CHAPTER 2

LITERATURE REVIEW

This chapter reviews the literature that is related to the work done as part of the thesis. The review includes literature on GSM architecture as that is major focus of the work done in this thesis. It also includes literature specifically dedicated to MSs and base stations. The most important issue is routing. Efficient routing of calls directly impacts the network’s overall performance. Hence, research work done in the area of routing algorithms is also covered in this chapter. There were several constraints with current GSM networks with GPRS/EDGE where 3G is not yet rolled. The major constraint is bandwidth. Due to low bandwidth, potential applications with huge social relevance are put on abeyance. So, the review also covers literature related to 3G. There are several applications that were developed for GSM networks. Some of such applications were also reviewed.

2.1 GSM Architecture

A large number of issues related to GSM were discussed by [Rahnema M., 1993]. It provides terminal mobility into the GSM network. Personal mobility is achieved by insertion of SIM. It also discusses cellular mobile communications, cellular network infrastructure. Also, discussed are network databases and standards specifications. Issues related to mobility management, call routing and signalling, numbering plan, radio channel structure, protocol layering architecture and signalling transport protocols of GSM networks were given in [Rahnema M., 1993]. The advantages and challenges of HLR of GSM were discussed by [Gabelgaard B., 1994].
GSM network consists of a centralized database called HLR. It includes data of subscribers. When subscriber is in roaming mode, the data of respective subscriber is copied to the remote database of the roaming network. Due to mobility, there is tremendous transaction processing load on the HLR. Using internet mobility and QOS enhancements, an integrated QOS architecture for GSM networks was discussed by [Mikkonen J. et al., 1998]. Using new GSM packet and HSCSD features, the elements required for integrated QOS architecture including their functionalities and interfaces are discussed by [Mikkonen J. et al., 1998].

By minimising the signalling load generated by the inter-segment location update procedure, [Zhao W. et al., 1997] designs an optimised GSM satellite integration system architecture. For various integration levels, dual mode mobile terminal location management scenarios are introduced. A solution to the base station placement problem was proposed by [Larry Raisanen, 2008]. To ensure that the traffic hold requirements are satisfied, base station sites are dimensioned only once. The maximum set of service test points that can handle without exceeding a hard traffic constraint is determined by it. Then, the ability of binary and permutation-coded evolutionary strategies to find minimum set cover are compared with each other. Three realistic GSM network simulations are engineered to test this approach by it.

A single chip GSM/EDGE transceiver solution for realization inefficiencies of conventional transmitter architectures was presented by [Hadjichristos A., 2003]. An architecture was proposed and performance overview of a highly integrated single package radio module for dual mode EGSM900/GSM1800 applications was done by [Ngompe E. et al., 2003]. All Radio Frequency (RF) functions required for the dual band GSM application are handled by this module.

The implementation of an architecture that is network based for mobile services that are seamless that support the full range of applications using devices that
interface to both GSM and Wi-Fi networks was discussed by [Kalmanek C. et al., 2006]. This solution provides solid migration path to full IP-based multimedia services which leads to provision of advanced functionality to existing cellular devices. The solution is based on interfaces and systems that are network based thus providing a multi-network capable scalable solution. The solution will have a unified service experience from a single device to the user. A5/3 encryption algorithm is more secure than A5/1. Some networks use A5/3, some use A5/1 and some don’t use any encryption algorithm.

2.2 Mobile Stations

The issues related to finding of location of radio emission source using MSs and Field Strength measurement [Anatoly Rembovsky et al., 2009]. Additional random component ensemble caused by the reflections from local objects is included in the electromagnetic field received by the direction finder under urban conditions. This increases the complexity of the problem. The random component includes diffraction, topography irregularities, tall structures, huge structures that are made of various materials, automobiles, electric transmission lines etc. The summary field will randomly change as these components have random amplitudes and phases. When the received signal level changes relative to some average value, the varying interference pattern will be observed at station movement.

An algorithm that uses probabilistic approach to find the location of a MS was presented and analysed by [Mirjana I. Simic et al., 2009]. Data in the form of two-dimensional probability density functions provided from various sources is collected that helps in determining the location of MS. Combining the probability density functions into a joined probability density function is addressed by it. A method to limit the space of a possible location of the MS to a rectangular region of the minimal size is presented to provide computational efficiency.
Probability density functions are reduced to matrices of probabilities due to performance of discretization of space. The algorithm for combining the probability density functions is adjusted for an application with the matrices of probabilities. Probability density functions of the exclusion type, taking only two values, zero and nonzero are introduced providing savings in storage space and computational time to reduce the computational complexity. Information about the timing advance parameter value and the received signal level are interpreted by probability density functions of the exclusion type. Two sets of measurements performed in an urban and a suburban region illustrate the application of the algorithm.

The channel sounder measurements at 890MHz in a dense urban environment where the receiver was located at the MS site were analysed by [Alexander Kuchar, 2006]. A serious study of the main propagation mechanisms is enabled by the joint information on delay, azimuth and elevation. According to it, there is a clear indication that street canyons dominate propagation in a dense urban environment. The results in it corroborate the hypothesis of multiple reflections/diffractions in urban macro cells.

In [Dong-Jun Lee et al., 2002], based on the derivative and correlation properties of received wave envelope in additive noise and Rayleigh fading channel environments, the speed of a MS is estimated. The effects of noise and nonzero sampling interval on the accuracy of the speed estimation are derived. A method to correct the estimation errors due to noise and sampling interval is also proposed by it. The speed estimation using level crossing rate and the method proposed are compared. When there is background noise, the proposed estimation method for speed of the MS is showing better performance than the method using the level crossing rate.
The communication mechanism for protocol handling in a MS being used for the pan European digital mobile network was discussed by [Rudolf Jager, 1992]. The specification as well as development of the protocol stack for a MS is done using Specification Description Language (SDL). The real time inter process communication mechanism employed to meet time constraints imposed by the application is emphasized. An example to discuss the properties of the employed SDL based real time system was given by it.

