An Analysis of Traffic and Throughput for UMTS Packet Core Networks

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ABSTRACT

Mobile packet services are penetrating mobile markets rapidly. The mobile industry relies heavily on data services to replace the traditional voice services with the evolution of the wireless technology and market. Designing a reliable packet service network is critical to the mobile operators’ ability to maintain their core competence in data service market. The current literature provides many practical tools or theoretical methods to design, plan and dimension Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) radio networks but overlooks the algorithms of network plan and dimensioning for the core networks.

This paper introduces the algorithms to dimension the throughput for packet switched domain of UMTS network. The analysis is based on the traffic and data throughput generated or absorbed in the interfaces of network entities in UMTS PS network. A case study is provided to verify the algorithms created for UMTS PS network. This paper is aimed at helping UMTS PS network operators dimension an optimum network size and build a network structure to deliver an optimum quality of service for users.

Key Words: UMTS, WCDMA, Core Network, Packet Switch, Network Throughput, Network Dimensioning, Network Plan, Mobile Network Design.

INTRODUCTION

Packet switched domain of third generation (3G) UMTS network serves all data related services for the mobile subscribers. Nowadays people have a certain expectation for their experience of mobile data services that the mobile wireless environment has not fully met, since the speed at which they can access their packet switched (PS) services has been limited. Mobile operators realize that if they are to succeed in today’s wireless
communications landscape, they must address the quality of service for their packet service users. Simply adding more bandwidth to accommodate increased packet switched traffic is an expensive alternative. Hence, the mobile operators are faced with the issue of how to do more with less? The answer is to ensure a reasonable dimensioning for UMTS packet switched (PS) network while maintain the network quality of service.

Radio access solutions are a primary concern of the UMTS deployment strategy, as it impacts the mobile operators’ most valuable asset: spectrum. As an equally important part of this formula, the core network will play an essential role in enhancing mobility, service control, efficient use of network resources and a seamless migration from 2G/3G to 4G. Hence the network evolution calls for a transition to a “flat,” all-IP core network with a simplified architecture and open interfaces.

UMTS Packet Switched (PS) network is a typical data network in which data traffic, particularly with streaming media services, is live, extremely time sensitive to delay, latency, jitter, and non-tolerant of congestion. For example, a small minority of packet service subscribers running File Transfer Protocol (FTP), streaming video or peer-to-peer (P2P) file sharing applications can generate enough traffic to congest UMTS PS networks and impact the majority of subscribers using interactive Web browsing and E-mail applications. As a result, mobile operators must find algorithms and rules that will dimension their emerging 3G PS networks, while addressing their potential 4G deployment requirements and that will not require a “forklift” upgrade.

In order to accurately plan, design, and dimension the UMTS PS network, this paper will develop the algorithms of traffic and throughput for the UMTS PS network entities (NEs) described in Section 3. The analysis will be based on the live traffic and throughput generated or absorbed in the interfaces of PS NEs. A case study is provided to verify the algorithms created for UMTS PS domain. This paper is aimed at helping UMTS PS network operators dimension an optimum network size and build an optimum network structure to deliver an optimum quality of service for users.

In addition, the network optimization and expansion is the further effort for the mobile operator after the rolling out of mobile networks. To minimize the CAPEX/OPEX and maintain the QoS of mobile core networks, we propose that the impact of cell site re-homing on the mobile core should be studied. It is believed that the appropriate cell site re-homing in radio domain, via correct algorithms applied, not only optimizes the radio network but also helps improve the QoS of the core network and minimize the mobile operator’s CAPEX/OPEX investment in their core networks.

The rest of the article is organized as follows: Section 2 summarizes the literature in the related area and the challenges in dimensioning mobile packet core networks. Section 3 introduces the architecture of the UMTS packet core network and in particular the key network entities in UMTS packet domain. Section 4 which is the core of the paper discusses the algorithms for traffic and throughput in those interfaces of UMTS packet core networks such as Iu-PS, Gn, Gp, Gr, and Gi interface. Section 5 provides a case study to illustrate application of the algorithms created in Section 4 for Iu-PS interfaces. Section 6 is the conclusion to the paper.

LITERATURE REVIEW
The current literature provides many practical tools and theoretical methods to design, plan and dimension GSM and UMTS radio networks but overlooks the algorithms of network plan and dimensioning for GPRS (General Packet Radio Service) network, packet switched domain of UMTS network, and IP Multimedia Sub-system (IMS). Also no previous literature provides a unified approach to calculate the throughput or traffic for UMTS packet switched network. Very few studies have been made on the wireless core network planning and dimensioning topics. This can be explained by two facts that both packet switched domain and circuit switched domain in UMTS core network are logically or physically more complicated in structure than radio access network and the internal throughput or traffic may vary by different vendors’ NEs.

Kunz, A. et al. (2005) have studied the QoS mechanism for GPRS and UMTS PS network. The analysis is still from the aspect of radio access network. Ludwin, W. (2002) has a systematic review for GPRS and UMTS network planning work in which the dimensioning work also stresses the radio interfaces. Similar studies by Sadhukhan S. K., et al (2009) and Ting, S. (2008) also introduce planning methods applied to GPRS or UMTS PS network from the radio access network perspective. Neruda, M. and Bestak, R. (2008) summarizes the evolution path from GSM, UMTS to IMS from the aspect of network entities so that service providers will be able to progressively migrate from GSM to UMTS and IMS.

A service specific paper for UMTS PS network, by Li, Z. et al. (2007) investigates location management solutions for PS services in UMTS networks and propose an inactivity counter mechanism in PS domain to reduce the location management cost of the inactivate users. Shalak, R. et al. (2004) make a qualitative study of the performance of UMTS core network, in which multiple vendors’ UMTS CN equipments are compared. Other literatures such as Jamaa, S.B., et al (2004), Juttner, A. et al (2005), Maple, C. (2004), and Wu, Y. (2004) have provided many mature solutions to plan, dimension and deploy UMTS radio network. Different models and methods have been developed to find the optimal topology of the cells if the basic traffic models and information of locations to install base-stations can be provided.

Therefore, the current literature is relatively mature on dimensioning of the radio networks. The literatures on planning the mobile core networks are limited to high level description for designing core network architecture. This literature gap in the detailed planning and dimensioning of the 3G packet core networks was the motivation behind our study and the specific focus on estimating the throughput and traffic generated and absorbed in the interfaces in the UMTS core network.

ARCHITECTURE OF UMTS CORE NETWORKS

Packet Switched (PS) domain and Circuit Switched Domain comprise the Core Network (CN) of a 2G Global Systems for Mobile Communications (GSM) or a 3G UMTS network. Whether in 2G or 3G phase, the CN plays an essential role in the mobile network system to provide such important capabilities as mobility management, call and session control, switching and routing, charging and billing, and security protection.
In R99 version, the first version of 3G UMTS network, the CN domain still consists of the same network entities (NE) and the same network architecture as that in GSM phase. However, there is a change in the circuit switched domain of R4, the second version of UMTS, which supports a networking mode where bearer is separated from control. Meanwhile multiple bearer modes such as ATM/IP/TDM are supported by CN. Consequently the Mobile Switching Center (MSC) in GSM/UMTS R99 is split into two NEs: MSC Server (MSS) and Media Gateway (MGW). We should note that no changes happen in packet switched domain from R99 to R4 except for a new Iu-PS interface which is used to connect PS domain with 3G radio access network (RAN).

