key signalling links[7] are operating around the 98% utilisation mark, hence resulting in large waiting times in buffers (16k buffer = 0.25seconds on a 64kbits/s link). This explains the large delays associated with the *classical IN* and the *pseudo IN* GSM-IN physical architectures.

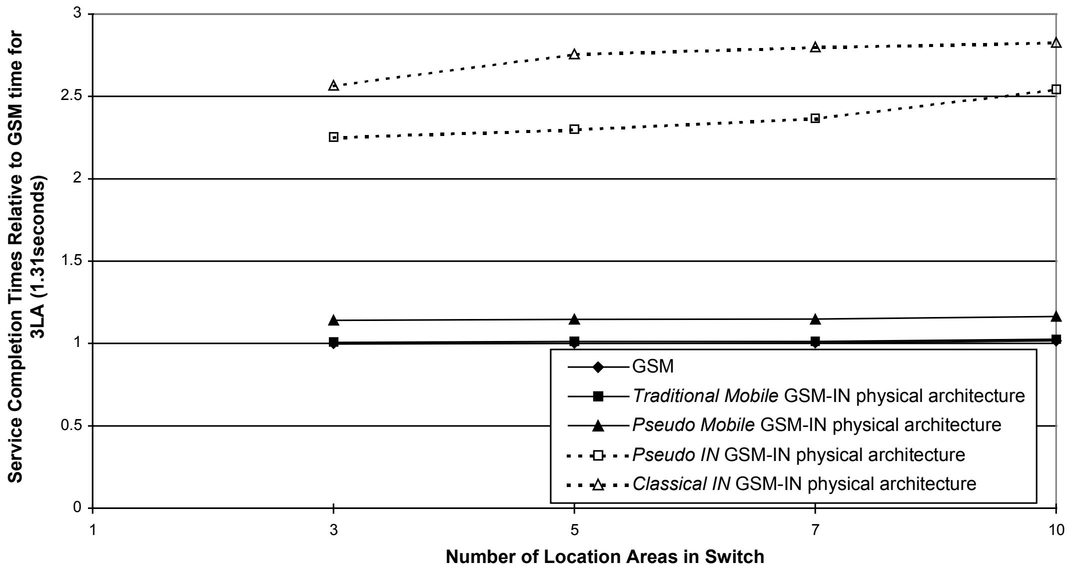

Figure 6-7 : Comparison of intra-MSC location update service completion times.

The signalling volume generated by the *pseudo IN* physical architecture is greater than that for the *classical IN* physical architectures (Figure 6-3) and therefore longer service completion times for *pseudo IN* physical architecture would be expected. In Figure 6-7 this is not the case. The reason for that is: the signalling load for the pseudo IN case concentrated on the MSCP - MSSP link; as a result, the probability of packet

[7] For the pseudo IN physical architecture the key link is between the MSCP and the MSSP. For the classical IN physical architecture the key links are between the MSCP and the MSSP, and the MSCP and the MSDPs.

loss is higher in the *pseudo IN* physical architectures (Figure 6-13) compared with the *classical IN* architecture where the traffic from the MSCP is distributed fairly evenly between the MSSP and MSDPs. When a packet is lost, the service associated with that packet is terminated and hence the service produces no further signalling packets. The higher packet loss in the *pseudo IN* architecture has the net effect of reducing the volume of signalling traffic below levels generated by the *classical IN* architecture. Hence shorter service completion times are experienced in the *pseudo IN* architecture than those of the *classical IN* architecture. This is also true for all other services.

Figure 6-8 illustrates the performance of inter-MSC location update service completion times relative to the GSM time for 1 location area (1.58seconds). The *pseudo mobile* GSM-IN physical architecture shows a 6% improvement on GSM. This is a result of the smaller signalling volume the inter-MSC location update service generates for the *pseudo mobile* physical architecture than for GSM. The GSM and *traditional mobile* GSM-IN physical architecture experience near identical levels of performance. The *classical IN* physical architecture experiences a 19% increase for 1 location area; for 3 location areas or more, the service completion times for inter-MSC increase by over 100%. For 1 location area, the network is able to cope with the volume of signalling generated by the *classical IN* architecture, but for 3 or more location areas, the volume of signalling exceeds the capacity resulting in excessive delays as explained earlier. For the *pseudo IN* physical architecture an increase ranging from 80% for 1 location area to 105% for 10 location areas was recorded.

Figure 6-9, Figure 6-10 and Figure 6-11 show the performance of mobile to fixed, fixed to mobile and mobile to mobile calls respectively. These values are relative to the time taken for the equivalent GSM service with one location area. The general trends observed for the location update services are present here as well. For both mobile to fixed (mobile originating) and fixed to mobile (mobile terminating) the *pseudo mobile* GSM-IN physical architecture generates twice the signalling traffic in the core network as does GSM. This does not result in a two fold increase in the time taken to complete these services, but only a 6% increase. The rate of signalling over the radio interface is approximately 1/64th of the SS7 signalling links and, as a result, even a large increase in core signalling traffic has only a small influence on the service completion times. The relative performance of the mobile to mobile calls are better, because the ratio of radio interface signalling volume to core network signalling is higher, therefore the portion of the delay due to the core network is even smaller. In Figure 6-11 no values are shown for the *pseudo IN* physical architecture or for 10 location areas in the *classical IN* physical architecture because the services took longer than 5 seconds to be completed. This is as a result of excessive delays and packet loss in the core networks.

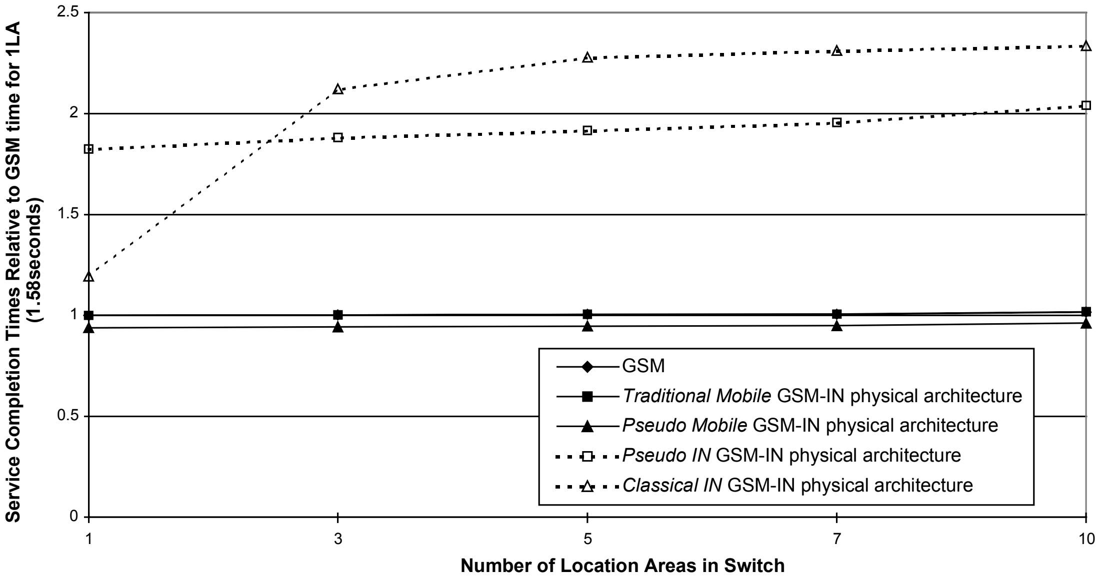

Figure 6-8 : Comparison of inter-MSC location update service completion times.