A new paging strategy in which the paging sequence in a location area is optimized according to both the location probability of a mobile terminal and the paging load distribution among the cells was introduced by [Dong-Jun Lee et al., 2006]. It also proposes a simple polynomial-time heuristic algorithm to determine sub-optimal paging sequence. It also demonstrates that the strategy proposed outperforms the conventional paging scheme with respect to a paging delay.

The improvements obtained from analysis of the GSM communication network, architecture of the specialized environment, and descriptions of GSM handset voice qualities and coverage areas were indicated by [Yu Duan et al., 2004]. By arranging suitable network coverage and analysing the speech coding will lead to improvement in voice qualities and coverage areas for GSM handsets. Instantaneous radio interference is deduced due to the operation of GSM system in a discontinuous transmission mode. A background acoustic noise is introduced to by a comfort noise subsystem to compensate for the annoying switched muting that occurs due to discontinuous transmission mode. When mobile users are communicating with each other, improvement of voice qualities and network coverage is evident as indicated in it.
2.3 Base Stations

An algorithm that was implemented using which the broadcast data of base stations of GSM networks can be received is given by [Manelis V.B. et al., 2009]. The data enables to obtain identification parameters of base stations as well as analyse the mutual interference effects. It also presented the case study of the analysis of frequency channels in the 900 MHz band at the fixed point of industrial centre.

The problem of power management from multiple agent perspective has been tackled by [Philippe Leroux et al., 2009]. It was done in the context of a wireless network comprised of distributed base stations using macro diversity. Efficient use of macro diversity resources and high energy efficiency when compared with traditional algorithms is the result of proposed design.

The power control mechanism is completely decentralized, while avoiding direct information exchange or excessive signalling, which makes it highly scalable. Its auto-configuration property enables higher adaptation when experiencing high or low interference levels. The auto-configuration property is due to its multiple agent perspective. Low cost electronic implementation has become practical as the impact of auto-configuration property lead to a naturally balanced resource usage, while also maintaining nearly full efficiency with only a reduced set of discrete power levels.

In IEEE 802.16e, Fast Base Station Switching (FBSS) is a significant handover mechanism [I-Kang Fu et al., 2008]. Today’s mobile WiMax technology is the Orthogonal Frequency Division Multiple Access (OFDMA) of IEEE 802.16e. When compared to hard handover and macro diversity handover, the handover performance in FBSS is better due to use of one radio link connection and multiple network connection for user of handover. A FBSS with reuse partitioning cell structure to improve the performance was proposed by [I-Kang Fu et al., 2008]. The packet loss rate of FBSS was reduced by a ratio from 38.33 to 84.08% at a slight
expense by reserving some of the radio resource for use of high reuse factor and using that radio resource to accommodate those handover users with bad radio link performance.

The Smart Universal Beamformer (SUNBEAM) project which focuses on software radio and smart antennas was summarized by [Joel Thibault et al., 2002]. The most important techniques that were used in the SUNBEAM were digital smart antennas. Digital smart antennas techniques lead to performance improvements in transmissions in the era of 3G. The benefits of following the software-radio idea in the design concept of base stations were outlined by [Wolfgang Konig et al., 2002]. It also outlines be limitations of usage of the technology. The benefits and limitations were discussed from the perspectives of both the manufacturer and mobile network services provider.

In a communications receiver, channelization is the task of channel selection [Tim Hentschel, 2002]. During channelization, down conversion of the signal to base-band as well as channel filtering takes place. Large number of channels are received in parallel in base stations. This task is accomplished by employing separate channelizers for each channel. A technique where in filter banks are employed was proposed by [Tim Hentschel, 2002]. The advantage of this technique is that effort is reduced as necessary filter is implemented only once for all channels. It compares both the techniques with respect to their multiplication rates. While demarcating a geographical area into cells, a number of factors are to be considered. They include terrain, distribution of traffic, required height of antenna for the base stations, frequency etc. These factors are to be assessed keeping in view of the QOS requirements, power control types, maximum output power of transmitters etc. Base stations should be installed in such a way that optimal number of base stations are assigned to them.
The issues related to optimization of base stations positioning in Mobile networks were discussed by [Surgwon Sohn et al., 2006]. In 3G WCDMA uplink environments, it presents a constraint satisfaction problem model for the location of base stations. This is Nondeterministic Polynomial (NP)hard problem and exact solution cannot be arrived at. So, [Surgwon Sohn et al., 2006] applies variable ordering and value ordering which are constraint satisfaction techniques to get good approximate solutions. It implemented the algorithm using both integer programming and constraint programming.

An optimized Digital Signal Processing (DSP) implementation of GMSK software modem for GSM transceiver was proposed by [Ghazel A. et al., 2000]. It presents the experimental results with a fixed point 16-bit DSP to show the efficiency of the optimized GMSK software modem.

To deal with saturation in amplification at base transceiver stations, [Murillo-Fuentes J.J. et al., 1999] introduced predistortion in GSM base stations. It focused on the architectures and elements in signal predistortion for one carrier and multicarrier modulations. To provide the design with adaptive, digital and practical features, Generalized Cerebellar Model Articulation Controller (GCMAC) neural network has been introduced as predistorter. It was shown that predistortion enables the GSM base stations to overcome saturation and continue working. The advantage is that cells can be reassigned to the base stations which is the consequence of increase in coverage area. Predistortion introduced also leads to the avoidance of the co-channel interference, intermodulation distortion, aging etc. which further leads to enhanced amplification.

To overcome many of the traditional problems associated with direct conversion, [Strange J. et al., 2000] proposed a receiver architecture that was applied in the design of a GSM multi-band transceiver. It also had offset Phase Locked Loop
PLL) transmitter together with a fast locking fractional-N synthesizer. The architecture and technology for the multi-standard transceivers was discussed by [Mattison S., 2001]. A triple-standard transceiver architecture for GSM, WCDMA and Wi-Fi applications to facilitate multi-standard data communication was proposed by [Ling Zhang, 2005]. This architecture permits sharing of hardware to the maximum extent possible.

