KADIR HAS UNIVERSITY

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

BANDWIDTH ALLOCATION AND TRAFFIC SHAPING IN MOBILE BROADBAND NETWORKS USING DEEP PACKET INSPECTION

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JANUARY,2015

RAMAZAN ÖZBİLEN Master Thesis 2015

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B.S., Computer Engineering, Kadir Has University, 2010
M.S., Computer Engineering, Kadir Has University, 2015

Submitted to the Graduate School of Science and Engineering in

partial fulfillment of the requirements for the degree of
Master of Science
in
Computer Engineering

KADIR HAS UNIVERSITY
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APPROVAL DATE: 09 / 01 /2015

"I, Ramazan Özbilen, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis"

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ABSTRACT

BANDWIDTH ALLOCATION AND TRAFFIC SHAPING IN MOBILE BROADBAND NETWORKS USING DEEP PACKET INSPECTION

RAMAZAN ÖZBİLEN

Master of Science in Computer Engineering

Advisor: Assist. Prof. Dr. Taner ARSAN

JANUARY,2015

In this thesis, it is intended to estimate bandwidth and control mobile data usage by utilizing PCC (Policy and Charging Control) function. According to increase in number of mobile devices, data explosion occurs. It is becoming a must to analyze traffic and sharing resources between subscribers according to their usage habits. It is aimed to provide better a better connected world with service assurance by sharing available bandwidth and estimate it to users according to their needs by protocol level and service based QoS. Due to increase in amount of services like Facebook, Twitter, Mobile TV, in general IP networks, providing service assurance becomes more important day by day. That's why the issue of controlling bandwidth is raised.

In the most basic sense, system architecture consists of three main components: A cell phone to generate user based traffic, Gateway GPRS Support Node (GGSN) for Deep Packet Inspection (DPI), and Policy and Charging Rule Function (PCRF) for initiating PCC or Non-PCC rules to GGSN according to services that are needed by user. Shortly, the main idea in this thesis is assigning service based QoS to subscribers to provide better service assurance according to their usage.

As thought, the reason of preparing this study is to show the dramatical increase in service based traffic, to explain insufficiency in current bandwidth estimation approaches, and the idea of what can be used in the work of providing better service assurance to an end user. PCRF is the best component for providing required bandwidth when they needs.

ÖZET

MOBIL GENİŞ BANT AĞLARDA DERİN PAKET TARAMASI İLE BANT GENİŞLİĞİ ATAMASI VE TRAFİĞİN ŞEKİLLENDİRİLMESİ

RAMAZAN ÖZBİLEN

Bilgisayar Mühendisliği, Yüksek Lisans

Danışman: Yrd.Doç.Dr.Taner ARSAN

OCAK,2015

Bu çalışmada, günümüzde gittikçe artan akıllı cihazlar ile sınırlı kapasitedeki bant genişliğinin policy ve ücretlendirme fonksiyonu kullanılarak, optimum düzeyde kullanılması ve kullanıcı deneyiminin bu doğrultuda mümkün olan en üst düzeye çıkarılması hedeflenmektedir. Mobil cihazlar üzerinden kullanıcıların network üzerinde yoğun şekilde kullandığı uygulamalar analiz edilerek, bu uygulamaların bant genişliğini düşüren arka plan trafiği ve diğer uygulamalara göre network paket analizi ile önceliklendirilmesi ve aynı hücre altından servis alan kullanıcı trafiğinin çeşitli analizler ile uygun bir şekilde bölüştürülmesi amaçlanmaktadır. Bu sayede mobil internet kullanıcıları en iyi deneyime ulaşabilecek ve operatör tarafındaki transmisyon kapasite maliyetleri ihtiyaca göre bant genişliği ataması ve paket önceliklendirmesi ile minimuma düşürülebilecektir.

Sistem en basit şekli ile üç ana parçadan oluşnmaktadır. Trafiğin analizi ve yönelndirilmesi için sürekli kullanımı olan bir mobil cihaz, paket analizi ve analiz doğrultusunda uygun bandwidth yönetimini içeren kuralların gerçekleştirilmesi için Gateway GPRS Support Node (GGSN), PCC ile PCC olmayan uçtan uca kuralların anlık network dinamikleri ve kullanılan uygulamaya göre atanmasını sağlayan Policy and Charging Rule Function (PCRF). Kısaca projenin amacı çevresel şartlara göre değişebilen bandwidthin en uygun şekilde dağıtımı ve uygulama bazlı paket önceliklendirmesi yapılarak en yüksek verimliliğe ulaşılmasıdır.

Bu uygulama mimarisinin amacı, günümüzde giderek artan akıllı cihaz sayısı ve bu doğrultuda yükselen mobil internet kullanımını en iyi kullanıcı deneyimi ile sunmak, client tarafında herhangi bir değişiklik yapılmasına gerek olmaksızın network optimizasyonu ile daha düşük maliyetlerde daha verimli servis kullanımını sağlamaktır.

Acknowledgements

First of all, I would like to thank my supervisor Assist. Prof. Dr. Taner ARSAN who always supported and helped me during the thesis period. Thanks for his useful advices and encouragement.

Last but not least, I would like to thank my family for their patience, support and encouragement. Words are not enough to express my thankfulness, as well as to my friends.

To My Family

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List of Abbreviations

3G	3rd Generations
3GPP	3rd Generation Partnership Project
AF	Application Function
API	Application Programming Interface
BA	Bandwidth Allocation
BSS	Base Station Subsystem
CA	Certificate Authority
DB	Database
ECMA	European Computer Manufacturers Association
ETSI	The European Telecommunications Standards Institute
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
IDE	Integrated Development Environment
HTTP	Hyper-Text Transfer Protocol
HTTPS	Secure Hypertext Transfer Protocol
IEC	The International Electrotechnical Commission
ISO	International Organization for Standardization
IP	Internet Protocol
IT	Information Technologies

MYSQL	My Structured Query Language
OS	Open Source
OSI	Open Systems Interconnection
PCC	Policy Control and Charging
PDP	Packet Data Protocol
REST	Representational State Transfer
RF	Radio frequency
RFID	Radio-frequency identification
SGSN	Serving Gateway Support Node
SMS	Short Message Service
SMTP	Simple Mail Transfer Protocol
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
SSL	Secure Socket Layer
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TS	Traffic Shaping
UE	User Equipment
UI	User Interface
UPCC	Unified Policy and Charging Controller
URL	Uniform Resource Locator
VoIP	Voice Over IP

WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
WSDL	Web Service Definition Language
W3C	The World Wide Web Consortium
XML	Extensible Markup Language

Chapter 1

Introduction

Computer networks have too much importance in every part of our life. Not just in companies, also too many people use them in their daily life. Mobile phone usage is growing up so fast. Everyone is using internet on their phones to check something instantly and to communicate with their friends, especially in social media. Today, a mobile phone can handle more services, not used for just voice communication, such as mobile TV, streaming, VoIP, internet browsing etc. If one uses a part of these services, he wants this service to work properly. No one wants to miss a business call while watching one episode of his favorite series.

Technology improves quickly. According to this improvement, smart phone prices fall, and it becomes much easier to gain access to them. Everything is getting more mobile in these days. Also people start to communicate over VoIP and the amount of users that are using VoIP instead of legacy call services are getting higher.

Because of that increase in internet usage there is a new gap born in bandwidth assignment. Everyone is getting the same bandwidth for all applications that they are using. Thus, while downloading something over internet, they can’t communicate properly on VoIP. There are lots of advantages of being able measure and guarantee quality of service in a specific application. Prioritize traffic usage, assigning URL based QoS values or application based bandwidth is becoming more and more important day by day.

As an operator, it has also too much importance to divide available bandwidth to subscriber of their services. Bandwidth of a link is limited. Every usage is aggregating inside this link. The best way of guarantee a certain quality in this usage is prioritize in traffic flows and bandwidth based on usage of a specific application.

1.1 Overview

This thesis aims to provide service assurance in specific applications that is becoming more and more important in today’s networks. Additional benefits, the evolution in traffic management, will be discussed in next chapters. And in the following chapter the scope of project to which ways will be used to manage this kind of traffic will be discussed. Current deep packet Inspection technologies, policy functions, traffic classification and general inspection overview will be focused on coming chapters.

1.2 Related Work

There has been a lot of research on this area. Many techniques have been proposed and lots of studies have been done.

One critical issue is that traffic shaping cannot allocate excess bandwidth to active subscribers in the long term. This is because the traffic shaper based on token bucket cannot take into account the status of other subscribers. A large-size token bucket enables sharing of excess bandwidth among active subscribers, but only in the short period of time corresponding to the token bucket size. In the journal discusses the major requirements for the excess bandwidth allocation in shared access networks and proposes, ISP traffic control schemes based on core-stateless fair queuing (CSFQ) and token bucket meters. [2]

In order to accommodate the rapid increase in speed and bandwidth demands, many methods and algorithms were developed and implemented. The conference paper is about algorithms that allow flattening the utilization profile of network resources by optimizing network resources. In addition, we tested various scheduling techniques to reduce the effect of traffic delays. [3]

How to deal with increasing requirements for Network Intelligence and QoS signaling in IP multimedia subsystem of UMTS. UMTS network needs to find QoS requests of IP multimedia session through signaling protocol before it reserves resources for communication. Network intelligence is gathered by various techniques from evolving network functions, LTE (long term evolution) and IMS (IP multimedia subsystem). Nl is utilised to build rules under policy and charging control (PCC) standard architecture, which instructs the bearer network to enforce them. Latest mobile standards enhance the collaboration between core network (IMS) and access (e.g. LTE), through events reporting. Advanced heuristic DPI (deep packet inspection tools) can deliver more accurate user and session intelligence. [4]

High-speed Internet services, IP video, and Smartphone applications significantly increase the average revenue per user. For these high bandwidth services to become profitable, the cost per bit must drop, which packet and optical technologies make possible to a degree. Packet Network architectures have been and will be constantly evolving to adapt to new applications, services and requirements. In the past, newly developed packet network architectures have been mainly focused on the transport plane, whose purpose is to deliver user packets. End-to-end and manage transport resources such as bandwidth, buffers, packet processing elements, etc. [8]

The successful deployment of Universal Mobile Telecommunication System (UMTS) is heavily dependent on Quality of Service (QoS) to be achieved. The main focus of this thesis is traffic conditioning related issues for QoS provisioning in UMTS. Assuming an end-to-end QoS scenario supported by IntServ or/and Diffserv architectures, the thesis initially presents an all nodes traffic conditioning-enabled framework in UMTS. [6]

1.3 Service Assurance

Service assurance is the entire of policies to ensure service quality to provide predefined values for best user experience.

In practice, the pinpoint of service assurance is to identify faults as soon as possible and to minimize bad effects on user. In today's network it is more important to guarantee a service rather than just delivering it.

1.3.1 Benefits of Applying Service Assurance

Implementing service assurance has lots of advantages. Quality is a key value for a subscriber. Assuring the expected quality makes your network more trustable.

Dividing service into pieces makes it easier to manage and troubleshoot the network. Also operational expenditure (OPEX) will be decreased because of the improvement in operational processes and network transmission cost. When an service assurance is applied on a shared network capacity, network usage will be more efficient. It will reduce the network resource requirements because network usage will be more scalable and a great quality level will be achieved. [9]

Service Assurance takes cares of the promised service according to requirements. Besides, creating and activating process it is needed to address any issues subscribers might have with its service. That's why Service Assurance has as much as importance with the creation process in intelligent and automated networks.

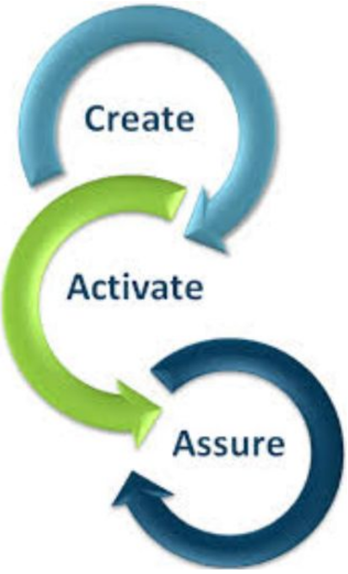


Figure 1: Establishing Service Assurance [25]

Chapter 2

GPRS Network Elements and Interfaces Overview

This chapter provides a brief explanation about General Packet Radio Service (GPRS). Network equipments, interfaces between these equipments and general architecture are explained. GPRS has a complex network architecture that contains air interface and core interfaces as can be seen in the figure below:

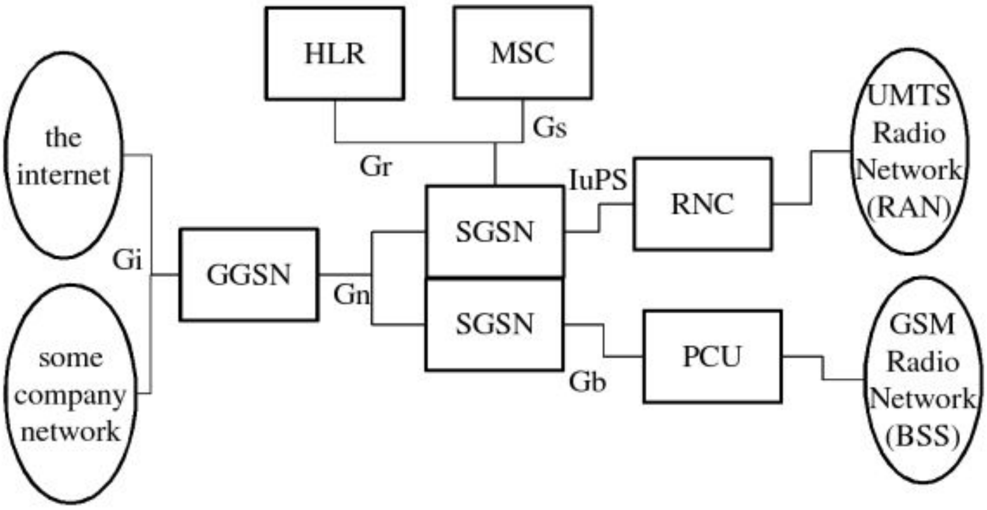


Figure 2: Network Elements and Interfaces in MBB Networks [24]

2.1 Radio Access Network

Radio Access Network is the air interface with base station system in the network. GSM/UMTS includes GERAN (GPRS EDGE Radio Access Network) and UTRAN (Universal Terrestrial Radio Access Network).

2.1.1 GPRS EDGE Radio Access Network – GERAN

BTS-BSC

Base Station Subsystem contains BTS (Base Transceiver System) that is used for transmitting and receiving radio signals and BSC (Base Station Controller) that controls hundreds of BTS and relation between them. BSC is connected to PCU for packet controlling.

2.1.2 Packet Controller Unit – PCU

Packet Control Unit performs tasks for packet data and directly connected to SGSN over Gb interface. Channel allocation between voice and data is under control of BTS but if BTS allocates a channel to data PCU takes its control completely. BSS systems, including BTS, BSC and PCU are belong to GERAN architecture.

2.1.3 Universal Terrestrial Radio Access Network – UTRAN

NodeB-RNC

Universal Terrestrial Radio Access Network contains NodeBs (UMTS equivalent of BTS) and RNCs (Radio Network Controller). It controls connectivity between UE and Core Network.

2.1.4 Radio Network Controller – RNC

Radio Network controller is responsible for controlling NodeBs located under it and handles radio resource management. It is connected over Iu interface to Core Network.

2.2 Core Network

Core Network is the main part of a network. Main functions like services and subscriptions are handled in this part of the network. Switches, routers and mobility management devices are located in Core Network.

2.2.1 Home Location Register – HLR

Home Location Register is the main database for controlling every mobile subscriber authorized to use a GSM operator. Primary network profile of subscriber is stored in HLR. HLR is directly connected to SGSN over Gr interface.

2.2.2 Serving GPRS Support Node – SGSN

Serving GPRS Support Node is responsible for delivery of packet data in a defined geographic area. [10] It routes packets to the connected Gateway Support Node over Gn interface on a GTP tunnel and controls mobility management.

2.2.3 Gateway GPRS Support Node – GGSN

Gateway GPRS Support Node is the main node that connects GPRS network to packet switched networks. It is responsible for routing packets into Packet Data Protocol (PDP) to related SGSN over Gn interface and to a packet switched network over Gi interface. IP pool management, Deep Packet Inspection (DPI), traffic management and QoS enforcement are controlled by GGSN.

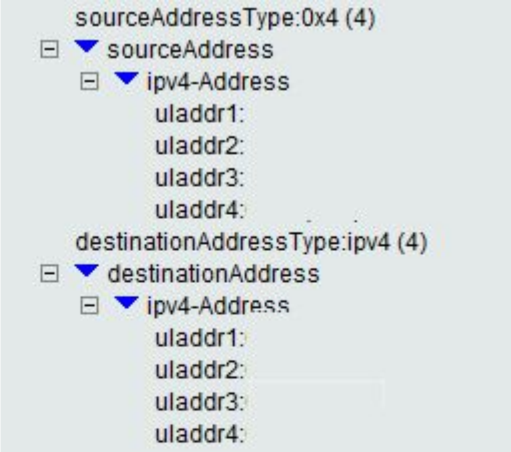
2.2.4 Policy and Charging Rules Function – PCRF

PCRF is an equipment for policy function of real-time bandwidth and charging in multimedia broadband networks. PCRF takes control of policy decisions on its own according to given conditions. Send PCC or Non-PCC rule to GGSN over Gx interface for controlling high bandwidth applications, QoS guarantees and URL based speed allocations.

2.3 PDP Context

PDP context stands for Packet Data Protocol context. It is a connection between a user equipment and GGSN passing through SGSN. It includes subscriber information to forward call to next hop.[10] When user wants to communicate with an external IP address, PDP context must be activated before sending data through GTP tunnel between SGSN and GGSN.

At first a control message (create PDP context request) comes from SGSN to GGSN that includes source and destination addresses (Figure 3), RAI (Figure 4), NSAPI (Figure 5), APN (Figure 5), DNS (Figure 6), QoS Profile (Figure 7), and RAT type (Figure 7).

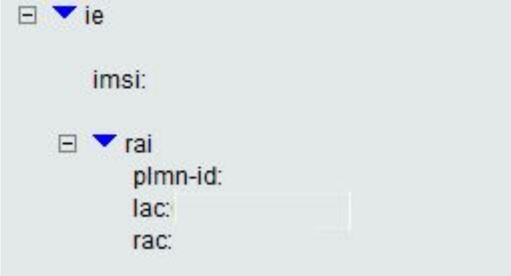


```
    sourceAddressType:0x4 (4)
⊟ ▼ sourceAddress
   ⊟ ▼ ipv4-Address
          uladdr1:
          uladdr2:
          uladdr3:
          uladdr4:
    destinationAddressType:ipv4 (4)
⊟ ▼ destinationAddress
   ⊟ ▼ ipv4-Address
          uladdr1:
          uladdr2:
          uladdr3:
          uladdr4:
```

Figure 3: IP Header in PDP Context Message

2.3.1 Routing Area Information (RAI)

RAI is a location area in PS domain. It specifies the identity of SGSN that UE is connected. (3GPP TS 23.003.) It is required for mobility management.

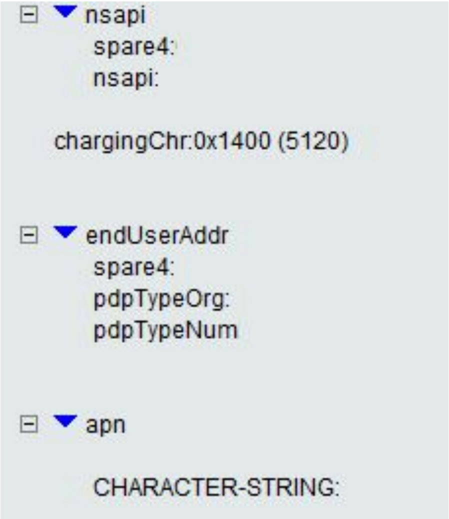


```
⊟ ▼ ie

      imsi:

   ⊟ ▼ rai
          plmn-id:
          lac:
          rac:
```

Figure 4: Routing Area Information in PDP Context Message

2.3.2 Network Service Access Point Identifier (NSAPI)

NSAPI is a dynamically allocated number (provided by MS) between 0 and 15 for a PDP context in a unique session. When UE creates a PDP context activation request, it sends an NSAPI value to identify its session. In case of a routing area update, It changes this value and its used as an identifier of GTP tunnel between SGSN and GGSN.

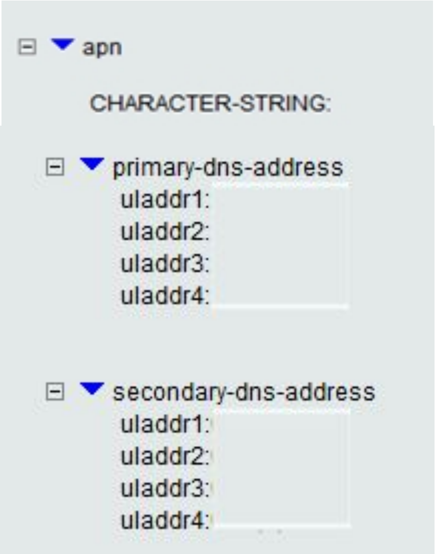


```
⊟ nsapi
    spare4:
    nsapi:

  chargingChr:0x1400 (5120)


⊟ endUserAddr
    spare4:
    pdpTypeOrg:
    pdpTypeNum


⊟ apn

    CHARACTER-STRING:
```

Figure 5: NSAPI Information in PDP Context Message

2.3.3 Access Point Name (APN)

APN tells what kind of a connection will create. An APN must be configured for establishing a data connection with a carrier. It includes Mobile Country Code (MCC) and Mobile Network Code (MNC) information. Also internet DNS information is located under APN. These values are unique for each operator and included in PDP context message like in the figure 6.