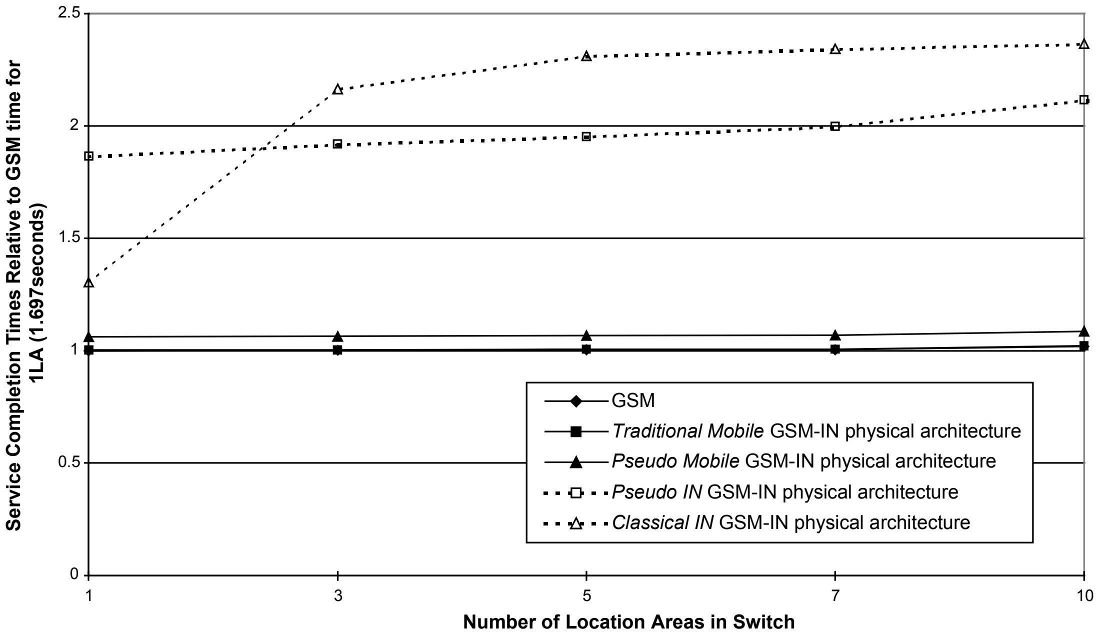

Figure 6-9 : Comparison of call setup times for a mobile to fixed network calls.

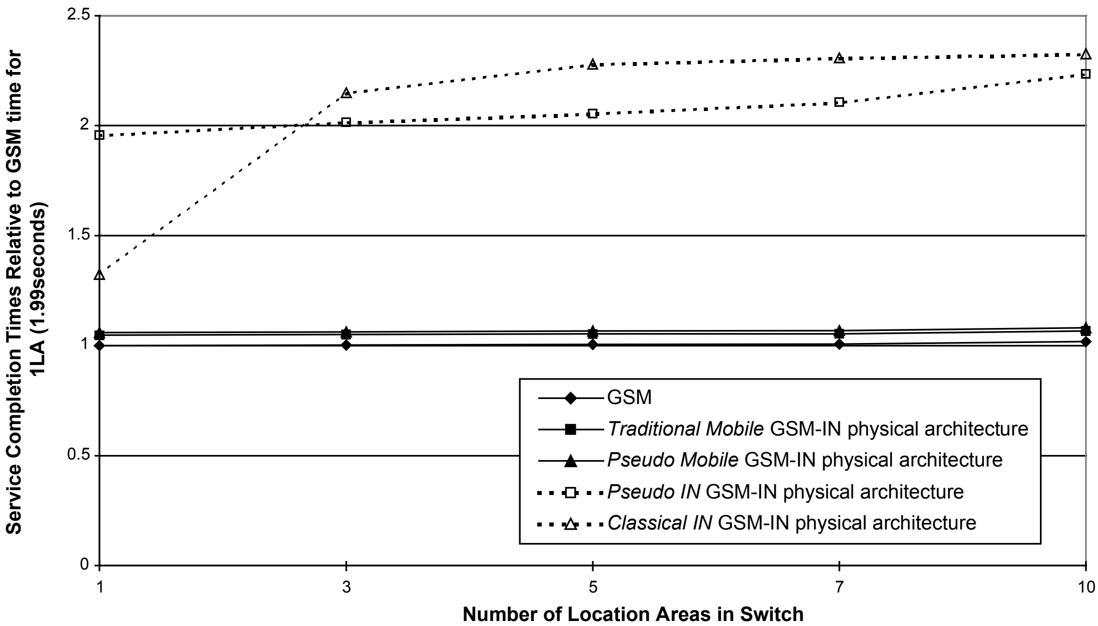

Figure 6-10 : Comparison of call setup times for a fixed network to mobile calls.

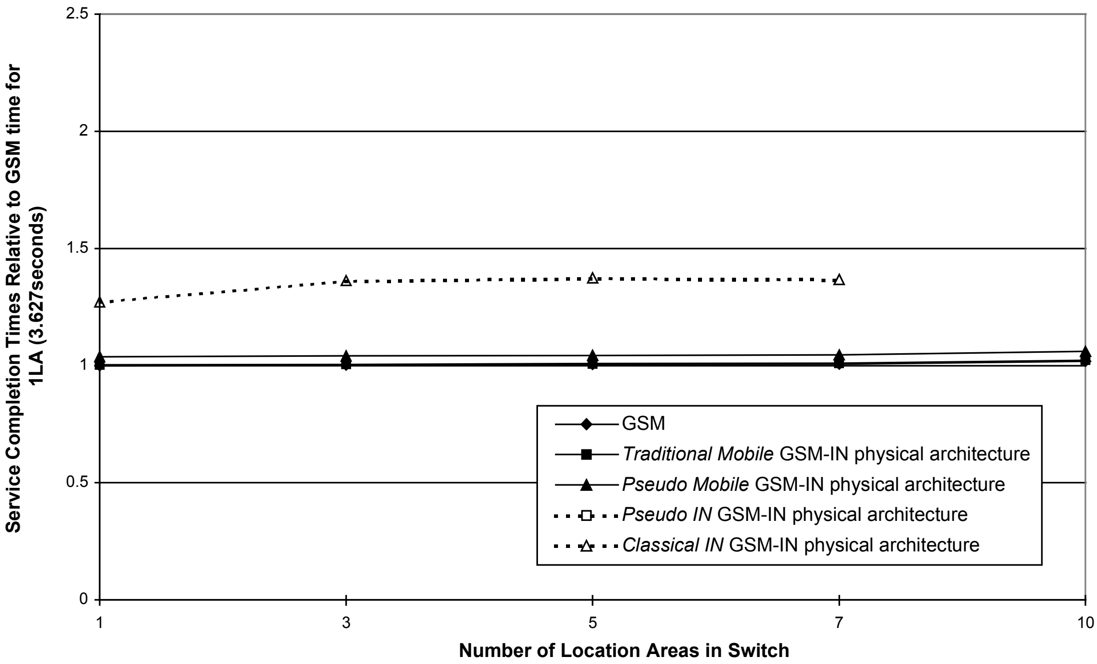

Figure 6-11 : Comparison of mobile to mobile call setup times.