Several techniques that help select the transceiver architecture for multi-standard design were discussed by [Pui-In Mak et al., 2007]. It proposed two receivers in a base station, namely, a high gain receiver and a low gain receiver. High gain receiver serves distant terminals and the low gain receiver serves nearby terminals.

The presence of a narrow band receiver in a base station in addition to high gain and low gain receivers for a provision which ensures serving of any terminal at any location within the cell was considered by [Posti H. et al., 1999]. However, it is essential to plan separately for a suburban macro cellular environment and an urban microcellular environment. Hence, in smaller base stations, it is enough to have a high gain receiver and a narrow band receiver which will take care of nearby terminals thus avoiding low gain receiver. It will lead to the simplification of the base station architecture. This automatically leads to the need for the intracell handover. To avoid loss of traffic capacity, allocation of channels in different receivers need to be done with utmost care. Receiver architectures for GSM handsets were discussed by [Fitz S.M., 1998].

2.4 Routing Algorithms

Traffic is routed through shortest path possible in most of the networks. Whenever there is need to transmit, the network obtains the lengths of the concerned links of the network and takes that route which is shortest from the source to the destination. For the minimum congestion unsplittable shortest path routing problem, [Andreas Bley,
2010] presents an integer programming algorithm. The objective of the algorithm is to find unique shortest path for each demand such that the congestion across the links of the network is reduced to the maximum extent. The input to the algorithm will be a capacitated directed graph and a set of communication demands. The integer and linear programming models that are used to solve the master and the client problem were presented by [Andreas Bley, 2010].

A MANET accessing internet Routing algorithm Based on Dynamic gateway Adaptive Selection (MRBDAS) was proposed by [Xin Li et al., 2009]. It uses the idea of group decision making method for reference as well as candidate gateway’s connecting degree, load degree, residual energy, and movement rate synthetically. To maintain routing adaptively, it uses the methods of multipaths and query localization technique based on old path information. It shows that, MRBDAS with dynamic gateways colony function leads to the improvement of throughput, reduction in average transmission delay of data packets and routing overhead.

A genetic algorithm for finding minimal cost light-forest of multicast routing on Wavelength Division Multiplexing (WDM) networks was proposed by [Der-Rong Din, 2008]. To meet bandwidth requirements, WDM is used in optical fibres. Whenever there is a request for multicast in a WDM network, the aim is to find a set of light-trees, the assigned wavelengths of light-trees and construct a light-forest. Minimal Cost Multicast Routing Problem (MCMRP) on WDM networks with tap-and-continue nodes was defined in it. Also, a model for calculating cost that includes wavelength usage and communication cost as parameters is also defined in it.

The sum of the cost of used wavelengths and the communication cost of the light-forest is to be minimized when the algorithm proposed in it is used. Two genetic algorithms are proposed to solve the WDM multicast routing problem as MCMRP is NP-hard. Routing paths are represented by a path oriented encoding chromosome in
the proposed genetic algorithms. A source based light-forests is constructed to represent a solution to the multicast request for which the routing paths are used. It also proposes a Farthest-first greedy heuristic algorithm to speed up the convergence of genetic algorithms. It is also used generate one of the initial chromosomes. Some of the critical features of Mobile Adhoc Network (MANET) are high dynamics, link vulnerability and complete decentralization. Providing network security in MANET is a challenging task. Also, existing routing calls cannot be easily employed in MANET due to security risks.

A secure routing algorithm for MANET was proposed by [Shudong Shi, 2009]. The proposed algorithm suggests connectivity keeping in view of the malicious behaviour of various network elements. So, the connectivity suggested by the algorithm can be considered fool proof. The features of the algorithm include the rejection of fabricated, compromised or replayed route replies. For the algorithm to perform in expected lines, a security association is essential between the node initiating the query and the destination. It indicates that the algorithm is robust in the presence of non-colluding nodes.

A detailed comparison of various routing algorithms for MANETs that are based on swarm intelligence was given by [Jin Wang et al., 2009]. A self adaptive key flow routing adjustment algorithm was proposed by [Yujie Pei et al., 2009]. Throughput is negatively affected by the congestion in a network. This will lead to deterioration of QOS. Most of the existing algorithms assume that the congestion is available at only single point. They do not consider multi-point congestion. When several flows are adjusted simultaneously, the algorithm proposed in it will solve the interference problem. This algorithm will reroute important flows across the network simultaneously as it detects the possibility of congestion occurring at different points.
The algorithm ensures that the traffic distribution across the links is appropriate will not lead to congestion by confining the flows across the network to a specific path length. It shows that the algorithm proposed leads to better load balance which automatically leads to the increase in throughput of the network. Due to heavy data flow in a network, routing becomes important to avoid congestion and other important QOS issues.

A genetic algorithm and variable neighbourhood search for point to multipoint routing problem was proposed by [Noor Hasnah et al., 2008]. Local search heuristics used in finding the neighbourhood in the algorithm proposed in it are different when compared to other algorithms. A priority based genetic algorithm for shortest path routing problem in Open Shortest Path First (OSPF) algorithm was proposed by [Lin Lin et al., 2009]. Rabin’s routing algorithm that employed covering problem and assignment problem was analysed by [Ilyong Chung, 1997].

2.5 WLAN

To harness the power of any infrastructure by any location independent connections, multi-standard terminals are needed. The architectural and design choices of error rates at bit or packet levels validated with a multi-standard simulator developed by [Agnelli F. et al., 2006]. It proposes a design which consists of two chips that include both TX and RX for cellular, LAN and Bluetooth radio interfaces. A linear amplification with a non-linear component architecture that uses direct modulation of a carrier is used by the cellular and Bluetooth transmitter. Since Digital to Analog Converter (DAC) and up-conversion mixers are not required, power is saved.

