

UNIFIED PROTOCOL STACK FOR THE NEXT GENERATION  
MOBILE TERMINAL TO SUPPORT MULTIPLE RADIO ACCESS  
TECHNOLOGIES

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***L&T Infotech***

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**Abstract:**

The next generation Mobile Handhelds need to focus on seamless Mobility and session continuity when the subscribers move frequently across different radio access networks. This paper presents a Generic Radio Access Abstraction layer (GRAAL) outlining the additional functionalities required to support multimode operation of the protocol stacks, where the mobile terminal is able to decide on the fly for selecting the best radio access network according to the users choice and applications preferences. The proposed GRAAL will enable subscribers to benefit from high throughput and to maintain session continuity during roaming across several mobile networks.

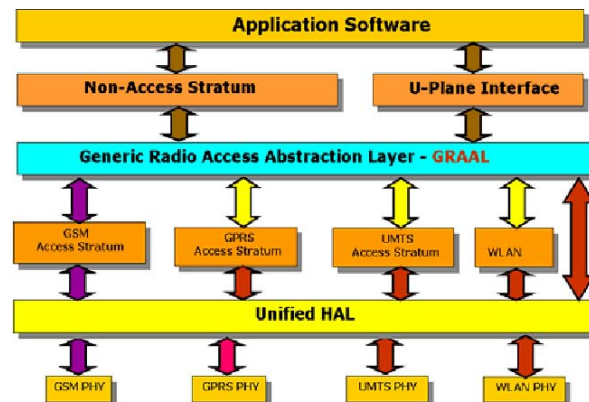
**Keywords:**

QoS, GPRS, UMTS, WLAN, Seamless mobility, Vertical Handover, Dual-mode, Multi-mode, Unified Protocol Stack.

## 1. INTRODUCTION

First step to provide an effective communication, on the move is a multi-access solution and today there are several wireless networks with different access mechanisms like GSM, GPRS, UMTS, CDMA2000 1-X EVDO, and WLAN. A mobile user needs to communicate with the best connection available at any instant of time, but when a user changes networks, the main challenging task is that how to keep the communication session alive with another parallel available network without having to restart all the running applications. It would be interesting for a mobile user with multiple wireless network interfaces available to always use the best current wireless network. The idea is that a mobile user should be able to switch from one network access to another depending on the availability of different networks and should always be able to choose the best connection with out any interruptions of an on-going voice, data and/or video call.

For example, GPRS network provides country wide coverage, but with limited bandwidth and comparatively high cost per bit, whereas WLAN coverage provides low cost, high bit rate services, but with restricted coverage. By integrating both these technologies into a single mobile device, it is possible to support the establishment of an application sessions across whichever best interface meets the applications requirements and user preferences and to dynamically switch this application between interfaces as the user moves in and out of the particular wireless networks.



*Figure 1: Generic Software Architecture of a Mobile Terminal*

Keeping above points in mind and to provide seamless handover across various radio access networks for both Voice and Packet data sessions, we have introduced a Generic Radio Access Abstraction Layer (GRAAL) between Access Stratum and Non-Access Stratum in the wireless Protocol Stack of the Mobile terminal as shown in Fig 1. The GRAAL will automatically detect and select the best wireless networks in order to connect and transition the voice, data and video connections anywhere and anytime.

The main design objectives of the Generic Radio Access Abstraction Layer are listed below:

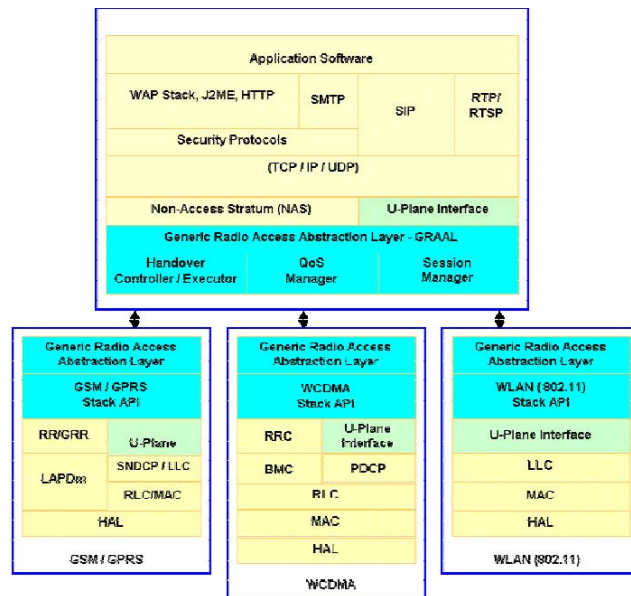
- Seamless continuity of wireless services when the Mobile user moves across the cellular networks
- To ensure required QoS for multimedia services
- Execute Handover procedures based on signal strength, QoS or Change of service.