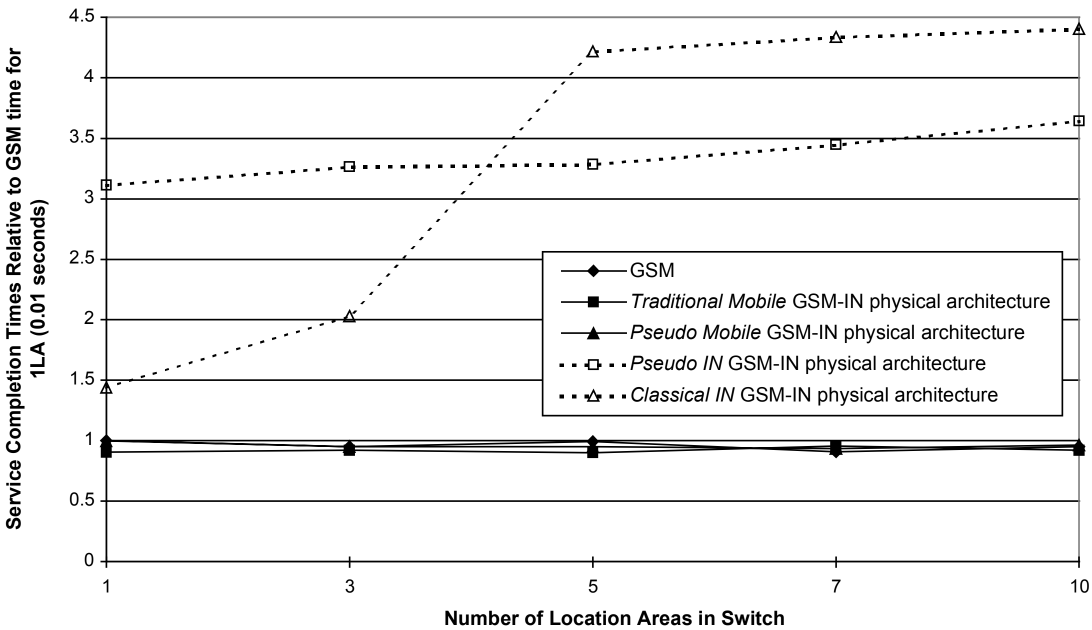

Figure 6-12 : Comparison of inter-MSC handover times.

For the *traditional mobile* and *pseudo mobile* physical architectures, the time taken to conduct inter-MSC handovers is comparable with GSM. As with other mobility services, inter-MSC handovers experience in excess of 2 fold delays for the *classical*

IN and *pseudo IN* physical architectures. The comparison of inter-MSC handover times is shown in Figure 6-12.

Figure 6-13 shows the probability of losing a service either through to packet loss or through the service completion time exceeding the 5 second limit set for all services. For the *classical IN* physical architecture; the signalling capacity is capable of coping with the volume of traffic for 1 location area, but experiences increasing amount of loss for increasing number of location areas in the switch. For the *pseudo IN* physical architecture, the signalling capacity used in this scenario is inadequate and is reflected in the service loss probability. All other physical architectures operate at near loss less levels.

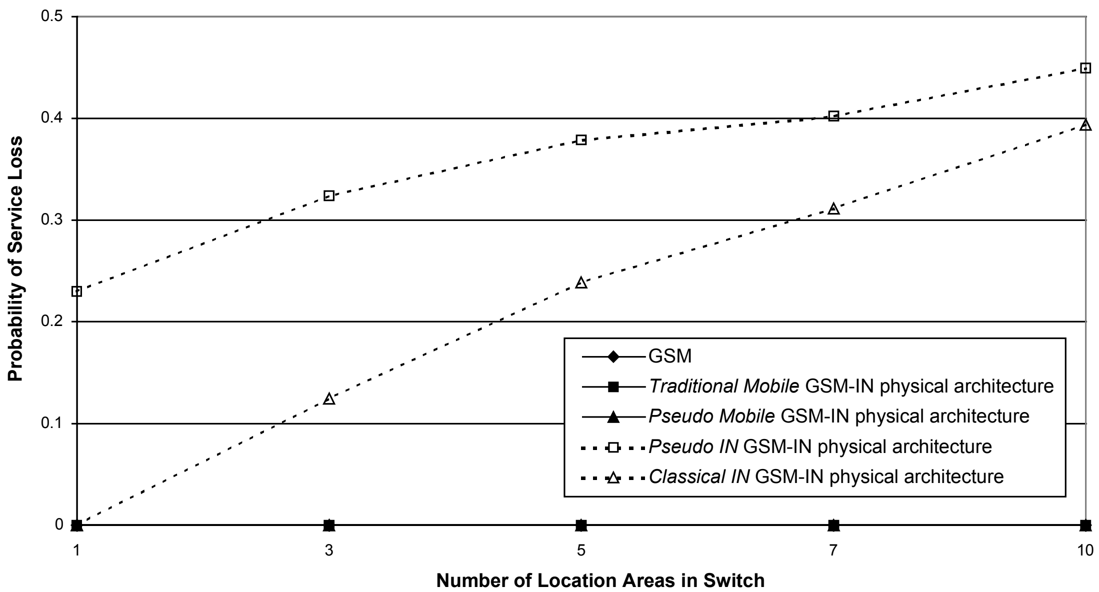

Figure 6-13 : Probability of losing a service due to either packet loss or an expired timer.

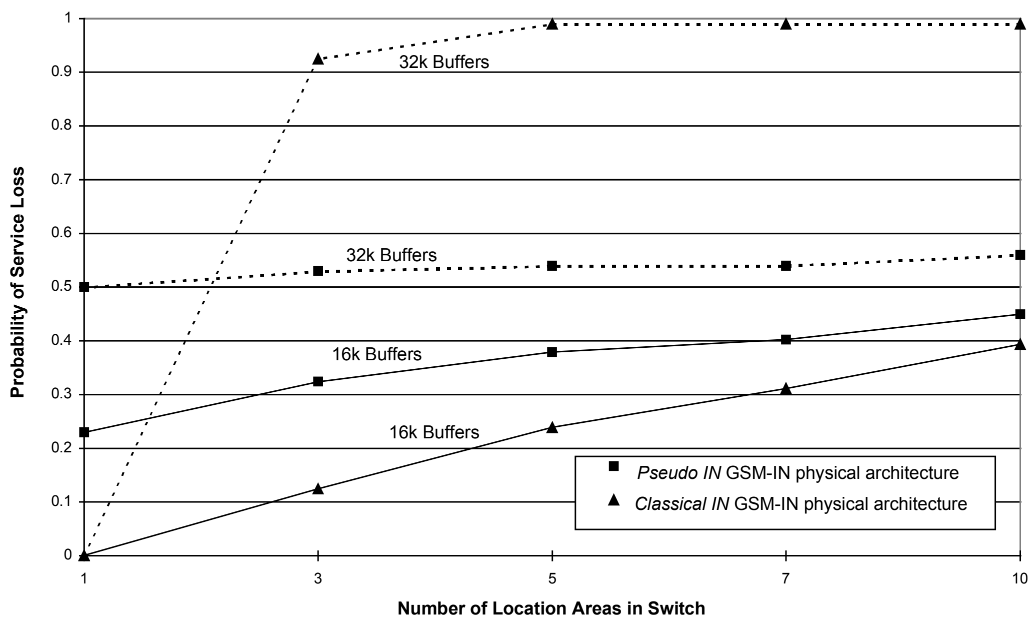

Figure 6-14 : A comparison of service loss probability for 16kbit and 32kbit buffers.

