A Set-top Box with Virtual Platform Support for QoS Management in IMS Based Multiple Provider Networks

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Abstract

Set-top Box (STB) has evolved from being a device just sitting on top of a TV shelf to a device providing a gateway to the Internet for a home network, receiving services from multiple content providers, and enabling and ensuring Quality of Service (QoS) for the streaming media. IP Multimedia Subsystem (IMS), with its promise to provide a converged access network for multimedia service delivery (such as Triple play & Quadruple play services), has to guarantee QoS support. To enable QoS in IMS-based networks, we have designed a set-top box which provides feedback to the service provider to ensure end-to-end QoS. Our set-top box is designed to provide virtual platforms such that it can support multiple service providers. Each service provider is able to manage its own multimedia streams and ensures the desired network performance for each flow. The set-top box also works as a Home Gateway and provides end-to-end QoS support to the client nodes.

Keywords: IP Multimedia Subsystem (IMS), Set-top box, Platform Virtualization, end-to-end QoS

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1. Introduction

The IP Multimedia Subsystem (IMS) is a key component in 3rd Generation (3G) networks. IMS enables the seamless provision of multimedia services to the end user. IP Multimedia Subsystem (IMS) [1] was defined by 3GPP (3rd Generation Partnership Project) [2] as a standard architecture which provides horizontal, cross-functional layers of intelligence on top of IP, enabling the creation, control, and execution of new and rich user-to-user, server-to-user and multi-user media services. The next generation solutions are designed to provide converged services, such as, Triple Play [3] and Quadruple Play [4] services, which are going to become the most celebrated services in the near future. This rapid growth of multimedia services augments the need of end-to-end QoS between the consumer and the service provider so that future market satisfaction can be met.

A Set-top Box (STB) [5] is used as an end device to provide multimedia services to the consumers. Mostly, a set-top box is controlled by one service provider . However, a service provider can interact with many content providers (CP). We believe that as a set-top box acts as a single access point that connects the home network to the Internet (i.e. the home gateway), it can be used by many service providers to deploy their services. In other words, a set-top box should be a service independent entity, which can be used by many services. Although the set-top box is provided by one enterprise, however, it enables the consumer to receive services from many service providers. **Fig. 1** shows the simple overview of different parties involved in the IP Multimedia Subsystem (IMS) based service provisioning network.

In our previous work [6], we proposed a set-top box for a single service provider. For a single service provider environment, our set-top box provides the network flow performance feedback to the IP Multimedia Subsystem (IMS)-Service Delivery Platform (SDP) Management Server (ISMS) which in turn maintains and manages the multimedia flows. The result of this fine-tuning (for a single flow) is discussed in our paper referred as [6] in this manuscript.

We extended our previous work and have upgraded the design of our set-top box to provide virtual management platforms for multiple service providers [7]. With this enhancement each service provider owns its own management platform (a virtual manager) at the set-top box and

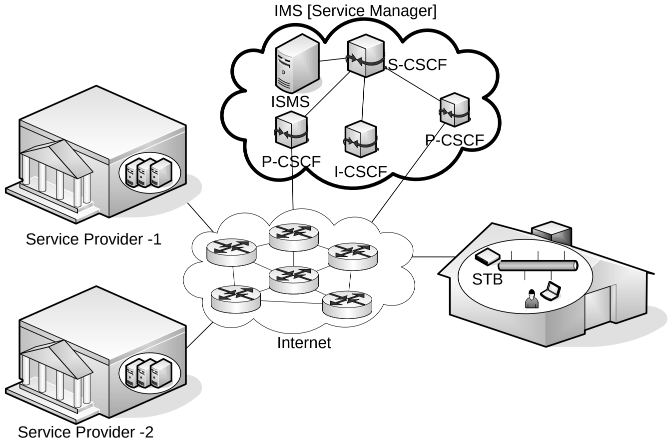


Fig. 1. IMS-SDP Service provisioning environment with major devices involved in the system.