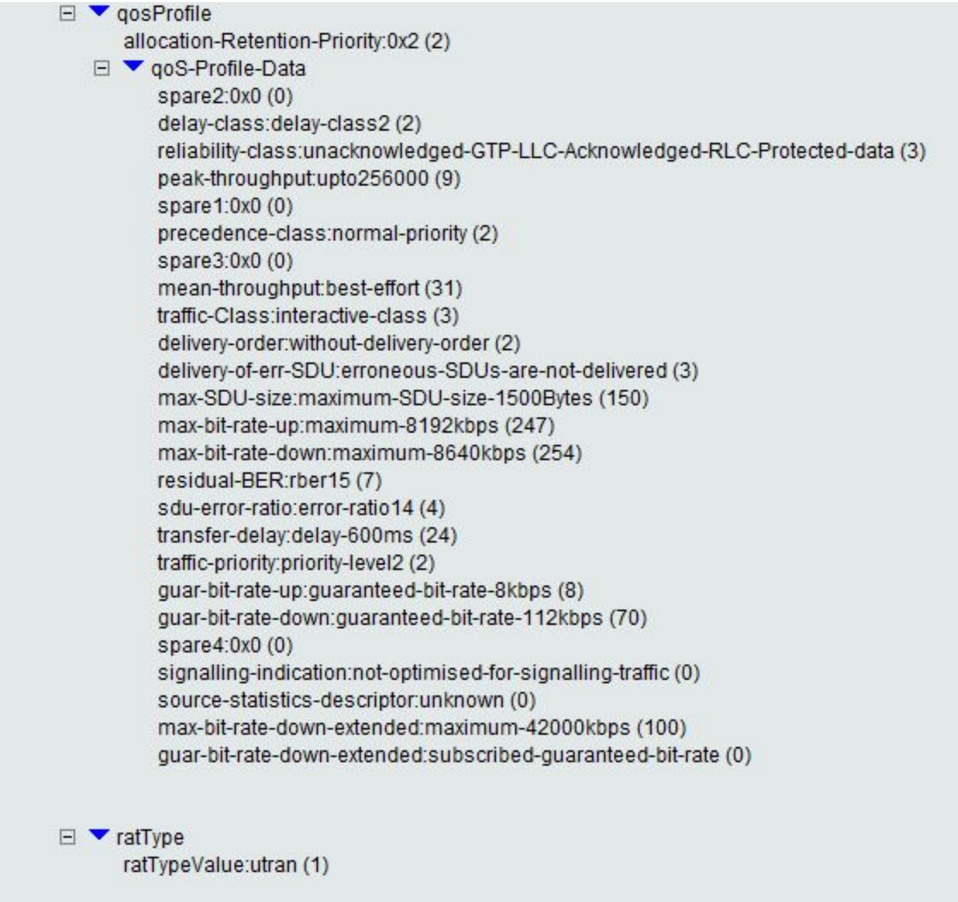
```
⊟ apn

    CHARACTER-STRING:

  ⊟ primary-dns-address
      uladdr1:
      uladdr2:
      uladdr3:
      uladdr4:


  ⊟ secondary-dns-address
      uladdr1:
      uladdr2:
      uladdr3:
      uladdr4:
```

Figure 6: Access Point Name in PDP Context

2.3.4 QoS Profile

It includes delay and traffic class, erroneous service data unit (SDU) and bit rate information. Then related parameters are changed by PCRF.

Network Services are considered end-to-end. An End-to-End Service has a Quality of Service (QoS) which is provided for the user of a network service. To realize a certain network QoS a Bearer Service with clearly defined characteristics and functionality is to be set up from the source to the destination of a service.

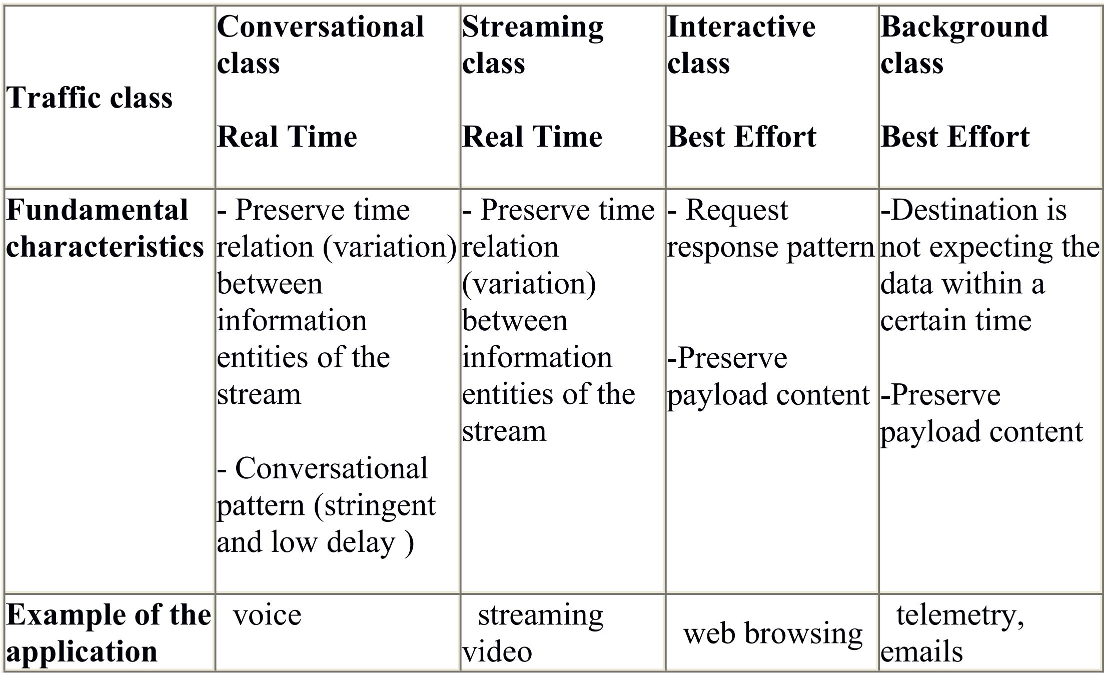


```
⊟ ▼ qosProfile
      allocation-Retention-Priority:0x2 (2)
    ⊟ ▼ qoS-Profile-Data
          spare2:0x0 (0)
          delay-class:delay-class2 (2)
          reliability-class:unacknowledged-GTP-LLC-Acknowledged-RLC-Protected-data (3)
          peak-throughput:upto256000 (9)
          spare1:0x0 (0)
          precedence-class:normal-priority (2)
          spare3:0x0 (0)
          mean-throughput:best-effort (31)
          traffic-Class:interactive-class (3)
          delivery-order:without-delivery-order (2)
          delivery-of-err-SDU:erroneous-SDUs-are-not-delivered (3)
          max-SDU-size:maximum-SDU-size-1500Bytes (150)
          max-bit-rate-up:maximum-8192kbps (247)
          max-bit-rate-down:maximum-8640kbps (254)
          residual-BER:rber15 (7)
          sdu-error-ratio:error-ratio14 (4)
          transfer-delay:delay-600ms (24)
          traffic-priority:priority-level2 (2)
          guar-bit-rate-up:guaranteed-bit-rate-8kbps (8)
          guar-bit-rate-down:guaranteed-bit-rate-112kbps (70)
          spare4:0x0 (0)
          signalling-indication:not-optimised-for-signalling-traffic (0)
          source-statistics-descriptor:unknown (0)
          max-bit-rate-down-extended:maximum-42000kbps (100)
          guar-bit-rate-down-extended:subscribed-guaranteed-bit-rate (0)


⊟ ▼ ratType
      ratTypeValue:utran (1)
```

Figure 7: QoS Profile and RAT Type in PDP Context

There are four different QoS traffic classes (Figure 8):

- Conversational Class
- Streaming Class
- Interactive Class
- Background Class



Traffic class	**Conversational class** **Real Time**	**Streaming class** **Real Time**	**Interactive class** **Best Effort**	**Background class** **Best Effort**
Fundamental characteristics	- Preserve time relation (variation) between information entities of the stream - Conversational pattern (stringent and low delay)	- Preserve time relation (variation) between information entities of the stream	- Request response pattern -Preserve payload content	-Destination is not expecting the data within a certain time -Preserve payload content
Example of the application	voice	streaming video	web browsing	telemetry, emails

Figure 8: QoS Traffic Classes

2.3.5 RAT Type

It identifies the radio access technology. It can be GERAN(2G), UTRAN(3G), EUTRAN(4G) according to connection type.

According to 3GPP standards, RAT type value 1 represents UTRAN, 2 GERAN, 3 WLAN, 6 EUTRAN [26].

2.4 Diameter Protocol

Diameter is an authentication, authorization and accounting protocol. It is developed to replace RADIUS protocol.

2.4.1 Diameter Protocol on Gx interface

AVP code values from 0 to 255 are reserved for Radius and values between 256 and 16777213 are reserved for specific commands. In Gx interface for PCRF signaling below codes are being used.

Command-Name	**Abbr.**	**Code**	**Explanation**
Abort-Session-Request	ASR	274	Sends for requesting identified session id be stopped.
Abort-Session-Answer	ASA	274	Response message to an ASR message. Indicates a result code.
Credit-Control-Request	CCR	272	Credit control is an application to provide real-time charging.
Credit-Control-Answer	CCA	272	Response message to an CCR message. Indicates a result code.
Capabilities-Exchange-Request	CER	257	Communication between to Diameter peers to establish TCP connection.
Capabilities-Exchange-Answer	CEA	257	Response message to a CER message. Indicates a result code.
Device-Watchdog-Request	DWR	280	If there is no CER/CEA message between peers for a time. DWR is sending to check peer device.
Device-Watchdog-Answer	DWA	280	Response message to an DWR message. Indicates a result code.
Re-Auth-Request	RAR	258	Diameter server peer (PCRF) can send a re-authentication-request to client peer (PCEF/GGSN) to inform changes in an active session.
Re-Auth-Answer	RAA	258	Response message to an RAR message. Indicates a result code.

Figure 9: Gx Diameter Messages

In PDP context activation process, Credit Control Request (CCR) message is sent to PCRF to get required charging rule information. It sends a session id, origin host and realm information, network type and requested QoS information. A random session id is generated for each session. PCRF identifies the rule to be sent to GGSN according to these parameters and responds with a Credit Control Answer message to GGSN. This message includes QoS information according dedicated services and network conditions to this subscriber.

Chapter 3

Concept of Quality of Service

3.1 Overview

QoS is a term that describes relations between demands and supplies. It is a measurement of quality that is supplied to meet demands of subscriber. Sometimes, legacy QoS does not provide accurate results [6]. It only focuses on quality of service under certain conditions. Some applications can use their own protocols but their application type is still same. (e.g. Skype is using its own protocol but it is still a VoIP application.)That's why assigned QoS can be defective. On the Internet, QoS is using for evaluating the ability of the network to transmit packets includes delay, jitter, and packet loss ratio.

3.2 Delay

Network delay is an important characteristic of a telecommunication network. It means how long it takes a packet transmission from source node to destination. The reason for delay can be queues or network congestion.

3.3 Jitter

Jitter is the difference between the delay of packets (successive) in a flow. It has effects on audio and video streams causes corruption of motion and loss of video. Against this kind of issue a jitter buffer can be used.

3.4 Packet Loss Ratio

Packet loss is the failure percentage in the transmission of packet to their destination. IP is a best effort service; if network guarantees reliable delivery it should apply store and forward mechanism. But for some services, reliability is not needed. That's why in a live audio or a video stream, packets should be delivered in a short time. To achieve this, IP allows routers to drop packets if transmission line is too busy or the transmitted packet is broken.

3.5 Traditional Packet Transmission Application

It is difficult to ensure QoS in the traditional IP network. Because routers in the network handle packets according to First In, First Out (FIFO) method for packet transmission. All packets share the bandwidth of network. Resources are used according to arrival times of packets. Traditional best effort mode is applied on services such as World Wide Web, VoIP, and email but has no specific bandwidth and delay.

3.6 New Applications Requirements

By the rapid technology development, number of networks connected to internet is also increased to a large amount. Resources are limited and applications demand larger bandwidths, little jitter and delay. [23] For example social services like Facebook and Twitter is getting %47 of internet usage [27], and this kind of applications include voice and video streaming that need larger bandwidth values. For this kind of things subscribers are expecting improved service transmission. Or for other applications, these services should be limited. So, different QoS should be provided for different services.

3.7 QoS Negotiation

In traditional Global System for Mobile Communications (GSM) or UMTS networks, NEs negotiate GPRS QoS parameters with each other. During the negotiation, the values of the following QoS parameters are generally decreased: MS-requested QoS, subscribed QoS in the home location register (HLR), SGSN-defaulted QoS, and QoS capability of the SGSN and peripheral NEs. This mechanism ensures that end-to-end QoS on the mobile packet switched network is lower than the subscribed QoS. However, the QoS negotiated on the network side may not meet the requirements for services at the application layer because whether the QoS is proper depends on the associated service type. As a result, services cannot operate normally and network resources are wasted. To prevent wasting network resources, 3GPP R7 provides the QoS control function on the network side, which allows the network side to raise QoS based on the specific service type. [5]

QoS can be determined in two modes:

- Negotiating QoS on the network side
- Controlling QoS on the network side

3.7.1 Negotiating QoS on The Network Side

The SGSN is the center of this negotiation and responsible of negotiation for MS-requested QoS , given QoS in HLR, GGSN initiated PDP context update. After receiving SGSN requested QoS other equipments negotiate QoS according to their capabilities. If UE rejects the QoS on the network side, starts PDP deactivation. This signaling can be found in the figure below:

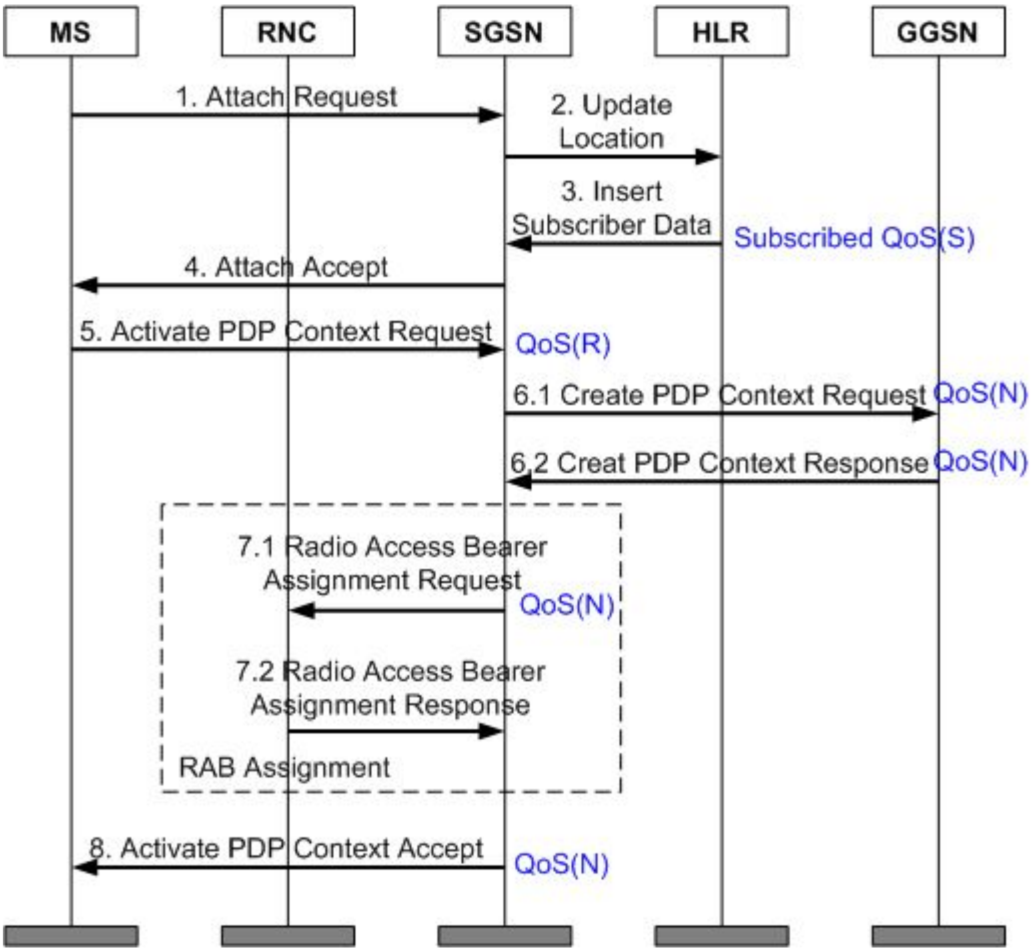

MS
RNC
SGSN
HLR
GGSN
1. Attach Request
2. Update Location
3. Insert Subscriber Data
Subscribed QoS(S)
4. Attach Accept
5. Activate PDP Context Request
QoS(R)
6.1 Create PDP Context Request
QoS(N)
6.2 Creat PDP Context Response
QoS(N)
7.1 Radio Access Bearer Assignment Request
QoS(N)
7.2 Radio Access Bearer Assignment Response
RAB Assignment
8. Activate PDP Context Accept
QoS(N)

Figure 10: QoS Negotiation Signaling

QoS Negotiation Procedure in Network Side
QoS (R) stands for requested QoS requested in PDP context activation.
QoS (S) stands for given QoS in HLR after network attach mechanism.
QoS (N) stands for negotiated QoS by RNC, SGSN and GGSN. After the negotiated QoS SGSN compares subscribed and negotiated QoS.

The QoS negotiation procedure is described as follows: [3GPP]

1. The MS sends an attach request to the SGSN.
2. If the SGSN number has changed since the last detach, or if the MS attaches to the network for the first time, the SGSN instructs the HLR to obtain subscription data.
3. The HLR sends the Insert Subscriber Data message carrying the subscribed QoS to the SGSN.
4. The SGSN sends the Attach Accept message to the MS.

5. The MS sends an Activate PDP Context Request message carrying the requested QoS to the SGSN. The MS can also set the value of the QoS parameter carried in the Activate PDP Context Request message to **0**.
6. The SGSN checks whether the MS can apply for the relevant QoS profile based on the subscribed QoS. If the MS can apply for the relevant QoS profile and the SGSN has sufficient resources (including the bandwidth and the load-related resources), the SGSN sends a Create PDP Context Request message to the GGSN. If the SGSN does not have sufficient resources, it restricts the QoS profile, degrades the QoS, or rejects the PDP context activation request.
7. The SGSN sends a Radio Access Bearer Assignment Request message to the RNC based on the QoS negotiated with the GGSN.
8. If the RAB is successfully created, the SGSN sends an Activate PDP Context Accept message carrying the negotiated QoS to the MS. The MS determines whether to continue the service. If the MS accepts the negotiation result, the PDP context of the MS is activated. If the MS does not accept the negotiated QoS, the MS initiates the PDP context deactivation procedure.

3.7.2 Controlling QoS on The Network Side

The PCRF controls the QoS. SGSN sends a message that includes QoS value to GGSN. After GGSN sends a response SGSN, SGSN uses the value in this response message. If QoS upgrade is not supported or QoS negotiation is rejected, control procedure fails.

3.8 QoS Upgrade

QoS upgrade means changing one of these parameters: Traffic Class (TC), Traffic Handling Priority (THP), Allocation Retention Priority (ARP), Maximum Bit Rate (MBR), QoS Class Indicator (QCI). [18]

In current 3G network conditions QoS can be upgraded directly by PCRF. In PDP context activation GGSN sends an initial Credit Control Request (CCR-I) to PCRF or can send a Re-Auth-Request (RAR) while user has an active PDP context. Signaling in QoS upgrade process is like below:

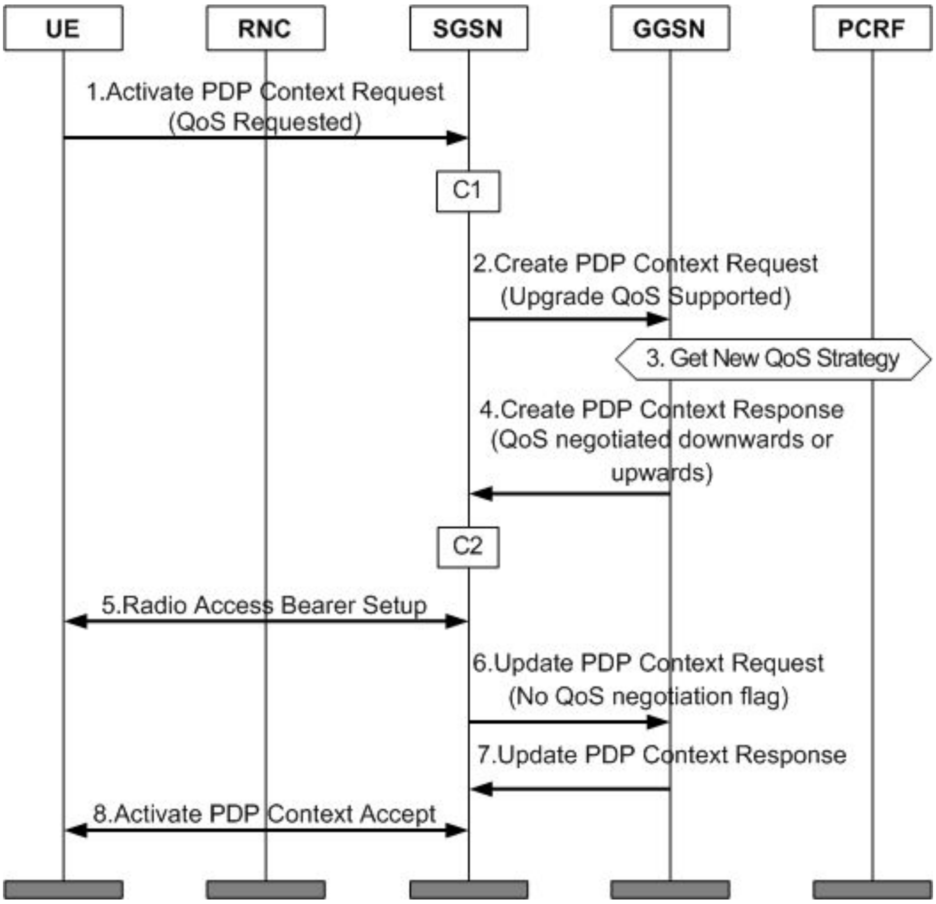

UE
RNC
SGSN
GGSN
PCRF
1.Activate PDP Context Request
(QoS Requested)
C1
2.Create PDP Context Request
(Upgrade QoS Supported)
3. Get New QoS Strategy
4.Create PDP Context Response
(QoS negotiated downwards or
upwards)
C2
5.Radio Access Bearer Setup
6.Update PDP Context Request
(No QoS negotiation flag)
7.Update PDP Context Response
8.Activate PDP Context Accept

Figure 11: QoS Upgrade Signaling

QoS upgrade procedure [10]

1. The MS sends the SGSN an Activate PDP Context Request message carrying QoS(R) to initiate a PDP context activation procedure.