For the *pseudo IN* and *classical IN* physical architectures, increasing the buffer on the signalling links from 16kbits to 32kbits has an adverse effect on the overall performance. The increase in the buffer size reduces the packet loss probabilities, but increases the overall service completion for all services due to the larger buffers and the network running at its full capacity. Therefore, the number of services taking longer than 5 seconds to be completed is far greater and in the case of the *classical IN* physical architectures nearly all services take longer than 5 seconds.

6.2.2 SCENARIO 2

It is known that classical IN and pseudo IN GSM-IN physical architectures generate a greater volume of signalling traffic than the other physical implementations. In this scenario allowance is made in the network's capacity for the increased volume of signalling traffic. Simulation scenario 2 has the same input parameters as scenario 1 and the total capacity of core signalling network has been increased by 66% (from 3 links between nodes to 5 links). Only the two physical architectures (the *classical IN* and the *pseudo IN* GSM-IN) that required the increased signalling capacity are considered here. The results are presented relative to the equivalent GSM service completion time for a GSM network with 3 signalling links (i.e. scenario 1). The graphs also include the results for the two physical architectures from scenario 1 for comparison.

If sufficient provision is made for the higher volume of signalling load generated by the *classical IN* and the *pseudo IN* GSM-IN physical architectures, then the level of performance is quite acceptable as illustrated in Figure 6-15 to Figure 6-20. With the exception of the results for 10 location areas for the *pseudo IN* architecture, all mobility procedures are completed within a range of 5% to 30% in excess of the GSM times. Considering the distributed nature of these two physical implementations, these levels of performance are promising. The deterioration of performance occurs for 10 location areas because the level of signalling traffic approaches even the increased signalling capacity.

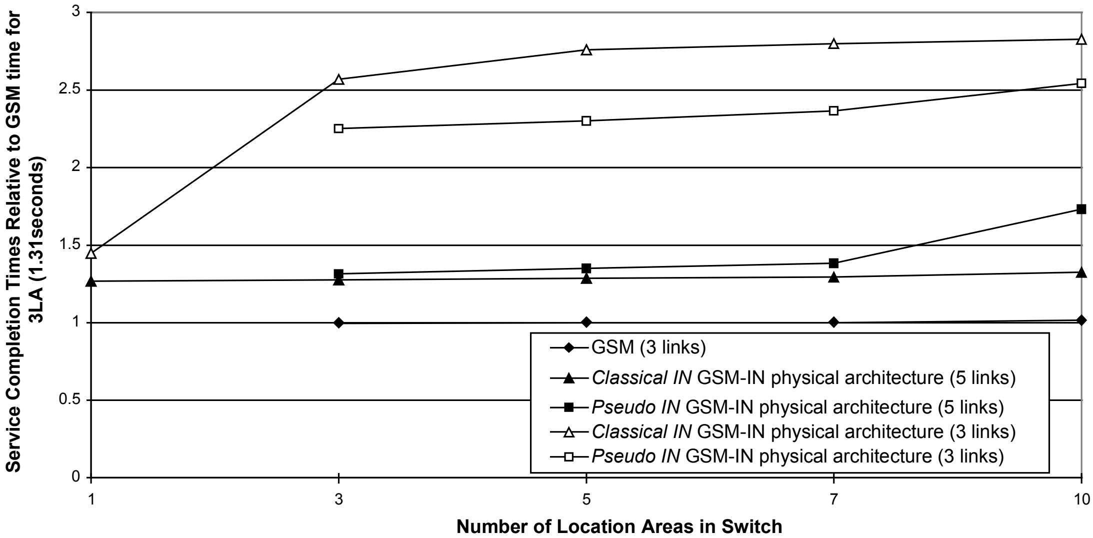

Figure 6-15 : Comparison of intra-MSC location update service completion times for the *classical IN* and *pseudo IN* physical architectures.

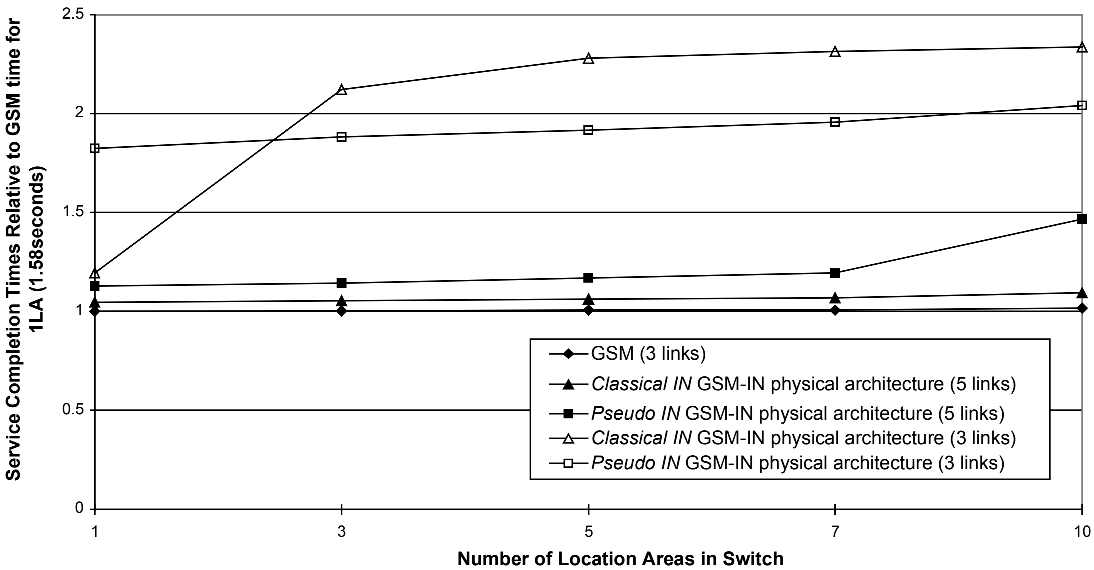

Figure 6-16 : Comparison of inter-MSC location update service completion times for the *classical IN* and *pseudo IN* physical architectures.