easily manages the services it provides. All virtual managers are run and managed by a core Virtual Platform Manager hosted inside the set-top box, and operated by a centralized service gateway, that is the ISMS node (shown in **Fig. 2**). To formally outline the innovation of this paper, we state the contribution of our paper as follows:

1. One of the first efforts to design a set-top-box which works as a home gateway, a conventional set-top box, a QoS enabler and a centralized home network manager.
2. Supports the service provider to monitor its flow by providing flows' performance parameters such that it can maintain the QoS according to the SLAs.
3. Supports virtual set-top boxes (by using process virtualization) to each service provider for managing their own flows. The virtual platforms enable the set-top box to support multiple service providers at the same time.

This paper is the extended version of [7] and is articulated as follows: Next section provides a brief background and related knowledge in the field of set-top box, Home Gateway, end-to-end QoS provisioning, and Virtual Platforms. Section 3 briefly discusses the management in the IP Multimedia Subsystem (IMS) environment. Section 4 shows the design of our set-top box and section 5 presents the mechanism of the proposed set-top box. Section 6 provides the mathematical calculations for the network performance parameters. Section 7 discusses the hardware and software aspects and customization possibilities for the set-top box. Section 8 discusses the simulation performed to validate our design and shows the results and analysis. Finally, section 9 concludes our work.

2. Related Work

In this section the existing QoS solutions of Set-top Box or Regional Gateway are reviewed and their limitations are identified for end-to-end QoS provisioning in multimedia service delivery scenarios. Some of the works in virtualization of service gateway are also discussed.

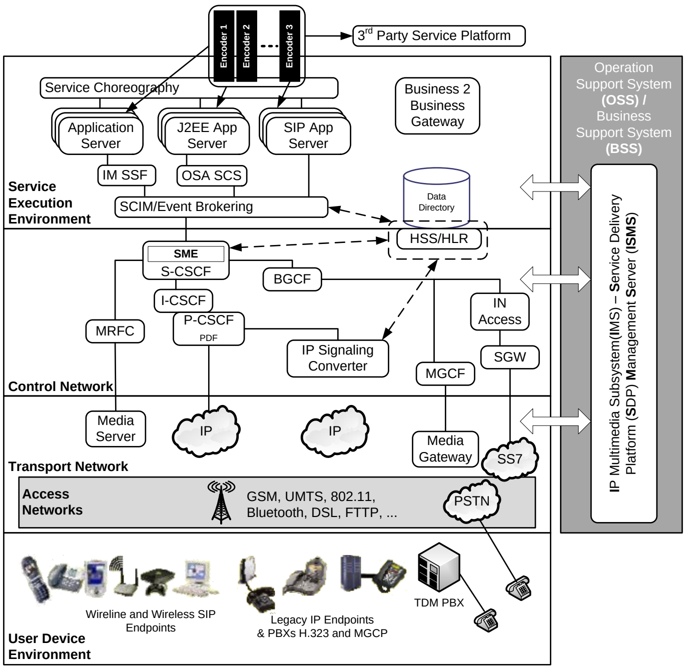
Many solutions are proposed to ensure end-to-end QoS in IP Multimedia Subsystem (IMS) architecture, such as [8] and [9]. In [8], a Hierarchical QoS Management Framework was proposed that incorporates access independent and policy based network administration to control and monitor resources. However, it does not involve the service provider's side for QoS enablement. In [9], the authors claim to provide a complete end-to-end Session Initiation Protocol (SIP) resource signaling and in-session adaptive QoS control scheme for IMS based networks by using resource availability signaling. However, the details on how the QoS is enhanced or ensured are not provided. Reference [10] provides a solution for QoS support for home environments. The solution includes using Wi-Fi Multimedia (WMM) and IEEE 802.1p priority schemes on MAC layer and managing the QoS with UPnP QoS architecture. However, he solution is only for home network and supports QoS within home environments. Authors in [11] discuss a series of core and aggregation-layer approaches, collectively referred to as Visual Quality of Experience (VQE) to address these issues. The VQE approach encompasses on-path video connection admission control (CAC) employing Resource ReSerVation Protocol (RSVP) in the core and aggregation layers, and a real-time signaling mechanism operating between the provider aggregation edge and the IP Set-top boxes to address packet losses, long channel change times and quality monitoring. However, it is a video connection admission control (VCAC) solution based on RSVP. In VCAC, per-flow admission control is performed and the initiation of new VoD sessions is denied until the necessary network bandwidth can be re-captured. RSVP is a heavy protocol which would deny more flows as compared to a signaling based CAC solution. In [12], authors address two problems, error concealment and channel zapping for further enhancement of IPTV-Set-top box. For error concealment, they use the AL-FEC based adaptive error recovery approach; for channel zapping reduction, they propose to employ peer-to-peer communication as a supplement in the channel switching period. It is a pure IPTV network solution and may not work on the traditional IP network environment such as a home networks.