2. The SGSN sends a Create PDP Context Request message carrying QoS(S) to the GGSN. In the Common flags IE of this message, the Upgrade QoS Supported flag bit is set to **1**.

3. The GGSN determines the QoS based on its QoS capability or negotiates the QoS with the PCRF.

4. The GGSN responds to the SGSN with a Create PDP Context Response message carrying QoS(N). The GGSN then processes the upgrade as follows:

   - If the GGSN does not receive the Upgrade QoS Supported flag bit or the Upgrade QoS Supported flag bit is set to **0**, the GGSN cannot upgrade the QoS(N). This is because the QoS that is sent to the SGSN cannot be higher than the QoS that the GGSN receives.

   - If the Upgrade QoS Supported flag bit is set to **1**, the GGSN can upgrade the QoS(N). This is because the QoS that is sent to the SGSN can be higher than the QoS that the GGSN receives.

5. The SGSN performs a radio access bearer setup procedure with the MS.
6. After the radio access bearer setup procedure ends normally, the SGSN sends the Update PDP Context Request message to the GGSN only when the SGSN supports the Direct Tunnel feature. This message carries the No QoS Negotiation flag bit and the No QoS negotiation flag bit is set to **1**, which instructs the GGSN to update the PDP context information. If the RNC degrades the QoS during the RAB creation process, the SGSN initiates a PDP context deactivation procedure.
7. The GGSN responds to the SGSN with the Update PDP Context Response message. The PDP context update procedure ends.
8. The SGSN responds to the MS with the Activate PDP Accept message. The PDP context activation procedure ends.

The SGSN processes the QoS upgrade result as follows:

- Case 1: The upgraded QoS is higher than the QoS that the SGSN can provide.

  The SGSN uses the supported highest QoS in this QoS upgrade, and sends a Modify PDP Context Request message to the MS and an Update PDP Context Request message to the GGSN.

- Case 2: The upgraded QoS is higher than the QoS that the RNC can provide.

  The SGSN notifies the RNC that the PDP contexts involved fail to be activated or updated.

The GGSN performs the following operations in a QoS upgrade:

- Configures different QoS control modes for the MSs with different IMSIs and sets corresponding QoS control parameters.
- Controls whether to renegotiate QoS parameters after a CN, radio access technology (RAT), routing area (RA), or RAN node changes.

Chapter 4

Concept of Bandwidth Allocation and Traffic Shaping

4.1 Concept of Bandwidth Allocation

As predicted in future 5 years, global mobile user will increase to more than 5 billion.

At the time all users can access the network and mobile broadband users will exceed 2 billion. By the way, mobile terminal technologies like data cards and smart phones develop faster. Therefore, customized services and applications increase rapidly.

Mobile broadband network traffic is increased 1587% from 2008 to 2013. Transmission capacities are also increasing according to the increment in amount of data users and sometimes reaches its limits. In this case we have to use a better allocation of bandwidth. According to network analysis, network traffic is greatly unbalanced.[4]

Bandwidth-hungry services and applications like P2P and social networking apps consumes upto %50-60 of traffic capacity. When bandwidth is shared among users, there must be a bandwidth allocation mechanism unless user experience can be effected. By network expansions, this amount of traffic can be handled but it will take too much time and user experience will also be affected. That's why we need bandwidth management policies based on PCC architecture according to user access type, user subscription data, service type and bandwidth usage to utilize traffic better. [22]

In below figures (Figure 12, 13) network elements and interfaces that are included in bandwidth allocation can be seen:

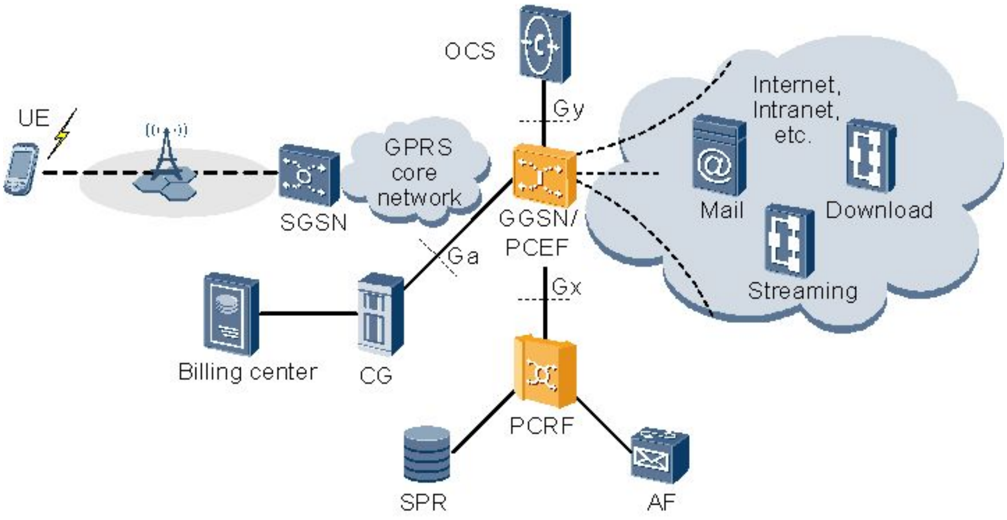


Figure 12: Bandwidth Allocation in Mobile Broadband Networks

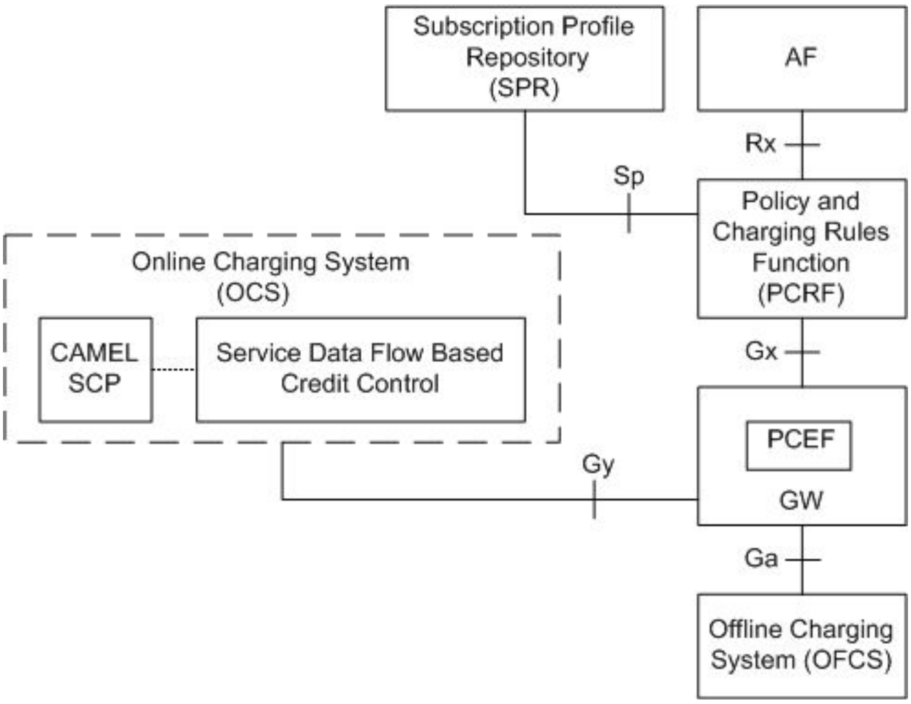

Subscription Profile Repository (SPR)
AF
Rx
Sp
Policy and Charging Rules Function (PCRF)
Online Charging System (OCS)
CAMEL SCP
Service Data Flow Based Credit Control
Gx
PCEF
GW
Gy
Ga
Offline Charging System (OFCS)

Figure 13: Bandwidth Allocation in Mobile Broadband Networks Detailed

The PCRF matches policies based on time periods, user location, user category, service type (facebook, twitter, etc..) and delivers them to GGSN (PCEF). GGSN implements QoS control and policies. QoS control is used to manage bandwidth and QoS level. For e.g. when user reached its maximum quota, GGSN can reduce bandwidth from 7 Mbit/s to 128 kbit/s. Or according to application type(Facebook, Twitter, Mobile TV) used by subscriber GGSN can reduce bandwidth to 5 kbit/s. (depends on the rule coming from PCRF)

The GGSN (PCEF), matches service based on rules delivered from PCRF or AAA (authentication authorization accounting) and implements the matched rule and performs actions in this rules by triggering an update mechanism in PDP context. This action can be QoS control, bandwidth management, and redirection. Application scenario of smart bandwidth management can be seen in figure below:

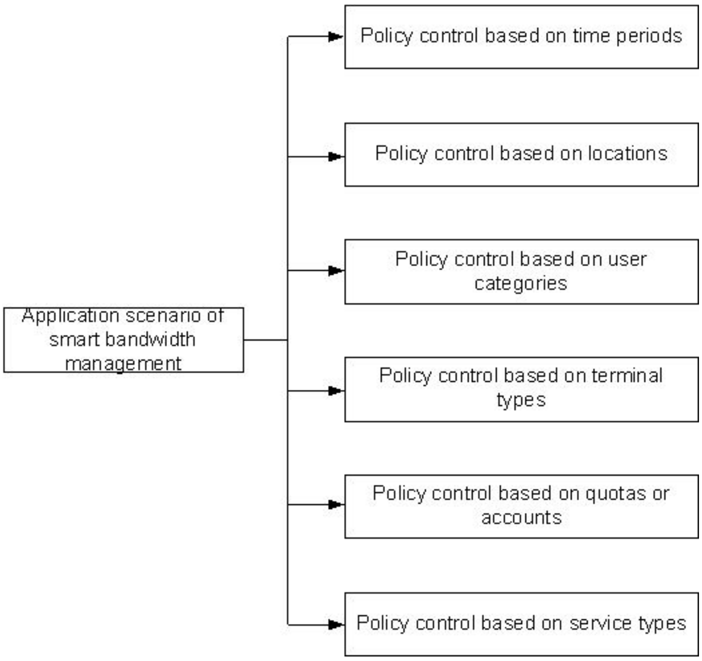

Application scenario of smart bandwidth management
Policy control based on time periods
Policy control based on locations
Policy control based on user categories
Policy control based on terminal types
Policy control based on quotas or accounts
Policy control based on service types

Figure 14: Policy Control Scenario

- Policy control based on time periods

This policy control enables to set different bandwidths according to specified time. According to user habits and network congestion, network resource usage can be optimized. For e.g. in busy hour when network traffic peaks bandwidth can be limited to defined values.

- Policy control based on user categories

This policy controls the user category according to MSISDN. Different bandwidths can be allocated according to customer category

- Policy control based on quotas

This policy can be set according to quota of subscriber. Users bandwidth can be limited according to its quota level.

- Policy control based on service types

Policy control based on service type enables to allocate bandwidth according to application type used by subscriber. HTTP, FTP etc...

4.2 Concept of Traffic Shaping

Traffic shaping means controlling the service traffic of a subscriber by using the bandwidth controller. Bandwidth controller rates the packets. This enables subscribers to achieve a steady network access rates.

In traffic shaping method, GGSN uses shaping based bandwidth control of services. PCRF delivers the pre-defined rules for traffic shaping.

4.2.1 Token Bucket & Leaky Bucket

Token bucket acts as a container for storing tokens. A capacity is set for the token bucket after that, system puts tokens in to the token bucket at defined speed.[7] It can be used as a packet scheduler that determines the timing scheduler according to limits defined for the bandwidth and burstiness.

By this algorithm;

- Packet can be queued for the next transmission when enough tokens accumulated in bucket.
- Packets can be dropped
-They can be transmitted or marked as improper when network is overloaded.

According to formula of Token Bucket;

1/r is the time of adding tokens (second).

M is the maximum transmission rate (bytes/second)

b is the maximum token amount

If **k** bytes arrived **k** tokens are removed from the bucket.

r, token rate.

Maximum burst size can be calculated as below:

$$T_{\max} = \begin{cases} b/(M-r) & \text{if } r < M \\ \infty & \text{otherwise} \end{cases}$$

$$L_{\max} = T_{\max} * M$$

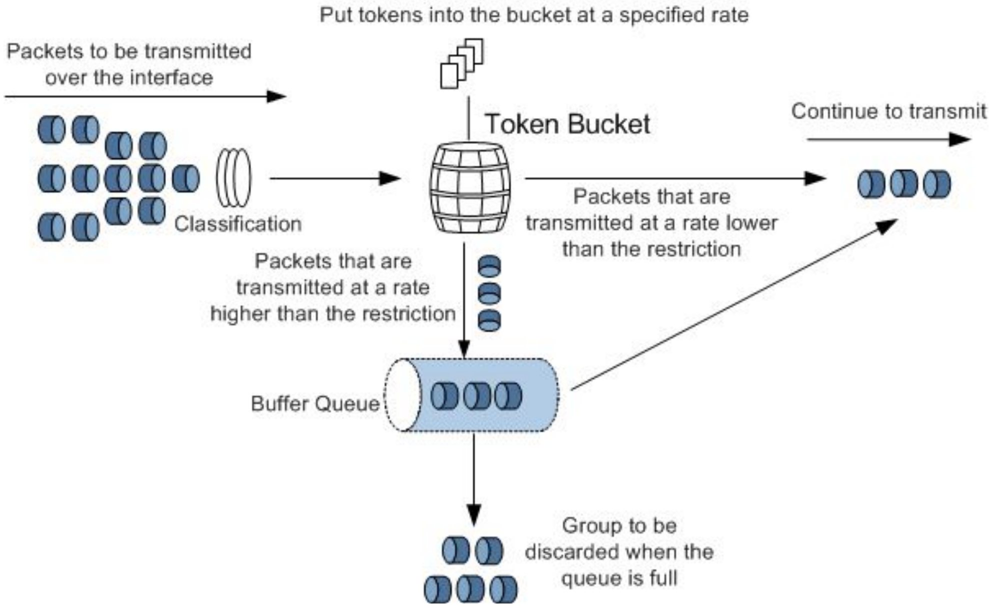
Figure 15: Token Bucket Algorithm

How it works:

Parameters: *rate, burstiness.*

1. Token bucket smooths traffic too but permits burstiness - which is equivalent to

the number of tokens accumulated in the bucket.
2. Discards tokens when bucket is full, but never discards packets (infinite queue).
3. Application: Network traffic shaping or rate limiting.
4. Remarking excess packets



Put tokens into the bucket at a specified rate
Packets to be transmitted over the interface
Token Bucket
Continue to transmit
Classification
Packets that are transmitted at a rate lower than the restriction
Packets that are transmitted at a rate higher than the restriction
Buffer Queue
Group to be discarded when the queue is full

Figure 16: Traffic Shaping Using Token Bucket

There are three types of Token Bucket Algorithm**.**

- **Single Rate, two color**

  In this algorithm there is only one bucket (Bc) to be filled that can hold limited amount of tokens. Traffic cannot exceed committed information rate (CIR) value.

- **Single Rate, three color**

  By this algorithm, new rate information is added called excess burst size (Be). In this type of algorithm, spilled tokens form Bc bucket which are exceeding the committed information rate, replenish the Be bucket. By the addition of Bc bucket, it is possible to support burstiness.

- **Dual Rate, three color**

  Dual rate bucket also has bursting feature. The only difference from the previous type is not to work with a single rate. It uses peak information rate (PIR). This new PIR is above the CIR value and makes it possible to burst.

In Leaky Bucket Algorithm, average rate of data flow is regulated. It is token independent, does not save tokens. Packets are transmitted continuously at a constant rate.

According to formula of Leaky Bucket;

M = Maximum size of burst
T = Emission interval
τ = Maximum Jitter Tolerance
δ = Time taken to receive and transmit a packet

$$M = \left\lfloor 1 + \frac{\tau}{T - \delta} \right\rfloor \tau = (M - 1)(T - \delta)$$

How Leaky bucket works (Figure 17):

Parameters: *rate*
1. Smooth out traffic by passing packets only when there is a token. Does not permit burstiness.
2. Discards packets for which no tokens are available (no concept of queue)
3. Application: Traffic shaping or traffic policing.

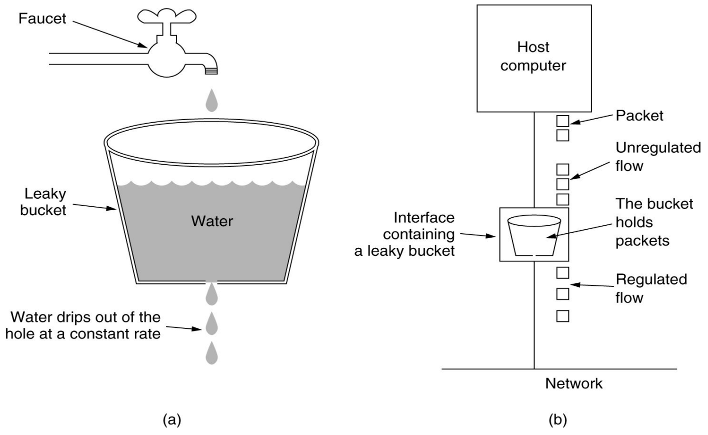


Figure 17: (a) Leaky Bucket with Water, (b) Leaky Bucket with Packets

4.2.2 Proposed Algorithm: Dual Token Bucket

Dual Token Bucket algorithm is used in out model. The dual rate with two token buckets has a bursting feature but it works differently compared to the other token bucket algorithms. Dual rate means that we don’t work with a single rate but we have a CIR (Committed Information Rate) and PIR (Peak Information Rate). This new PIR is above the CIR and allows us to burst.

- Packets that are under the CIR value are called conforming.
- Packets that are exceeding the CIR value and are also below the PIR are called exceeding.
- Packets that are above the PIR value are called violating.

As can be seen in the figure below (Figure 18)

1. Tokens are replenished into the token buckets.
2. When a packet arrives, the algorithm will check if there are enough tokens in the bucket to allow the packet to get through.

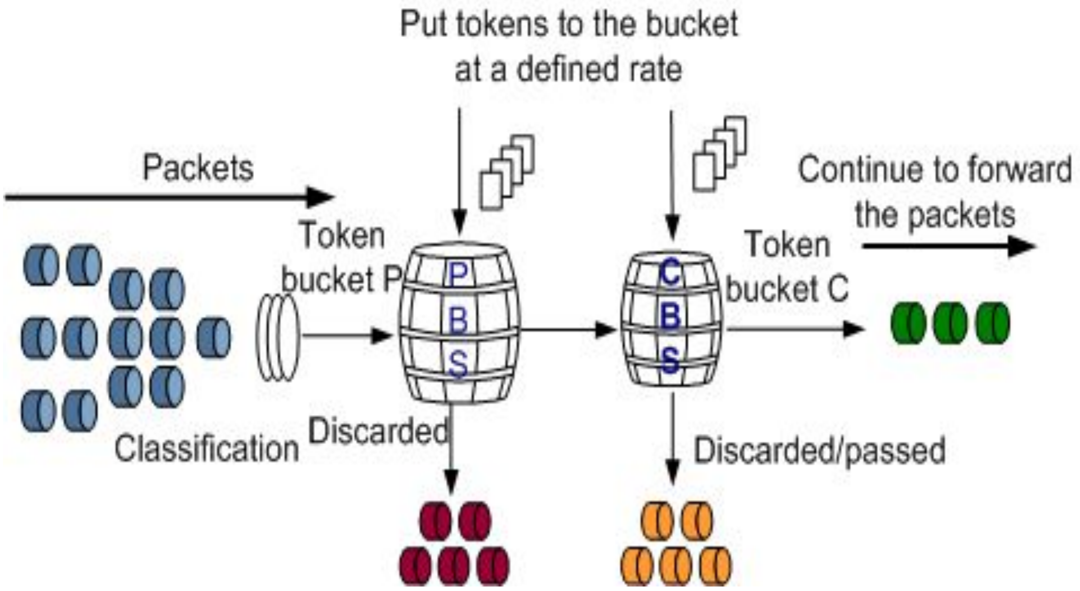
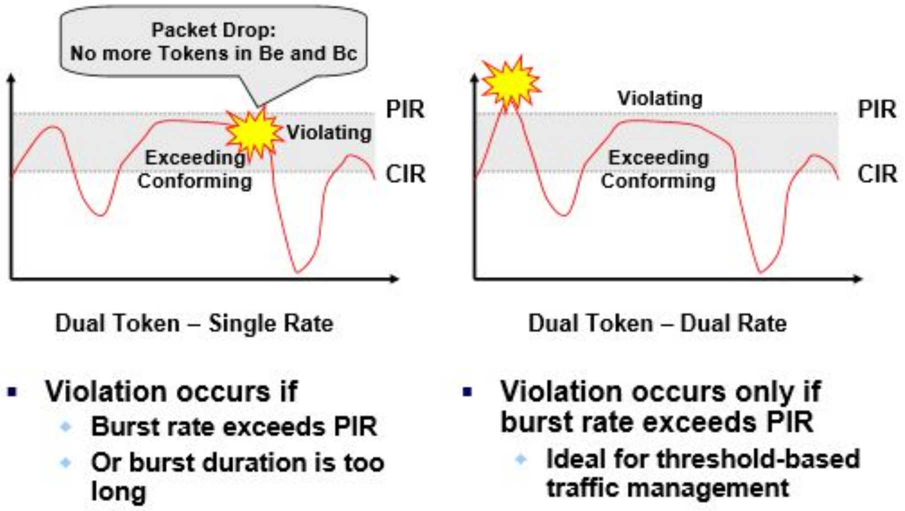


Figure 18: Dual Token Bucket Algorithm

The reason why we used Dual Token Bucket algorithm is the bursting feature. Dual Token Bucket allows us to burst traffic without a duration limit. It is ideal for threshold based traffic management as can be seen in the example below:



- Violation occurs if
  - Burst rate exceeds PIR
  - Or burst duration is too long
- Violation occurs only if burst rate exceeds PIR
  - Ideal for threshold-based traffic management

Figure 19: Differences between Single and Dual Rate Token Bucket [28]

4.2.3 Traffic Shaping

Traffic shaping is a method that adjust traffic output rate. While policing traffic, GGSN caches packets that exeed the traffic specifications then sends cached packets when there are enough token in the bucket to ensure service requirements.

Service Flow

1- GGSN identifies the type of service according to Layer 3/Layer 4 filters, Layer 7 protocol type, or Layer 7 protocol characteristics.
2- GGSN matches service control rules coming from PCRF.
3- GGSN shapes service traffic according to the matched service control rules.

Detailed flow chart is given in the figure 20.