The CN in UMTS is logically classified into the circuit switched domain (CS) and packet switched domain (PS). The CS domain includes such logical NEs as MSC Server, MGW, Visitor Location Register (VLR) integrated in MSC Server physically, Home Location Register (HLR), Authentication Center (AUC), and Equipment Identity Register (EIR). The packet switched domain (PS) includes Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). More specifically, PS domain consists of data service NEs: SGSN and GGSN as well as auxiliary NEs like Charging Gateway (CG), Border Gateway (BG) and Domain Name System Server (DNS), and different service platforms attached to PS domain. Figure 1 displays the topology of UMTS CN with the logical NEs mentioned above.

Figure 1. Topology of UMTS Core Network: CS+PS Domain

From 3GPP TS23.060, 3GPP TS24.008, 3GPP TS23.002, Packet Switched domain physically consists of SGSN, GGSN, and Charging Gateway. Below is a short description of these NEs. On the other hand, the other NEs in CS domain such as HLR, MGW and MSS coordinate with SGSN or GGSN to implement some PS related functions.
From 3GPP TS29.060 and 3GPP TS29.061, SGSN is responsible for the delivery of data packets from and to MSs within its serving area. Its tasks include packet routing and transfer, mobility management (attach/detach and location management), logical link management, and authentication and charging functions. Its interfaces include Iu-Ps interface connecting to RNC, Gn/Gp interface to GGSN, Gr interface to HLR, Gs interface to MSC Server or MSC, Gd interface to Short Message Center (SMC), and Ga interface to Charging Gateway.

GGSN is a gateway between UMTS PS/GPRS network and external data networks (e.g., Internet). It performs such functions as routing and data encapsulation between a MS and external data network, security control, network access control and network management. From UMTS PS/GPRS aspect, a MS selects a GGSN as its routing device between itself and external network in the activation process of PDP context in which Access Point Name (APN) defines the access point to destination data network. From external data network aspect, GGSN is a router that can address all MS IPs in UMTS PS/GPRS network. GGSN provides Gc interface to connect with HLR, Gn/Gp interface with SGSN, Gi interface with external data networks, and Ga interface with CG.

Charging Gateway is the billing unit for PS domain. Sometimes coupled together with SGSN, it collects, merges, filters and stores the original Call Detail Record (CDR) from SGSN and communicates with billing center, and then transfers sorted CDR to billing center.

HLR is responsible for storing, updating, revising or deleting subscriber related information, covering the basic service subscription information, supplementary service subscription information and location information of subscribers. In addition, it also implements the function of subscriber security management. From physical connection aspect, HLR provides D interface to connect with VLR in MSC Server, C interface to connect with MSC Server or MSC in GSM CN, Gr interface with SGSN, and Gc interface with GGSN. The type of signaling message delivered from and to HLR is Mobile Application Part (MAP).

In UMTS circuit switched domain, MSC Server is a functional entity that implements mobile call service, mobility management, handover, and other supplementary services. Due to the philosophy of separation of control function from bearer function in UMTS CN, it is actually a controller of MGW to establish call routes between Mobile Stations (MS) via Mc interface. MSC Server also physically integrates with a VLR to hold subscriber’s data. MSC Server provides the optional Gs interface with SGSN.

In addition, a MGW in a UMTS implements bearer processing functions between different networks. It implements UMTS voice communication, multimedia service, CS domain data service, and interworking between PSTN and UMTS CN and between GSM CN and UMTS CN. MGW provides Iu-CS interface to connect with the Radio Network Controller (RNC) in the Radio Access Network (RAN), Nb interfaces with its peer MGW, E interfaces with 2G MSC, Mc interfaces with MSC Server, A interface with BSC, and Ai interface with Public Switched Telephone Network (PSTN).
ALGORITHMS FOR THROUGHPUT IN INTERFACES OF UMTS PACKET CORE NETWORKS

Since Iu-PS interface is newly defined in UMTS CN, this section will first introduce the algorithms for Iu-PS interface. The throughput algorithms for the other interfaces such as Gn, Gi, Gs and Gr interface, since they have been existing in GPRS network, will also be introduced based on a general rule: total traffic (Erlang or message size) times traffic proportion to obtain the traffic distribution for each NE and each link.

Iu-PS Interface

Iu-PS interface, situated between Radio Network Controller (RNC) and Serving GPRS support Node (SGSN) and Iu-CS interface between RNC and Media Gateway (MGW) composes the Iu interface. Iu-PS and Iu-CS interface define the same protocol stacks of transport network user plane and control plane, whereas they have the different transport network user plane. Ouyang. Y. and Fallah M.H. (2009) illustrate the throughput algorithm for Iu-CS interface. Table 1 displays the protocol stacks of Iu-CS interface. Defined by 3GPP TS 25.401, ITU-T I.363.2, 3GPP TS 25.415, and 3GPP TS 25.413, the data of user plane in Iu-CS interface is transparently transported and carried by ATM Adaption Layer 2 (AAL2) while the voice data such as Adaptive Multi Rate (AMR) frame is supported by User Plane Protocol (Iu-UP) stands on the top layer and follows by AAL2 and ATM.

According to 3GPP TS23.060, 3GPP TS 32.015, and 3GPP TS 25.413, the protocol stacks of Iu-PS interface are shown in Table 2, in which a significant difference is AAL5 rather than AAL2 in Iu-CS interface is adopted in layer 2 of Iu-PS to transport the data in both control and user plane via IP over ATM. The total throughput in Iu-PS interface is the sum of the throughput of user plane and control plane in Iu-PS interface. The following paragraphs will respectively introduce the algorithms of user plane and control plane of Iu-PS interface.

Table 1. Protocol Stack of Iu-CS interface

<table>
<thead>
<tr>
<th>Radio Network Control Plane</th>
<th>Transport Network Control Plane</th>
<th>Circuit Switching Data User Plane</th>
<th>CS Voice User Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM/SM/CC</td>
<td></td>
<td>Application</td>
<td>AMR Codec</td>
</tr>
<tr>
<td>RANAP</td>
<td></td>
<td>TAF</td>
<td></td>
</tr>
<tr>
<td>SCCP</td>
<td></td>
<td>ALCAP</td>
<td>RLP</td>
</tr>
<tr>
<td>MTP3-D</td>
<td>MTP3-D</td>
<td>STC</td>
<td></td>
</tr>
<tr>
<td>SCCF NNI</td>
<td>SCCF NNI</td>
<td>STC</td>
<td></td>
</tr>
<tr>
<td>SSCOP</td>
<td>SSCOP</td>
<td>STC</td>
<td>Iu UP</td>
</tr>
<tr>
<td>AAL5</td>
<td>AAL5</td>
<td>STC</td>
<td>AAL2-SAR SSCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ATM</td>
<td>AAL2</td>
</tr>
</tbody>
</table>

Table 2. Protocol stack of Iu-PS interface
Radio Network Control Plane | PS Data User Plane
---|---
RANAP | Iu-UP
SCCP |  
MTP3-B | M3UA | GTP-U
SSCF-NNI | SCTP | UDP
SSCOP | IP
  AAL5
  ATM

**Suggested GTP-U Header Size for Throughput Algorithm of User Plane**

Another difference in Iu-PS interface is that GPRS Tunneling Protocol (GTP-U) is inserted between Iu-UP and UDP for the reason of tunneling transmission in PS network. 3GPP TS29.060 defines the GTP protocol that allows multi-protocol packets to be tunneled through the UMTS/GPRS Backbone between GPRS support nodes (GSNs) and between SGSN and RAN. In the control plane, GTP specifies a tunnel control and management protocol (GTP-C) which allows the SGSN to provide packet data network access for a Mobile Station (MS). In the user plane, GTP uses the GTP-U to provide a service for carrying user data packets. The GTP-U protocol is implemented by SGSNs and GGSNs in the UMTS/GPRS Backbone and by Radio Network Controllers (RNCs) in the UMTS Terrestrial Radio Access Network (UTRAN).