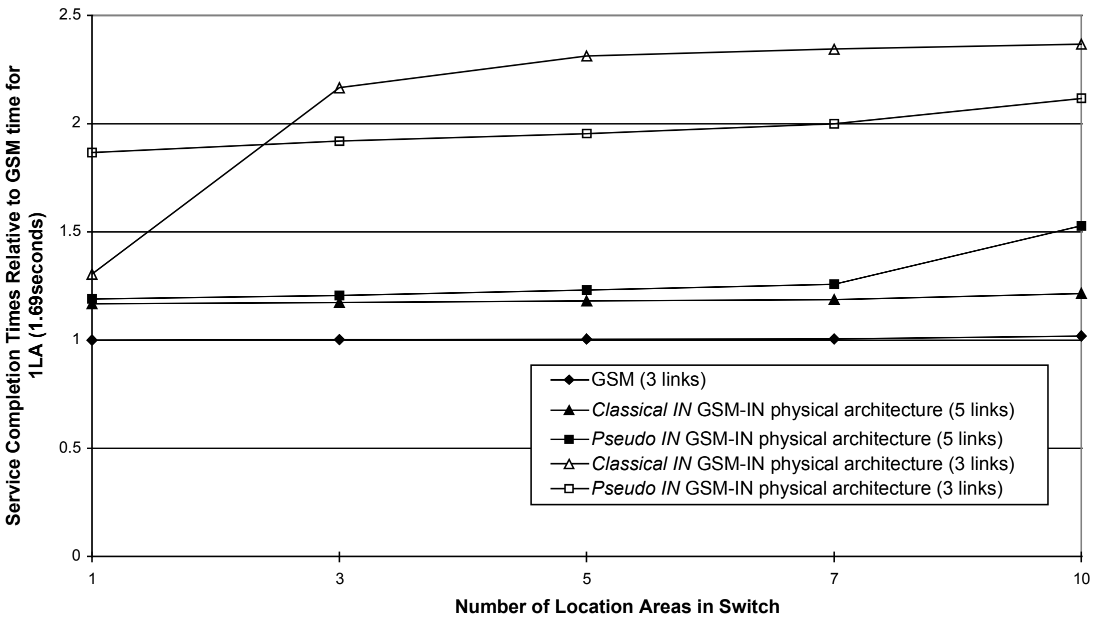

Figure 6-17 : Comparison of mobile to fixed network call setup times for the *classical IN* and *pseudo IN* physical architectures.

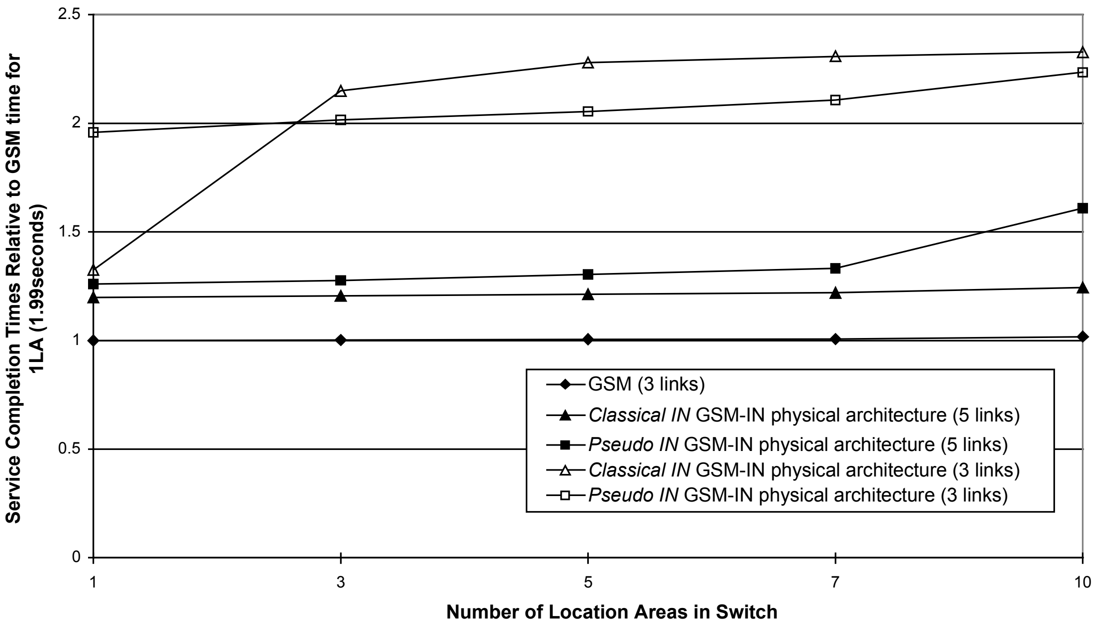

Figure 6-18 : Comparison of fixed network to mobile call setup times for the *classical IN* and *pseudo IN* physical architectures.

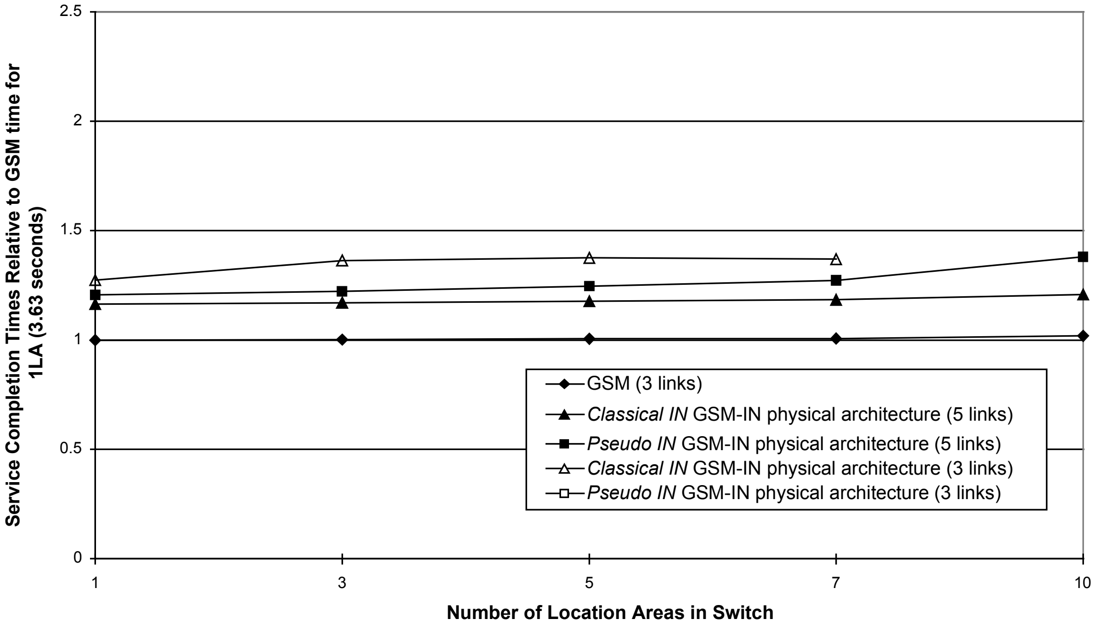

Figure 6-19 : Comparison of mobile to mobile call setup times for the *classical IN* and *pseudo IN* physical architectures.

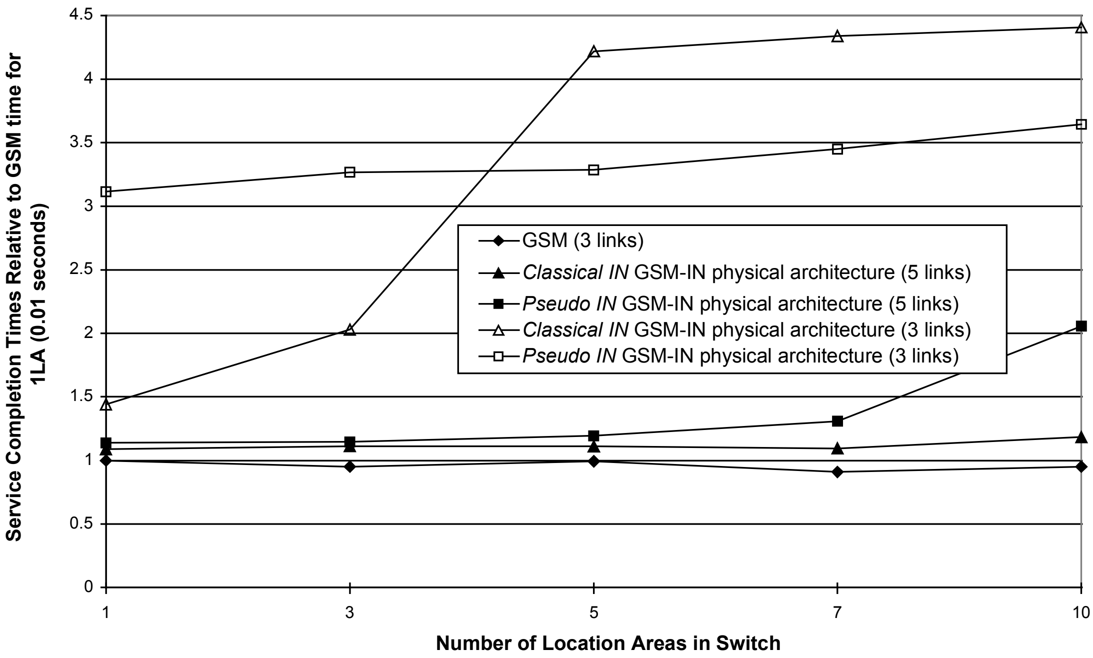

Figure 6-20 : Comparison of inter-MSC handover times for the *classical IN* and *pseudo IN* physical architectures.