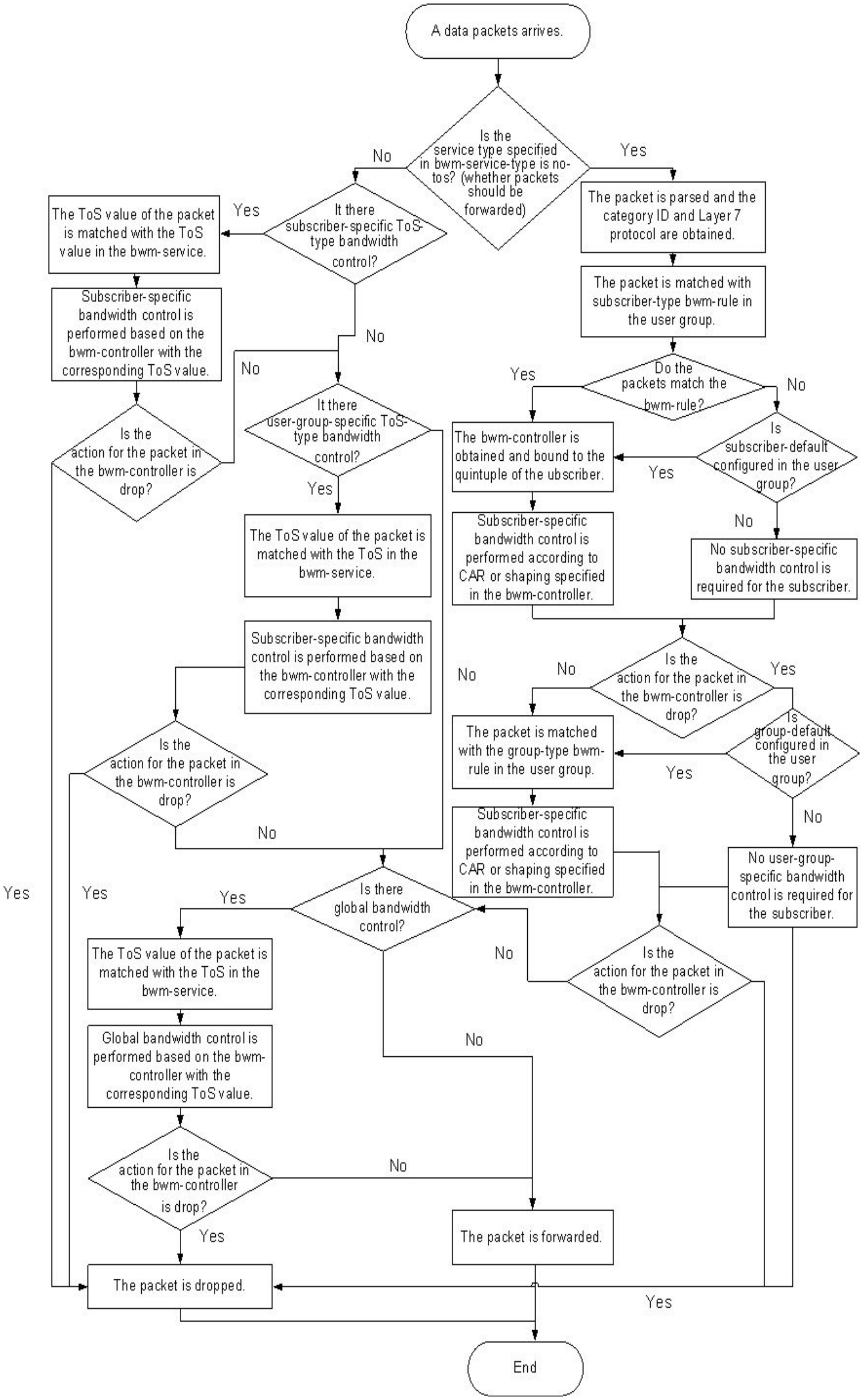

A data packets arrives.
Is the service type specified in bwm-service-type is no-tos? (whether packets should be forwarded)
No
Yes
The packet is parsed and the category ID and Layer 7 protocol are obtained.
The packet is matched with subscriber-type bwm-rule in the user group.
Do the packets match the bwm-rule?
Yes
No
The bwm-controller is obtained and bound to the quintuple of the ubscriber.
Is subscriber-default configured in the user group?
Yes
No
Subscriber-specific bandwidth control is performed according to CAR or shaping specified in the bwm-controller.
No subscriber-specific bandwidth control is required for the subscriber.
Is the action for the packet in the bwm-controller is drop?
No
Yes
The packet is matched with the group-type bwm-rule in the user group.
Is group-default configured in the user group?
Yes
No
Subscriber-specific bandwidth control is performed according to CAR or shaping specified in the bwm-controller.
No user-group-specific bandwidth control is required for the subscriber.
Is the action for the packet in the bwm-controller is drop?
No
Yes
It there subscriber-specific ToS-type bandwidth control?
Yes
No
The ToS value of the packet is matched with the ToS value in the bwm-service.
Subscriber-specific bandwidth control is performed based on the bwm-controller with the corresponding ToS value.
Is the action for the packet in the bwm-controller is drop?
No
Yes
It there user-group-specific ToS-type bandwidth control?
Yes
No
The ToS value of the packet is matched with the ToS in the bwm-service.
Subscriber-specific bandwidth control is performed based on the bwm-controller with the corresponding ToS value.
Is the action for the packet in the bwm-controller is drop?
No
Yes
Is there global bandwidth control?
Yes
No
The ToS value of the packet is matched with the ToS in the bwm-service.
Global bandwidth control is performed based on the bwm-controller with the corresponding ToS value.
Is the action for the packet in the bwm-controller is drop?
No
Yes
The packet is forwarded.
The packet is dropped.
End

Figure 20: Traffic Shaping Flowchart

4.3 Implementation of Dynamic Bandwidth Allocation and Traffic Shaping

Dynamic bandwidth allocation is a technique to allocate bandwidth in a shared medium fairly on demand between subscribers. This is a type of managing available bandwidth. All subscribers in a network are not connected at same time, even if they're connected; all of them are not transmitting data over network. Besides, some users need more bandwidth according to application they are using. For example, VoIP users or users that are watching video on internet should get more bandwidth than the users that are using P2P services.

The idea of assigning available bandwidth fairly to subscribers also depends on shaping their traffic. To optimize a traffic or guarantee performance (improving latency, increasing the usable bandwidth) you need to classify traffic, according to this classification traffic shaping and policing should be applied to the traffic of subscribers.

4.3.1 General Architecture in Basic

UPCC comprises two main parts, Backend (BE) and Frontend (FE). Provisioning Gateway (PGW) and Physical DB is located in BE. Policy Control and Rule Function is located in FE side. A service can be assigned to the subscriber over SOAP interface by provisioning system. This service can include bandwidth update or notification message.

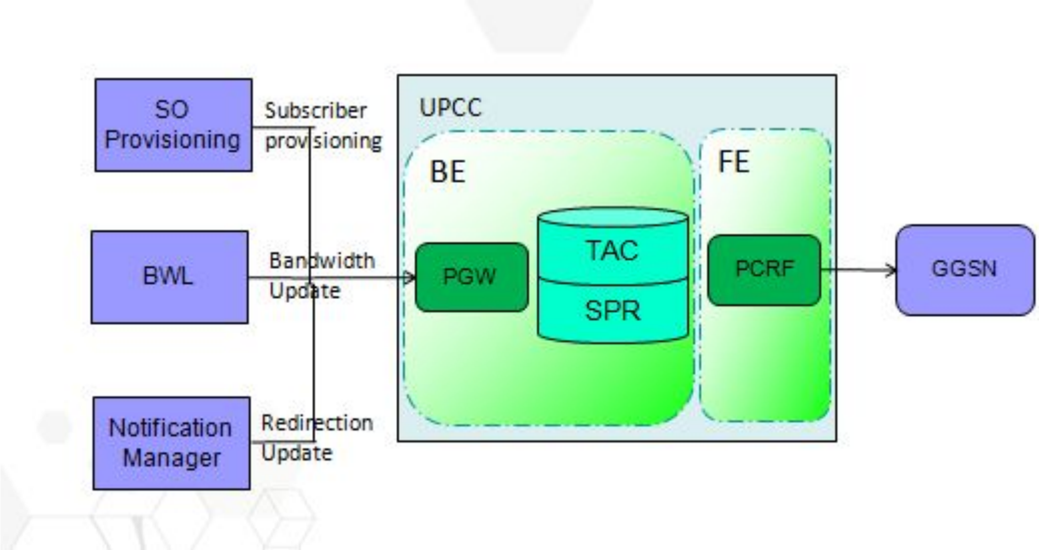


Figure 21: General UPCC Architecture for Bandwidth Assignment

4.3.2 QoS Policy Control Logic

PCRF has a QoS policy control logic as shown below:

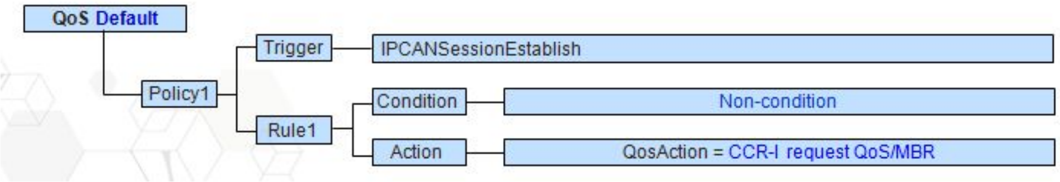


Figure 22: QoS Policy Control

Policies include a trigger and rules. According to defined state of connection rules are selected if condition matches and action under the rule is sent to Policy and Charging Rule Function (PCEF, GGSN).

Signaling process in this policy enforcement can be seen with the following figures:

- Sending 256Kbps of E2E QoS to the subscriber:

At first, in PDP activation request, GGSN sends a Credit Control Request - Initial (CCR-I) to the PCRF and in the response coming from PCRF (Credit Control Answer – Initial, CCA-I) gets allow all default service. Then, service includes E2E QoS value of 256 Kbps is provisioned from provisioning system (BWL) and Policy and Charging Rule Function (PCRF) sends a Re-Auth Request (RAR) to the PCEF (GGSN) side. After that QoS is applied along the network and GGSN replied RAR message with a Re-Auth Answer that contains diameter success (2001) message.

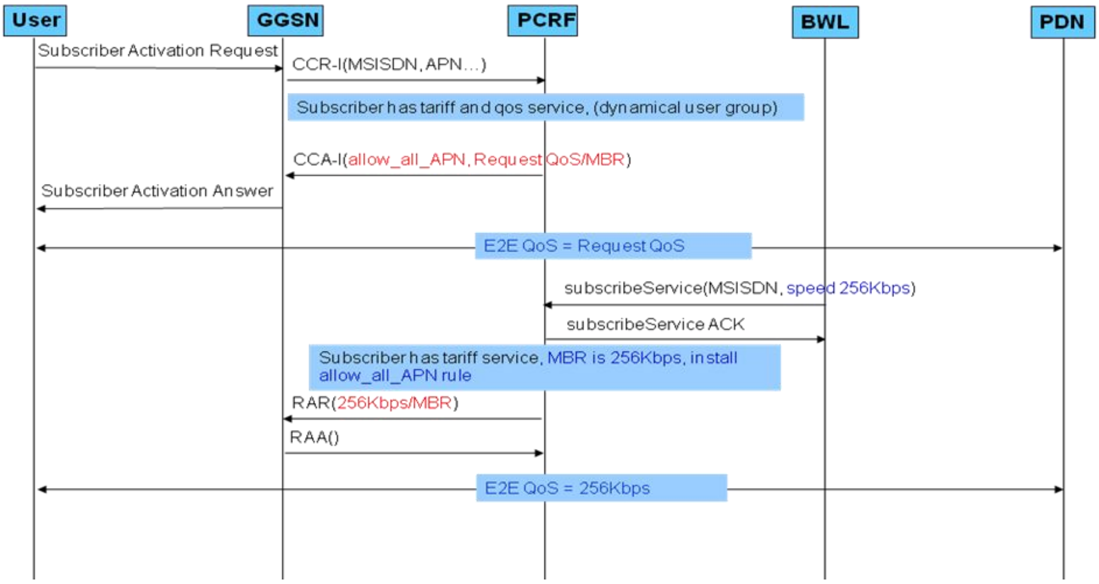

User
GGSN
PCRF
BWL
PDN
Subscriber Activation Request
CCR-I(MSISDN, APN…)
Subscriber has tariff and qos service, (dynamical user group)
CCA-I(allow_all_APN, Request QoS/MBR)
Subscriber Activation Answer
E2E QoS = Request QoS
subscribeService(MSISDN, speed 256Kbps)
subscribeService ACK
Subscriber has tariff service, MBR is 256Kbps, install allow_all_APN rule
RAR(256Kbps/MBR)
RAA()
E2E QoS = 256Kbps

Figure 23: 256Kbps Bandwidth Allocation Signaling

In signaling process below, subscriber has a 256kbps of bandwidth then 7.2 Mbps QoS is provisioned to customer. Bandwidth is extended to 7.2 Mbps with a Re-Auth message.

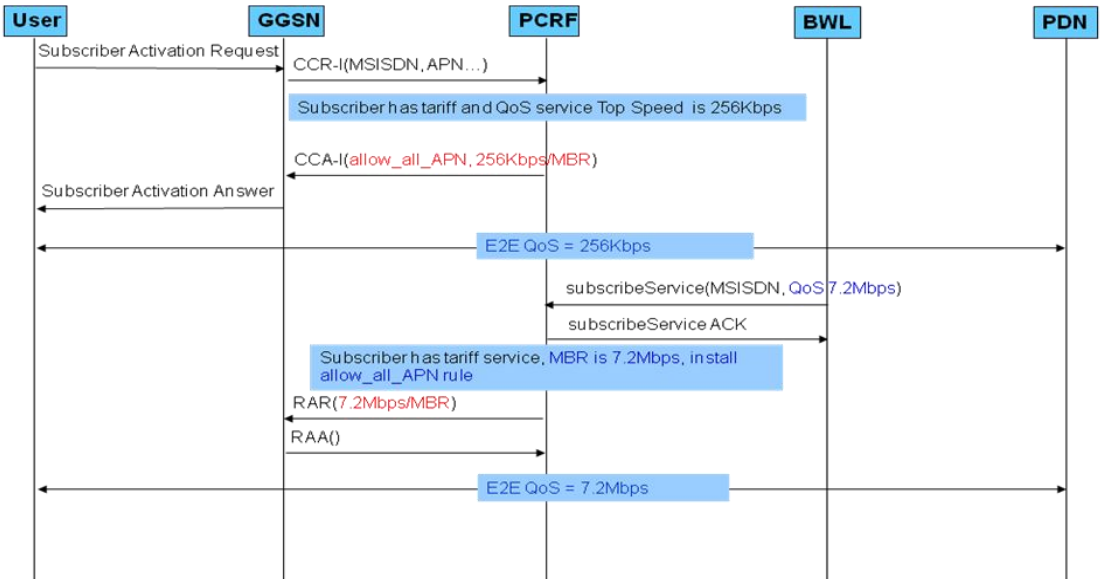

User
GGSN
PCRF
BWL
PDN
Subscriber Activation Request
CCR-I(MSISDN, APN…)
Subscriber has tariff and QoS service Top Speed is 256Kbps
CCA-I(allow_all_APN, 256Kbps/MBR)
Subscriber Activation Answer
E2E QoS = 256Kbps
subscribeService(MSISDN, QoS 7.2Mbps)
subscribeService ACK
Subscriber has tariff service, MBR is 7.2Mbps, install allow_all_APN rule
RAR(7.2Mbps/MBR)
RAA()
E2E QoS = 7.2Mbps

Figure 24: 7.2Mbps Bandwidth Allocation Signaling

In this case, subscriber has 7.2 Mbps of bandwidth and a policy that limits bandwidth to 128 Kbps within a time interval. When the defined time is reached, system automatically sends the removal rule of limit_128k service so, E2E QoS becomes 7.2 Mbps again.

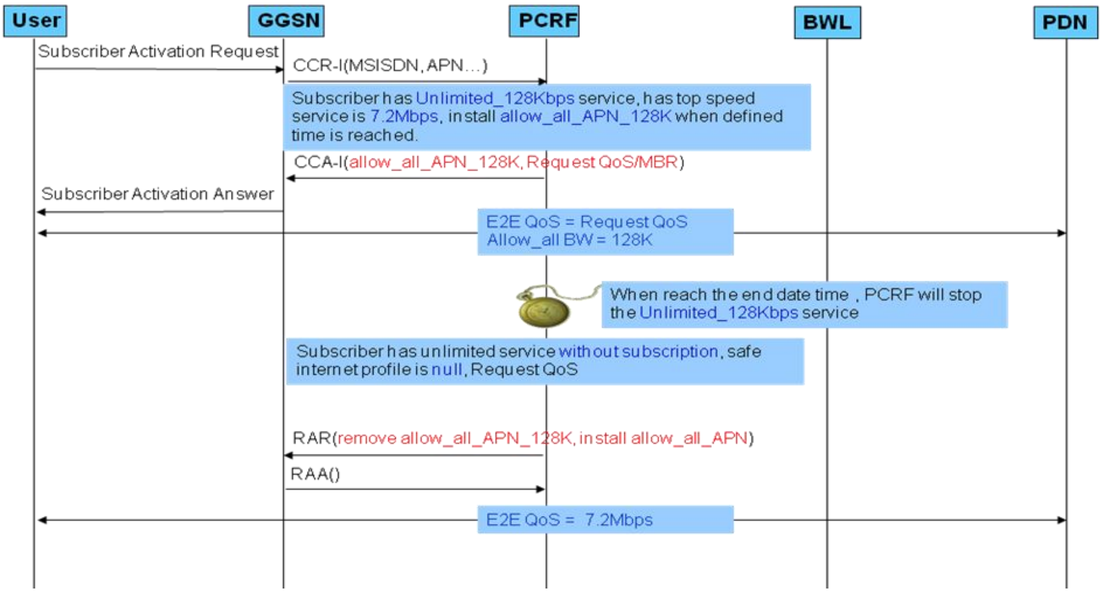

User
GGSN
PCRF
BWL
PDN
Subscriber Activation Request
CCR-I(MSISDN, APN…)
Subscriber has Unlimited_128Kbps service, has top speed service is 7.2Mbps, install allow_all_APN_128K when defined time is reached.
CCA-I(allow_all_APN_128K, Request QoS/MBR)
Subscriber Activation Answer
E2E QoS = Request QoS Allow_all BW = 128K
When reach the end date time , PCRF will stop the Unlimited_128Kbps service
Subscriber has unlimited service without subscription, safe internet profile is null, Request QoS
RAR(remove allow_all_APN_128K, install allow_all_APN)
RAA()
E2E QoS = 7.2Mbps

Figure 25: Limit 128K Traffic Shaping Signaling

4.3.3 General Policy Control Logic of Facebook service

PCRF has a service policy control logic as shown in the example below:

Service is triggered according to logic explained in previous topic. Besides them, a quota manager is added. After assigned service quota is finished, PCRF can limit the usage of this service. This logic is like given below:

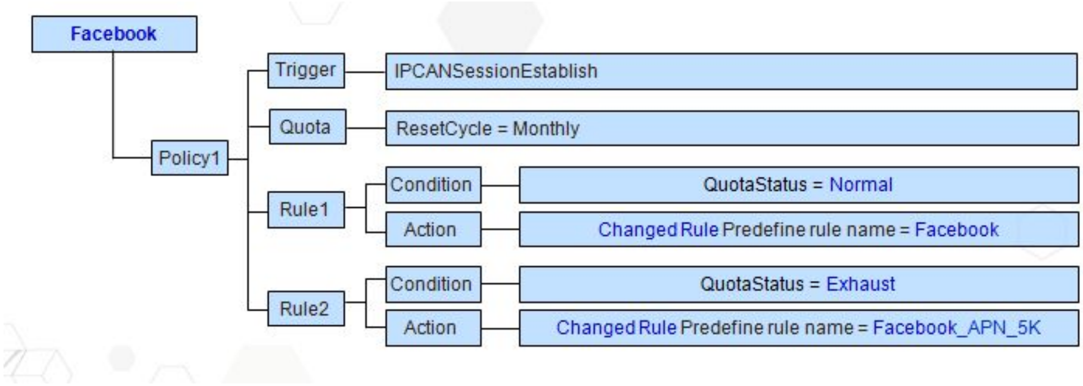


Figure 26: Facebook Rule Logic

As can be seen in the figure below, facebook service is provisioned from BWL. Then, subscriber can use facebook service, till the end of its quota. In this case, GGSN is reporting the usage amount of facebook service and PCRF is holding the remaining quota information according to updates coming from GGSN. After quota is exhausted, PCRF sends an RAR message to GGSN to remove the defined facebook rule and install the new rule limits facebook usage.

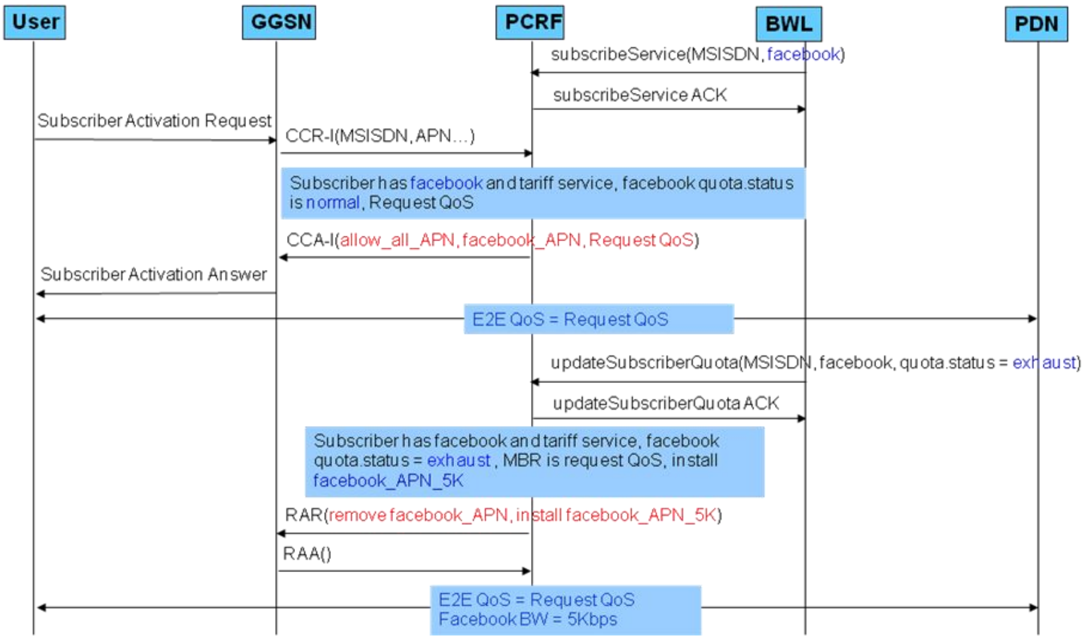

User
GGSN
PCRF
BWL
PDN
subscribeService(MSISDN, facebook)
subscribeService ACK
Subscriber Activation Request
CCR-I(MSISDN, APN…)
Subscriber has facebook and tariff service, facebook quota status is normal, Request QoS
CCA-I(allow_all_APN, facebook_APN, Request QoS)
Subscriber Activation Answer
E2E QoS = Request QoS
updateSubscriberQuota(MSISDN, facebook, quota status = exhaust)
updateSubscriberQuota ACK
Subscriber has facebook and tariff service, facebook quota status = exhaust, MBR is request QoS, install facebook_APN_5K
RAR(remove facebook_APN, install facebook_APN_5K)
RAA()
E2E QoS = Request QoS
Facebook BW = 5Kbps

Figure 27: Facebook Rule Install Diameter Signaling

This quota amount can also be renewed when quota cycle resets or given time interval is reached. PCRF removes limitation rule and install Facebook rule again automatically with a Re-Auth message flow.