**Table 3. GTP-U header**

<table>
<thead>
<tr>
<th>Octets</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Version</td>
<td>PT</td>
<td>(*)</td>
<td>E</td>
<td>S</td>
<td>PN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Message Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Length (1st Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Length (2nd Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Tunnel Endpoint Identifier (1st Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Tunnel Endpoint Identifier (2nd Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Tunnel Endpoint Identifier (3rd Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Tunnel Endpoint Identifier (4th Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sequence Number (1st Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Sequence Number (2nd Octet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>N-PDU Number</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Next Extension Header Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The header of GTP-U protocol is a variable header with a minimum length of 8 bytes. As Table 3 shows, Octet 1 includes three flags which are the PN flag, the S flag and the E flag. The PN flag is used to signal the presence of N-Packet Data Unit (PDU) Numbers. The S flag is used to signal the presence of the GTP Sequence Number field. The E flag is used to signal the presence of the Extension Header field, used to enable future extensions of the GTP header defined in this document, without the need to use another version number. Version field is used to determine the version of the GTP
protocol. Protocol Type (PT) is used as a protocol discriminator between GTP (when PT is '1') and GTP' (when PT is '0'). Octet 2 indicates the type of GTP message. Octet 3 and 4 indicate the length in octets of the payload. Octet 5 to 8 contains the information of Tunnel Endpoint ID (TEID) which identifies a tunnel endpoint in the receiving GTP-U or GTP-C protocol entity. The first 8 octets form the compulsory fields of the GTP-U header while octets 9-12 compose the optional fields in which Sequence Number is used as a transaction identity for signaling messages having a response message defined for a request message; N-PDU Number is used at the Inter SGSN Routing Area Update procedure and some inter-system handover procedures (e.g. between 2G and 3G radio access networks); and Next Extension Header Type defines the type of Extension Header that follows this field in the GTP-PDU. As a summary, the maximum length of a GTP-U header is 12 octets. It’s applied in our calculations later.

**Suggested Iu-UP Header Size for Throughput Algorithm Of User Plane**

In Iu-PS interface user plane, Iu Interface User Plane Protocol (Iu-UP) stands on the top layer and follows by AAL5 and ATM. The Iu-UP protocol is located in the User plane of the Radio Network layer over the Iu interface. The Iu-UP protocol is used to convey user data associated with Radio Access Bearers (RAB). Two operation modes of Iu-UP protocol are defined by 3GPP TS 25.415:

- **Transparent mode**
  - It is used by those radio access bears that do not request any particular feature from the Iu UP protocol other than transfer of user data.
  - The Iu-UP protocol instance does not perform any Iu-UP protocol information exchange with its peer over the Iu interface.
  - The Iu-UP protocol layer is crossed through by Packet Data Units (PDUs) being exchanged between upper layers and transport network layer.

- **Support mode**
  - It is used by those radio access bears that do require particular features from the Iu-UP protocol in addition to transfer of user data.
  - When operating in a support mode, the peer Iu-UP protocol instances exchange Iu-UP frames whereas in transparent mode, no Iu-UP frames are generated.

In this paper, the support mode is primarily considered for the calculation since its complexity is comparable to transparent mode. Several types of packet data unit (PDU) have been defined for Iu-UP protocol---type 0, type 1 and type 14 are typical PDU formats.

Take type 0 as an example. PDU Type 0 is defined to transfer user data over the Iu-UP in support mode for pre-defined SDU sizes. Error detection scheme is provided over the Iu-UP for the payload part. Table 4 displays the PDU type 0 of Iu-UP, in which the header field consists of Frame Control Part (FCP) and Frame Check sum Part (FCSP). The header size of type 0 is 1+1+2=4 octets.

**Table 4. PDU type 0 of Iu-UP protocol**

<table>
<thead>
<tr>
<th>Bits</th>
<th>Octets number</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
One exception is that FCSP in type 1 occupies 1 octet only. Hence the header size of type 1 is 3 octets. However, most of other types have 4 octets header size. Hence, we will use a 4-octet header size for Iu-UP later in our analysis.

**Throughput Algorithm for User Plane Of Iu-PS Interface**

Besides the header length of Iu-UP and GTP-U protocol, the header sizes of other protocols in Iu-PS user plane can also be easily identified based on ITU-T I.363.2, ITU-T I.363.5, IETF RFC 2225, IETF RFC 791, and IETF RFC 761. Table 5 displays the header size of each protocol in user plane of Iu-PS interface.

**Table 5. Suggested header size for Iu-PS interface**

<table>
<thead>
<tr>
<th>User Plane</th>
<th>Header Size (Octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iu-UP</td>
<td>4</td>
</tr>
<tr>
<td>GTP-U</td>
<td>12</td>
</tr>
<tr>
<td>UDP</td>
<td>8</td>
</tr>
<tr>
<td>IP</td>
<td>20</td>
</tr>
<tr>
<td>AAL5</td>
<td>3</td>
</tr>
<tr>
<td>ATM</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>

The packets sent via Iu-PS are carried by ATM. So in order to calculate the throughput in Iu-PS interface, the first step is to obtain how many ATM cells are needed to load the transported packets. The total packet size consists of the sum of average packet size, header of Iu-UP, header of GTP-U, header of UDP, header of IP and header of AAL5. The actual size in an ATM cell to load encapsulated packets is 53-header of ATM. As a result, the number of ATM Cell to load the encapsulated packets is given by

\[
N_{ATMCell} = \left( S_{Packet} + H_{IuUP} + H_{GTP} + H_{UDP} + H_{IP} + H_{AAL5} \right)/(53 - H_{ATM})
\]

in which \( S_{Packet} \) denotes the average packet size which can be obtained from the traffic model provided by the mobile operators,

\( H_{IuUP} \) denotes the header of Iu-UP packet which is obtained from Table 1,

\( H_{IP} \) denotes the header of IP packet which is obtained from Table 1,

\( H_{AAL5} \) denotes the header of AAL5 packet which is obtained from Table 1,

\( H_{ATM} \) denotes the header of ATM cell which is obtained from Table 1.

In planning a packet switched network, the mobile operators will estimate some important traffic parameters given by a traffic model, such as the average packet size, the
estimated number of subscribers, the ratio of attached users in busy hour, and the average throughput per user in one busy hour and redundancy factor. With these conditions provided by the traffic model, the “pure throughput” value without any overhead can be obtained by

$$\text{PureThroughput} = N_S \times R_{\text{Attach}} \times R_{\text{Active/Attach}} \times \frac{\text{Th}_{\text{User}}}{S} \times 8$$

(2)

where $N_S$ denotes the number of subscribers with 3G packet switched service subscription,

$\text{Th}_{\text{User/S}}$ denotes the average throughput per user per second (bps),

$R_{\text{Attach}}$ denotes the ratio of attached users in busy hour,

$R_{\text{Active/Attach}}$ denotes the rate of attached users who activate PDP in busy hour.

8 denotes the conversion to bits from bytes,

However, in the actual network environment the extra overhead and redundancy shall be considered. So based on formula 2, the throughput of user plane of Iu-PS interface is given by

$$\text{TH}_{\text{UuPaaS}} = N_S \times R_{\text{Attach}} \times R_{\text{Active/Attach}} \times \left( R_{\text{Down}} \times \frac{\text{Th}_{\text{User}}}{S} \right) \times \left( N_{\text{ATMCell}} \times 53 / S_{\text{Packet}} \right) \times 8 / F_{\text{Redundancy}}$$

(3)

where $N_S$ denotes the number of subscribers with 3G packet switched service subscription,

8 denotes the conversion to bits from bytes,

$R_{\text{Attach}}$ denotes the ratio of attached users in busy hour,

$R_{\text{Active/Attach}}$ denotes the rate of attached users who activate PDP in busy hour.