In [13], authors provide the QoS provisioning for multimedia services. The paper utilizes the DiffServ and MPLS QoS mechanisms to assure the guaranteed QoS for real-time multimedia services. The authors concisely use SIP feedback signaling for monitoring, however, the solution is for either MPLS based network or networks with DiffeDerv support. Otherwise the solution may not work in conventional IP networks. Reference [14] proposed a method for preserving the QoS values and charging data of users communicating over IMS networks. This is done by allowing original descriptions of user sessions and charging records to migrate, along with the data call, across the entire communication path, via a complementary network in order to be used by local networks for the restoration of service quality and billing accuracy. Reference [15] presents a SIP based IPTV architecture with a new dynamic QoS adaptation method and signaling structure. But it lacks the QoS enabling mechanism. In [16], authors described the QoS concept of the evolved packet system (EPS) that was standardized in the 3GPP Release 8 specifications. This concept is based on two fundamental principles: Network-initiated QoS control, and Class-based mapping of operator services to packet-forwarding treatment in user-plane nodes. However, this paradigm assumes that there is network intelligence, for example, application functions or deep-packet inspection functions that can both identify the service that a subscriber is initiating and trigger QoS control. In [17], the authors discuss the QoS support in wireless mobile networks. This paper proposed a new adaptive QoS mechanism based on utility function borrowed from the field ofmicroeconomics, call setup and handover signaling mechanism integrating QoS and mobilitymanagement.

A probe-based architecture for monitoring end-to-end multimedia services has been presented in [18]. Non-intrusive probes are used to gather all the traffic generated in the network in order to monitor its behavior. On the other hand, active probes allow interacting with the offered services from the users' point of view and provide precise information of service usage, even with lack of traffic. In addition, this architecture has already been used to monitor multimedia services. The developed functionality is based on the reconstruction of each multimedia session in terms of detailed records (IPDRs). The quality of service parameters are calculated by making use of that records, since they contain the full description and result of a service. Although, it presents an efficient monitoring architecture, however, it does not present a QoS enabling architecture or the mechanism by which QoS is assured is not provided.

For single service provider, managing a multimedia stream is easy if the set-top box is collaborating with the service provider. However, with multiple providers, we need a different approach. One option is to enable the management of QoS using a centralized entity, such as, a management server, as shown in [6]. The other solution is to provide a virtual or logical set-top box to each provider. Some of the research papers have provided good solutions for this approach, like [19] and [20]; but both of them lack an efficient QoS enabling mechanism.

For Digital video broadcasting, set-top boxes have been used for quite a while now. They provide audio and video decoding at the user's end. Some intelligent set-top boxes have been designed to provide better QoS in the network. With the concept of digital home, home network gateways are being used to provide centralized network control within a home network. With a set-top box as the end device from the service provider, it can be used to