## 2. KEY ASPECTS OF GRAAL:

Fig 2 Shows the GRAAL placement in the Wireless Protocol stack of various RAT's and the basic concepts of GRALL are listed as below:

Interfaces with

- Layer 1 (PHY) for measurements
- Layer 2 for Circuit and Packet data switching
- Layer 3 for Radio Resource management



*Figure 2: GRAAL Placement in Protocol Stack*

Resides just below the IP layer and is uniform across all bearer types.

Facilitates in Inter-System handover decision-making process.

*Fast:* Detect and respond to Radio link status changes quickly

*Seamless:* Minimum interruption for data transportation service

*Rich in function:* Provides sufficient support for both basic connectivity handover

Interface: Interacts with Layer3 and Management layers of different Radio Access networks.

### 2.1 Functionalities of GRAAL:

The GRAAL provides the following functionalities:

- Collects Signal Strength information from local PHY layers (From GSM, UMTS and WLAN)

- Performs various activities needed to select the specific RAT based on the measurement parameters

- o Example: RSCP, RSSI, Ec/Io

- Consolidates information from various interfaces (i.e from Physical layer, RTCP, Data link layer) and generates triggers for making handover decisions

- Analysis of QoS Measurement Mechanism to monitor the status of the QoS parameters during the actual data flow.

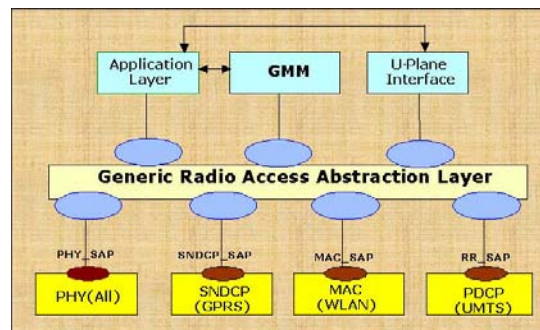
*Figure 3: GRAAL Software Modules*

Compare the defined QoS parameters with the actual QoS based on the type of service.  
 Negotiate network resources for better QoS and further improvement in case of quality degradation.  
 Continuous monitoring and comparison of QoS parameters with the defined and actual parameters for specific service (e.g., Video Telephony, Video Streaming)..  
 Session continuity and Handover Management during and after Vertical Handover.  
 User to choose an option for downloading a large data or media file that may require handover to a network capable of supporting a higher data rate.  
 Takes decision to perform vertical handover and invokes appropriate RAT specific ACCESS STRATUM inside the Mobile Terminal for signalling and actual data flow.

## 2.2 GRAAL Services:

GRAAL provides two kinds of Service. They are:

- o Event Service
- o Command Service



*Figure 4: GRAAL Service Access Points* SSI QOSM SDM SM LLC (W-LAN) SM (GPRS) GMM (GPRS) SNDP(GPRS)STM

### 2.2.1 Event Service:

In this service, GRAAL receives link layer event information from the underlying Physical Layer E.g. WLAN, GERAN, UMTS etc., The GRAAL obtains event notifications from WLAN SAPs as well Cellular SAPs and execute the received events to perform specific operation (e.g.: Inter-system Handover decision)

### 2.2.2 Command Service:

In this service, GRALL performs various activities as requested by Upper and lower layers (Ex): authenticate, attach. It also invokes appropriate Radio access technology based on the command received through L1 SAP's and executes specific algorithm through to perform smooth handover.

### 3. GRAAL SOFTWARE MODULES:

The software modules and its sub-modules shown in Fig 3, which are part of the GRAAL are identified for providing seamless mobility across different cellular networks. The Software Modules functionalities of GRALL are explained as below

- o Handover Controller (HC)
  - o Signal Strength Indicator (SSI)
  - o Profile Manager (PM)
  - o QoS Manager (QM)
  - o Smart Decision Maker (SDM)
- o Handover Executor (HE)
  - o Session Manager (SM)
  - o Session Transfer Manager (STM)

#### 3.1 Handover Controller Module (HCM):

The Handover Controller Module (HCM) is responsible for all aspects related to the handover decision-making process. The HCM measures the signal strength of respective RAT's (Radio Access Technologies) and gets information about the profile management such as user preferences, Mobile Terminal profiles and Application profiles as well as the QoS actually needed for various services. The HCM takes smart decision based on the triggers given to it from various sources.