$S_{\text{Packet}}$ denotes the average packet size which can be obtained from the traffic model provided by the mobile operators,

$R_{\text{Down}}$ denotes the ratio downstream throughput to down + upstream data throughput.

$\text{Th}_{\text{User/S}}$ denotes the average throughput per user per second (bps),

$N_{\text{ATMCell}}$ denotes the number of ATM Cells which can be obtained by formula 1,

$F_{\text{Redundancy}}$ denotes the redundancy factor. Normally is set at 0.7.

The $\left( N_{\text{ATMCell}} \times 53 / S_{\text{Packet}} \right)$ portion denotes the proportion of ATM cell sizes to pure packet size. It explains the impact of network overhead on Iu-PS interface.

The $\left( R_{\text{Down}} \times \text{Th}_{\text{User/S}} \right)$ portion denotes the data throughput per subscriber in one way direction. It is assumed that downstream is heavier than upstream. If reversed, $R_{\text{Down}}$ should be changed to $R_{\text{up}}$.

**Primary Messages Going Through Control Plane**

The control plane of SGSN provides such four major functions as mobility management, session management, path management and short messages services etc. The primary messages adopted for throughput calculation are categorized by each function.

- Mobility management
  - Authentication message

  The authentication process in packet switched domain is jointly completed by Mobile Station (MS), SGSN, and HLR. Figure 2 shows the authentication flow: SGSN first sends out the authentication information to HLR; HLR returns the acknowledgement of authentication information, that is a set of authentication including RAND (Random Number), XRES (Expected Response), IK (Integrity Key), CK (Cipher Key), and AUTN
(Authentication Token); SGSN then sends an authentication request to the MS; and the MS has a response back to SGSN. In particular, the messages of authentication request and authentication response contribute a portion of throughput in control plane of Iu-PS interface.

Figure 2. Authentication process

---

– Attach message

Attach is a must step before a mobile station tries to access packet switched network. Step 1, 6 and 7 compose a complete attach message set. In step 1, the MS sends an attach request to the new SGSN; after several steps, the new SGSN in step 6 accepts the attach request; and last step 7 complete the attach process. Hence step 1, 6 and 7 contribute a portion of throughput in control plane of Iu-PS interface.

Figure 3. Attach process

---

– Detach message

Three types of detach are defined by 3GPP TS29.061: MS initiated detach, SGSN initiated detach, and HLR initiated detach. No matter what type it is, the three messages go through Iu-PS interface are the same: Detach request; detach accept, and PS signaling connection release. Those three messages also contribute a portion of throughput in
control plane of Iu-PS interface. As an example, Figure 4 shows the entire HLR triggered detach process.

**Figure 4. HLR triggered detach**

![HLR triggered detach diagram]

- Intra SGSN routing area update message  
  As Figure 5 displays, four primary steps contributing to the throughput of user plane of Iu-PS interface. The MS sends to the SGSN a route area update request. The RNS adds in the request the cell global identification that contains RAC and LAC. The encryption is then activated between the MS and the SGSN. In the next step, the SGSN updates the MM context of the MS, and when necessary, allocates a new P-TMSI to it. After that, it returns to the MS a route area update acceptance message. If a new P-TMSI is allocated, the MS returns the route area update complete message.

**Figure 5. Intra SGSN route update**

![Intra SGSN route update diagram]

- Inter SGSN routing area update message  
  Clint S. (2006) introduces the details of inter SGSN routing area update in which four critical steps contribute some traffic for control plane of Iu-PS interface: Routing area update request, Security functions, Routing area update accept, and Routing area update complete.

- Service RNC relocation  
  There are three statuses of mobility management in packet switched domain: (Packet Mobility Management) PMM-connected, PMM-detached, and PMM-idle, all of
which are stored in the mobility management context (MM context) in SGSN. Service RNC relocation message can only be implemented in the status of MM-connected.

As per Figure 6, Step 2, 6, and 13 are implemented between RNC and SGSN. In step 2, The SRNC initiates through sending the relocation required message to the old SGSN the relocation procedure, and the message contains relocation type, old ID, destination ID, and other parameters. Step 6 enables the old SGSN to continue the relocation process. Step 13 at last release the Iu interface. Hence the message of relocation required, relocation command, Iu release command, and Iu release complete contribute a portion of throughput for control plane of Iu-PS interface.

**Figure 6. Service RNC relocation**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Decision to perform SRNS relocation</td>
</tr>
<tr>
<td>2.</td>
<td>Relocation Required</td>
</tr>
<tr>
<td>3.</td>
<td>Forward Relocation Request</td>
</tr>
<tr>
<td>4.</td>
<td>Relocation Request Acknowledge</td>
</tr>
<tr>
<td>5.</td>
<td>Forward Relocation Response</td>
</tr>
<tr>
<td>6.</td>
<td>Relocation Command</td>
</tr>
<tr>
<td>7.</td>
<td>Relocation Commit</td>
</tr>
<tr>
<td>8.</td>
<td>Forwarding of data</td>
</tr>
<tr>
<td>9.</td>
<td>Relocation Complete</td>
</tr>
<tr>
<td>10.</td>
<td>UTRAN Mobility Information</td>
</tr>
<tr>
<td>11.</td>
<td>Update PDP Context Request</td>
</tr>
<tr>
<td>12.</td>
<td>Relocation Complete</td>
</tr>
<tr>
<td>13.</td>
<td>Iu Release Command</td>
</tr>
<tr>
<td>14.</td>
<td>Iu Release Complete</td>
</tr>
<tr>
<td>15.</td>
<td>Uplink Area Update</td>
</tr>
</tbody>
</table>

- **Session management**
  - Packet data protocol (PDP) activation message

  After completing the service request process with RNC and SGSN, the MS can request the initiation of PDP context activation. Figure 7 defines 5 steps for a PDP activation process in which step 1, 2, 3, and 5 contribute a portion of throughput generated in control plane of Iu-PS interface.

**Figure 7. PDP context activation initiated by MS**
Also the PDP context activation can be initiated by network. In Figure 8, request PDP context activation in step 4 contributes a portion of throughput in control plane of Iu-PS interface.

*Figure 8. PDP context activation initiated by network*

---

PDP deactivation message

Similar to PDP activation, PDP deactivation also has two modes: MS initiated and network initiated, in which a pair of messages: Deactivate PDP context request and deactivate PDP context accept contribute a portion of throughput in control plane of Iu-PS interface. Figure 9 displays the MS initiated process of PDP deactivation.

*Figure 9. PDP context deactivation initiated by MS*

---

**Throughput Algorithm for Control Plane Of Iu-PS Interface**
The 8 primary messages compose the majority of the throughput in control plane of Iu-PS interface. However, Table 6 lists 11 primary types of messages in total which can be estimated and provided by the mobile operators according to their historical operation data. The first 8 messages are what we introduced above while the last 3 messages, as the optional messages, may also be adopted by mobile operators and applied into the throughput formula 4.

The throughput in control plane of Iu-PS interface is given by

$$TH_{CP_{IuPS}} = N_S \times R_{Attach} \times \frac{\sum_{i=1}^{11} (N_{IuPSi} \times L_{IuPSi}) \times 8}{3600} \tag{4}$$

where $N_S$ denotes the number of subscribers with 3G packet switched service subscription,
8 denotes the conversion to bits from bytes,
3600 denotes the conversion to second from busy hour,
$R_{Attach}$ denotes the ratio of attached users in busy hour,
The other parameters are explained in Table 6.