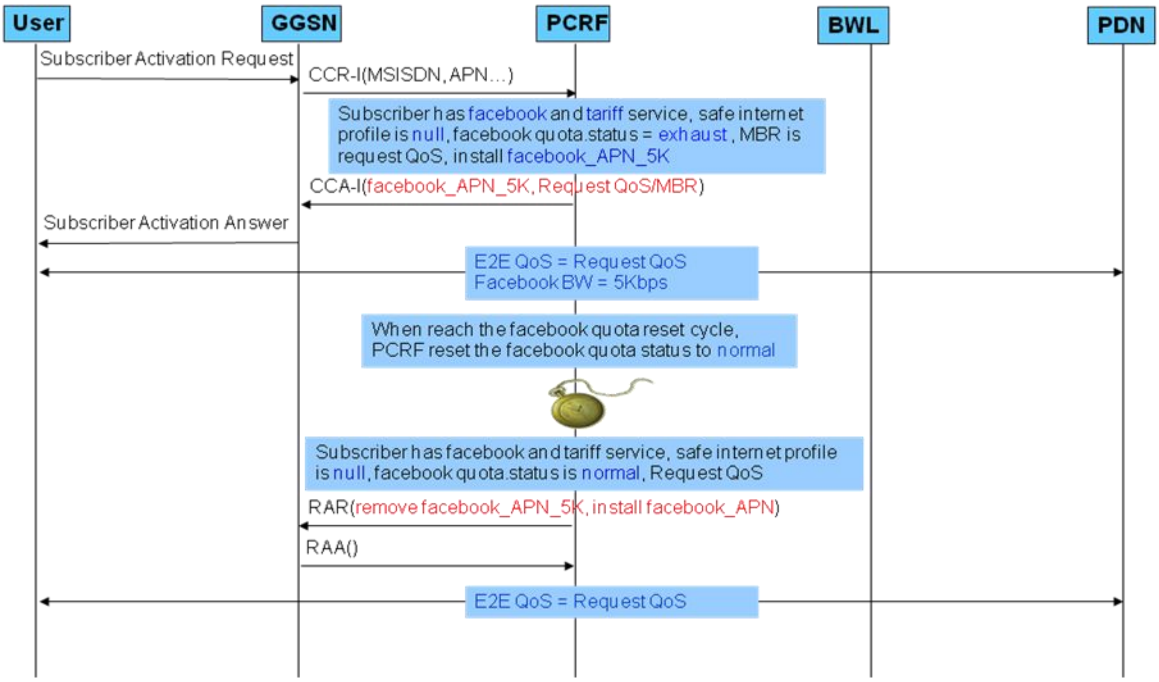

User
GGSN
PCRF
BWL
PDN
Subscriber Activation Request
CCR-I(MSISDN, APN…)
Subscriber has facebook and tariff service, safe internet profile is null, facebook quota status = exhaust, MBR is request QoS, install facebook_APN_5K
CCA-I(facebook_APN_5K, Request QoS/MBR)
Subscriber Activation Answer
E2E QoS = Request QoS
Facebook BW = 5Kbps
When reach the facebook quota reset cycle, PCRF reset the facebook quota status to normal
Subscriber has facebook and tariff service, safe internet profile is null, facebook quota status is normal, Request QoS
RAR(remove facebook_APN_5K, install facebook_APN)
RAA()
E2E QoS = Request QoS

Figure 28: Exhausted Service Quota and Quota Cycle Reset

Chapter 5

SOAP and WEB SERVICES

5.1 Web Services

Web Service is a technology that communicates two devices over a network. A Web service is a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL).[11] It is developed as a solution to insufficient connection between devices that allows software systems to exchange data over internet or intranet. It’s useful because it can be used to provide data exchange softwares even they’re built in different languages. Web services can use XML for data exchange.

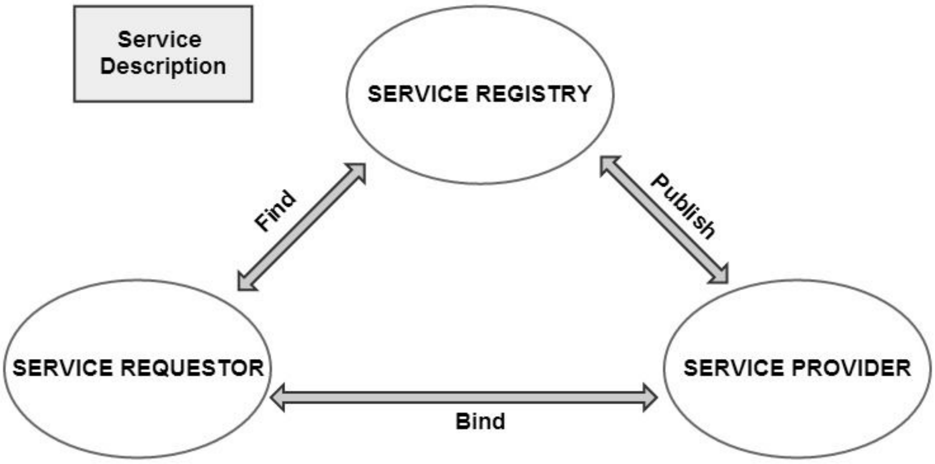


Figure 29: Web Service System[12]

Service Requester: Service requester is a system that request data. It finds and calls required parameters related how to call web service.

Service Provider: Service provider enables requester to access services. Software system is processing the request and provide the data.

Service Registry: It stores web service definitions about how to call each service. Service providers publish and enables them to be provided when needed.

5.2 Advantages of Using Web Services

Web services operates platform independent and also can work in all platforms and implement easily. A web service written in Python language and operating on Linux server platform can be called by a Windows terminal. It provides efficiency in time and cost. It is using HTTP thus information communication does not interrupt by security systems (through designated port mechanism). [13] Since HTTP requests are generally permitted to communicate over firewall. We can be sure that software programs that are using SOAP can communicate with other programs anywhere.

5.3 WSDL (Web Services Description Language)

WSDL is a standard XML format for describing network services. WSDL definition describes how to access a web service and operations will be performed. WSDL is used in combination of SOAP and XML scheme for providing web services over internet or intranet. Every special data types are defined in a WSDL file in XML format. Client can use SOAP to call functions listed in WSDL. It is developed by Microsoft and IBM. [14]

5.4 SOAP (Simple Object Access Protocol)

The Simple Object Access Protocol provides a simple and lightweight mechanism for exchanging structured and typed information between peer ends in a decentralized, distributed environment in which extensible markup language (XML) is used.Simple Object Access Protocol is a type for establishing communication between programs that are written in different languages and operating in different OS by using Hyper-Text Transfer Protocol (HTTP) and Extensible Markup Language (XML) for exchanging data.

It is a standard defined by W3C. XML is a standard used by web services to serve data. WSDL (Web Service Description Language), identifies the interface of the web service serves. WSDL describes the return types and parameters of functions existing in the web service. With the help of Discovery Protocol all web services in a server are organized. UDDI standards enable web services' organization on web. Web service to web service sender and receiver mode is like in the figure below:

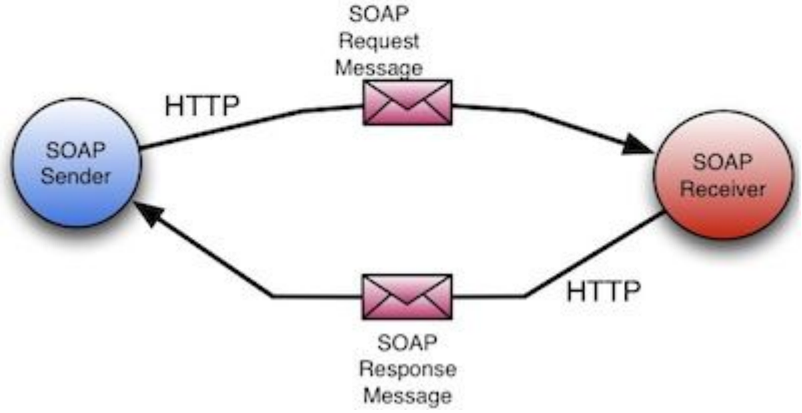


Figure 30: Web service to Web service in sender-receiver mode

SOAP consists of four parts:

SOAP envelope: It defines an overall framework, which determines what are contained in messages, who can process the contents and whether the contents are optional or mandatory.

SOAP coding rule: It defines a series of mechanisms used for exchanging data type instances defined by application programs.

Remote procedure call (SOAP RPC): It defines a convention that represents remote procedure call and response.

SOAP binding: It defines a convention in which SOAP envelopes are exchanged between nodes through underlying protocols.

5.5 REST (REpresentational State Transfer)

Rest architecture is based on client-server communication. The services that are using this architecture called RESTful services. [17]

- Platform free
- Language free
- Operates on HTTP
- Flexible and can be extended.

RESTful Interface for Application QoS

Representational State Transfer (REST) is an architectural style that is based on widely used protocols and standards such as HTTP, URI, XML, and HTML.

In 2G, 3G, or 4G mobile networks, the RESTful Interface for Application QoS allows the PCRF to provide fast access for RESTful third-party application functions (AFs) by simplifying access. This helps guarantee resources for services initiated from third-party AFs. For example, when a subscriber uses an audio, video, or conference service provided by the AF, the PCRF needs to provide QoS guarantee demanded by the AF to ensure subscriber's service experience over Rx interface. [19] The AF can use simple HTTP for fast access to the PCRF.

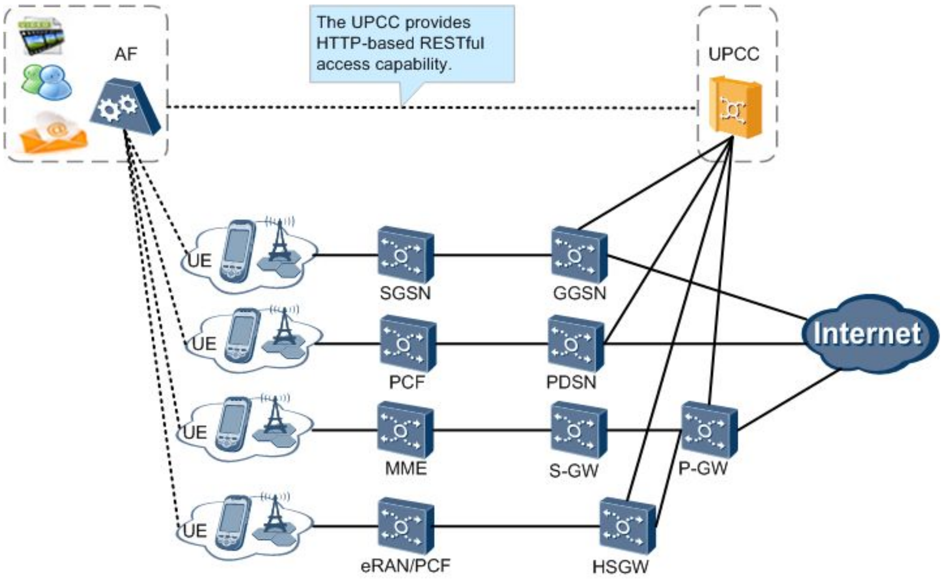

The UPCC provides HTTP-based RESTful access capability.

Figure 31: RESTful Interface for Application QoS [19]

5.6 REST and SOAP

Advantages of REST

- Lightweight and easily extendable.
- Input and output data is so small considering SOAP.
- Easy to design and implement, there is no need an extra tool.
- Works on HTTP.

Advantages of SOAP

- Easy to consume comes with a scheme.
- Type-free, no need validations.
- Has many development tools.
- Security implementations are easier than REST.

5.7 Service Provisioning (Gx SOAP Operations)

The subscription profile repository (SPR) provides the Extensible Markup Language (XML)/Simple Object Access Protocol (SOAP) interface, with which carriers can provide subscriber data management interfaces for the provisioning system, and realize secondary development.

Chapter 6

Deep Packet Inspection (DPI)

6.1 What is DPI

Deep packet inspection (DPI) is a method of filtering packets in network. In OSI (Open System Interconnection) layer, it works at application layer. It examines the header and data part of a packet. Packets are inspected according to defined criterias.

DPI makes it possible to find, identify, classify and block packets. By this features, Service providers can allocate available resources. For example, a packet that signed with high importance can be reached ahead according to low priority packet. It can also used be used for throttling data transfer abusive traffic according to demand on network to improve network performance of subscribers.

DPI can be used for multiple purposes. But the most popular usage in MBB networks is traffic shaping to manage congestion. Because congestion management protocols that used in end to end networks are insufficient. Growth in MBB networks is almost doubling in every year. And enhancement in the technology is not the cure for this amount of growth. [16]

The statistical amount of growth in MBB networks is given in below figures:

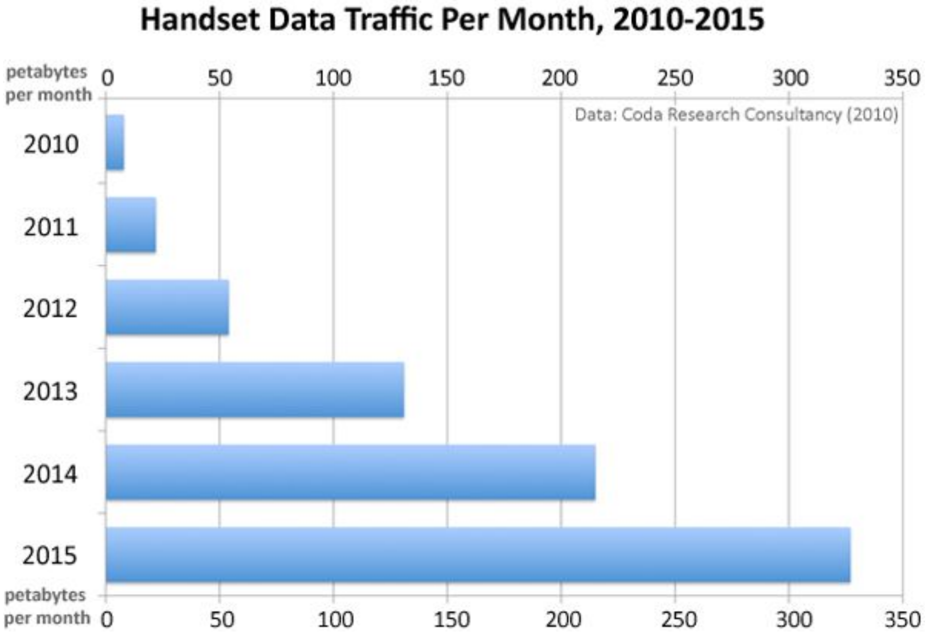


Figure 32: Data Traffic per Month[21]

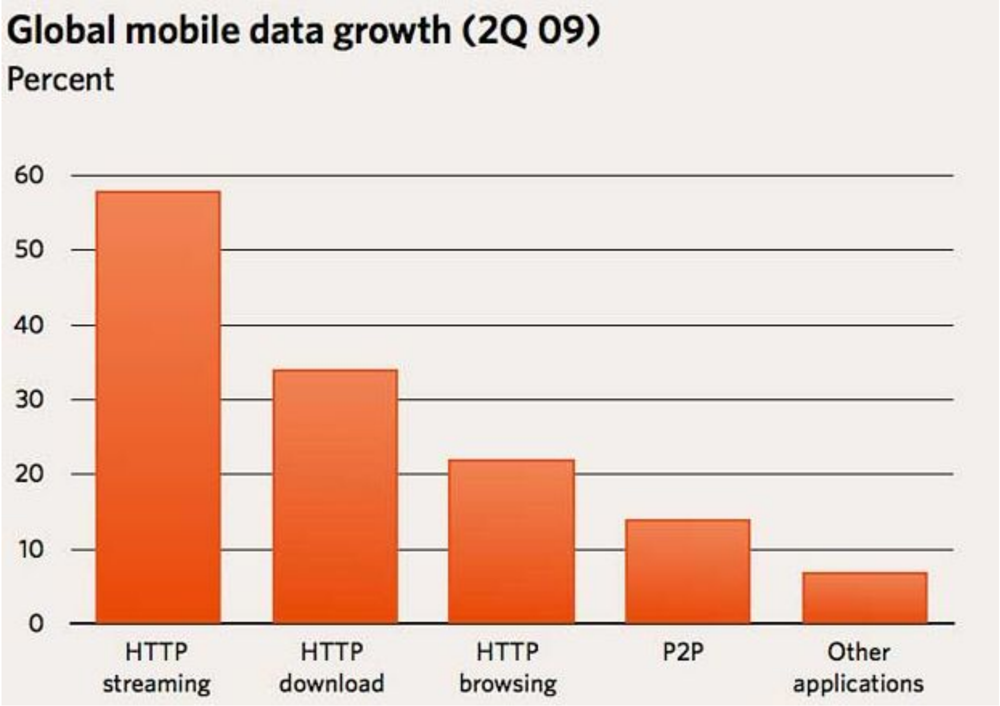


Figure 33: Mobile Data Growth[21]

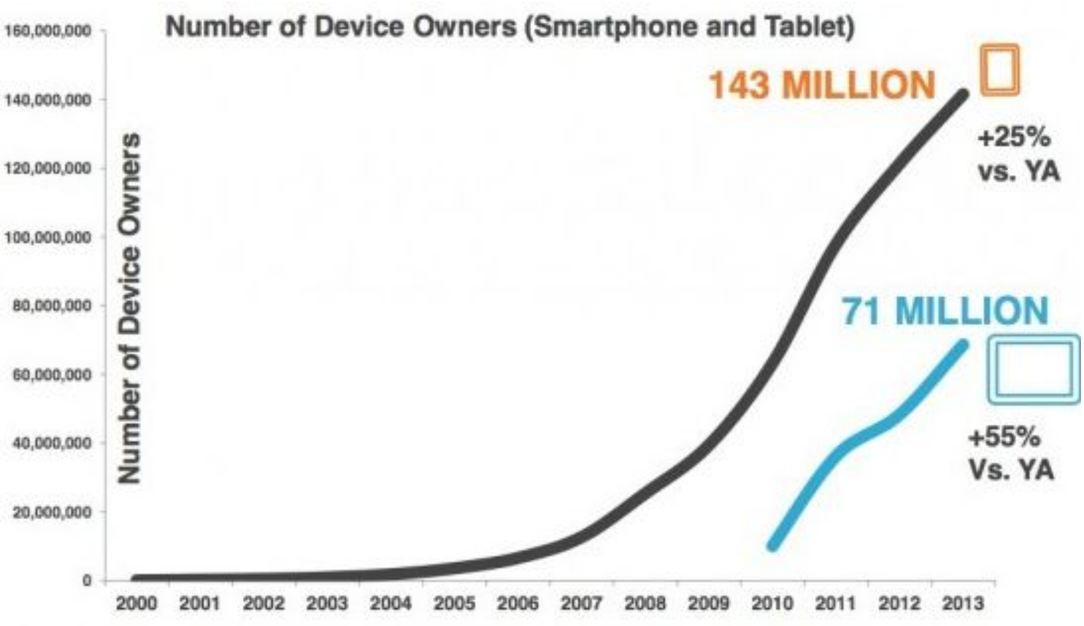


Figure 34: Number of Smart Phone and Tablet Owners by Year

According to given graphs, there is no possible solution for congestion in the network other than policy based DPI. As can be seen in scenario below;

- A subscriber is streaming a large video causes poor data performance for all other subscribers who are getting service in same cell of a station.

- Applying traffic management and sharing resource between all subscribers is a solution but not affordable to fulfill subscriber requirements. Because all subscribers need different bandwidth amounts according to their usage. Like the difference between subscribers who are using streaming and instant messaging. It is impossible to watch a video without interruptions in case of a fixed bandwidth sharing and same for message delivery, there will be delay.

- Deploying a deep packet inspection based traffic shaping method to adjust allocation of available bandwidth. This will allow subscribers to use application prioritized and can improve Quality of Experience (QoE).

6.2 End-to-End Internet

In early design of internet, it just cares sending data packets from sender to the receiver. It does not care what is inside of a packet. Even in early design, it does not check end side received or not. In today's network applications and their usage are evolved. Packet loss issues, network address translation (NAT), filtering viruses, in short securing internet and allocating bandwidth on demand according to application type got more and more important. [15] They changed the architecture of internet. That's why we need to investigate inside of packages by moving more intelligence to network.

The only way two end-points can obtain a completely reliable transfer is by transmitting and acknowledging a checksum for the entire data stream; in such a setting, lesser checksum and acknowledgement (ACK/NACK) protocols are justified only for the purpose of optimizing performance - they are useful to the vast majority of clients, but are not enough to fulfil the reliability requirement of this particular application. Thorough checksum is hence done at the end-points, and the network maintains a relatively low level of complexity and reasonable performance for all clients.

6.3 DPI Functions

Deep packet inspection can operate between Layer 2 and Layer 7 of the OSI model. In this process packet header and data part of the packet are inspected. Implementation of DPI has both hardware and software.