A direct conversion architecture is employed to implement an internal output matching over all the frequency bands by WLAN and Bluetooth transmitter. Power and chip area were saved as the same building blocks are used. Between Low-IF for GSM and direct conversion for UMTS and Bluetooth, cellular receiver architecture is
reconfigured. Due to high reconfigurability, base band blocks can be shared among all standards.

Important RF blocks and some circuit implementations are described by [Agnelli F. et al., 2006]. A WLAN AN architecture for mobile operators was proposed by [Ala-Laurila J. et al., 2001]. The public wireless broadband technology systems whose capacity is higher than cellular systems are in demand due to IP based office applications. For an indoor environment, WLAN technology provides services that are broadband instead of GSM and GPRS services. The drawbacks of public WLAN technology when compared to cellular networks are that they have modest authentication and roaming capabilities.

A WLAN architecture that combines WLAN radio access technology with SIM and roaming infrastructure of cellular operators was proposed by [Ala-Laurila J. et al., 2001]. In the system proposed by it, using GSM SIM, WLAN access is authenticated and charged. Also, roaming between cellular and WLAN ANs is supported by it which will lead an all-IP network architecture.

2.6 3G and UMTS

The complementary use of 3G WCDMA and GSM/GPRS cellular radio networks was evaluated by [Jeich Mar et al., 2007]. From simulation, it was found that the traffic performance has significantly improved due to the complementary use when compared to the use of GSM/GPRS cellular radio networks. With the new call generation rate, both handoff failure probability and carried traffic rates increased due to the selection of high data rate transmission for low mobility subscribers. However, as the new call generation rate increases and crosses a critical value, then, both handoff failure probability and carried traffic rates decrease. This leads to the saturation of integrated networks.
Lower new call blocking probabilities and total carried traffic are due to higher mean speed for the mobile terminals. As the size of the soft handoff region increases, the new call blocking probabilities and the total carried traffic also increases. A preferential treatment for the UMTS subscribers in GSM network by way of specific resource allocation to them was proposed by [Robert Mullner et al., 2008]. This arrangement will ensure that the subscribers of UMTS in GSM network will experience the same QOS as they experience in the UMTS network.

It was found that the subscribers of dual-RAT terminals have increased speech quality advantages when compared to GSM subscribers or subscribers of high bandwidth services. Evolution of UMTS to an open architecture so that multimedia delivery and IP friendly data communications within 3G get enabled is the focus of discussion in [Lobley N.C., 2001].

The issues related to smart antennas for both CDMA and GSM systems are examined by [Feuerstein M.J. et al., 2000]. The first smart antenna was designed for CDMA networks. The second smart antenna was designed in the subsystem of 3G CDMA base stations. The third smart antenna was designed for GSM and GPRS/EDGE networks.

A three dimensional (3D) cellular system for air/ground (A/G) personal communications was proposed by [Elnoubi S.M., 2005]. The system enables the subscribers of GSM to communicate with MSs in air space. SIM as well as mobile number remain unchanged. A multilayer service volume in which the entire coverage area is divided into three coaxial cylindrical cells was also proposed by it. Each cell covers a part of the air space. A common architecture covering the entire GSM/UMTS/WAN was proposed by [Pereira J.M., 1998].
2.7 Applications

A Wireless Convergence Architecture (WCA) that enables different wireless interfaces in the same mobile terminal was proposed by [Nikos A. Nikolaou, et al., 2002]. The significance of the architecture is that, depending on the availability of signal of different interfaces, the mobile terminal switches between different interfaces automatically as applicable. Continuous connectivity is maintained at the transport layer. At both terminal and network side, software components are introduced. Based on the IEEE 802.11 and GSM, it presents a specific implementation.

A capacity based compressed mode control algorithm for intersystem measurements in a UMTS system was proposed by [ChengTa Chang et al., 2008]. The objective of the algorithm is to reduce the usage of system resources without reducing the UMTS to GSM border cell handover quality. Based on the location of mobile terminal and the absolute signal strength thresholds, an initiation algorithm based on intersystem handover is proposed by [Brahmjit Singh, 2007]. Interworking is based on GSM and UMTS networks. Handover rate was decreased by 50% due to algorithm proposed in it which lead to the improvement in network resource efficiency when compared to efficiency based on signal thresholds only.

An analytical framework for modelling scarce channels in any cell for maximizing channel utilization and efficient handling of handover requests was presented by [Irfan Awan, 2006]. Various trends in cellular and cordless communications were described by [Goodman D.J., 1991]. The factors that are associated with the network such as goal of the network design, its architecture, radio transmission technology, control channels, and the way the network coordinates its operations are explained. The standards that are covered include GSM, Interim
Standard (IS-54), Cordless Telephony Standard (CT2) and Digital Enhanced Cordless Telecommunications (DECT).

For remote data transmission and control, [Lin C.E. et al., 2003] presents a new development of mobile communication. It includes GPS, GSM, and geographic information system. System design and implementation with practical data verification is presented in it. It was shown that the proposed system achieved a two way point to point uplink and download data transmission within a 0.6s time delay.

A single-chip multimode receiver for GSM900, DCS1800, PCS1900, and WCDMA was introduced by [Ryynanen J. et al., 2003]. It operates with two different baseband bandwidths at four different radio frequencies. It consists of a low-noise amplifier, down conversion mixers with on-chip local oscillator I/Q generation, channel selection filters, and programmable gain amplifiers. Only four on-chip inductors are used in the single ended low-noise amplifier though there are four receive bands.

Architectures to support seamless IP-based service integration in both public and corporate network environments were described by [Wietfeld C. et al., 1999]. A direct conversion radio for tri-band GSM and GPRS applications was evaluated by [Faque D.E. et al., 2000].

A prototype of the event driven messaging service over integrated cellular and wireless sensor networks was presented by [Yu-Chee Tseng et al., 2005]. In data networks, instant messaging is one of the most widely used and is the efficient tool for communication. The same is the case with SMS in telecommunication networks. However, these messages get triggered when a button such as SEND is pressed or are scheduled for a particular time in future.