6.3 SUMMARY OF GSM-IN PHYSICAL ARCHITECTURES PERFORMANCE

From the results it is possible to make the following comparisons between the types of architectures.

- ***Tradition mobile* GSM-IN physical architecture** : Overall performance on par with GSM.
- ***Pseudo mobile* GSM-IN physical architecture** : Generates 20% to 30% more core network signalling traffic than GSM. Mobility services take 6% to 15% longer to complete than GSM, with the exception of inter-MSC location updates which is quicker by 6%.
- ***Pseudo IN* GSM-IN physical architecture** : If allowance is made for the increased signalling traffic volume; service times are 15% to 30% longer than GSM. The disadvantage is the four fold increase in signalling volume in the core network.
- ***Classical IN* GSM-IN physical architecture** : Generates 10% less signalling volume than *pseudo IN* GSM-IN physical architecture and services take 5% to 25% longer than GSM when allowance is made for the extra signalling volume.

Simulation results have clearly shown for a GSM-IN architecture based on the traditional mobile architecture, performance is identical to GSM. For architectures other than the traditional mobile architecture, different degrees of increase in the core signalling load is found, depending on the architecture. Although today the signalling traffic generated by mobility is greater than that generated by supplementary services, as the complexity of supplementary services increases it may not continue to be the case. Therefore the network architectures may be determined by efficiency of providing services rather than mobility. If this be the case, relatively larger mobility signalling volume might be acceptable. In material of the volume of signalling traffic in the core network, it has been shown the level of performance is within acceptable limits for mobile type network architectures or otherwise.

7. DISCUSSION

The aim of this research was to determine a path for the evolution of GSM to UMTS making minimal changes to the GSM radio access network and to develop an architecture to enable the rapid development of new services in GSM. Since it became apparent that GSM will be the backbone from which UMTS services will be introduced, the evolutionary platform must be more than just a GSM platform for UMTS, but rather a UMTS platform itself. The GSM-IN architecture proposed by the author meets these requirements and has resulted in an architecture that can be considered as a first phase UMTS platform.

First part of the work reported in this thesis establishes the validity of the architecture. The use in the proposed architecture of standardised IN functionality and interfaces ensures compatibility and conformance with existing and future IN platforms. The only non-standard (i.e. new) interface is that between the GSM access network and the IN platform at the *mobile service switching function*. By using an interworking function at this interface, both networks can retain standard interfaces and any incompatibility can be solved by the interworking function. Furthermore, by maintaining a strict separation between the radio access and core networks, the possibility of any conflicts or contentions have been avoided. The result is a trustworthy network architecture that adheres to the standards and solves the current issues of incompatibilities between the two networks.

The mapping of GSM mobility procedures to IN services was the next step in the verification. Unlike conventional MAP (where all mobility procedures are bundled together in a single package) the mobility procedures from the IN platform are offered as a combination of individual "mini procedures". This is because the break-up of MAP allows the relevant components to be efficiently included in new procedures; the complete protocol set, does not have to be included. Furthermore it offers the freedom to alter a single procedure without changing the whole protocol. Therefore, the issue of mapping GSM procedures to IN SIBs needs to be done with care. In a recent paper 'Performance evaluation of IN based mobility management' by *M. Bafutto et al* [51] the methodology for deriving service logic description using SIBs is outlined and a performance modelling approach for IN is also given. This methodology describes the mapping of services from their service description, from which the service logic is derived and then mapped onto the different IN conceptual planes. The resulting functional entity actions and signalling message flows in the physical plane are identified: hence the SIBs are also defined. The same approach is used in this thesis, the service description being derived from the GSM mobility management procedure requirements and the service then mapped on to the different conceptual planes. Following this the functional entities are identified and the signalling flow between the physical implementation of the functional entities are defined. Furthermore, the signalling flows are tied to the GSM signalling flows at the appropriate interfaces. The approach used to map GSM mobility procedures to IN services in this thesis is therefore consistent with the approach presented in the above paper and hence validates the approach used here.

In mapping the GSM mobility procedures, no modifications have been made to the procedures as described in the GSM standards[9]. Adhering to the standards ensures backward compatibility is maintained, at the same time allowing for modifications and improvement in GSM mobility procedures in the future. By applying this approach to mapping, the result is a trustworthy set of GSM mobility procedures offered from an IN platform. Although modifications have been made to some of the mobility procedures to accommodate the changes in the architecture (such as the option not to have a temporary database $MSDP_{temp}$) the procedures have not been changed in principle. The use of GSM's tried and tested mobility management procedures in generating mobility services for IN has resulted in a reliable set of IN mobility services.

Although MAP is a complete package, within the package the sub-procedures are defined in a modular fashion. These sub-procedures were used in identifying the SIBs for the IN procedures, thereby adhering to GSM MAP recommendation (GSM 09.02) in defining the SIBs.

In chapter 5 the simulation models produced in the research were discussed, the results being presented in chapter 6. Throughout the various stages of producing the models, verification was carried out in the form of single step tracing, testing in isolated modules and using models derived using data from the Cellent's GSM network. These steps only validate the operations but not the approach to modelling the GSM-IN network.

The approach taken used to model the GSM-IN is identical to the approach used by Bafutto *et al* [51] for developing a performance evaluation tool for IN networks. The four step approach is:

- performing a flow analysis for IN which yields the signalling exchanges;
- using this to perform a flow analysis for the signalling network and the load on signalling elements;
- performing a SS7 delay analysis;
- using the SS7 delay analysis to perform IN delay analysis.

The difference between the two models is the lack of priority mechanism in the GSM-IN model. However, in the research here, the signalling protocol, message exchanges and flow, have been implemented in a very detailed manner. Using, where possible, data from the Cellnet GSM network as a base for assumptions and to scale and fine tune the simulation model and characterisation of the radio network. This coupled, with the fluid flow technique [60] for modelling mobility, results in an accurate model of the GSM-IN network. This is reinforced by the comparison between the results of the simulation and the GSM network data, described in chapter 6.

To assess the feasibility of the GSM-IN architecture proposed here, it needs to be compared with other proposals addressing similar issues. The aim of this comparison is to establish whether the integration approach meets the requirements of such an integrated architecture and how it compares against other similar approaches. Publications in this area are few, of which most discuss GSM and IN integration in terms of supplementary service integration [26-28, 30] and not mobility or architectural integration. The two papers that have addressed the relevant areas discussed here.