Table 6. Footnotes for Formula 4

<table>
<thead>
<tr>
<th></th>
<th>$N_{IuPSi}$</th>
<th>$L_{IuPSi}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Authentication times per busy hour</td>
<td>Length of messages per authentication</td>
</tr>
<tr>
<td>2</td>
<td>Attachment times in busy hour</td>
<td>Length of messages per attachment in Iu-PS</td>
</tr>
<tr>
<td>3</td>
<td>Detachment times in busy hour</td>
<td>Length of messages per detachment in Iu-PS</td>
</tr>
<tr>
<td>4</td>
<td>Inter SGSN route update times in busy hour</td>
<td>Length of messages per inter SGSN route update</td>
</tr>
<tr>
<td>5</td>
<td>Intra SGSN route update times in busy hour</td>
<td>Length of messages per intra SGSN route update</td>
</tr>
<tr>
<td>6</td>
<td>Intra SGSN SRNC times in busy hour</td>
<td>Length of messages per intra SGSN SRNC.</td>
</tr>
<tr>
<td>7</td>
<td>PDP activation times in busy hour</td>
<td>Length of messages per PDP activation</td>
</tr>
<tr>
<td>8</td>
<td>PDP deactivation times in busy hour</td>
<td>Length of messages per PDP deactivation</td>
</tr>
<tr>
<td>9</td>
<td>Periodic SGSN route area update times In busy hour</td>
<td>Length of messages per periodical SGSN route update</td>
</tr>
<tr>
<td>10</td>
<td>Short message service mobile originated (SMS MO) times in busy hour</td>
<td>Length of messages per SMS service</td>
</tr>
<tr>
<td>11</td>
<td>SMS MT times in busy hour</td>
<td>Length of messages per SMS service</td>
</tr>
</tbody>
</table>

The sum of the throughput of those 8 or 11 messages composes the total throughput in control plane of Iu-PS interface. Besides the 11 messages discussed, other messages such as P-Temporary Mobile Subscriber Identity (TMSI) re-allocation message, identification check message, and service request message etc, due to the smaller message size and lower utilization, are not considered in our throughput calculation for control plane of Iu-PS interface. If one or some of these messages are requested by
mobile operators and their parameters are difficult to estimate, a redundancy factor can be imposed in the formula 4 as a rough calculation.

**Total Throughput in Iu-PS Interface**

Based on the results from three sub-sections, the total throughput in Iu-PS interface is the sum of the throughput in control plane and user plane of Iu-PS interface. The algorithm is given by

\[ TH_{IuPS} = TH_{UPIuPS} + TH_{CPIuPS} \]  \hspace{1cm} (5)

**Gn/Gp Interface**

Gn/Gp interface locates between the SGSN and GGSN. In particular, Gn interface is situated between GSN nodes in the same Public Land Mobile Network (PLMN), whereas Gp interface is situated between GSN nodes from different PLMNs. Both interfaces use the same protocol stack in which GPRS Tunneling Protocol (GTP) is adopted to transport encapsulated packets via a GPRS tunnel between SGSN and GGSN. Table 6 shows the protocol stack from top to end layer is GTP/UDP/IP/LLC/MAC.

**Table 6. Protocol Stack of Gn/Gp Interface**

<table>
<thead>
<tr>
<th>User Plane</th>
<th>Header size</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTP</td>
<td>12</td>
</tr>
<tr>
<td>UDP</td>
<td>8</td>
</tr>
<tr>
<td>IP</td>
<td>20</td>
</tr>
<tr>
<td>LLC</td>
<td>N/A</td>
</tr>
<tr>
<td>MAC</td>
<td>N/A</td>
</tr>
</tbody>
</table>

GTP defines 255 types of messages between two associated GSNs which can be classified into three message categories: GTP-U, GTP-C and GTP’.

In calculating the throughput in Gn/Gp interface, the GTP-U data rather than GTP-C contributes the majority of the throughput.

**Throughput Algorithm for GTP-U Packets in Gn/Gp Interface**

In dimensioning the throughput in Gn/Gp interface, mobile operators will estimate such parameters in the traffic model as the number of subscribers with 3G packet switched service subscription, the ratio of attached subscribers and the ratio of attached subscribers who activate packet data protocol (PDP) context.

The overhead ratio shall be similarly considered as the case of Iu-PS interface. The rate of overhead in Gn/Gp interface is given by

\[ RO_{Gn/Gp} = \left( \frac{\tilde{S}_{Packet} + H_{GTP} + H_{UDP} + H_{IP}}{\tilde{S}_{Packet}} \right) \]  \hspace{1cm} (6)
With the conditions provided from the mobile operator’s traffic model and the rate of overhead in formula 4, the throughput of GTP-U packets in Gn/Gp interface is obtained by

\[
TH_{U \text{ Gn/Gp}} = N_S \times R_{\text{Attach}} \times R_{\text{Attach} \rightarrow \text{Active}} \times (Th_{\text{User} \rightarrow S} \times R_{\text{Down}}) \times R_{\text{Overhead}} \times 8
\]

where \(N_S\) denotes the number of subscribers with 3G packet switched service subscription, 
8 denotes the conversion to bits from bytes, 
3600 denotes the conversion to second from busy hour, 
\(S_{\text{Packet}}\) denotes the average packet size which can be obtained from the traffic model provided by the mobile operators, 
\(Th_{\text{User} \rightarrow S}\) denotes the average throughput per user per second (bps), 
\(R_{\text{Attach}}\) denotes the ratio of attached users in busy hour, 
\(R_{\text{Active} \rightarrow \text{Attach}}\) denotes the rate of attached users who activate PDP in busy hour. 
\(R_{\text{Overhead}}\) denotes the overhead rate which is given by formula 6. 
\(R_{\text{Down}}\) denotes the ratio downstream throughput to down + upstream data throughput. 
The \((R_{\text{Down}} \times Th_{\text{User} \rightarrow S})\) portion denotes the data throughput per subscriber in one way direction. It is assumed that downstream is heavier than upstream. If reversed, \(R_{\text{down}}\) should be changed to \(R_{\text{up}}\).

**Throughput Algorithm for GTP-C Packets in Gn/Gp Interface**

In Formula 7, the GTP-U packets are assumed to be the majority of throughput for Gn/Gp interface. Sometimes GTP-C packets are considered to be a minority of the throughput for Gn/Gp interface. To calculate the contribution of GTP-C packets to the throughput for Gn/Gp interface, we identify the major GTP-C messages going through Gn/Gp interface. The major GTP-C messages include PDP context activation, PDP context modification, and PDP context deactivation. In this paper, activation and deactivation process are considered to contribute most to the GTP-C throughput in Gn/Gp interface. Therefore the throughput of GTP-C packets in Gn/Gp interface is obtained by

\[
TH_{C \text{ Gn/Gp}} = N_S \times R_{\text{Attach}} \times \sum_{i=1}^{N_{Gni}} (N_{Gni} \times L_{Gni}) \times 8 / 3600
\]

where \(N_S\) denotes the number of subscribers with 3G packet switched service subscription, 
8 denotes the conversion to bits from bytes, 
3600 denotes the conversion to second from busy hour, 
\(R_{\text{Attach}}\) denotes the ratio of attached users in busy hour, 
The other parameters are explained in Table 7.

**Table 7. Footnotes for Formula 8**

<table>
<thead>
<tr>
<th>(N_{Gni})</th>
<th>(L_{Gni})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Create PDP context times in busy hour</td>
<td>Length of messages per create PDP context</td>
</tr>
<tr>
<td>2 Delete PDP context times in busy hour</td>
<td>Length of messages per delete PDP context</td>
</tr>
</tbody>
</table>

**Total Throughput in Gn/Gp Interface**
Based on the results from Section 4.21 and 4.22, the total throughput in Gn/Gp interface is the sum of the throughput of GTP-C and GTP-U packets in Gn/Gp interface. The algorithm is given by

\[ TH_{Gn/Gp} = TH_{Gn/Gp}^C + TH_{Gn/Gp}^U \]  

(9)

Gr Interface

Gr interface locates between SGSN and HLR. It is mainly responsible for transporting the subscriber related information in PS domain. SGSN reports the current location status of the subscribers to HLR and meanwhile receives the subscription information from HLR. The data exchange between HLR and SGSN through Gr interface usually happens only when a subscriber requests a packet switched service the SGSN or HLR respond to the service requested from the mobile station (MS). The protocol stack from top to end layer in Gr interface is MAP/TCAP/SCCP/MTP3/MTP2/MTP1. All the messages transported in the interface are encapsulated into MAP message, delivered upon the layer of TCAP and SCCP and carried by either TDM or IP.