Legends	
BGCF	Border Gateway Control Function
DSL	Digital Subscriber Line
FTTP	Fiber-To-The-Premises
GSM	Global System for Mobile Communications
HLR	Home Location Register
HSS	Home Subscription Server
I-CSCF	Interrogating- Call Session Control Function
IM SSF	IP Multimedia Service Switching Function
IP	Internet Protocol
MGCF	Media Gateway Control Functions
MGCP	Media Gateway Control Protocol
MRFC	Media Resource Function Controller
OSA-SCS	Open Service Access-Service Capability Server
PBX	Private Branch Exchange
P-CSCF	Proxy- Call Session Control Function
PDF	Policy Decision Function
PSTN	Public Switching Telephone Network
SCIM	Service Capability Interaction Manager
S-CSCF	Server- Call Session Control Function
SGW	Serving Gateway
SIP	Session Initiation Protocol
SME	Session Management Enabler
SS7	Signaling System # 7
TDM	Time-Division Multiplex
UMTS	Universal Mobile Telecommunications System

Fig. 2. Model view of the IMS-SDP architecture with ISMS as a vertical layer.

perform the functionalities of the home gateway to extend the Internet connection. Reference [5] and [21] are the examples of efficient set-top boxes with home gateway support, however QoS enablement is not discussed in these papers.

To the best of authors' knowledge, the proposed set-top box in [6] is one of the first systems which provide network performance feedback for ensuring QoS management in IMS based systems and also works as the Home Gateway. We extend our work presented in [6] with virtual platform support, by which this set-top box is able to provide management platform to multiple service providers.

3. Management in IP Multimedia Subsystem & Service Delivery Platform (IMS/SDP)

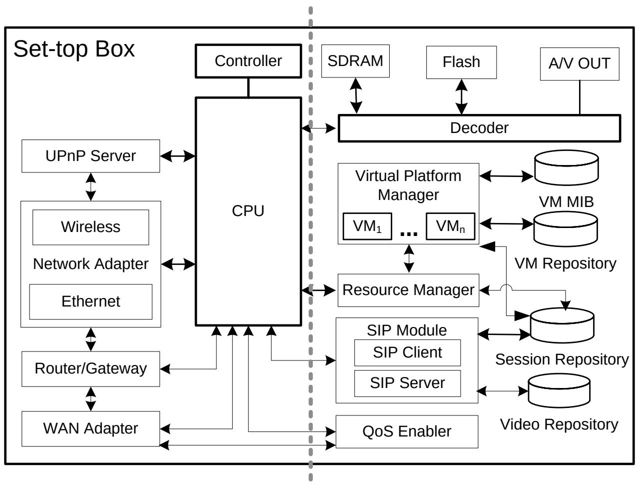
IP Multimedia Subsystem (IMS) is thought to be the common service platform for the next generation networks. However, IMS applications require adequate management solutions for the efficient delivery of services they promise to provide. IMS is an emerging overlay architecture, hence, decisive measurements need to be taken so that the near future technologies are in coherence with the standardized management framework designed for IMS-SDP (IP Multimedia Subsystem-Service Delivery Platform) [1][2].

Our research has been focused on identifying the key management roles in this system. Therefore, we designed our management framework around a single management server named IMS-SDP Management Server (ISMS) [22]. ISMS is a fundamental part of IMS-SDP system as shown in **Fig. 2**. It supervises the vital states of IMS-SDP components. IMS-SDP processes and traffic are constantly monitored, both actively and passively. The captured traffic is collected, correlated and analyzed. At the same time, performance information of session control layer and quality of delivered services are also diagnosed. Management server also gathers different performance, security, fault, and configuration parameters from all over the network to maintain a healthy state of the system. For this, it uses SNMP agents at each managed node to gather the required information. The ISMS server is located in the access layer of IMS. ISMS provides a logical vertical layer to the horizontal layers of IMS. The physical location of ISMS is in the control network of IMS. The Serving Call Session & Control Function (S-CSCF) has an agent named Session Management Enabler (SME) of ISMS, which is used to capture traffic for the multimedia flows. SME is responsible for the management of the multimedia sessions within the system. SME uses Session Initiation Protocol (SIP) [23] signaling to monitor and manage the call and media sessions between the service providers and users. For the management of services, ISMS uses service-level managed objects (SMOs) (which provide the performance, configuration, and fault parameters of services) provided by the servers in the application layer or third party servers [22]. Traffic capturing for network management is done at the Network Entities, Gateway, Application Servers (AS) and at other servers of IMS.