However, there is need to trigger messages due to changes in environmental information. It also focuses on the later part. GSM and Bluetooth technology are
adopted as cellular and sensor networks in the prototype. The technology developed in the prototype is immediately deployable as most of the MSs are Bluetooth enabled and are GSM based. The prototype is implemented for a visitor system. In the visitor system, a message gets triggered whenever a person enters or leaves office. The events of entering and leaving are collected by the Bluetooth surveillance network.

It was indicated by [Yu-Chee Tseng et al., 2005] that it is also possible to develop system that works on compound logic such as multiple people entering or leaving the system. An architecture for signalling analysis in GSM and IS41/136 cellular networks was presented by [Mesquita T. et al., 2001]. It implemented power up, power down, call setup, handover and location updating. It used Cellular Signalling Analyzer (CELSA) as the simulation tool. A GSM speech coder on a customized processor architecture was implemented by [Owall V. et al., 1993]. It proposed a new DSP architecture for equalizing, channel coding and decoding, and encryption and decryption that is required by GSM MSs.

A solution for remote network management was proposed by [Viera Junior A.C. et al., 2004]. It proposed a tool that can perform network management using GSM/GPRS mobile devices. The proposal included the interface for mobile devices. After reviewing the literature, the following research questions arise:

- Is it essential to query HLR to find the location of callee in roaming mode?
- What are the scenarios when HLR need not be queried to find the location of callee in roaming mode?

2.8 Chapter Summary

In this chapter, the research work carried out in the areas of GSM architecture, MSs, base stations, routing algorithms, WLANs, applications of wireless communications and 3G and UMTS was reviewed.
Insertion of SIM enables mobility in a GSM handset. It is key to receipt of various services by the concerned MS user. HLR and VLR enable the movement of the MS mostly. Various routing algorithms are responsible for efficient communication. With lot of types of networks such as GSM, CDMA, Wireless Fidelity (Wi-Fi) etc. in place, a MS should be in a position to receive services seamlessly for which [Kalmanek C. et al., 2006] described architecture.

An algorithm that uses probabilistic approach to find the location of a MS is presented by [Mirjana I. Simic et al., 2009]. The literature related to network coverage and QOS is also reviewed. An algorithm using which the broadcast data of base stations of GSM networks can be received was indicated by [Manelis V.B. et al., 2009]. FBSS which is a significant handover mechanism is reviewed. The issue of optimization of positioning of base stations was discussed. The receiver architectures of various GSM handsets were also discussed. In most of the networks, traffic is routed through shortest path from source to destination. Some routing algorithms such as OSPF, Rabin’s routing algorithm, etc were also reviewed.

WCA was reviewed vide which different wireless interfaces can be enabled in the same mobile terminal. The prototype of an event driven messaging service for cellular and wireless sensor networks is reviewed. The complementary use of GSM /GPRS and 3G WCDMA networks was evaluated and it was found that the traffic has significantly improved in comparison to only GSM/GPRS services. Also, a common architecture was proposed by [Pereira J.M., 1998] for GSM/UMTS/WAN.
CHAPTER 3

RESEARCH METHODOLOGY

This chapter explains the research methodology followed for the entire work. There were different research methodologies possible for carrying out any work. For the work mentioned in the current thesis, survey method was used to start with. GSM architectures that were collected during survey method were compared. It was followed by the finding that all architectures are accessing HLR for setting up calls in roaming mode.

A system model was proposed which introduced two new nodes, namely, THLR and AHLR apart from all the nodes that are part of GSM architecture. Then, algorithms were written for setting up calls in roaming mode which use THLR and AHLR but avoid HLR. Avoidance of HLR has directly led to the reduction in overall call setup path as the call is set up in roaming mode without connecting to any other node outside the network of the caller when the callee is also present in the same cell as that of caller or the callee is present in an adjacent cell to that of caller. In both the cases, callee is in roaming mode. For all other cases, a call to HLR is essential.

The system models that are proposed are based on a GSM architecture which includes all the elements of the existing GSM architecture apart from THLR and AHLR. Also, it is assumed that the architecture is implemented circle-wise. So, in each circle, there will be HLR, THLR and AHLR for each operator. The networks, namely, X1, X2, X3, and X4 are at circle-level. It is also assumed that a single cell spans the entire circle. Across the thesis, BSS-1, BSS-2 and BSS-3 represent BSSs;
MSC-1, MSC-2 and MSC-3 represent MSCs; VLR-1, VLR-2 and VLR-3 represent VLRs; HLR-1, HLR-2, HLR-3 and HLR-4 represent HLRs; MS-1, MS-2 and MS-3 represent MSs in various networks.

3.1 GSM architectures of Industry

This section gives various GSM architectures followed by different GSM network equipment manufacturers.

3.1.1 Alcatel-Lucent GSM architecture

Figure 3.1 depicts the Alcatel-Lucent GSM architecture [Alcatel-Lucent, 2007]. The architecture consists of Radio Access Network (RAN) and Mobile Core and Backbone.

Figure 3.1 : Alcatel-Lucent GSM architecture

RAN consists of BTS, BSC, and RNC. A MS, depending on the technology enabled, communicates with BTS or Node B or WiMax station. BTS communicates with BSC using Time Division Multiplexing (TDM). Node B communicates with RNC using Digital Subscriber Line (DSL) and Asynchronous Transfer Mode (ATM). WiMax station communicates with WiMax Access Control (WAC) using IPoMLPPP
and IPO Ethernet. BSC, RNC and WAC communicate with Mobile core and Backbone network.

Mobile core and Backbone consists of SGSN, Call Server, GGSN, Media Gateway (MGW) and MSC. They interface Internet, IMS and PSTN. SGSN, MGW, Call server and GGSN communicate using IP backbone. MSC and MGW communicate using circuit switching core network.