Primary Messages Going Through Gr Interface

In Gr interface, we mainly consider four types of messages: Authentication, Attach, Detach, and inter-SGSN route update. Other messages such as purge, user data insertion, and user data deletion, because of their small message size and low utilization rate, are not considered in our calculation below. The throughput generated by them may be considered by setting a redundancy factor in the formula.

- **Authentication message**
  Section 4.14 introduced the authentication process in which the messages of send authentication information and send authentication information acknowledgement generate a portion of throughput in Gr interface.

- **Attach message**
  Figure 3 introduces the entire attach procedure in which step 5 is completed by SGSN and HLR through Gr interface. The messages transported through Gr interface in the attach process are location update, cancel location, cancel acknowledgement, insert subscriber data to HLR, insert acknowledgement and location update acknowledgement. So the messages in step 5 contribute a portion of throughput in Gr interface.

- **Detach message**
  Having discussed in Section 4.14, there are three types of detach between MS and SGSN in which HLR initiated detach is meaningful to Gr interface. Figure 4 shows the entire HLR triggered detach process. Two messages in this type of detachment are transported via Gr interface. In the HLR initiated process, HLR first sends the cancel location request message to SGSN through Gr interface and SGSN at last replies the request with cancel location acknowledgement message.

- **Inter SGSN Routing area update message**
  Clint S. (2006) introduces the details of inter SGSN routing area update in which 3 critical pair of messages go through Gr interface. A message pair: cancel location and cancel location acknowledgement contribute some traffic for Gr interface between the HLR and source SGSN from which the MS moves out; the other two message pairs:
update location and update location acknowledgement and insert subscriber data and insert subscriber data acknowledgement contribute some traffic for Gr interface between the HLR and target SGSN from which the MS moves in.

**Throughput Algorithm for Gr Interface**

Based on the four major messages, we can calculate the throughput for Gr interface. Table 9 lists the needed parameters which can be estimated by the mobile operators according to their historical operation data. The sum of the throughput of those four messages forms the total throughput in Gr interface. If other messages need to be considered, a redundancy factor can be imposed in the formula 10.

The throughput in Gr interface is given by

\[
TH_{Gr} = N_S \times R_{Attach} \times \sum_{i=1}^{4} (R_{Gri} \times N_{Gri} \times L_{Gri}) \times 8 / 3600
\]

where \(N_S\) denotes the number of subscribers with 3G packet switched service subscription,

8 denotes the conversion to bits from bytes,

3600 denotes the conversion to second from busy hour,

\(R_{Attach}\) denotes the ratio of attached users in busy hour,

The other parameters are explained in Table 9.

**Table 9. Footnotes for Formula 10**

<table>
<thead>
<tr>
<th></th>
<th>(R_{Gri})</th>
<th>(N_{Gri})</th>
<th>(L_{Gri})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Authentication Rate</td>
<td>Authentication times per busy hour</td>
<td>Length of messages per authentication</td>
</tr>
<tr>
<td>2</td>
<td>Attach Rate</td>
<td>Attach times per busy hour</td>
<td>Length of messages per attachment</td>
</tr>
<tr>
<td>3</td>
<td>N/A</td>
<td>Inter SGSN route update times per busy hour</td>
<td>Length of messages per inter SGSN route update</td>
</tr>
</tbody>
</table>

As regards the inter SGSN route area update, there is no rate for this message. So the item for SGSN route area update is just composed of \(N_{Gr3} \times S_{Gr3}\). In formula 10, the rate and times of each message can be given by the traffic model from the mobile operators. The size of each message is slightly different based on vendors’ equipments. The suggested parameters are given in a traffic model in the case study section.

**Gs Interface**

Gs interface is an optional interface between MSC and SGSN. Although it’s not required, some joint services between CS and PS domain can be implemented via this interface such as joint location update, joint attachment, and joint detachment. The circuit switched domain can also send paging and mobility management messages via Gs interface. The protocol stack is BSSAP+/SCCP/MTP3/MTP2/MTP1.

In this interface, three primary messages are considered: joint route update, joint location update and paging. Other messages such as joint detachment or joint attachment,
because of their small message size and low utilization rate, are not considered in our
calculation below. The throughput generated by them may be considered by setting a
redundancy factor in the formula. All the messages transported in Gs interface are carried
by BSSAP+ protocol upon the layer of SCCP.

Similar to that in Gr interface, the throughput in Gs interface is provided by
\[
TH_{Gs} = N_s \times R_{Attach} \times \sum_{i=1}^{3} (R_{Gsi} \times N_{Gsi} \times L_{Gsi}) \times 8 / 3600
\]
where \(N_s\) denotes the number of subscribers with 3G packet switched service
subscription,
8 denotes the conversion to bits from bytes,
3600 denotes the conversion to second from busy hour,
\(R_{Attach}\) denotes the ratio of attached users in busy hour,
The other parameters are shown in Table 10.

\[\begin{array}{|c|c|c|}
\hline
& R_{Gsi} & N_{Gsi} & L_{Gsi} \\
\hline
1 & Joint route update rate & Joint route update times per busy hour & Length of messages per joint route update \\
\hline
2 & Joint location update rate & Joint location update per busy hour & Length of messages per joint location update \\
\hline
3 & Paging rate & Paging times per busy hour & Length of messages per paging \\
\hline
\end{array}\]

**Gi Interface**

Gi interface is a reference interface between GGSN and an external packet data network
(PDN) such as Internet or Intranet. This interface specifies the end of packet switched
domain as the connected PDN normally belongs to another service provider or carrier.

A Remote Authentication Dial in User Service (RADIUS) server is set at Gi
interface to implement Authentication, Authorization, and accounting (AAA) functions.
Before a user is allowed to access the network, the AAA information is checked by
RADIUS server which holds the user related data such as login name, password profile
information and is also capable of collecting and recording accounting statistics.

Another network entity at Gi interface is Dynamic Host Configuration Protocol
(DHCP) server, a central unit to manage all the IP addresses. The DHCP server allocates
a IP address to the user via GGSN in a PDP activation request.

Theoretically the “pure” throughput at Gn interface should be equivalent to the
“pure” throughput at Gi interface. The data transported through Gi interface is actually
composed of the data payload (such as IP datagram), the optional VPN encapsulation,
and the header (such as Ethernet header). Assume most subscribers not to be
encapsulated by VPN, the rate of overhead in Gi interface can be obtained by
\[
RO_{Gi} = (S_{Packet} + H_{Datagram}) / S_{Packet}
\]
where \(S_{Packet}\) denotes the average packet size which can be obtained from the traffic
model provided by the mobile operators,
$H_{\text{datagram}}$ denotes the header of the media in Gi interface. For example the header that IP carried by packet over SDH (PoS) is 10 octets; the header of IP carried by Multi Protocol Label switching (MPLS) and PoS is 14 octets.