The first by M.Laitinen *et al* have considered the question of integrating IN services into future GSM networks[37]. The paper is based on a project of the European Institute for Research and Strategies studies in Telecommunications (EURESCOM), 'Enabling Pan-European Services by Co-operation of Public Network Operators IN Platforms' (PEIN). The paper proposes two stages of integration as shown in Figure 7-1. The first stage is the addition of *service switching function* and *service resource functionality* to the MSC and the second stage is integration of the HLR with the *service data point*. In both stages multiple signalling protocols are used and MAP is used for all mobility management. The paper does not discuss the integration in any great detail but it does identify; the advantages of the two integration stages, the problems faced with integration beyond the second stage and a 'wish list' for future interworking between the two platforms. These issues were discussed in the paper using UPT service as an implementation example.

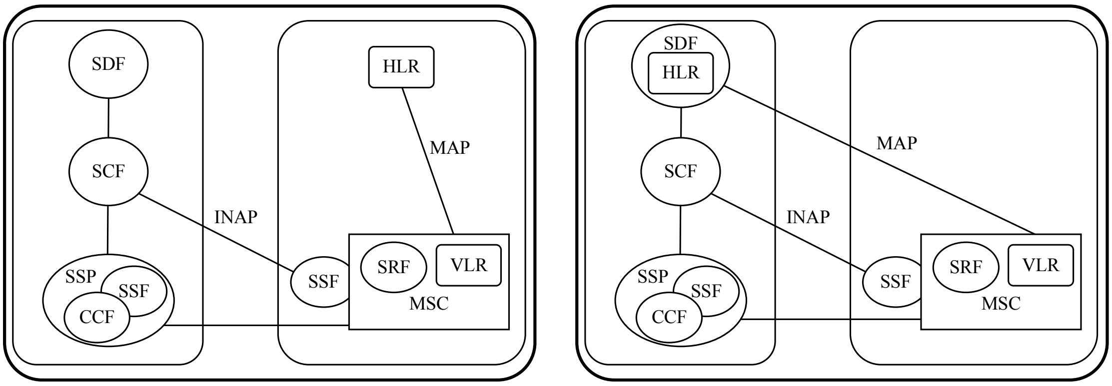

Figure 7-1: Stage 1 and stage 2 of integration.

The paper identifies the lack of a direct signalling link between IN and GSM architectures today and the need to set up a connection for GSM to access IN services. In the first stage of integration this is overcome by adding a *service switching function* to the MSC which provides a direct signalling link to the *service control function*. In the second stage the GSM and IN databases are integrated into the IN database allowing the IN functionality access to GSM mobility data. The GSM-IN architecture proposed in this thesis incorporates both these stages of integration and more. As with stage one a direct signalling link is provided between GSM and IN and furthermore, by the use of INAP for both service provision and mobility management, the need for multiple signalling protocols within the core network is eliminated. However, in the two stages proposed by Laitinen multiple protocols are needed, to allow for the continued use of MAP without any alterations. The disadvantage of that approach is that complete integration is not possible; incompatibilities between the two protocols will continue to exist, mobility cannot be integrated into IN services and the result will be two sets of standards duplicating services. These problems are eliminated by the use of only INAP in the GSM-IN architecture.

In the second stage integration proposed by Laitinen, the databases are integrated such that the IN has access to GSM mobility data from the *service data point* and not *visa versa*. In the GSM-IN approach, by using only IN control functionality for both networks and forming a unified character set, both networks have access to data related to the other. Laitinen points out that if a unified service profile exists, then authentication for IN services like UPT can reuse GSM authentication. This is exactly what the GSM-IN architecture offers.

Laitinen identified a shortcoming for stage one: inter-MSC handovers should be prevented during UPT user procedures. If a UPT service is active at the time of inter-MSC handover, then the *service control function* must be informed of the address of MSC_{new} by MSC_{old}. MSC_{new} will also need to be informed of the *service control point's* address and both MSCs must be enhanced to handle UPT services and posses the ability to exchange user status information. The GSM-IN architecture does not face this problem because all the complexity is taken away from the MSCs: inter-MSC handover is seen as any other service and using the service interaction mechanisms it is possible to determine if the handover service is compatible or not with an existing service or not. Furthermore by having the complexity in the *service control function*, a new service request will be co-ordinated with any existing services so avoiding Laitinen's problems. Furthermore with the 'intelligence' away from the switches (MSC) it is not necessary to check if the MSC_{new} is capable of catering for the service; all that is necessary is that the MSC_{new} is a *mobile service switching point*.

It is possible that two service associated with a call are handled by separate *mobile service control points* (MSCP) or *service control points*. Consider an example where MSCP A sets up a UPT call to a GSM terminal. An inter-MSC handover is required by the GSM terminal, which contacts the MSCP closest to it, MSCP B. Now there are two *service control functions* involved. The co-ordination of services between separate *service control functions* and handover of control is being studied by IN CS3 working group. The co-ordination and handover of control between service control points in a mobile environment is an area that requires further study.

A further issue raised by Laitinen is that new services for IN and GSM will be developed at different times and that one system may not be able to support the new service developed for the other. Furthermore, services developed for different systems may be incompatible or conflict. Assuming that the new service is independent of the access technology, the above problems will not arise in the GSM-IN architecture, because all services will be IN services and the GSM-IN platform will be able to offer all IN services.

As part of the wish list, Laitinen points out that close integration of IN and GSM network architectures, including shared services and subscriber data will allow new kinds of mobility-related IN services. Furthermore, these services can take advantage of GSM subscriber data by accessing it during IN service operations and will have the ability to trigger IN services from mobility management operations and not just from IN call models. The GSM-IN architecture offers all these capabilities plus a fully integrated environment for mobility and IN services.

The paper does identify the challenges associated with charging in a integrated network. Although charging issues are not addressed in this thesis, it is felt that complex charging issues can be resolved by using sophisticated charging SIBs. The advantage of having a modularised approach is the ability to add to the existing system as the required level of complexity dictates.

As the Laitinen paper does not present the methodology behind their approach, it is difficult to make a one to one comparison of techniques. As shown the issues and criteria identified by the paper have been addressed by the approach presented in this thesis.

In the paper 'Intelligent Network Concepts in Mobile Communications' by B.Jabbari[36], two possible integration architectures are identified. In the first architecture, HLR functions (including equipment registry and the authentication centre) are implemented from the *service control point.* The VLR functionality is implemented as an adjunct as high speed transaction processing is required at the VLR. MAP is used as the signalling protocol. In the second architecture, both VLR and HLR functionality are transformed to separate *service control points*, the SCP_{VLR} and SCP_{HLR}. Again MAP is used for signalling between the *service control points* and other network entities.

This paper was published in 1992 and does not address the issues of supplementary services in GSM. Both architectures have been aimed at moulding IN principles to suit mobile network architectures. This is contrary to the approach taken in this thesis where the mobile network architecture is moulded to fit the IN architecture and concepts. The approach in this thesis to mobility is generic and independent of the network architecture which could be mobile specific or otherwise: this is required for UMTS. In Jabbari's paper, replacing the HLR or the VLR with a *service control point* provides a solution specific to GSM-like architectures. The signalling protocol used in both the architectures presented in the paper is MAP but, as pointed out earlier, the continuous use of MAP in an mobile IN environment will lead to the development of two sets of signalling protocols (MAP and INAP), each duplicating the other. This situation needs to be avoided. The paper does not discuss IN / GSM in any great depth or address any further issues on integration. Once again is it impossible to make one-to-one comparison between this thesis and the paper.