### 3.1.2 Altobridge GSM architecture

Figure 3.2 depicts the GSM architecture of Altobridge [Altobridge, 2008]. The figure included elements of GSM as well as elements that use the network. The earth station connects to MSC/HLR/VLR through Altobridge ground gateway. MSC/HLR/VLR connect to Private Branch Exchange (PBX) through ISDN.

### 3.1.3 Ericsson GSM architecture

Ericsson’s GSM network’s system model is depicted in figure 3.3 [Ericsson, 1998]. Different elements of it are Switching System (SS), Multistage Interconnection Network (MIN) and Base Station System.
Public data networks connect to GSM network through PSTN and ISDN. Other PLMNs also connect to GSM network. BSS includes RBS, BSC and Transcoder Controller (TRC). SS includes GMSC, EIR, AUC, HLR, Interworking Location Register (ILR), MSC/VLR, and Multipoint Controller (MC). EIR is connected to MSC/VLR. AUC and ILR are connected to HLR. HLR is connected to GMSC and MSC/VLR.

![Figure 3.3: Ericsson GSM network system model](image)

MIN includes Service Delivery Platform (SDP) and Service Control Function (SCF). SCF is connected to MSC/VLR. MSC/VLR is connected to MC. A MS communicates with the BSS. RBS is connected to BSC and BSC is connected to TRC. BSS is connected to SS. BSS and SS communicate with Operations Support System (OSS). Apart from OSS, SS also connects to BGW and Service Order Gateway (SOG).
3.1.4 Huawei GSM architecture

The GSM network architecture of Huawei is depicted in figure 3.4 [Huawei Worldwide, 2011]. It consists of RAN, CN, and other networks.

RAN consists of UTRAN which is connected to MGW and SGSN. It also communicates with MSC server. MSC server communicates with GMSC server that in turn communicates with MGW and PSTN. SGSN also communicates with GGSN and Internet. MSC server, GMSC server and SGSN communicate with HLR.

Figure 3.4: Network elements and architecture of a GSM core network of Huawei
3.1.5 Motorola GSM architecture

Figure 3.5 depicts the GSM architecture of Motorola [Motorola, 2003]. The entire network is divided into 3 parts. The first part is RAN, second part is Circuit core, and the third part is Packet core. The MS communicates with BTS. BTS communicates with BSC. BSC communicates with MSC and SGSN. MSC communicates with HLR and PSTN. SGSN communicates with GGSN and PDN. Apart from the nodes indicated above, there will be other nodes that will take care of issues related to billing, intercepts, and messaging.

3.1.6 Nokia GSM architecture

Figure 3.6 depicts the GSM network architecture of Nokia [Nokia, 2002]. There are 3 parts in its architecture. They are BSS, NMS and NSS. BSS consists of BSC, BTS and transcoder submultiplexer. NMS includes database server, communications server, and workstations. NSS includes HLR, AuC, EIR, MSC, VLR, SMSC, Data communications server, and IN service control point.
MS communicates with BSC through BTS. BSC communicates with transcoder submultiplexer. BSC communicates with communications server via data communication network which in turn communicates with other servers including workstations and network planning and network measurement systems. Transcoder submultiplexer and Data communication network communicate with HLR, AuC, EIR, MSC and VLR. MSC and VLR in turn communicate with servers related to voice mail, SMSC, data communications server etc.

3.2 Call Setup

Every country will have a nodal authority to take policy decisions related to wireless communications in its Country. In India, TRAI takes such decisions. The nodal authority demarcates the circles in which different mobile operators can offer mobile services. If a GSM network is implemented in a particular circle, then it is composed of all the elements of any of the architectures indicated in the above section. Invariably, HLR is part of every GSM network.

So, in two different circles, there will be two HLRs pertaining to an operator. So, in roaming mode, the HLR of the home network is contacted for setting up the call. This process of contacting HLR to set up the call to the MS in roaming mode leads to extra path in setting up of the call as the communication is going out of the visiting network.

In this thesis, alternative GSM architectures were proposed where there is no need to contact the HLR of the host network of the roaming MS at the time of setting up the call. However, it is possible only for two scenarios in which the caller and callee which is roaming are in the same network or the caller and callee which is roaming are in adjacent networks. To achieve it, two nodes, namely, THLR and
AHLR were proposed. THLR and AHLR will be present in every GSM network. Their presence will ensure that there is no need to contact the HLR of the host network of the callee which is in roaming mode at the time of call setup.

This provision will directly reduce the overall call setup path from the caller to the callee which is in roaming mode and is present in the same network as that of caller or in the network adjacent to the caller.

### 3.3 Existing System Model of GSM

The existing system model of GSM when the callee is in roaming mode in the same network as that of caller is depicted in figure 3.7 [Raj Pandya, 2000]. The caller can be a MS or a fixed line. Both the cases were included in figure 3.7.

![Figure 3.7: Existing System Model of GSM](image)

In figure 3.7, X1 and X2 are networks. The host network of MS1 is X1 and that of MS2 is X2. HLR-1 is home location register of X1 and HLR-2 is home location register of MS2. However, MS2 is in roaming mode in X1. A fixed line is also present in X1.
When the fixed line calls MS2, the algorithm for call setup is as follows [Raj Pandya, 2000]:

1. Start
2. Fixed line dials the mobile number of MS2
3. The call goes to Local Telephone Exchange (LTE) i.e. PSTN (a)
4. LTE finds that the dialled number is a mobile number belonging to external network and forwards it to GMSC (b)
5. GMSC contacts HLR-2 of the service provider of MS2 and sends the mobile number to find the location of MS2 (c)
6. HLR-2 will communicate with serving VLR-2 of MS2 (d)
7. VLR-2 will communicate information about serving MSC of MS2 to HLR-2 (e)
8. HLR-2 forwards that information to GMSC (f)
9. GMSC routes call to serving MSC-2 (g)
10. MSC-2 finds the current Location Area Identity (LAI) of MS2 from serving VLR-2 (h,i)
11. MSC-2 forwards the request to BSS-2 (j)
12. BSS-2 pages the information for which MS2 responds (k,l)
13. BSS-2 confirms to MSC-2 that the necessary radio links are established (m)
14. Call is delivered to MS2
15. When MS2 answers, call setup is complete
16. End of Algorithm

The call setup path is a $\rightarrow$ b $\rightarrow$ g $\rightarrow$ j $\rightarrow$ k

In the above algorithm, HLR-2 is contacted to find the location of MS2.
Though MS2 is present in the network as that of fixed line which made the call to MS2, there is no way for fixed line to know that MS2 is in the same network, hence the call to HLR-2. The proposed system models of GSM as given in section 3.4 will eliminate the need to contact HLR of callee’s MS.