Therefore the throughput in interface Gi is given by

$$TH_{\text{Gi}} = N_S \times R_{\text{Attach}} \times R_{\text{Active/Attach}} \times (Th_{\text{User/S}} \times R_{\text{SUser/Down}}) \times RO_{\text{Gi}} \times 8 \quad (13)$$

where $N_S$ denotes the number of 3G GPRS subscribers,
8 denotes the conversion to bits from bytes,
3600 denotes the conversion to second from busy hour,
$R_{\text{Attach}}$ denotes the ratio of attached users in busy hour,
$R_{\text{Active/Attach}}$ denotes the rate of attached users who activate PDP in busy hour.
$Th_{\text{User/S}}$ Denotes the average throughput per user per second (bps),
$F_{\text{Redundancy}}$ denotes the redundancy factor. Normally set at 0.7.
The $(R_{\text{SUser/Down}} \times Th_{\text{User/S}})$ portion denotes the data throughput per subscriber in one way direction. It is assumed that downstream is heavier than upstream. If reversed, $R_{\text{down}}$ should be changed to $R_{\text{up}}$.

**Summary of Section 4**

Section 4.1 to 4.5 create the algorithms of throughput for Iu-PS, Gn/Gp, Gr, Gs and Gi interfaces in UMTS packet switched network. Other optional interfaces such as Gc and Gb are not considered since it’s optional to configure in UMTS packet switched networks. Whether to configure Gd interface which connects to short message center depends on the requests from the mobile operators.

In the calculation of throughput for control plane of Iu-PS, Gr, and Gs interfaces, only the primary messages that contribute the majority of the throughput for control plane are selected. Considering the throughput from control plane only accounts for a very small portion of total throughput (less than 1-5%), overlooking the non-primary messages is acceptable. Those additional messages, if required by operators, can be considered by imposing a redundancy factor into the formulas. A more precise alternative is to collect the value of $R_i$, $N_i$, and $S_i$ for the additional messages and accumulate their product into formulas. But it depends on the availability of these required parameters to the mobile operator. Another approximation is the throughput of Gi interface since we assume no VPN encapsulation is imposed in the original datagram. So the result of overhead rate in formula 12 may be smaller than the actual value. A smaller overhead rate may further result in a smaller value of throughput in interface Gi in Formula 13.

**CASE STUDY**

Figure 10 shows, a mobile operator intends to build a new 3G UMTS Packet Switched Network in the red color (represents heavy traffic loading) covered area to enhance the data service coverage. The blue markers in the map represent the cell sites. The plan is to provision one SGSN and GGSN to supports 100,000 3G GPRS subscribers in the area. Figure 11 depicts the architecture of the UMTS PS network for this case.
Table 11. Traffic Model for Packet Switched Domain

<table>
<thead>
<tr>
<th>Traffic parameters</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network volume</td>
<td>100,000</td>
<td>Subscribers with UMTS PS subscription.</td>
</tr>
<tr>
<td>ThUser/bps</td>
<td>600</td>
<td>Average data throughput per user per second Unit:bps.</td>
</tr>
<tr>
<td>SPacket</td>
<td>400</td>
<td>Average size of a IP packet.</td>
</tr>
<tr>
<td>RAttach</td>
<td>75%</td>
<td>The ratio of attached users to total UMTS PS users.</td>
</tr>
<tr>
<td>RActive/Attach</td>
<td>25%</td>
<td>The ratio of activated to attached users</td>
</tr>
<tr>
<td>NAttach</td>
<td>0.75</td>
<td>Attachment times per user in busy hour.</td>
</tr>
<tr>
<td>NDetach</td>
<td>0.75</td>
<td>Detachment times per user in busy hour.</td>
</tr>
<tr>
<td>NPDP-Activation</td>
<td>1.5</td>
<td>PDP activation times per user in busy hour.</td>
</tr>
<tr>
<td>NPDP-Deactivation</td>
<td>1.5</td>
<td>PDP deactivation times per user in busy hour.</td>
</tr>
<tr>
<td>NRoute-intraSGSN</td>
<td>4</td>
<td>Intra SGSN route area update times per user in busy hour.</td>
</tr>
<tr>
<td>NRoute-interSGSN</td>
<td>0.1</td>
<td>Inter SGSN route area update times per user in busy hour.</td>
</tr>
<tr>
<td>NRoute-periodic</td>
<td>0.3</td>
<td>Periodic route area update times</td>
</tr>
<tr>
<td>NRoute</td>
<td>4.4</td>
<td>NRoute= NRoute-intraSGSN+interSGSN+periodic</td>
</tr>
<tr>
<td>RJoint-Route</td>
<td>18%</td>
<td>Ratio of Joint route area update</td>
</tr>
<tr>
<td>RJoint-Location</td>
<td>18%</td>
<td>Ratio of joint location update</td>
</tr>
</tbody>
</table>
Table 12 defines the traffic model with required parameters for dimensioning a UMTS PS network. Those parameters shall be pre-estimated and provided by mobile operators. The parameters in Table 11 comprise the traffic model (traffic parameter template) in which most of the parameter values are identified by the mobile operator based on a multivariate analysis of its real time statistical performance data in a long term.

Table 12 provides the suggested length of messages in a certain service in UMTS PS domain. The values may be slightly varied from vendors’ products since some fields in the message defined by 3GPP are optional to adopt. In addition, this case is used to verify the algorithms, so roaming, intelligent network users and pre-paid users are not considered. All users are assumed to be post paid UMTS PS users.

As per Formulas 1, 3, and 4, the throughput for Iu-PS interface is calculated The number of ATM cells is obtained by:

Table 12. Parameters of PS Domain

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Suggested message length at single direction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAttach at Iu-PS</td>
<td>336</td>
<td>Length of messages per attachment at Iu-PS interface.</td>
</tr>
<tr>
<td>LDetach at Iu-PS</td>
<td>336</td>
<td>Length of messages per detachment at Iu-PS interface.</td>
</tr>
<tr>
<td>LPDP-Active at Iu-PS</td>
<td>768</td>
<td>Length of messages per PDP activation at Iu-PS interface.</td>
</tr>
<tr>
<td>LPDP-Deactive at Iu-PS</td>
<td>768</td>
<td>Length of messages per PDP deactivation at Iu-PS interface.</td>
</tr>
<tr>
<td>LRoute at Iu-PS</td>
<td>144</td>
<td>Length of messages per route area update at Iu-PS interface.</td>
</tr>
<tr>
<td>LSRNC at Iu-PS</td>
<td>1152</td>
<td>Length of messages per SRNC relocation at Iu-PS interface.</td>
</tr>
<tr>
<td>LAuthen at Iu-PS</td>
<td>192</td>
<td>Length of messages per authentication at Iu-PS interface.</td>
</tr>
<tr>
<td>LSMs at Iu-PS</td>
<td>1022</td>
<td>Length of messages per short message at Iu-PS interface.</td>
</tr>
<tr>
<td>LPDP-Active at Gn</td>
<td>300</td>
<td>Length of messages per PDP activation at Gn interface.</td>
</tr>
<tr>
<td>LPDP-Deactive at Gn</td>
<td>50</td>
<td>Length of messages per PDP deactivation at Gn interface.</td>
</tr>
<tr>
<td>LAttach at Gr</td>
<td>294</td>
<td>Length of messages per attachment at Gr interface.</td>
</tr>
<tr>
<td>LRoute at Gr</td>
<td>71</td>
<td>Length of messages per route area update at Gr interface.</td>
</tr>
<tr>
<td>LAuthen at Gr</td>
<td>259</td>
<td>Length of messages per authentication at Gr interface.</td>
</tr>
<tr>
<td>LRoute at Gs</td>
<td>82</td>
<td>Length of messages per route area update at Gs interface.</td>
</tr>
</tbody>
</table>
The throughput of user plane in Iu-PS interface is given by:
\[
TH_{IUPA} = NS \times RAM \times (TH_{User/S} \times RD) \times (N_{AMC} \times 53 / 8) / 8 \approx 10 \text{ Mbps}
\]

The throughput of control plane in Iu-PS interface is provided by:
\[
TH_{CPA} = NS \times RAM \times \sum_{i=1}^{11} (N_{UPSI} \times LD) / 8 \times 3600 = 100,000 \times 75\% \times 4829 \times 8 / 3600 = 804833.33 \text{ bps} = 0.80 \text{ Mbps}
\]

Total throughput of Iu-PS interface: \(TH_{IUPA} + TH_{CPA} = 127.77 + 0.80 = 128.57 \text{ Mbps}\)

As per Formulas 7, 8 and 9, the throughput for Gn interface can be calculated.