DPI needs a great amount of processing while inspecting inside of all packets. Besides, performance is very important. Traffic conditions shouldn't be affected much. Software based approaches are good to filter packets. They're easy to implement, flexible and cost effective. Because of the performance issues they need to use a dedicated hardware to reach realistic traffic rates.[20]

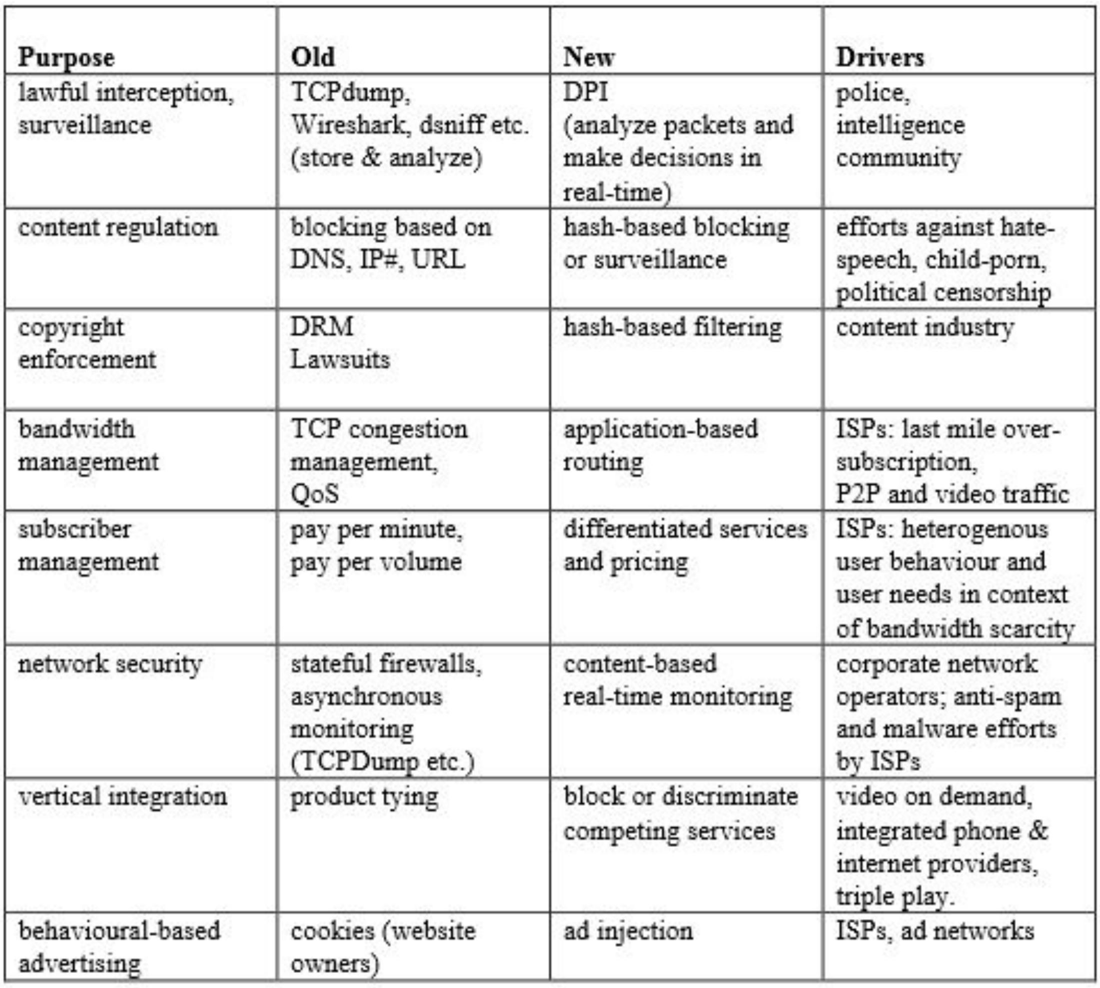
- Dangerous traffic that is directed to subscribers can be identified and blocked
- In a shared network media, ISPs can use traffic more effective with bandwidth on demand functions. And also unwanted traffic can be blocked.
- It is also used in governmental monitoring purposes of the internet.

The first DPI methods are developed for network security. Traditional firewalls located in local network were only checking the application and its port. But in this approach port 80 was always open for http and other applications can also use this port to send data. For example, web services use this http port to send datas over http packets. It was impossible to block this kind of traffic by port blocking. That's why all packets going through a media should be inspected to understand its kind and applying a filter.

Bandwidth management is also an important function. Resources are limited and in any shared system users can encounter congestion problems. In today's networks, amount of bandwidth hungry applicaitons are increasing. Instant video messaging, video presence (requires 10 Mbps), High definition television (requires between 5 and 8 Mbps), Real-time data backup (requires 2Mbps and 10 miliseconds of latency) are a few examples of these bandwidth hungry applications. Due to these bandwidth consumer applications there will be bottleneck in network. Even if one or two subscriber is consuming large amount of available bandwidth.

In mobile broadband networks logic, bandwidth is shared in last mile. Because of the limitation of frequencies. [2]

By the way, file sharing or messaging programs are always running in background. Normal TCP/IP congestion methods are not useful to find a solution for sharing total bandwith to subscribers fairly. The only solution is applying bandwidth management. Deep packet inspection is the only solution for detecting this kind of traffic and limiting bandwidth allocated for this application.



Purpose	Old	New	Drivers
lawful interception, surveillance	TCPdump, Wireshark, dsniff etc. (store & analyze)	DPI (analyze packets and make decisions in real-time)	police, intelligence community
content regulation	blocking based on DNS, IP#, URL	hash-based blocking or surveillance	efforts against hate-speech, child-porn, political censorship
copyright enforcement	DRM Lawsuits	hash-based filtering	content industry
bandwidth management	TCP congestion management, QoS	application-based routing	ISPs: last mile over-subscription, P2P and video traffic
subscriber management	pay per minute, pay per volume	differentiated services and pricing	ISPs: heterogenous user behaviour and user needs in context of bandwidth scarcity
network security	stateful firewalls, asynchronous monitoring (TCPDump etc.)	content-based real-time monitoring	corporate network operators; anti-spam and malware efforts by ISPs
vertical integration	product tying	block or discriminate competing services	video on demand, integrated phone & internet providers, triple play.
behavioural-based advertising	cookies (website owners)	ad injection	ISPs, ad networks

Figure 35: DPI, Old & New Approaches

Curent DPI platforms can be seperated into two categories:

- General purpose packet processing platforms

This architecture uses blade servers to apply traffic shaping. Load balancing, special packet routing and processing can be handled in these nodes. This kind of servers are using CPU cores for deep packet inspection and packet shaping.

- Dedicated purpose packet processing platforms (ASICs or FPGAs)

This architecture is more common in DPI technologies. Because it can be optimised to run on a specific issue. These equipments are integrated to GGSN. GGSN is not a network element designed for packet inspection but with an integrated ciscuit it can handle this issue successfully.

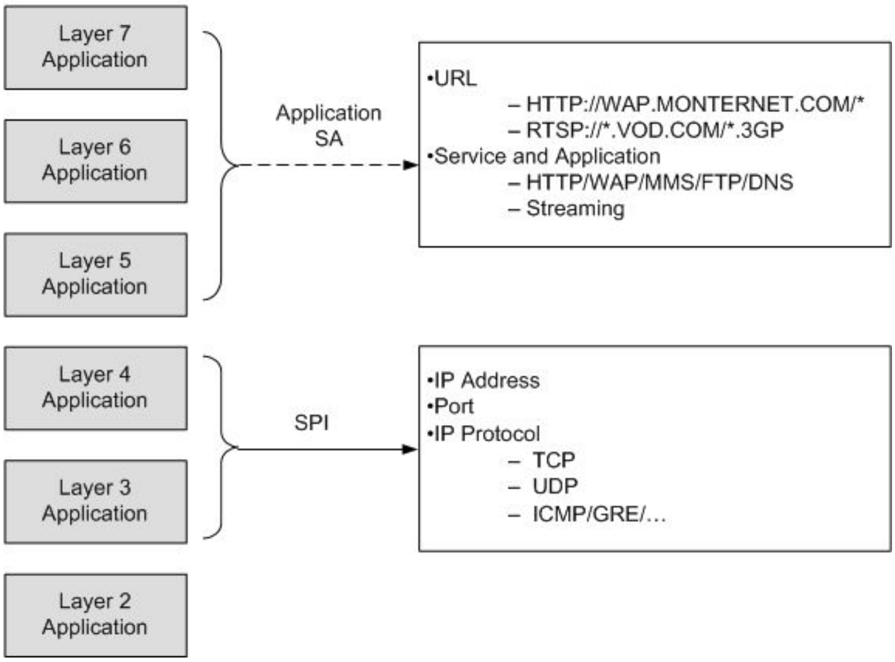


Figure 36: DPI in OSI Layers

6.3.1 Shallow Packet Inspection (SPI)

SPI analyzes source and destination IP addresses, source and destination ports and protocol type at Layer 3 and 4 to identify information about network traffic. A traditional IP router also performs traffic identification and QoS guarantee to some extent by using the same information. A traditional IP router, however, analyzes only the contents below layer 4 in the IP header and identifies applications based on TCP/UDP port numbers.

6.3.2 Service Awareness (SA)

SA, in contrast of SPI, SA focuses on L7 (application layer) parsing in addition to L3/4 packet parsing. SA involves protocol identification, packet characteristic identification, and associated identification.

- Packet Characteristic Identification

  - Identification of known protocols, such as FTP, HTTP, DNS, and SMTP. With standards, special messages, commands, and state transition mechanisms, these protocols can be identified accurately and reliably through an analysis of these special fields at the application layer.

  - Identification of most P2P, IM, and VoIP protocols. These packets need to be identified by its characteristic fields in packet streams.

- Associated Identification

  Network applications like VoIP, P2P and FTP that are used for voice, video and file transfer are using dynamically negotiated ports. If only port identification is used, there is no way to identify data part of this communication. The traffic needs to be marked with its type.

6.4 Encryption: The Death of DPI?

In first phases of this project Facebook and twitter was allowing http connections then they changed their mind to encrypt its content. Now, it is optional to choose content encrypted or plain according to customer. And encryption is a big problem for Deep Packet Inspection. Also for VOIP and tethering issues, it is more complex to identify packets. Does this mean the end of DPI technologies? Actually, it was not. By these kind of changes in technology, signature based DPI developed. Increase in Facebook and Twitter usage was enormous as can be seen in the following figure and it is still a need to identify their traffic flow to manage network.

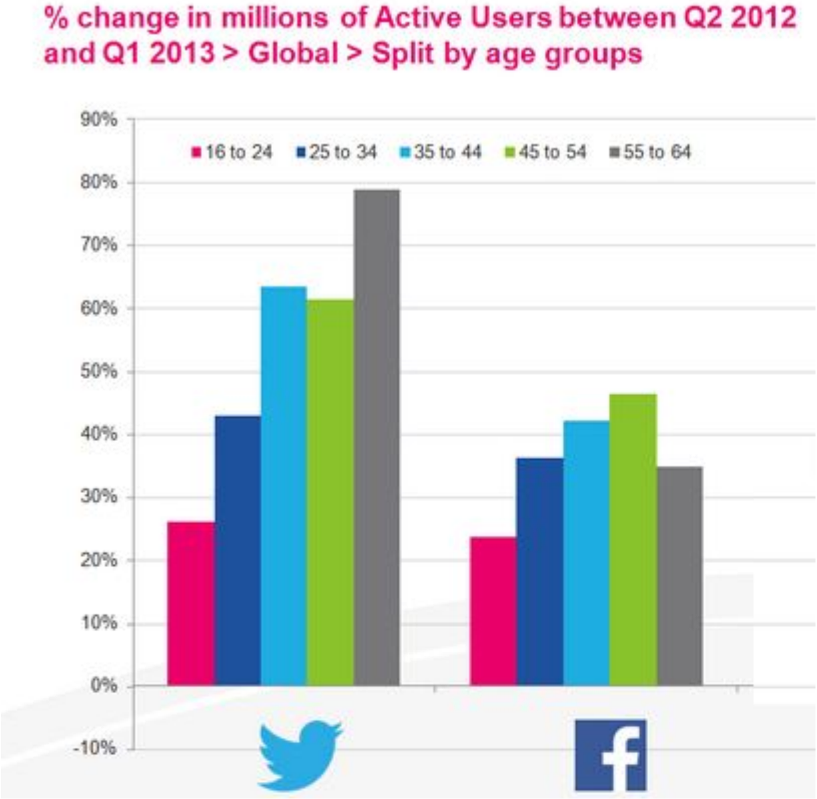


Figure 37: Change in Active Users of Social Platforms [29]

6.4.1 Heuristic Analysis (H-SA)

H-SA is for complex and encrypted protocol to be identified. Some protocols have no characteristic or encrypted for protocol identification. No difference can be seen between encrypted packages. But every application has a behavior while sending packets over network. By analyzing the behavior of packets over its port range, packet length, packet sending interval and frequency, identifying applications using P2P, VoIP and FTP protocols is possible.

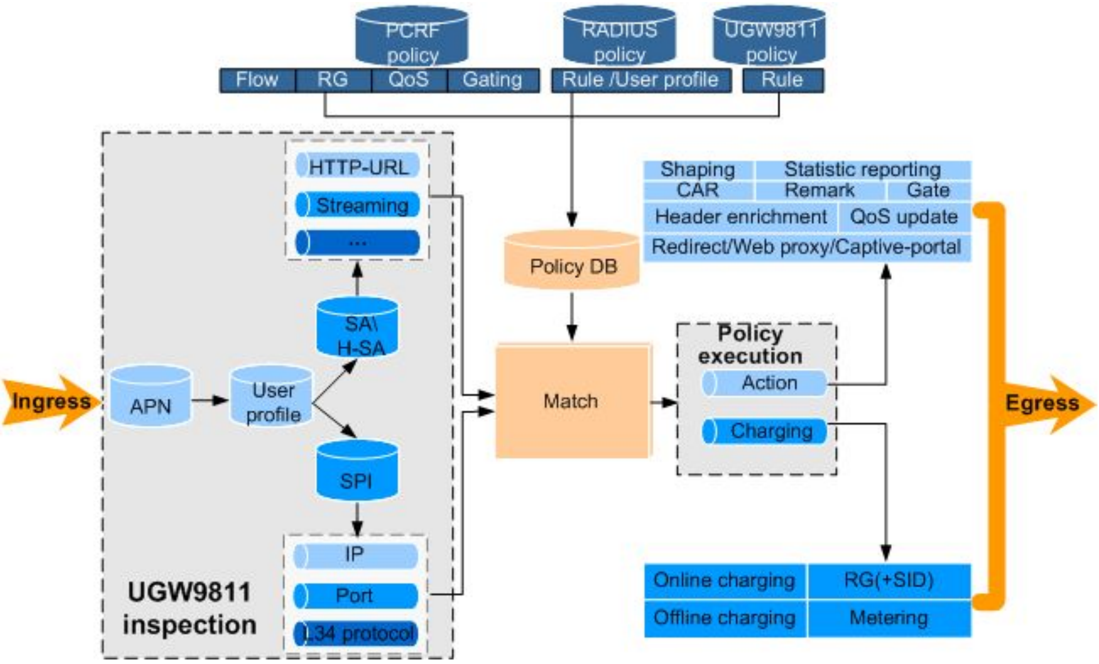


Figure 38: Heuristic Analysis (H-SA)

Chapter 7

Testbed and Test Results

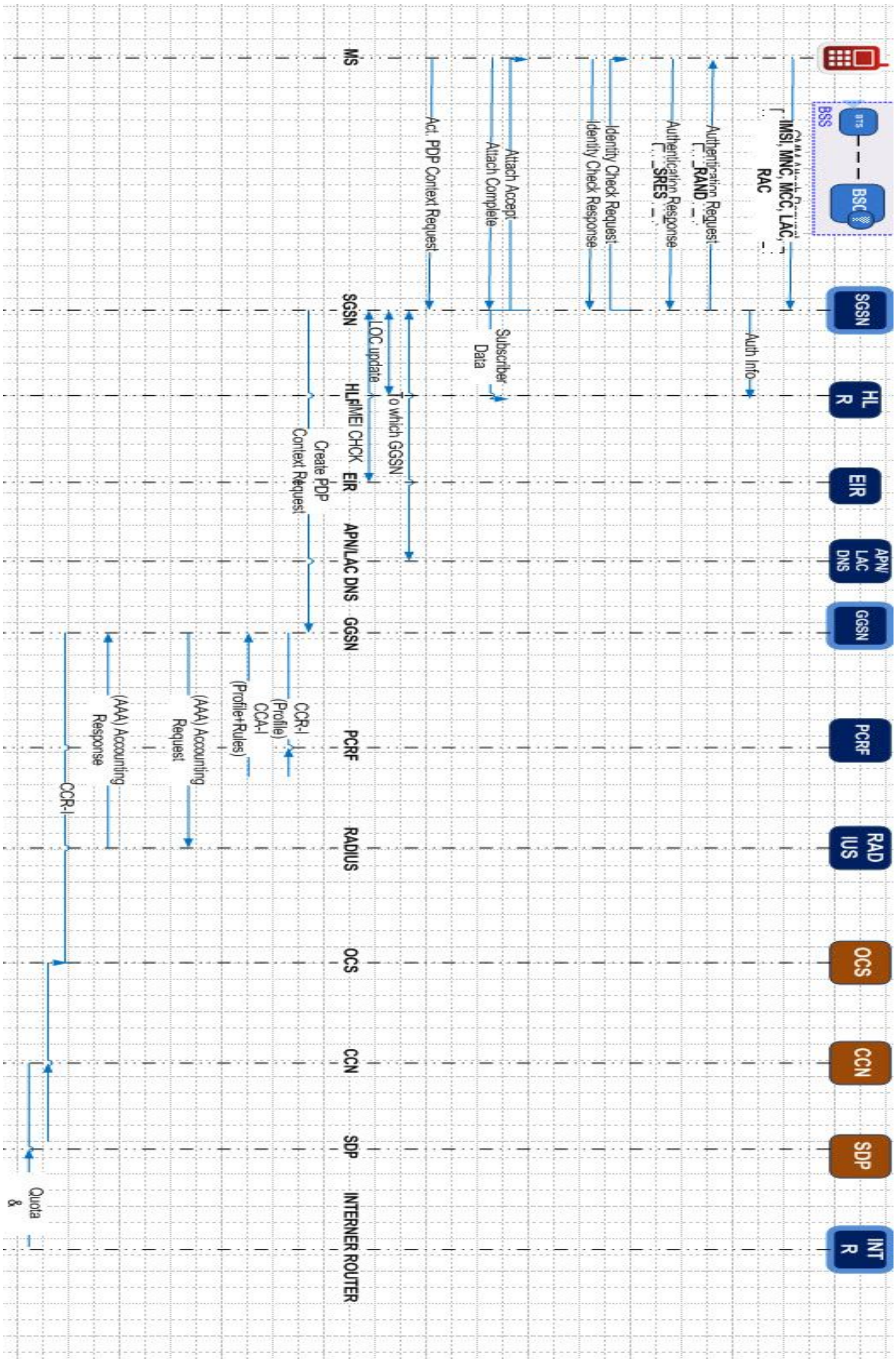
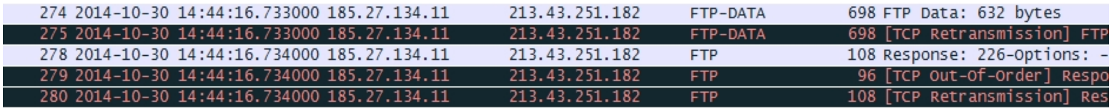


Figure 39: GPRS Flow Diagram

7.1 TC1 – Allocate 256K of Bandwidth to Subscriber

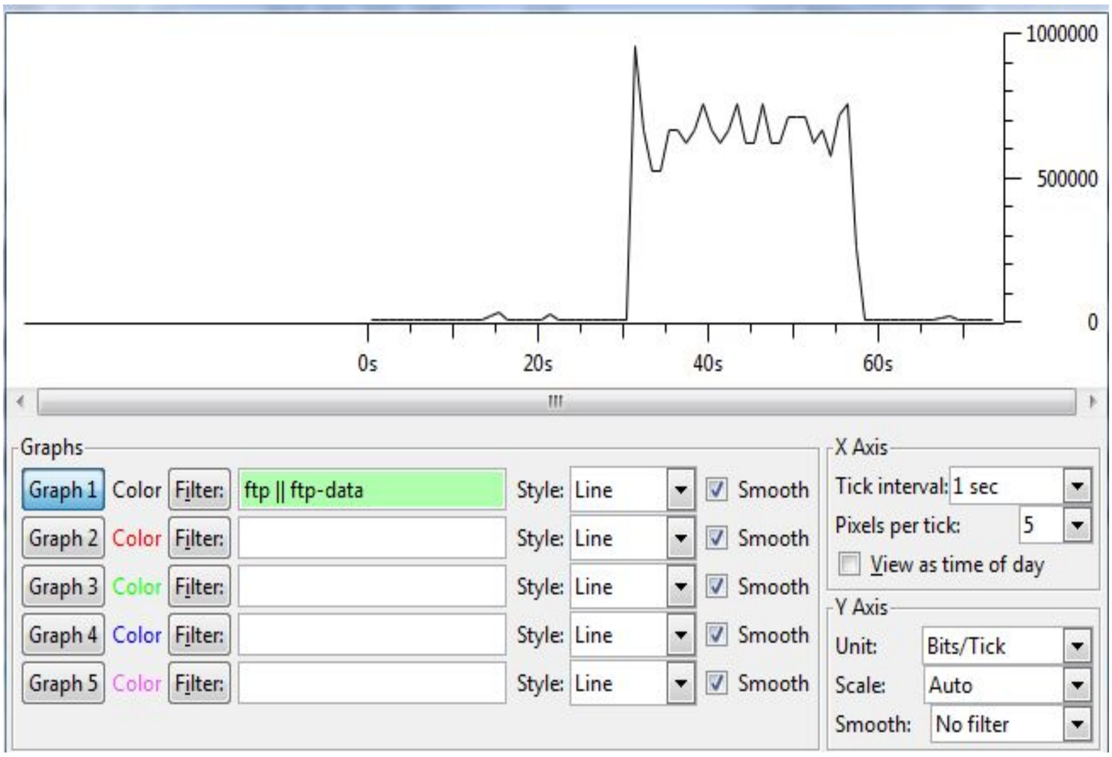
In this test case, 256Kbps of bandwidth and traffic THP 3 is assigned to subscriber and FTP data transfer is done to test available E2E bandwidth. To separate FTP traffic from the remaining traffic we applied a wireshark filter ftp || ftp-data as can be seen below. Then, the traffic rate is measured according to E2E QoS strategy assigned from PCRF (Network Controlled QoS). Avarage speed of FTP data transfer is limited to 256Kbps as seen in figure 7.1 and 7.1.1.