When MS1 calls MS2, the algorithm for call setup is as follows [Raj Pandya, 2000]:

1. Start
2. MS1 dials the number of MS2
3. The call set up request goes to BSS-1 (a1)
4. BSS-1 forwards the request to MSC-1 (b1)
5. MSC-1 forwards the request to VLR-1 (c1)
6. VLR-1 contacts the HLR-2 of MS2 in X2 (d1)
7. HLR-2 of MS2 contacts the VLR-2 in X1 of MS2 (d)
8. VLR-2 sends the information pertaining to MSC-2 to HLR-2 of MS2 (e)
9. HLR-2 of MS2 passes the information received from VLR-2 to VLR-1 (f1)
10. VLR-1 forwards the information to MSC-1 (g1)
11. MSC-1 contacts MSC-2 requesting call setup (h1)
12. MSC-2 forwards the request to BSS-2 (j)
13. BSS-2 pages the information for which MS2 responds (k,l)
14. BSS-2 completes the call set up (m)
15. End of Algorithm

The call setup path is a1 \rightarrow b1 \rightarrow h1 \rightarrow j \rightarrow k

When MS1 calls MS2, HLR-2 of MS2 is contacted to find the location of
MS2. This contact was made despite the fact that MS2 is present in the same network as that of MS1 because MS1 does not have any way to find the location of MS2 other than by contacting HLR-2. This need for contacting HLR-2 is eliminated in the proposed system models of GSM given in section 3.4.

3.4 Proposed System Models of GSM

There are two system models proposed for GSM instead of the existing system model mentioned in section 3.3. Both the system models are based on a GSM architecture which includes all the elements of the existing GSM architecture apart from THLR and AHLR. Also, it is assumed that the architecture is implemented circle-wise. So, in each circle, there will be HLR, THLR and AHLR for each operator.

The first system model eliminates the need to contact HLR of the callee when callee and caller are in the same network and callee is in roaming mode in the network of caller. The second system model eliminates the need to contact HLR of the callee when callee and caller are in adjacent networks.

3.4.1 Proposed System Model-1 for GSM

Figure 3.8 depicts the proposed system model for GSM when both caller and callee are in the same network and callee is in roaming mode in the network of caller.

![Figure 3.8: Callee is in roaming mode in the host network of caller](image-url)
The system model proposed includes both the cases where the caller is a fixed line and the caller is a MS. MS2 is callee in both the cases. A new element called THLR is introduced into the GSM network in the proposed system model. The significance of THLR is that THLR copies a record from HLRs of all the MSs that are in roaming mode in the network in which THLR is present. THLR deletes the record of the MS when that MS leaves its network.

Copying of record from HLR to THLR occurs as soon as MS enters the network of THLR. So, the overall call setup path decreases when there is a call request to the MS from any MS or fixed line from the same network as they search THLR for the presence of the callee before embarking on contacting HLR of the callee.

In figure 3.8, X1 and X2 are networks. The host network of MS1 is X1 and that of MS2 is X2. HLR-1 is home location register of X1 and HLR-2 is home location register of MS2. However, MS2 is in roaming mode in X1. A fixed line is also present in X1. THLR belongs to X1 which stores records of all the MSs that are in roaming mode in X1. So, THLR is having a record of MS2.

When the fixed line in X1 calls MS2, the algorithm for call setup is as follows [Venkata Suresh Pachigolla et al., 2010]:

1. Start

2. Fixed line dials the mobile number of MS2

3. The call goes to LTE i.e. PSTN (a)

4. LTE finds that the dialled number is a mobile number belonging to external network and forwards it to GMSC (b)

5. GMSC contacts the THLR of the service provider and sends the mobile number(c)
6. THLR will communicate with serving VLR-2 of the MS2 (d)

7. Serving VLR-2 will communicate information about serving MSC of MS2 to THLR (e)

8. THLR forwards that information to GMSC (f)

9. GMSC routes call to serving MSC-2 (g)

10. Serving MSC-2 finds the current LAI of MS2 from VLR-2 (h, i)

11. Serving MSC forwards the information to BSS-2 (j)

12. BSS-2 pages the information received from MSC-2 for which MS2 responds (k, l)

13. BSS-2 confirms to MSC-2 that the necessary radio links are established (m)

14. Call is delivered to MS2

15. When MS2 answers, call setup is complete

16. End of Algorithm

   The call setup path is a → b → g → j → k

   When MS1 calls MS2, the algorithm for call setup is as follows:

1. Start

2. MS1 dials the number of MS2

3. The call set up request goes to BSS-1 (a1)

4. BSS-1 forwards the request to MSC-1 (b1)

5. MSC-1 forwards the request to VLR-1 (c1)

6. VLR-1, after checking its database contacts the THLR in X1 (d1)

7. THLR contacts the VLR-2 in X1 of MS2 (d)

8. VLR-2 sends the information pertaining to MSC-2 to THLR in X1 (e)
9. THLR passes the information received from VLR2 to VLR1 (f1)

10. VLR-1 forwards the information to MSC-1 (g1)

11. MSC-1 contacts MSC-2 requesting call setup (h1)

12. MSC-2 forwards the request to BSS-2 (j)

13. BSS-2 pages the information for which MS2 responds (k,l)

14. BSS-2 completes the call set up (m)

15. End of Algorithm

The call setup path is a1 → b1 → h1 → j → k

In both the cases above where a fixed line called a MS which is in roaming mode in the same network as well as where a MS called another MS which is in roaming mode in the same network, HLR of the callee’s MS is not contacted. Instead, THLR of the network of caller was contacted to setup call to the callee. So, the system model proposed for GSM in this section will enable a call to be a local call rather than an external call though the callee’s MS is in roaming mode, but in the same network as that of caller.