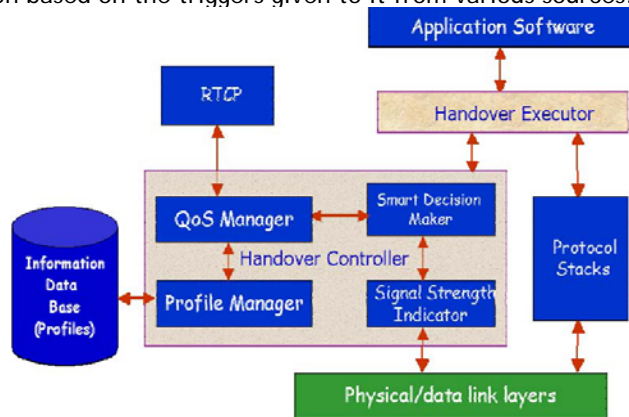


Figure 5: Handover Controller

The functionalities associated with the Handover Controller module are shown in Fig 5. They are:

- o Signal Strength Indicator
- o Smart Decision Maker
- o Profile Manager
- o QoS Manager

##### 3.1.1 Signal Strength Indicator (SSI):

The SSI provides an interface with the Physical layers to obtain information about the signal strength of respective RAT's. This Software module will generate events that may cause the triggering of handover decisions. The functionalities associated with this module are explained below:

### 3.1.1.1 SSI monitoring and Identification:

The SSI Monitoring and Identification functionality software module located inside the Handover Controller identifies and monitors the signal strength of different RAT's (Radio Access Technology) like GPRS and WLAN.

The SSI monitoring should be done periodically so as to check if the signal strength of existing home network (e.g.GPRS) and foreign network (WLAN) are above the threshold value, where it fails, gives a trigger to the handover connection Manager to initiate for an Handover process. The Key aspects of this functionality are:

- **RSS (Receive Signal Strength):** The RAT whose signal is being received with the largest strength is selected (choose the new RAT if  $RSS_{new} > RSS_{old}$ ).
- **RSS plus Threshold:** A handoff is decided if the RSS of a new RAT exceeds that of the current one and the signal strength of the current is below a threshold T (choose the new RAT if  $RSS_{new} > RSS_{old}$  and  $RSS_{old} < T$ ).
- **RSS plus Hysteresis:** A Handoff Trigger is decided if the RSS of a new RAT is greater than that of the old RAT by a Hysteresis margin H (choose the new BS if  $RSS_{new} > RSS_{old} + H$ ).
- **RSS, Hysteresis and Threshold:** A handoff trigger is decided if the RSS of a new RAT exceeds that of the current RAT by a hysteresis margin H and the signal strength of the current RAT is below a Threshold T (choose the new RAT if  $RSS_{new} > RSS_{old} + H$  and  $RSS_{old} < T$ ).
- **Algorithm plus Dwell Timer:** A timer is started when the condition in the algorithm is true. If the condition continues to be true until the timer

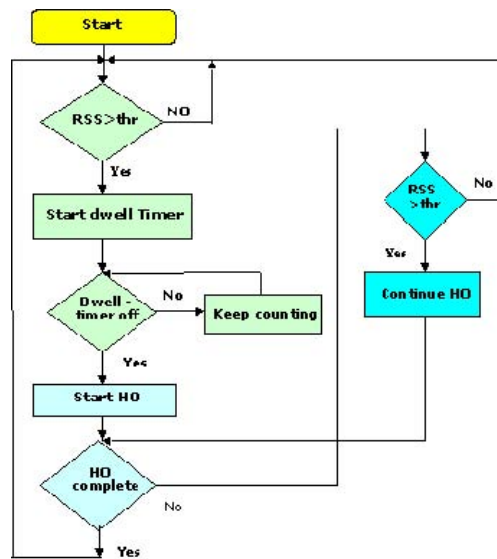


Figure 6: Dwell Timer Algorithm

expires, a handoff trigger is performed. The Dwell timer based algorithm is as shown in the Fig 6.