Overhead ratio is given by:
\[
RO_{Gn/Gp} = (\overline{S}_{Packet} + H_{GTP} + H_{UDP} + H_{IP}) / 400 = 1.1
\]

The throughput of GTP-U packets in Gn interface is provided by:
\[
TH_{Gn} = NS \times RAM \times (TH_{User/S} \times RD) \times (N_{AMC} \times 8) / 8 = 100,000 \times 75\% \times 8 \times 8 / 3600 = 875000 \text{ bps} = 0.0875 \text{ Mbps}
\]

Total throughput of Gn interface:
\[
TH_{Gn/Gp} = TH_{Gn} + TH_{CPA} = 74.25 + 0.0875 = 74.34 \text{ Mbps}
\]

The throughput of Gp interface can be obtained using Formula 10.

\[
TH_{Gp} = NS \times RAM \times \sum_{i=1}^{3} (R_{Gn} \times N_{Gn} \times LG) / 8 = 100,000 \times 356 \times 8 / 3600 = 59333.33 \text{ bps}
\]

If Gs interface is configured by T1 links, the number of E1 links required is given by
\[
N_{T1} = TH_{Gr} / [(56 \times 1024) \times LD] = 59333.33 / [(56 \times 1024) \times 0.2] \approx 6
\]

As per Formula 11, the throughput of Gs interface is given by:
\[
TH_{Gs} = NS \times RAM \times \sum_{i=1}^{3} (R_{Gn} \times N_{Gn} \times LG) / 8 = 100,000 \times 75\% \times 41 \times 8 / 3600 = 10166.67 \text{ bps}
\]

Since Gs interface is for SGSN to connect the 2G MSC, E1 or T1 links shall be configured for the interface as follows:
\[
N_{T1} = TH_{Gs} / [(56 \times 1024) \times LD] = 10166.67 / [(56 \times 1024) \times 0.2] \approx 2
\]

Based on Formulas 12 and 13, the throughput of Gi interface can be calculated. In this case, assume the IP is carried by MPLS and POS, so the header in this bearer mode is 14 octets.
\[
RO_{Gi} = (\overline{S}_{Packet} + H_{Data}) / \overline{S}_{Packet} = (400 + 14) / 400 = 1.035
\]

Therefore the throughput in interface Gi is given by:
\[
TH_{Gi} = NS \times RAM \times (TH_{User/S} \times RD) \times RO_{Gi} \times 8 = 100,000 \times 75\% \times 41 \times (600 \times 3 / 4) \times 1.035 \times 8 = 69.87 \text{ Mbps}
\]

Apparently the throughput value of Gi interface is close to that of Gn interface and Iu-PS interface without the redundancy factor imposed.
To verify the validity of the algorithms in this case, we captured 300 real time throughput values of Iu-PS interface from the network logs. Compared with the threshold value (128.57Mbps) obtained via the formulas 1, 3, and 4, 100% real time throughput value is below the threshold value. We randomly selected 48 sample values to plot the blue line in Figure 12. It shows all the throughput values is below the 68% of threshold value. This is consistent with the redundancy factor of 0.7.

Threshold 1=128.57Mbps when F\text{Redundancy}=0.7.
Threshold 2=112.50Mbps when F\text{Redundancy}=0.8.
Threshold 3=99.99Mbps when F\text{Redundancy}=0.9.

Figure 12. Actual vs. Threshold throughput for Iu-PS interface

\[ \text{SUMMARY AND CONCLUSION} \]

The paper first reviewed the current literature in planning and designing UMTS networks. The literature provides many applied methods and tools to plan and design 3G radio networks. The core network in this area however has not been thoroughly studied due to its complexity. This paper illustrated the encapsulation, delivery and transport process of the packets in UMTS packet switched domain. Based on the traffic flow, message flow and service process defined by 3rd Generation Partnership Project (3GPP) or International Telecommunications Union (ITU), the paper presents algorithms for dimensioning the UMTS PS network. Since some fields in the message are optional to
adopt, the length of some messages may slightly vary from vendors’ products. The authors also presented the results of a case study using the dimensioning algorithms presented in the paper and compared the calculated throughput to the actual traffic profile sampled from a mobile network operation. The results illustrates that the methodology presented in the paper can be effective and sufficient for infrastructure planning of core UMTS packet networks.

Also the current literatures introduced many applied methods and tools to plan and design 3G radio networks. However, not much effort has been focused on the evolution of the packet core network. This paper illustrated the encapsulation, delivery and transport process of packets and messages in UMTS packet core network. Since some parts in the message packet are optional to use by vendors according to 3GPP, the message size, header size and overhead size are suggested values in dimensioning the UMTS packet core networks. The actual values may slightly vary by different vendor’s products.

The most significant contribution of this article is to help mobile operators achieve vendor neutrality in network planning. The article provides detailed guidelines and algorithms for dimensioning the UMTS packet core networks to enable any mobile operator’s network planning process to be independent from the vendor bias. The dimensioning rules and guidelines provided in Section 4 could also help the mobile operators to appropriately size their networks to minimize their Total Cost of Ownership (TCO) which includes Capital Expenditure (CAPEX) and Operation Expenditure (OPEX). Our model and algorithms enable the operator to estimate its capacity needs totally independent of the vendor products, hence optimizing its investments in capital and operations.

Recently the industry started to talk about the move toward Long Term Evolution (LTE) from 3G. The transition to a pure IP network is critical to wireless carriers and is definitely a long way to go. The packet switched network will be the foundation of IP Multimedia Sub-system (IMS) from R5 phase and System Architecture Evolution (SAE) in LTE. The convergence with IMS domain and evolution to SAE requires a systematic and optimal approach. We are continuing to study the dimensioning and planning for prospective packet switched networks.

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**GLOSSARY OF TERMS**

AAA Authentication Authorization Accounting  
AAL2 ATM Adaption Layer 2  
ALCAP Access Link Control Application Part  
AMR Adaptive Multi-Rate  
APN Access Point Name  
APRU Average Monthly Revenue Per Unit  
ATM Asynchronous Transfer Mode  
AUC Authentication Center  
BCTP Bearing Control Tunneling Protocol  
BHCA Busy Hour Calling Attempt  
BICC Bear Independent Call Control message  
BSSAP Base Station System Application Part  
BSC Base Station Controller  
CAP CAMEL Application Part  
CN Core Network  
CPS Common Part Sub-layer  
CS Circuit Switched Domain  
DNS Domain Name System  
EIR Equipment Identity Register  
FCP Frame Control Part  
FCSP Frame Check Sum Part  
FMC Fixed Mobile Convergence  
GGSN Gateway GPRS Support Node  
GTP GPRS Tunneling Protocol  
HLR Home Location Register  
IMS IP Multimedia Sub-system  
IPBCP IP Bearer Control Protocol  
ISUP ISDN User Part message  
Iu-UP Iu Interface User Plane Protocol  
MAC Media Access Control  
MAP Mobile Application Part  
MPLS Multi Protocol Label Switching  
MGW Media Gateway  
MS Mobile Stations  
MSC Mobile Switching Center  
MSS MSC Server
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