3.4.2 Proposed System Model-2 for GSM

Figure 3.9 depicts the proposed system model for GSM when both caller and callee are in adjacent networks and callee is in roaming mode. The system model proposed includes both the cases where the caller is a fixed line and the caller is a MS. MS2 is callee in both the cases. A new element called AHLR is introduced into the GSM network in the proposed system model. The significance of AHLR is that AHLR copies respective records from HLRs of all the MSs which are in roaming mode in the adjacent networks. AHLR deletes the record of the MS which leaves the adjacent network. If the MS moves from one adjacent network to another adjacent network,
then, the record is deleted when it left one adjacent network and the record is copied from HLR when it enters another adjacent network.

Figure 3.9: Callee is in roaming mode in network adjacent to caller

Copying off record from HLR to AHLR occurs as soon as MS enters the adjacent network. So, the overall call setup path decreases when there is a call request to the MS from any MS or fixed line from the adjacent network as THLR is searched initially for the callee followed by a search in AHLR for the callee. Only, if the callee is not found in THLR and AHLR, then, the traditional method of contacting the HLR is followed.

In figure 3.9, X1, X2 and X3 are networks. X1 and X3 are adjacent networks. X2 is not adjacent to X1 and X3. HLR-1, HLR-2 and HLR-3 are HLRs of X1, X2 and X3 respectively. The host network of MS3 is X3 and is currently in its host network. Also, present is a fixed line in X3. The host network of MS2 is X2. But, MS2 is in roaming mode in X1.

In the traditional mode of call setup, When MS3 or fixed line in X3 calls MS2,
then HLR-2 is contacted to find the location of MS2 and eventually call setup is done. When the fixed line in X3 calls MS2, the algorithm for call setup is as follows [Venkata S Pachigolla et al., 2011]:

1. Start

2. Fixed line in X3 dials the mobile number of MS2

3. The call goes to LTE i.e. PSTN (a)

4. LTE finds that the dialled number is a mobile number belonging to external network and forwards it to GMSC (b)

5. GMSC contacts the THLR of X3 and sends the mobile number (c)

6. However, mobile number of MS will not be found in THLR as it is not present in X3.

7. So, THLR queries AHLR (d)

8. AHLR will communicate with VLR-1 of MS2 in X1 (e)

9. VLR-1 will communicate information about MSC-1 of MS2 to AHLR (f)

10. AHLR forwards that information to GMSC (g)

11. GMSC routes call to MSC-1 (h)

12. MSC-1 finds the current LAI of MS2 from VLR-1 (i)

13. VLR-1 sends LAI of MS2 to MSC-1 (j)

14. MSC-1 forwards the information to BSS-1 (k)

15. BSS-1 pages the information received from MSC-1 and MS2 responds (l, m)

16. BSS-1 confirms to MSC-1 that the necessary radio links are established (n)

17. Call is delivered to MS2 (k, l)

18. When MS2 responds, call setup is done
When MS3 calls MS2, the algorithm for call setup is as follows:

1. Start
2. MS3 dials the number of MS2
3. The call set up request goes to BSS-3 (a1)
4. BSS-3 forwards the request to MSC-3 (b1)
5. MSC-3 forwards the request to VLR-3 (c1)
6. VLR-3 contacts the THLR in its network (ie. X3) (d1)
7. THLR after checking its database and finding that the entry for MS2 is not available, it forwards the request of VLR-3 to AHLR (d)
8. AHLR checks its database and finds the entry for MS2
9. AHLR of X3 contacts the VLR-1 in X1 to which MS2 is connected (e)
10. VLR-1 sends the information pertaining to MSC-1 to AHLR of X3 (f)
11. AHLR of X3 sends the information about MSC-1 to which MS2 is connected to VLR-3 (f1)
12. VLR-3 forwards the information to MSC-3 (g1)
13. MSC-3 contacts MSC-1 requesting call setup (h1)
14. MSC-1 forwards the request to BSS-1 (k)
15. BSS-1 pages the information for which MS2 responds (l,m)
16. BSS-1 completes the call set up (n)
17. End of Algorithm
The call setup path is a → b → h1 → k → l

In both the cases where the call is from fixed line or MS to another MS that is in roaming mode in adjacent network, HLR is not contacted. This leads to better resource utilization and decrease in overall call setup path as the number of calls to HLR will be reduced and are confined only to those calls where the callee is not present in the same network or adjacent network of caller.

3.5 Chapter Summary

In this chapter, the research methodology adopted to do the work is stated. Among the different research methodologies available, initially survey method is adopted. As part of it, the basic GSM architecture and different variants of it adopted by GSM equipment manufacturers were examined. The methodology is adopted keeping in view of the objective of the work. The objective is due to the experience in real life where in call setup is done from a fixed line or a MS to another MS which is in roaming mode in the same network as that of caller or in the adjacent network of the caller in the same way by contacting HLR of the callee which is leading to increased call setup path.

The GSM architectures of various GSM equipment manufacturers were examined. It was followed by the examination of existing system model of GSM and the algorithms for call setup in the GSM when the callee is in roaming mode. Then, two system models were proposed for GSM for varied scenarios for both the cases where the caller and callee are in the same network and callee is in roaming mode which is the first case. The second case is where the caller and the callee are in adjacent networks and the callee is in roaming mode. Two elements, namely THLR and AHLR were introduced into the proposed system models of GSM. Four algorithms for call setup that complete both the cases were given where in it was found that it is possible to setup call without contacting the HLR.