The two drawbacks of the GSM-IN architecture presented in this thesis are the increased levels of signalling in the core for any physical architecture different to the traditional GSM architecture and the need to transform the current GSM core network architecture. In Chapter 6, the signalling volume in the GSM-IN architecture was compared with the signalling volume in the current GSM physical architecture. Any physical architecture different from the traditional mobile architecture resulted in increased signalling load in the core network: this is the price to be paid for a versatile and adaptable platform. However, the results showed that this increase in load is within acceptable bounds. The modular approach applied to mobility in this thesis is required as the future GSM network architecture may be very different to today's, because GSM will be used as the backbone for UMTS. For example the influence of computer network architecture in telecommunications networks is ever increasing and the future mobile architecture will be based on distributed processing, where dedicated servers will be interconnected via ATM switches [42]. These servers will be dedicated to functionality such as handover control, mobility management, connection control etc. With such an architecture in the future, the approach used in this thesis is essential as it enables the introduction of distributed processing. Having such a modularised approach enables the introduction of new efficient mobility management and user tracking mechanisms. Although increased levels of signalling volume will result, the benefits of an IN approach outweigh this.

Transforming the existing GSM network to GSM-IN architecture is not something that can be achieved in a single step. The most viable approach will be to introduce *service control points* when new MSCs are introduced or old ones replaced. This can be achieved with the existing network in place, although interworking functions will be required to continue to communicate with existing GSM MSCs and VLRs. These interworking functions can reside either at the *service control point* or the GSM nodes.

An issue not addressed in this thesis is the setup of the shortest path between users for inter-MSC handovers. In GSM, the anchor MSC concept is used, where the setting up of new paths as a result of handovers is only from the anchor MSC onwards. Switching at the anchor MSC might not result in the shortest path between users. For data calls the anchor MSC is the buffering point and changing the route during a handover would need the buffering point to be changed without the loss of data. As a result of this, the question of shortest path after a handover is left for further study.

Handovers in an IN environment pose several interesting challenges. In can be envisaged that inter *service control point* handovers will need to take place. This is a handover in the control plane rather than the transport plane and will involve the transfer of the users switch state and the associated control states. Therefore the area of handovers in the control planes needs to be studied further.

With the IN approach the need for complex handover procedures arise where the it may be necessary to 'handover an active service' as well. The issue of transferring the service status from an old switch to a new switch when a handover takes place has not been addressed in this thesis. For an example, GSM user A is engaged in call to party X and has party Y on hold using the call waiting service, suppose then the GSM terminal requires an inter-MSC handover. In this case a radio channel has to be allocated for the terminal in the MSC_{new}, two lines will need to be setup from MSC_{new} to the switching points for calls X and Y (which may or not be different) and the state of the switch in MSC_{old} has to be transferred to MSC_{new} prior to the execution of the handover. The FIM will have to check the status of active services, before a decision on the complexity of the handover procedure can be made. The handover capability covered in this thesis is for the basic call inter-MSC handovers and the transfer of service status is not included in the handover procedure defined. This area is marked for further study.

In chapter 4, the limitations of using the CS-1 BCSM in a mobile environment were identified and the thesis suggests the use of an enhanced version of the existing triggering mechanism and a service status monitor in place of the BCSM. The BCSM needs to be replaced because services are invoked in the absence of a call in mobile telephony and under these conditions a BCSM does not exist and parallel execution of service control are required in mobile networks, which is not supported by the sequential processing of CS-1 BCSM. Although the use of an enhanced GSM triggering mechanism and service status monitor are suggested, details of its implementation have not been defined here. It may be necessary to combine the triggering mechanism and status monitor to form a service state model whenever a service is invoked. Therefore, the service state model will exist even if a call is not present and if a call is present, the service state model will become a call state model capable of handling simultaneous execution of services. However, the concept of a state model appears to be too rigid for such a applications and a preferable solution lies in a more flexible approach to service triggering and status monitoring. The use of a more 'intelligent' service model needs to be investigated.

As mentioned earlier the UMTS core network control is based on the IN architecture. The introduction of UMTS is expected to be in islands feeding into the GSM backbone network with GSM continuing to offer umbrella coverage under which a multiplicity of different radio access networks will operate. By having a generic control platform (IN) each access network will be able to interwork with the other. As GSM will be the backbone in the initial phases of UMTS introduction, it is essential that GSM has a suitable control platform for interworking with other access networks and one which will evolve to be the UMTS control platform.

This evolutionary scenario has been the rational for the work of this thesis.

8. CONCLUSION

Intelligent Network is a concept introduced to enable the rapid creation and deployment of services in telecommunication networks, by the separation of service provision from call and bearer control (i.e. the switch). This is achieved by the *Intelligent Network Conceptual Model*, which provides a clear understanding of the intelligent network concept. The advantage of which is, it is implementation independent and hence independent of the access network the service is offered in. Intelligent networks are widely used in fixed networks and will be used in the UMTS core network. Mobility in UMTS will be provided as added intelligence from the intelligent network UMTS core platform. Furthermore, the intelligent network core will facilitate the convergence of fixed and wireless networks.

The GSM-IN architecture presented in this thesis which integrates GSM and IN networks as a step in the GSM evolution to UMTS, was shown to meet the requirements of such an architecture. Furthermore, the techniques used to implement GSM functionality on IN platforms has been validated against known service derivation techniques and backward compatibility with GSM has been maintained. The GSM-IN architecture has also facilitated the rapid creation and deployment of supplementary services in the GSM network; and the environment to integrate mobility functionality with supplementary services.

It was shown for a GSM network, replacing the core network with an intelligent network (traditional mobile physical architecture) results in no degradation in the quality of service offered and signalling traffic levels were of a similar level to GSM. A change in the physical architecture away from traditional mobile architecture did result in an increase in the core network signalling traffic, but the quality of service as perceived by the user remained comparable to GSM.

In comparison with other methodologies for integrating GSM and IN, this thesis offers the advantage of a modularised GSM protocol (i.e. modularization of MAP). This makes evolution and integration easier for the GSM network as the modules are more manageable than the complete set of MAP protocols. It also avoids having the complete set of MAP protocols on every node involved in a MAP transaction as it currently is in GSM. Furthermore by using a single protocol within the core network, the complexities of running two protocols simultaneously are removed.

This thesis aimed to investigate the feasibility of a concept (offering GSM mobility procedures from an IN platform) and has demonstrated its viability both in-terms of performance and implementation. In the process several issues that need to be resolved to enable and optimise the integrated scenario have been highlighted. Issues such as; improvements to the call state models to cope with out of call and services executed in parallel; improvements to the features interaction manager to cope with the large number of services and increase complexity of services; handover of service logic between service control points; and optimisation of the route to the new MSC after an inter-MSC handover. Some of these issues are for further study, while studies are underway on others.

This thesis has described in detail an architecture for integrating GSM and intelligent networks, and the implementation of GSM mobility functionality from the integrated platform. This method has enabled the evolution of GSM to UMTS and support the full potential of UMTS, which may otherwise have resulted in an evolution to support only a limited set of UMTS capabilities due to the limitations of the current GSM network. This integrated architecture has also provided the opportunity for fixed network operators with intelligent networks to operate a GSM access network.

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