Wireshark Filter: Filters to detect ftp signaling and data traffic, ftp || ftp-data



```
274 2014-10-30 14:44:16.733000 185.27.134.11     213.43.251.182     FTP-DATA        698 FTP Data: 632 bytes
275 2014-10-30 14:44:16.733000 185.27.134.11     213.43.251.182     FTP-DATA        698 [TCP Retransmission] FTP
278 2014-10-30 14:44:16.734000 185.27.134.11     213.43.251.182     FTP             108 Response: 226-Options: -
279 2014-10-30 14:44:16.734000 185.27.134.11     213.43.251.182     FTP              96 [TCP Out-Of-Order] Respo
280 2014-10-30 14:44:16.734000 185.27.134.11     213.43.251.182     FTP             108 [TCP Retransmission] Res
```

IO Graph:



Graph 1 Color Filter: ftp || ftp-data Style: Line ☑ Smooth

Graph 2 Color Filter: Style: Line ☑ Smooth

Graph 3 Color Filter: Style: Line ☑ Smooth

Graph 4 Color Filter: Style: Line ☑ Smooth

Graph 5 Color Filter: Style: Line ☑ Smooth

Tick interval: 1 sec

Pixels per tick: 5

□ View as time of day

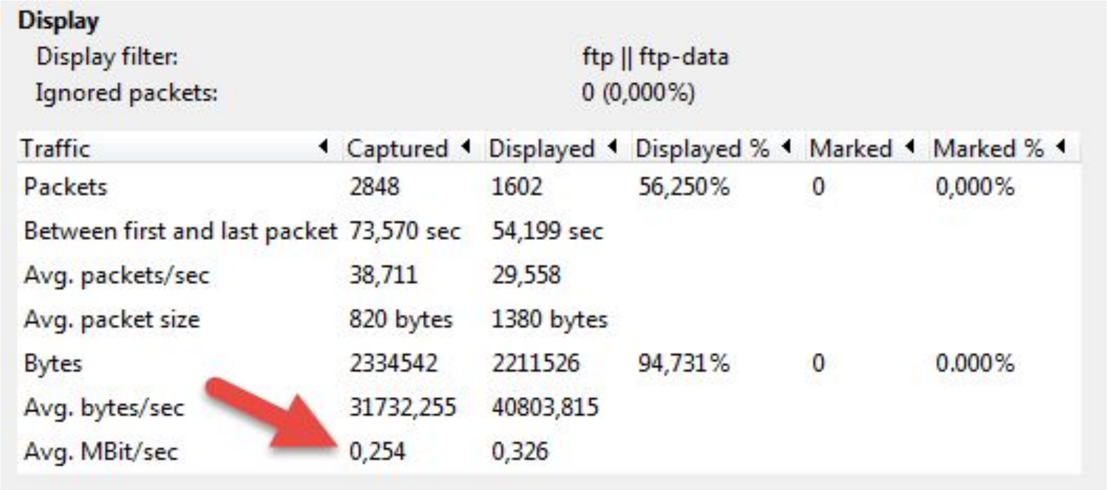
Unit: Bits/Tick

Scale: Auto

Smooth: No filter

Figure 40: IO Graph of 256K of Bandwidth

Avg Speed:



Display

Display filter: ftp || ftp-data

Ignored packets: 0 (0,000%)

Traffic	Captured	Displayed	Displayed %	Marked	Marked %
Packets	2848	1602	56,250%	0	0,000%
Between first and last packet	73,570 sec	54,199 sec			
Avg. packets/sec	38,711	29,558			
Avg. packet size	820 bytes	1380 bytes			
Bytes	2334542	2211526	94,731%	0	0.000%
Avg. bytes/sec	31732,255	40803,815			
Avg. MBit/sec	0,254	0,326			

Figure 41: AVG Speed Graph of 256K of Bandwidth (E2E)

7.2 TC2 – Limit Bandwidth to 256K with Traffic Shaping

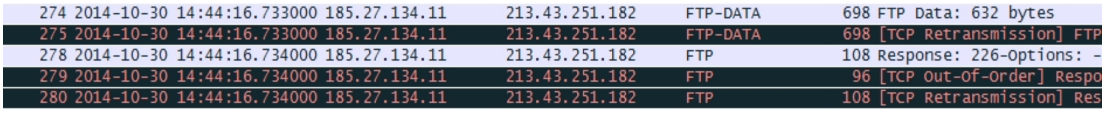
In this test case, traffic is limited to 256Kbps in a different way. Dual Token Bucket algorithm is applied in this case to limit traffic rate. Same filters are applied in wireshark. When I/O graph is examined in figure 7.2, there were oscillations at the beginning of file transfer then traffic is stabilized.

bwm-controller hw_uc5_bwm_control_down_256k car cir 128 cbs 24000 pir 256 pbs 48000 green pass yellow pass red drop

In the configuration given above, traffic is limited to 256Kbps (Peak information rate, PIR) but guaranteed to 128Kbps (Committed information rate, CIR). Committed burst size specifies the depth of first token bucket and it can be calculated according to this formula *cir-value(kbit/s)*1000/8*1.5s*. Peak burst size specifies the depth of second token bucket and can be calculated with this formula *pir-value(kbit/s)*1000/8*1.5s*. 3 Color algorithm is used in this formula. Red stands for violating and it is used for dropping packets, yellow stands for exceeding packets and the action used for this color is sending packet to a queue to be transmitted according to network conditions. In case of congestion, yellow marked packets are dropped. And the color green stands for conforming packets and the default action for this packets are pass.

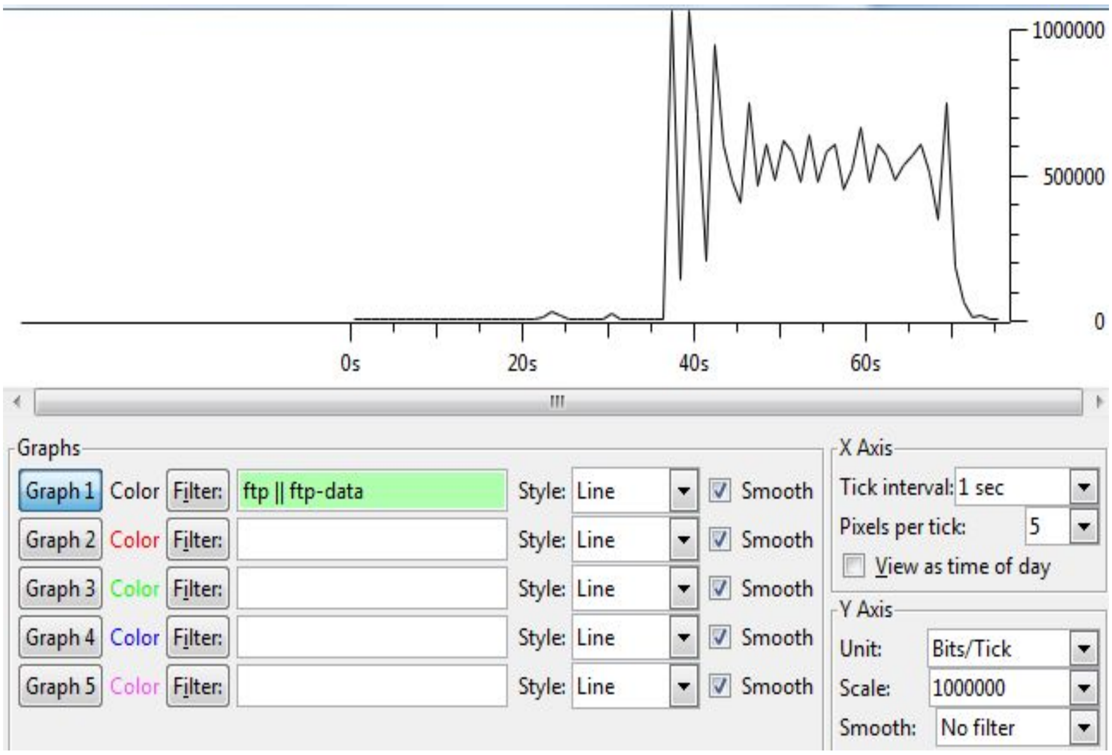
Bandwidth: Limited to 256K

Wireshark Filter: Filters to detect ftp signaling and data traffic, ftp || ftp-data



```
 274 2014-10-30 14:44:16.733000 185.27.134.11     213.43.251.182    FTP-DATA        698 FTP Data: 632 bytes
 275 2014-10-30 14:44:16.733000 185.27.134.11     213.43.251.182    FTP-DATA        698 [TCP Retransmission] FTP
 278 2014-10-30 14:44:16.734000 185.27.134.11     213.43.251.182    FTP             108 Response: 226-Options: -
 279 2014-10-30 14:44:16.734000 185.27.134.11     213.43.251.182    FTP              96 [TCP Out-Of-Order] Respo
 280 2014-10-30 14:44:16.734000 185.27.134.11     213.43.251.182    FTP             108 [TCP Retransmission] Res
```

IO Graph:



Graphs

Graph 1	Color	Filter:	ftp || ftp-data	Style:	Line	☑ Smooth
Graph 2	Color	Filter:		Style:	Line	☑ Smooth
Graph 3	Color	Filter:		Style:	Line	☑ Smooth
Graph 4	Color	Filter:		Style:	Line	☑ Smooth
Graph 5	Color	Filter:		Style:	Line	☑ Smooth

X Axis

Tick interval: 1 sec

Pixels per tick: 5

☐ View as time of day

Y Axis

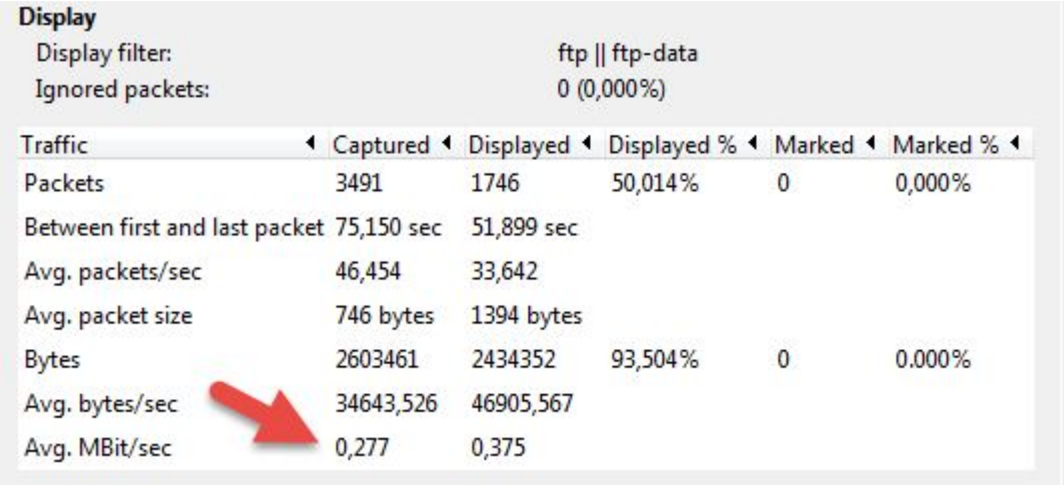
Unit: Bits/Tick

Scale: 1000000

Smooth: No filter

Figure 42: IO Graph of 256K of Bandwidth Limiting (Traffic Shaping)

Avg Speed:



Display

Display filter: ftp || ftp-data

Ignored packets: 0 (0,000%)

Traffic	Captured	Displayed	Displayed %	Marked	Marked %
Packets	3491	1746	50,014%	0	0,000%
Between first and last packet	75,150 sec	51,899 sec			
Avg. packets/sec	46,454	33,642			
Avg. packet size	746 bytes	1394 bytes			
Bytes	2603461	2434352	93,504%	0	0.000%
Avg. bytes/sec	34643,526	46905,567			
Avg. MBit/sec	0,277	0,375			

Figure 43: AVG Speed Graph of 256K of Bandwidth Limiting (Traffic Shaping)

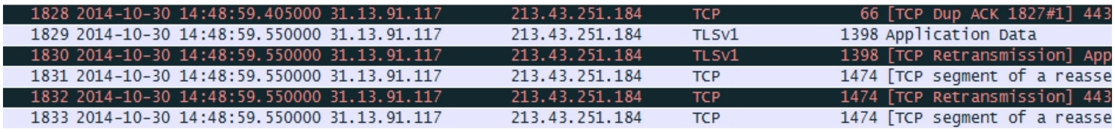
7.3 TC3 – URL Based Bandwidth Management (Unlimited and Limited Facebook Service)

In this test case, Facebook service is subscribed with E2E QoS of 42 Mbps. While using Facebook service, even if the limit service is applied to the subscriber, user will be connecting Facebook with 42Mbps as seen in figure 7.3. The difference between legacy bandwidth assignment and new bandwidth limitation can be seen with this test case. Now, it is possible to assign URL based QoS to the subscriber. Also it is possible to limit Facebook service speed (figure 7.3.2) and other applications will be able to connect with the speed of E2E QoS.

Bandwidth: Unlimited (General network E2E QoS 42Mbit) with unlimited and limited Facebook service

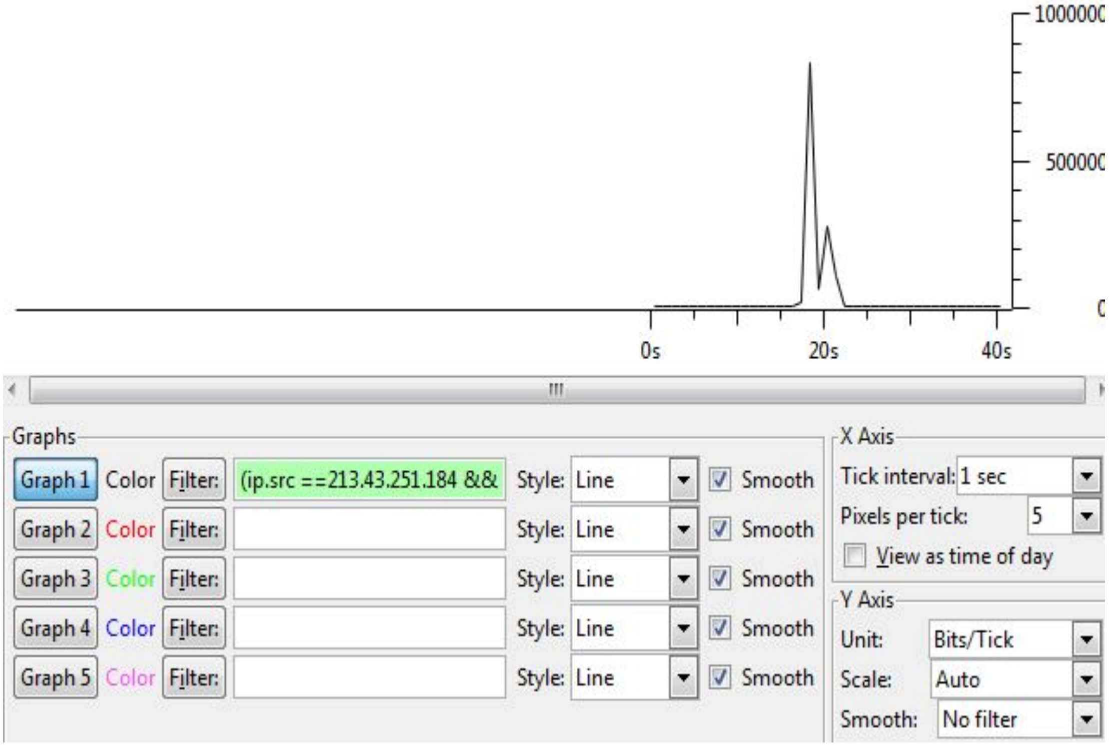
Wireshark Filters: To filter Facebook related traffic source and destination IPs are filtered for both limited and unlimited traffic.

Unlimited : (ip.src ==213.43.251.184 && ip.dst == 31.13.91.117) || (ip.dst ==213.43.251.184 && ip.src == 31.13.91.117)



```
1828 2014-10-30 14:48:59.405000 31.13.91.117     213.43.251.184    TCP        66 [TCP Dup ACK 1827#1] 443
1829 2014-10-30 14:48:59.550000 31.13.91.117     213.43.251.184    TLSv1    1398 Application Data
1830 2014-10-30 14:48:59.550000 31.13.91.117     213.43.251.184    TLSv1    1398 [TCP Retransmission] App
1831 2014-10-30 14:48:59.550000 31.13.91.117     213.43.251.184    TCP      1474 [TCP segment of a reasse
1832 2014-10-30 14:48:59.550000 31.13.91.117     213.43.251.184    TCP      1474 [TCP Retransmission] 443
1833 2014-10-30 14:48:59.550000 31.13.91.117     213.43.251.184    TCP      1474 [TCP segment of a reasse
```

IO Graph:



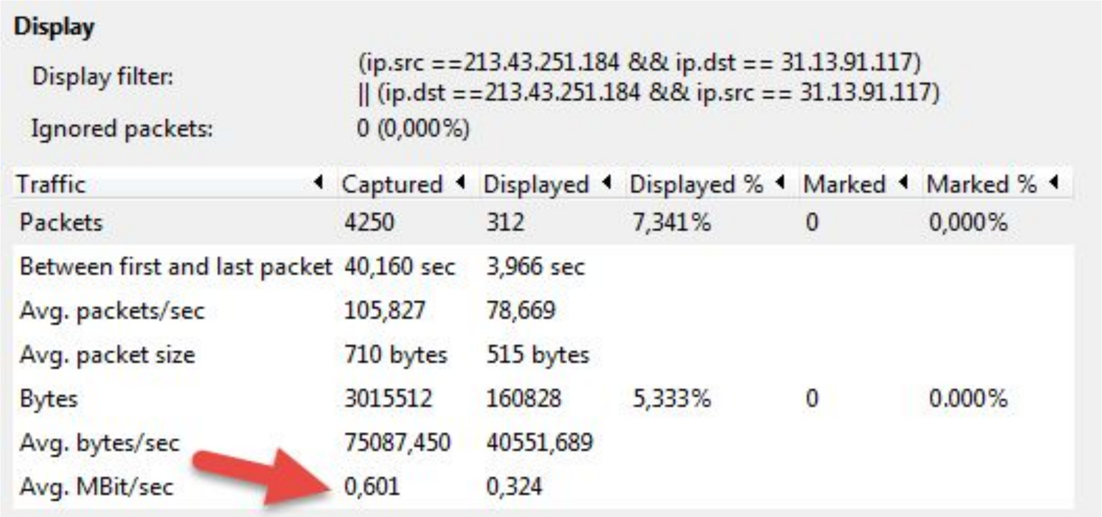
Graph 1 Color Filter: (ip.src ==213.43.251.184 && Style: Line ☑ Smooth
Graph 2 Color Filter: Style: Line ☑ Smooth
Graph 3 Color Filter: Style: Line ☑ Smooth
Graph 4 Color Filter: Style: Line ☑ Smooth
Graph 5 Color Filter: Style: Line ☑ Smooth

X Axis
Tick interval: 1 sec
Pixels per tick: 5
□ View as time of day

Y Axis
Unit: Bits/Tick
Scale: Auto
Smooth: No filter

Figure 44: IO Graph of URL Based QoS (Unlimited Facebook)

Avg Speed:



Display

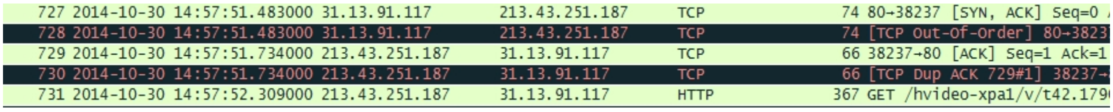
Display filter: (ip.src ==213.43.251.184 && ip.dst == 31.13.91.117) || (ip.dst ==213.43.251.184 && ip.src == 31.13.91.117)

Ignored packets: 0 (0,000%)

Traffic	Captured	Displayed	Displayed %	Marked	Marked %
Packets	4250	312	7,341%	0	0,000%
Between first and last packet	40,160 sec	3,966 sec			
Avg. packets/sec	105,827	78,669			
Avg. packet size	710 bytes	515 bytes			
Bytes	3015512	160828	5,333%	0	0.000%
Avg. bytes/sec	75087,450	40551,689			
Avg. MBit/sec	0,601	0,324			

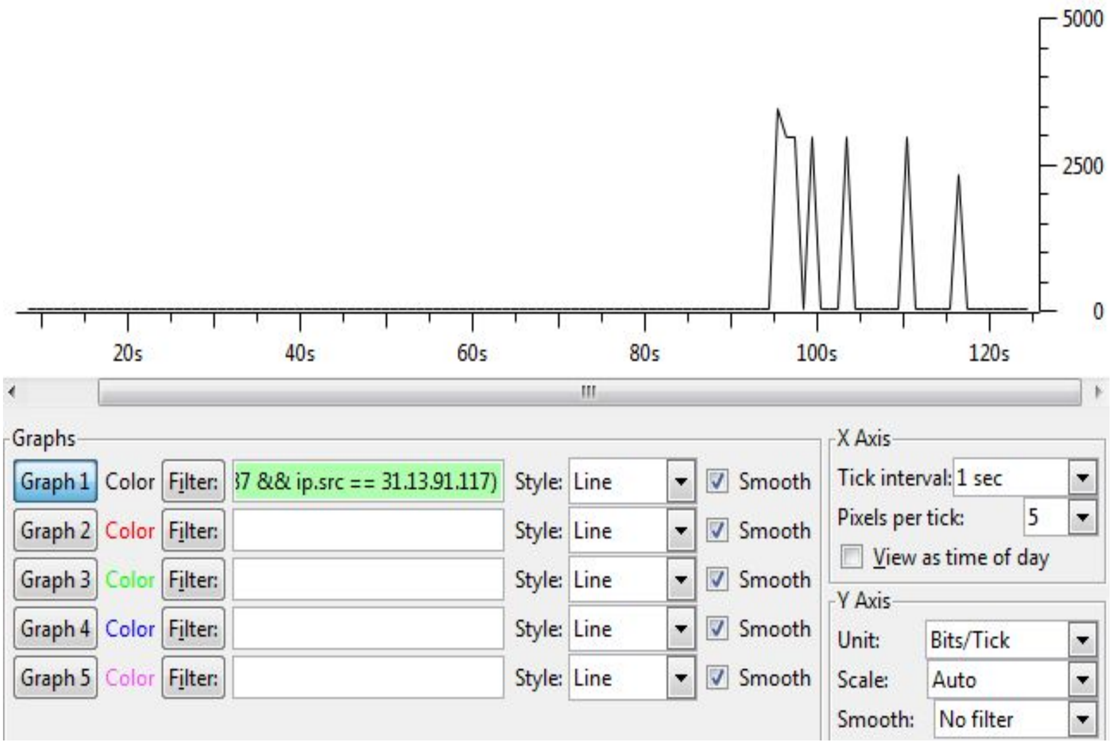
Figure 45: AVG Speed Graph of Facebook without Limitation