- **Neighbor (RAT Type, Threshold 1):** finds candidate RAT's (i.e.WLAN), which offer a radio link of acceptable quality.

### 3.1.2 Smart Decision Maker:

As shown in Fig 7, the Smart Decision Maker (SDM), which is part of Handover Controller, makes a decision on handover based on the inputs from Signal Strength Indicator for Receive Signal strength quality and from the QoS manager for the existing service quality and performs smart execution of the Handover decision-making process by giving a trigger to Handoff Executor.

The SDM Functionalities are explained below:

**Link Quality (RAT Type, Threshold):** establishes if the radio link with the RAT specified has acceptable quality (better than threshold).

**QoS (RAT Type):** Evaluates the quality of service provided by the serving RAT (as specified in the parameter field).

**Neighbor (RAT Type, Threshold):** Finds candidate RAT's which offer a radio link of acceptable quality.

**RAT Selection (RAT):** Selects the best RAT by making a comparison between performance metrics offered by the serving RAT and by the vector of neighbour RAT's.

**Handover Trigger (RAT Type, Threshold):** Gives an alarm if the QoS parameter (specified in the field type) provide by the serving RAT degrades behind the warning threshold (threshold 2).

The Smart Decision Maker procedures are listed as below:

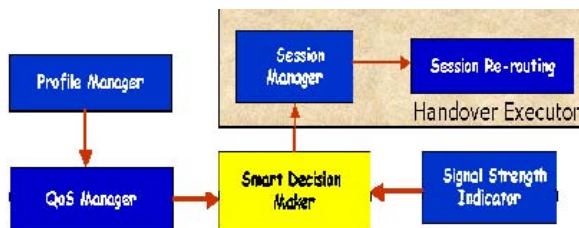
**User Requirements:** Requirements for establishing the session with the specific RAT for a specific service based on the trigger from the user.

**Application Requirements:** Mobile Applications configures the database based on the requirements specified through Profile Manager.

**Request Interface:** Applications triggers the Interface selection function to establish which interface function should be used for this session.

**Authorization Request and select interface:** Based on the information available on the Mobile terminal, the Interface selection function will select an interface that can support the application request.

**Selected Interface:** Interface selection function returns an indication of which interface the application should use.



*Figure 7: Smart Decision Maker*

The detailed functionalities of Profile manager and QoS manager are explained in the following sections.

### 3.1.3 QoS Manager:

The QoS manager is responsible for measurement and monitoring of QoS parameters from various protocols like RTCP for real-time multimedia sessions. Its main task is to monitor and compare the negotiated QoS parameters with the actuals such that if a change in the negotiated value occurs, then initiate the trigger to Smart Decision maker to perform vertical Handover. The QoS management functional entities are shown in Fig 8 and explanations of QoS Functional Entities are as given below:

#### 3.1.3.1 QMF (QoS Measurement Function):

The QMF entity is responsible for collecting all the information about the QoS Parameters of the current RAT from the RTCP protocol and passes the same to QCF (Quality Control Function).

### 3.1.3.2 QCF (Quality Control Function):

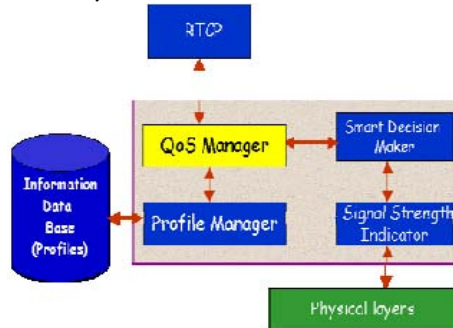


Figure 8: QoS Management Functional Model

The QCF entity receives QoS information from the QMF of the existing link for a specific service, compares negotiated QoS parameters and checks whether the QoS criteria for the existing service are fulfilled or not. If the Quality-of-Service are not fulfilled, then it re-negotiates with the packet data network for better resource allocation and still if the Quality of service is not satisfied, then the QoS manager issues the Handover request trigger to the smart decision maker accordingly to perform smooth handover.

### 3.1.4 Profile Manager (PM):

The Profile Manager is used to store Mobile Terminal profiles and Application profiles. The Static profile holds information that does not change very often and includes Mobile Terminal Profiles, Applications and its QoS requirements. The Dynamic profile holds the current information such as current QoS network parameters like Bandwidth, Delay, Jitter, Packet loss and Throughput.