Limited: (ip.src ==213.43.251.187 && ip.dst == 31.13.91.117) || (ip.dst ==213.43.251.187 && ip.src == 31.13.91.117)



```
727 2014-10-30 14:57:51.483000 31.13.91.117     213.43.251.187    TCP       74 80→38237 [SYN, ACK] Seq=0
728 2014-10-30 14:57:51.483000 31.13.91.117     213.43.251.187    TCP       74 [TCP Out-Of-Order] 80→3823
729 2014-10-30 14:57:51.734000 213.43.251.187   31.13.91.117      TCP       66 38237→80 [ACK] Seq=1 Ack=1
730 2014-10-30 14:57:51.734000 213.43.251.187   31.13.91.117      TCP       66 [TCP Dup ACK 729#1] 38237→
731 2014-10-30 14:57:52.309000 213.43.251.187   31.13.91.117      HTTP     367 GET /hvideo-xpa1/v/t42.179
```

IO Graph:



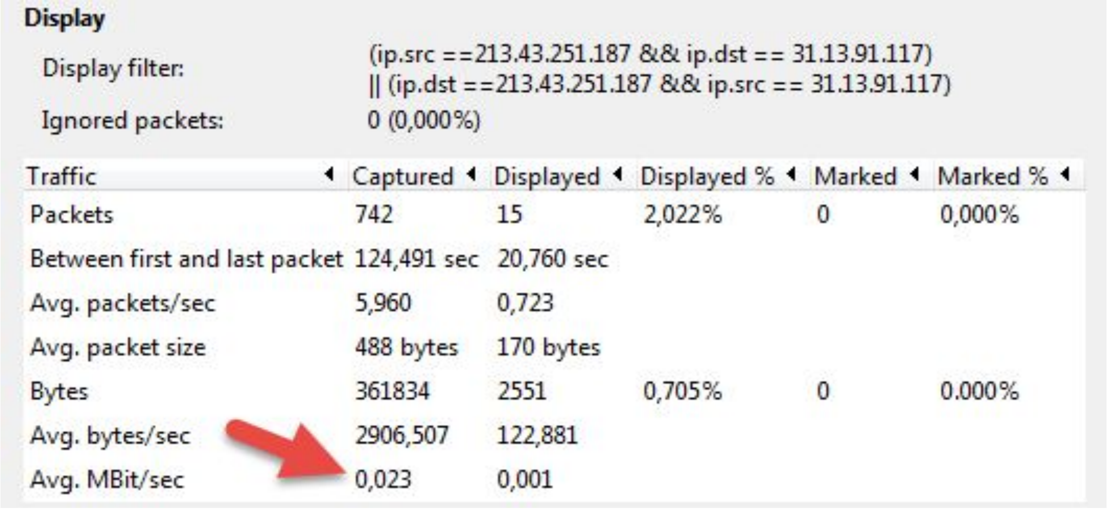
Graph 1	Color	Filter:	87 && ip.src == 31.13.91.117)	Style: Line	☑ Smooth
Graph 2	Color	Filter:		Style: Line	☑ Smooth
Graph 3	Color	Filter:		Style: Line	☑ Smooth
Graph 4	Color	Filter:		Style: Line	☑ Smooth
Graph 5	Color	Filter:		Style: Line	☑ Smooth

Tick interval: 1 sec
Pixels per tick: 5
□ View as time of day

Unit: Bits/Tick
Scale: Auto
Smooth: No filter

Figure 46: IO Graph of URL Based QoS (Limited Facebook)

Avg Speed:



Display

Display filter: (ip.src ==213.43.251.187 && ip.dst == 31.13.91.117)
|| (ip.dst ==213.43.251.187 && ip.src == 31.13.91.117)

Ignored packets: 0 (0,000%)

Traffic	Captured	Displayed	Displayed %	Marked	Marked %
Packets	742	15	2,022%	0	0,000%
Between first and last packet	124,491 sec	20,760 sec			
Avg. packets/sec	5,960	0,723			
Avg. packet size	488 bytes	170 bytes			
Bytes	361834	2551	0,705%	0	0.000%
Avg. bytes/sec	2906,507	122,881			
Avg. MBit/sec	0,023	0,001			

Figure 47: AVG Speed Graph of Facebook With Limitation

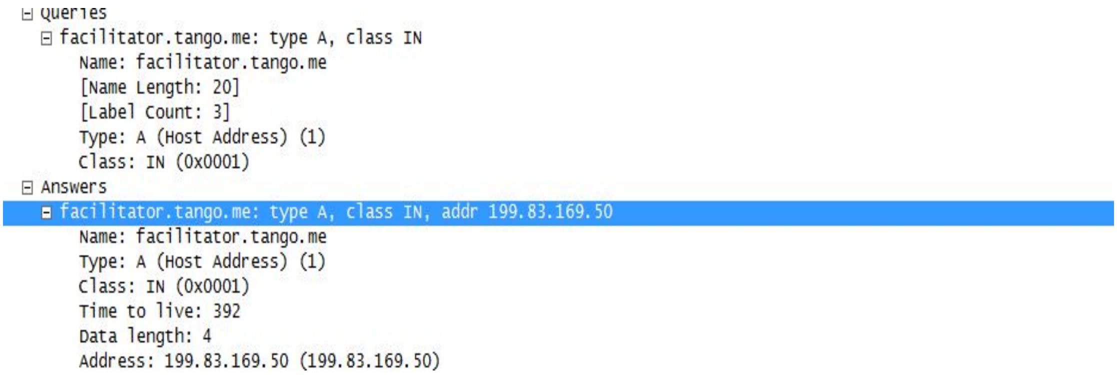
7.4 TC4 – Detection of VOIP and TETHERING Traffic

Bandwidth: Unlimited for voip and tethering. This test is just for detection of signature based detection of tethering and and prioritize the VoIP traffic and testing relation with limit services. With this service, service provider will be aware of VoIP and tethering usage, will be able to decrease the priority of tethering and subscriber will get rid of delays while talking over VoIP.

VOIP

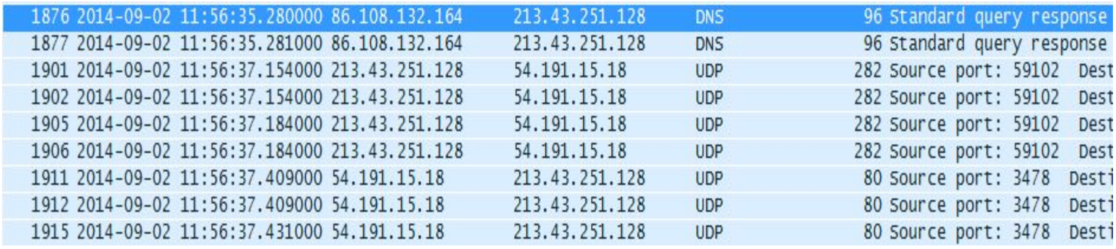
Filtering VoIP traffic depends on heuristic analysis that explained in previous chapters. We can also detect VoIP traffic and increase its priority with legacy QoS algorithm if it is using VoIP protocols like SIP, RVPoIP, MIME. But VoIP applications like Skype, Viber and Tango are using their own protocols. That's why traditional algorithms are insufficient. We used the behavior of Tango application using signature database. With this signature database it's possible to detect other VoIP applications.

Wireshark Filter: To show which application is used a dns and udp filter is applied dns || udp



```
⊟ Queries
  ⊟ facilitator.tango.me: type A, class IN
      Name: facilitator.tango.me
      [Name Length: 20]
      [Label Count: 3]
      Type: A (Host Address) (1)
      Class: IN (0x0001)
⊟ Answers
  ⊟ facilitator.tango.me: type A, class IN, addr 199.83.169.50
      Name: facilitator.tango.me
      Type: A (Host Address) (1)
      Class: IN (0x0001)
      Time to live: 392
      Data length: 4
      Address: 199.83.169.50 (199.83.169.50)
```

As can be seen in this DNS answer client starts traffic destinated to tango servers but it is impossible to identify / distinguish its usage text based or voip. As described in abobe topics this kind of traffic can be identified with a signature database. (Includes application specific packet sending interval, port range etc..)



```
1876 2014-09-02 11:56:35.280000 86.108.132.164    213.43.251.128    DNS     96 Standard query response
1877 2014-09-02 11:56:35.281000 86.108.132.164    213.43.251.128    DNS     96 Standard query response
1901 2014-09-02 11:56:37.154000 213.43.251.128    54.191.15.18      UDP    282 Source port: 59102  Dest
1902 2014-09-02 11:56:37.154000 213.43.251.128    54.191.15.18      UDP    282 Source port: 59102  Dest
1905 2014-09-02 11:56:37.184000 213.43.251.128    54.191.15.18      UDP    282 Source port: 59102  Dest
1906 2014-09-02 11:56:37.184000 213.43.251.128    54.191.15.18      UDP    282 Source port: 59102  Dest
1911 2014-09-02 11:56:37.409000 54.191.15.18      213.43.251.128    UDP     80 Source port: 3478  Desti
1912 2014-09-02 11:56:37.409000 54.191.15.18      213.43.251.128    UDP     80 Source port: 3478  Desti
1915 2014-09-02 11:56:37.431000 54.191.15.18      213.43.251.128    UDP     80 Source port: 3478  Desti
```

Figure 48: Voip Detection with Heuristic Analysis

TETHERING

Tethering enables devices, such as laptops, PCs, and tablets, to access packet data services by sharing the Internet access of a mobile intelligent UE that provides the tethering function.

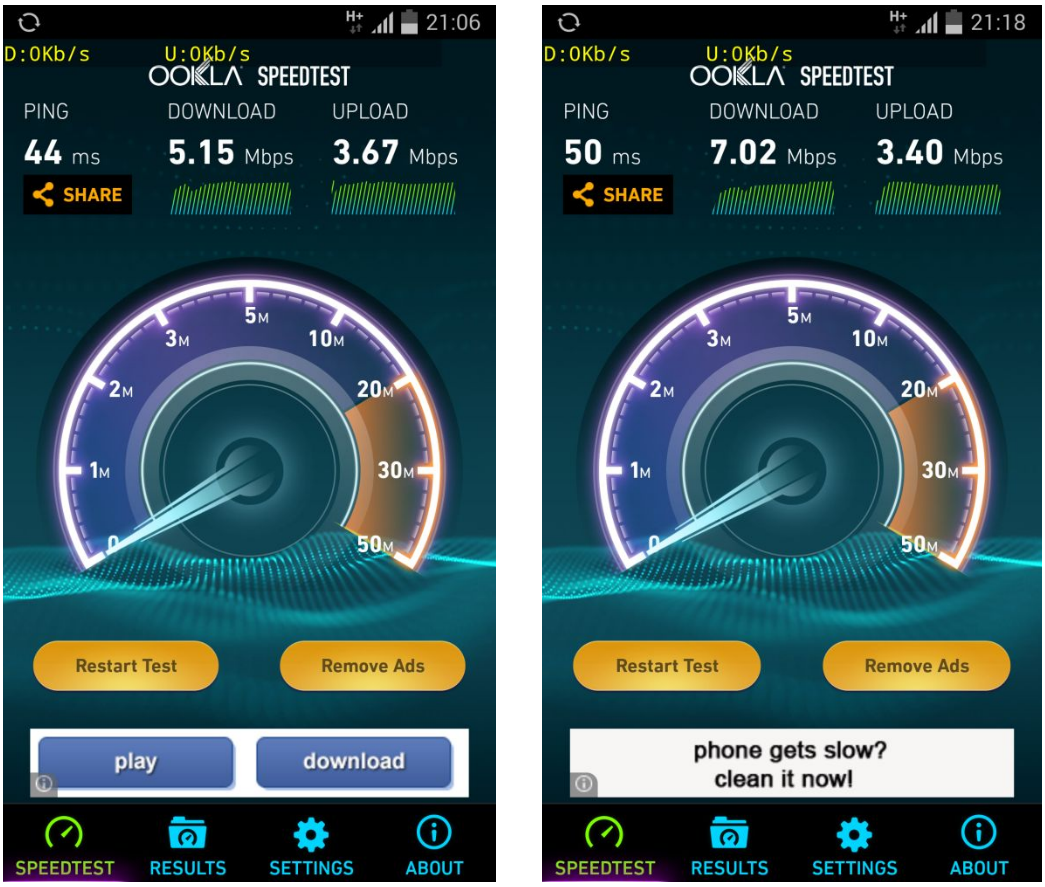
Every packet travelling across a network has a TTL value in the header.TTL number is decremented by one for every hop in the network. TTL is created for in case of a problem packet will stop travelling around network forever. If a laptop or a smart phone is connected internet over another smart phone. This smart phone behaves like a router and decrease the TTL number by one. Besides MAC address filtering can also used for detection of tethering. Every packet is stamped with the MAC address of originating device.

As can be seen in below traces tethering packages marked with a cbb id of 502.

```
---------------------
        Rating Group = 502
         Service ID = 2001
   Time quota mechanism = QCT (0 S)
          Duration = 0 S
      Up-link volume = 2053646 B
     Down-link volume = 6097598 B
        Report time = Empty
     Last charged time = Empty
     Change condition = openstate

        Rating Group = 207
         Service ID = 5001
   Time quota mechanism = QCT (0 S)
          Duration = 0 S
      Up-link volume = 124 B
     Down-link volume = 329 B
        Report time = Empty
     Last charged time = Empty
     Change condition = openstate
```

7.5 Performance Comparison after Changing Traffic Handling Priority and Effects on User Experience

After changing network negotiated QoS to network controlled QoS, in congestion situation THP value is set to 1 (QCI 6) and QoS of subscriber increased. By this change, traffic coming from the subscriber is prioritized and speed is also increased.



21:06

D:0Kb/s U:0Kb/s

PING 44 ms DOWNLOAD 5.15 Mbps UPLOAD 3.67 Mbps

21:18

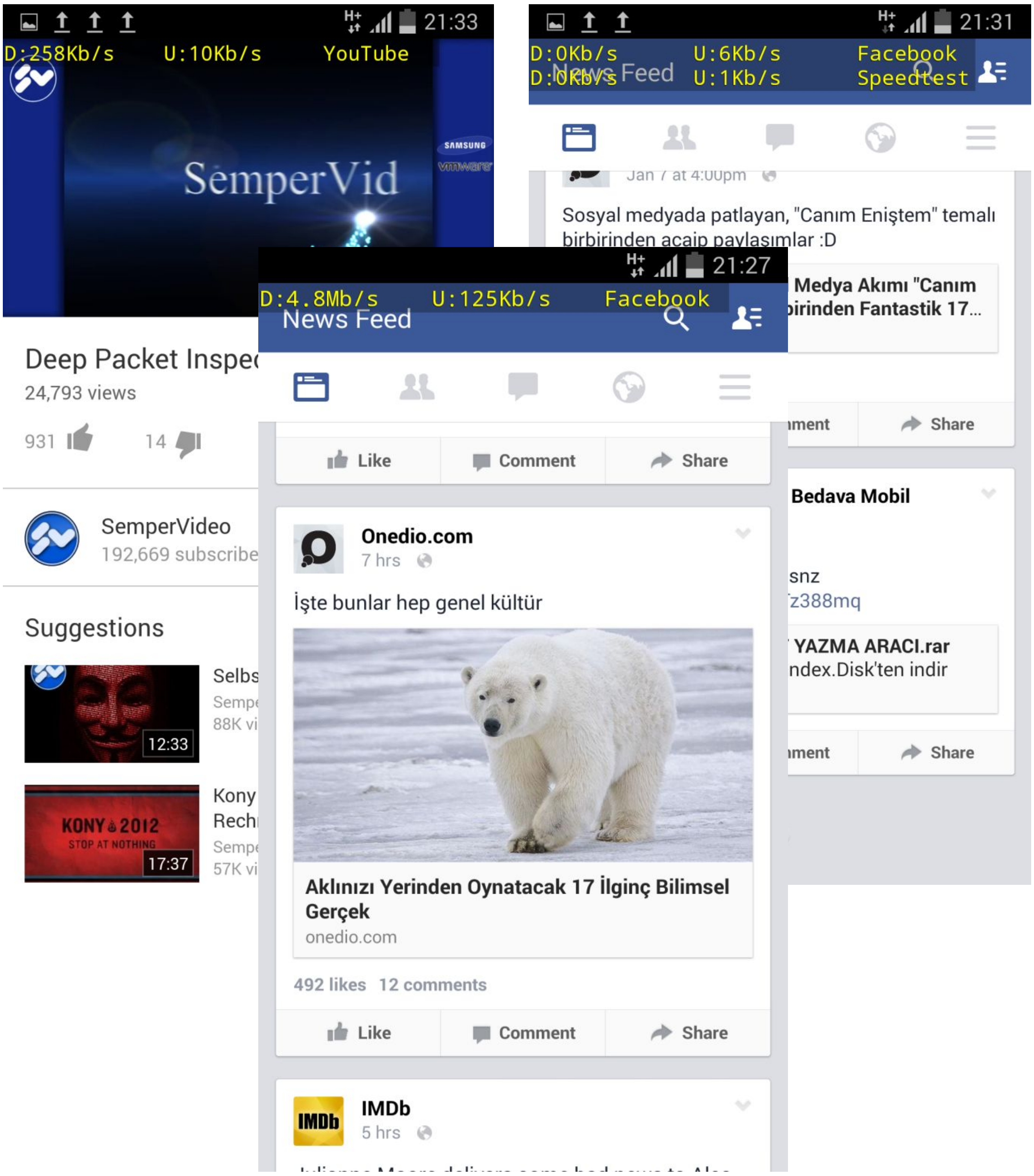
D:0Kb/s U:0Kb/s

PING 50 ms DOWNLOAD 7.02 Mbps UPLOAD 3.40 Mbps

phone gets slow? clean it now!

Figure 49: Dynamic QoS and THP assignment in Case of A Network Congestion

QoS for a specific URL can be set in PCEF. If user subscribed to a Facebook service, when IPs or URLs is matched in inspection process, Facebook speed can be limited but other traffic is still equal to E2E QoS of subscriber. It is also possible to assign special bandwidth for Facebook as can be seen below.



21:33
D:258Kb/s U:10Kb/s YouTube

SemperVid

Deep Packet Inspec
24,793 views
931 14

SemperVideo
192,669 subscribe

Suggestions

Selbs
Sempe
88K vi
12:33

Kony
Rech
Sempe
57K vi
17:37

21:31
D:0Kb/s U:6Kb/s Facebook
D:0Kb/s U:1Kb/s Speedtest
News Feed

Jan 7 at 4:00pm

Sosyal medyada patlayan, "Canım Eniştem" temalı birbirinden acaip paylaşımlar :D

Medya Akımı "Canım
birinden Fantastik 17...

ment Share

Bedava Mobil

snz
z388mq

YAZMA ARACI.rar
ndex.Disk'ten indir

ment Share

21:27
D:4.8Mb/s U:125Kb/s Facebook
News Feed

Like Comment Share

Onedio.com
7 hrs

İşte bunlar hep genel kültür

Aklınızı Yerinden Oynatacak 17 İlginç Bilimsel Gerçek
onedio.com

492 likes 12 comments

Like Comment Share

IMDb
5 hrs

Figure 50: Traffic Flow Detection According to URL

Chapter 8

Conclusion and Future Work

8.1 Conclusion

In this thesis, it is described that the smart bandwidth usage with concept of end to end bandwidth allocation, traffic shaping and URL based bandwidth limitation in the 3GPP specifications. This concept based on three fundamental principles.

- Network initiated QoS control
- Smart bandwidth allocation and limitation in user-plane using QCI, QoS and traffic shaping
- URL based bandwidth limitation

By the network initiated QoS control mechanism, only network can decide to modify a bearer.

With smart bandwidth allocation and limitation mechanism, user speed is limited to 256K and the difference between speed values are compared with QCI and traffic shaping methods.

In URL based bandwidth limitation, one of the most popular services is limited to 5K and the network behavior is investigated.

Deep packet inspection has ability to analyze every byte of information passed through the media.

With the help of DPI;

- Efficient use of network equipments. (By delivering customized services, the amount spend on network upgrades can be reduced.)
- Quality of Service per Service (It is possible to limit social services like Facebook and Twitter)
- Reducing cost
- Improving network security

can be achieved.

8.2 Future Work

Although the results presented here have demonstrated the effectiveness of bandwidth allocation and traffic shaping on user experience, it could be developed with an additional Application Function (AF) to Policy Control and Charging Rule Function (PCRF) via Rx interface. The Rx interface point is located between PCRF and AF.

As told in previous chapters, Gx interface located between Policy Control and Charging Rules Function (PCRF) and Policy and Charging Enforcement Function (PCEF). It is used for provisioning or removal of Policy and Charging Control (PCC) rules and transmission of traffic event from PCRF to PCEF by applying AVPs according to application but it requires a BWL (provisioning) system for a service subscription. PCRF was sending related service rules to PCEF and PCEF was providing detection of a packet belonging to a service. According to this detection uplink and downlink IP flows can be filtered and controlled. With the addition of Application Function (AF), information belongs to session, media and subscriber can be obtained directly from this node. AF interacts with the applications of services that require dynamic PCC. It gets session information from the application signaling and provides it to PCRF. For prioritization of VoIP traffic or video streaming, AF can be used. In an LTE network, it can establish dedicated bearers according to application usage. It would be possible to obtain more reliable results with the addition of AF and this would lead to a better global optimization.

Chapter 9

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