The following table 1 shows the requirement in terms of Data rate and QoS for GPRS and WLAN Networks.

Application	Air Interface	U/D	Tx Rate	QoS
Video Telephony	UMTS	Uplink	384 Kbit/s	<1% FER <400ms one way Delay
		Downlink	384 Kbit/s	
	WLAN	Uplink	2 Mbit/s	
		Downlink	6 Mbit/s	
Streaming video	UMTS	Uplink	384Kbit/s	<1% FER <10ms Delay
		Downlink	384Kbit/s	
	WLAN	Uplink	1.5 Mbit/s	
		Downlink	1.5 Mbit/s	
Streaming audio	UMTS	Uplink	384 Kbit/s	<1% FER <10ms Delay
		Downlink	384 Kbit/s	
	WLAN	Uplink	384 Kbit/s	
		Downlink	384 Kbit/s	
Web-Browsing	UMTS	Uplink	12.2 kbit/s	<0% FER <4sec Delay
		Downlink	384 Kbit/s	
	WLAN	Uplink	32 kbit/s	
		Downlink	1 Mbit/s	
E-mail	UMTS	Uplink	12.2 Kbit/s	<0% FER <4sec Delay
		Downlink	12.2 Kbit/s	
	WLAN	Uplink	64 Kbit/s	
		Downlink	64 Kbit/s	
File Transfer	UMTS	Uplink	384 Kbit/s	<0% FER <10 msec Delay
		Downlink	384 Kbit/s	
	WLAN	Uplink	2.5 Mbit/s	
		Downlink	2.5 Mbit/s	

Table 1: Application Profile Attributes

#### 3.1.4.1 Mobile Terminal Profile attributes:

Support of Radio interface (GSM, GPRS, UMTS, WLAN).

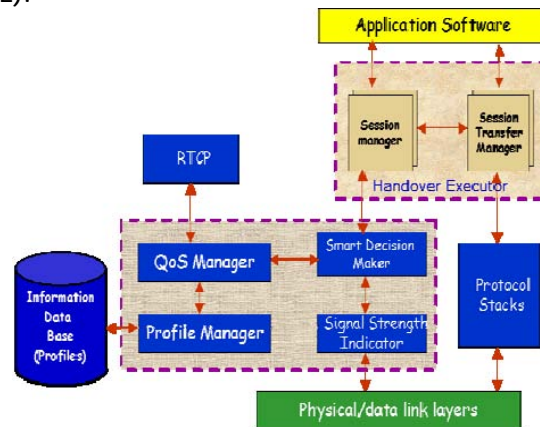
### 3.1.4.2 Application Profile attributes:

Maximum QoS for each type of application Table 1 shows the standard QoS details for the various applications stored in information database.

QoS for each application (within the limits of the subscription).

User preferences for certain networks (GPRS, UMTS or WLAN) for better throughput.

### 3.2 Handover Executor (HE):



*Figure 9: Handover Executor*

In Handover Executor, all functions related to Session Management are provided. This software module controls the negotiations between the terminal and the network concerning QoS Services, allocation of Radio Resources and Handover Execution process.

The Handover Executor (HE) offers an API allowing the higher layers to get information on available resources and perform the negotiation between the Mobile Terminal and Network. The HE provides an API to application software layer that allows informing the user about the results of decision-making process automatically when the change occurs from one RAT to another RAT. The Functional blocks in the handover executor are as shown in Fig 9:

- Session Manager (SM)
- Session Transfer manager (STM)

#### 3.2.1 Session Manager:

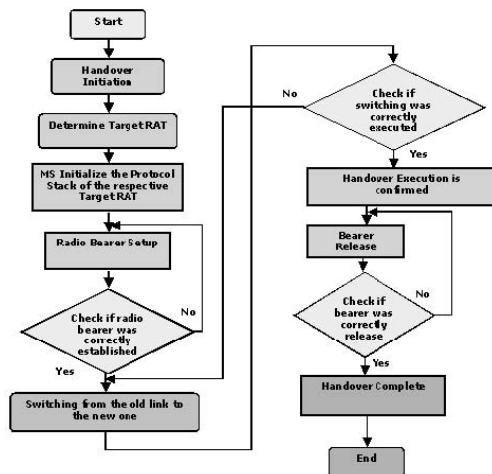


Figure 10: Handover Initiation Process

The main job of this module is to initiate the session or to activate the PDP context between the Mobile Station and the core network. The Session Manager modifies the primary PDP context or to deactivate the present or to activate a new PDP context with different PDP address, NSAPI, APN and QoS on a new network if QoS were not satisfied previously with the old network. It also includes establishment and removal of radio resources for new RAT. It supports the movement of session between various RAT's and makes user "Happier" on an alternate interface. The Procedure of session manager includes:

- Handover initiation.
- Radio bearer set-up
- Release of old Radio Bearers

Handover initiation starts when the handover initiation could be caused either by the receive signal strength quality degradation or other QoS requirements. The Handover Initiation Process is as shown in Fig 10.

**Selected Interface:** Interface selection API returns an indication to application layer of which RAT interface the application should use.

- Radio bearer set-up and switching are used to establish a new signaling link and switch signaling from the old link to the new one.
  - **Attach (RAT):** Provides a layer 3 and Layer 2 Connectivity between Mobile Terminal and new RAT.
- After the handover execution is performed, it is necessary to release the old radio bearer. Once the old bearer is released, the handover is completed.
  - **Detach (RAT):** Disconnects the MN from the serving RAT.

### 3.2.2 Session Transfer Manager:

The Session Transfer manager module supports the movements of packet data session between the GPRS and WLAN interfaces. It receives the data from the application layer in order to forward the same to U-plane path of the new selected RAT and allows rerouting or adaptation of user flows.

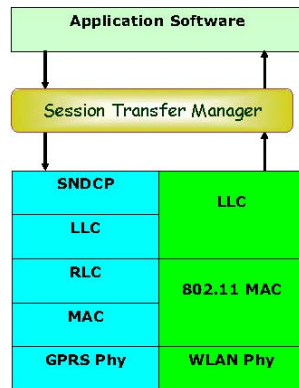


Figure 11: Session Transfer manager

#### 4. INTER-SYSTEM HANDOVER SCENARIOS

##### 4.1 Voice Call handover from GSM to UMTS:

When a subscriber moves out of the GSM coverage area, a handover to UMTS has to be conducted in order to keep the voice call continuity. The Handover from GSM is to transfer a connection between GERAN to UTRAN. When the Mobile Terminal receives HANDOVER TO UTRAN COMMAND message from GSM network based on the measurement report received by the network, the MT switches the current connection to other Radio Access System (UTRAN).

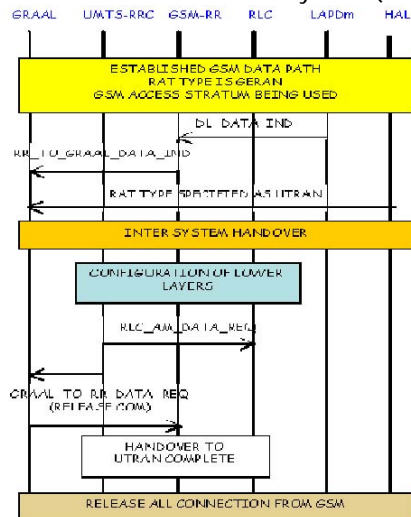


Figure 12: Inter-system handover (GSM->UMTS)

The signal flow between the different layers during inter-system handover is shown in Fig 12. The Handover Procedure from GSM to UMTS involves the following steps.

- Parameters identification and measurement
- RSSI (GSM)
- RSCP (UMTS)
- Ec/Io (UMTS)

Transmission of measurement reports to N/w by Mobile terminal.

- GSM N/w orders MT to make a Handover to UTRAN based on the measurement report received by the GSM N/w.
- Handover to UTRAN command message is sent to the MT via the GSM N/w.
- The MT shall be able to receive a **HANDOVER TO UTRAN COMMAND** message and perform an inter-system handover.
- If UE succeeds in establishing the connection to UTRAN, it will transmit an **HANDOVER TO UTRAN COMPLETE** message on the uplink DCCH.
  - Execution of Hand-over procedure
  - Call continuation with the UMTS network
  - Release of Network resources in the GSM n/w.

#### 4.2 Packet Call Handover from GPRS to WLAN:

The assumptions that have been made in this scenario is that Mobile Terminal is currently connected to GPRS and is moving towards WLAN (Hotspots). The following steps explain the GPRS to WLAN handover procedure with respect to Fig 13. (*Flow 1, 2 & 3*):

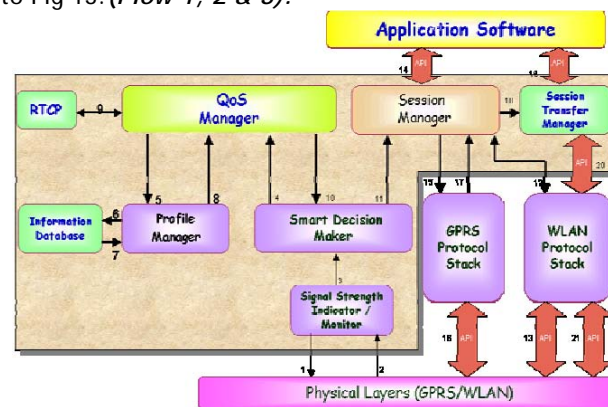


Figure 13: GPRS to WLAN Handover Process

After moving to WLAN, If the RSS of WLAN is much better than the GPRS Signal Strength based on beacons received from the first 802.11 cell, the SSI would trigger the Handover controller to initiate the Handover process.

The SDM (Smart Decision Maker) will initiate the Handover process, if the WLAN signal strength is satisfactory as shown in Fig 13, as the application requirements for high data rate would be available in WLAN when compared to the GPRS network. (*Flow 4, 5, 6, 7, 8, 9 & 10*):

Now the SDM will give trigger to QoS manager, which in turns triggers the internal function QMF (QoS Measurement Function) where the QMF would be continuously monitoring the QoS parameters like Throughput, delay, Jitter and packet loss from the RTCP protocol. These values are passed based on the ongoing GPRS data connection and QMF will be providing this data to the QCF function.

The QCF (*Quality Control Function*) will compare the QoS parameters of the present connection with the predefined values provided by the Profile manager by taking the data from the information database, which is stored in the MS. Now if the values of the present were degraded when compared to the stored values, then it would try to renegotiate the QoS parameters with the GPRS network (to modify the existing PDP Context).

If the Renegotiation also does not provide the required QoS, then the QCF (Quality Control Function) would indicate to smart decision maker. (*Flow 11, 12 & 13*)

The SDM would combine the received triggers from all the functions and take a smart decision in order to initiate for an Handover from GPRS to WLAN in order to maintain session continuity by giving a trigger to the session manager (SM).

Now the SM would trigger the WLAN Stack and the WLAN Messages like Association Request,

Association Response will be sent by calling respective IEEE 802.11 primitives and received by the mobile station to establish layer-2 connectivity, Router Advertisement procedure for knowing the IP address of WLAN Access Router, Binding Update procedure to get the care-of-address assignment for the Mobile Station (MS). (Flow 14, 15, 16, 17, 18, 19, 20 & 21)

Once the Radio bearer allocation procedures were completed on the WLAN Side, the data transfer switching will take place smoothly through Session Transfer Manager module based on the trigger given by the session manager. Now the data transfer control would take place with the WLAN protocol stack, the radio bearers will be released on the GPRS side by calling respective 3GPP primitives & messages and the stack goes to OFF mode.

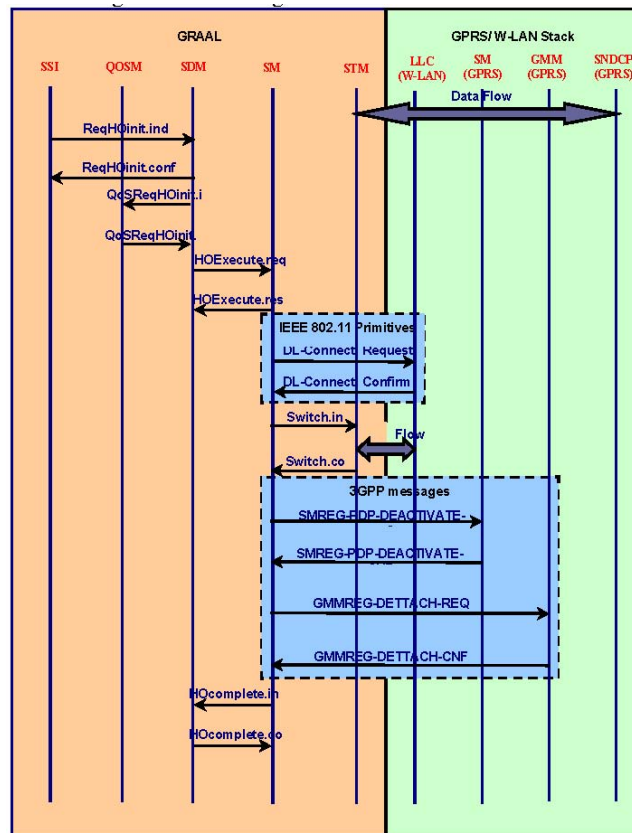


Figure 14: GPRS to WLAN - Message Sequence Chart

#### 4.3 Packet Call Handover from WLAN to UMTS:

The assumptions that have been made in this scenario is that Mobile Terminal is currently connected to WLAN and is moving away from the hotspot area as explained in Fig 15.

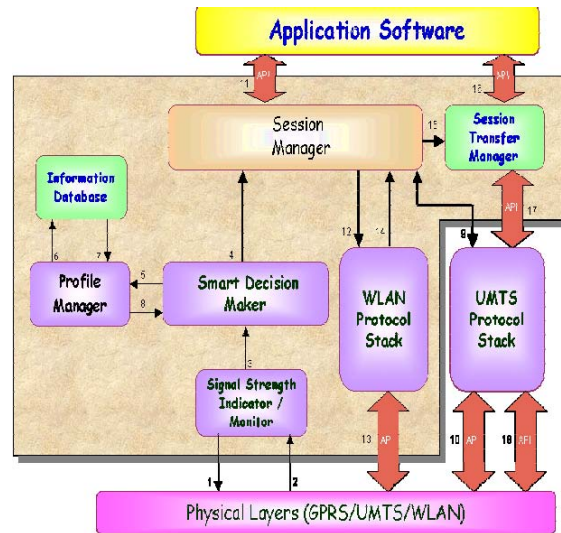


Figure 15: WLAN to UMTS Handover Process

- o When the Mobile node moves out of the WLAN coverage area, the signal strength indicator gives trigger to Smart Decision maker based on the set lower limit threshold value.
- o The SMD passes the information to Session Manager in order to trigger to the WLAN Interface to detect the Access Point (AP) by sending probe request messages.
- o Failure to receive the probe response message from the AP indicates the handover condition from WLAN to UMTS based on the user preferences.
- o Now the SMD gives trigger to session manager to send Routing area update message to SGSN through its UMTS stack interface by including information to indicate that it is disconnected from the WLAN network. The message includes the IP address of the last AR it was attached.
- o The data flow will continue to pass through the U-plane Protocol stack of UMTS and release of WLAN resources.

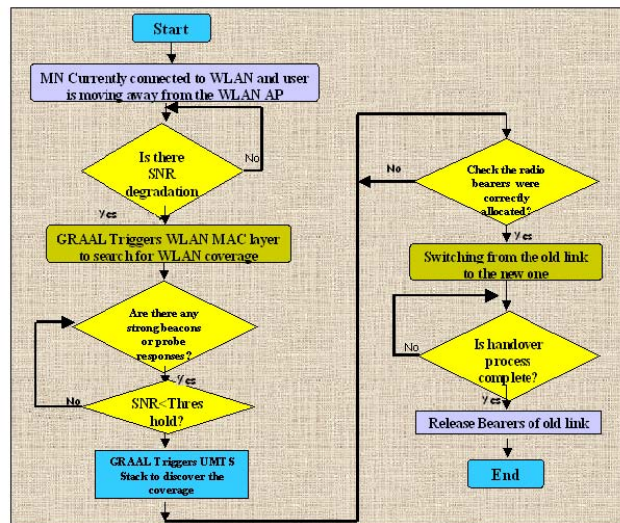


Figure 16: WLAN to UMTS Execution Process

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## 5. CONCLUSION

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In this paper, we have presented an important aspect of Generic radio access abstraction layer introduced in the protocol stack, to facilitate seamless roaming when the mobile user moves across cellular and wireless LANs (e.g. between UMTS and WLAN or between GPRS and WLAN). Key software modules like Handover Controller, QoS Manager, Session Manager, Profile Manager and Handover executor have been introduced in the GRAAL layer for interaction with the existing protocols to support required handover behavior. The GRAAL provides an overall solution for smooth handover by timely detection of different networks and smart selection of the target network based on user choice and applications preferences.

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