4. Proposed Set-Top Box

System and services in digital video streaming, are not yet robust. Therefore, in poor QoS conditions, a customer may face static interference, delayed images and/or non-synchronized audio video phenomenon [21]. We have designed a set-top box with focus on ensuring QoS in the IP Multimedia Subsystem (IMS) architecture (presented in [6]). However, in [6], we discussed the single service provider environment.

The main motivation of this study is to provide a similar increase in QoS in a multi-provider environment and enable the service provider to maintain its own flows. By providing a little control on the set-top box, a service provider can get feedback for its own flows and act accordingly to increase the QoS. This, in comparison to the previous approaches decreases the delay in achieving QoS and also takes off the load from the Session Management Enabler (SME) and the ISMS.



Legends	
A/V	Audio/Video Output
MIB	Management Information Base
QoS	Quality of Service
SDRAM	Synchronous Dynamic Random Access Memory
SIP	Session Initiation Protocol
UPnP	Universal Plug and Play
VM	Virtual Machine
WAN	Wide Area Network

Fig. 3. Modular design of the proposed Set-top box.

The set-top box provides a virtual manager (VM) to each service provider so that it can manage its own flows and multimedia streams. These virtual managers provide network performance parameters as a feedback to the service provider and the QoS session enabler in IMS network. The set-top box uses simple Session Initiation Protocol (SIP) signaling to communicate with the service provider and the management server, which monitors the network and ensures the optimal QoS.

A set-top box monitors network parameters (such as round-trip latency, jitter, throughput, and packet loss etc.) and signals them back to the management server and the service provider. When a flow is observing degraded services, its performance can be increased by the following solutions:

The resource manager at the IMS layer makes sure that the concerned flow is provided with enough resources, such as, bandwidth, high priority queues, etc. In MPLS, flows are classified as different traffic types. The concerned flow is classified as a higher priority traffic class by the service provider, thus having less delay, more bandwidth, etc.

4.1 Architecture

The modular architecture of our proposed set-top box is shown in **Fig. 3**. In addition to the usual components of a conventional set-top box, our set-top box includes a QoS enabler, a UPnP server, a Session Initiation Protocol (SIP) module, and a Virtual Platform Manager (VPM).

- A VPM is responsible for providing virtual managers (or management platforms) to each provider for managing its own media flows. Using virtualization, it makes sure that all service providers are isolated from one another. With each provider having its own separate management platform (logical set-top box), they can access the parameters related to their flows by collaborating with the service provider and can guarantee the promised QoS. The VPM uses a virtual manager (VM) repository and management information base (MIB) repository. VM repository maintains information about the virtual machines running on the set-top box, while MIB repository maintains the performance parameters related to the service flows.
- The QoS enabler tries to ensure the end-to-end QoS between an end-user and the service provider.
- The UPnP server is responsible for managing the home network in a centralized manner. The UPnP architecture with plug and play functionality helps in maintaining the information of all the devices connected to the home network. A simple interface at the set-top box can be used for providing simple and easy-to-use management functionalities (for instance, turn on, turn off and set timer etc.) to the devices connected to the network.
- The Session Initiation Protocol (SIP) module is consisted of SIP client and SIP server modules. In IP Multimedia Subsystem (IMS), it acts as a SIP client while in Home Network it behaves as a SIP server, such as the Proxy- Call Session and Control Functions (P-CSCF). The SIP module is also connected to Session Repository and Video Repository. Session Repository helps the SIP module by storing and managing the multimedia sessions. On the other hand, Video Repository is used to provide the functionality for audio/video trick functions such as rewind, forward, fast forward and pause etc.
- For the internal (set-top box and Home Network) management the set-top box uses SNMP protocol. The most of the MIBs for this management are borrowed from Session Initiation Protocol (SIP) protocol and are custom defined for virtual platform management.

4.2 Protocols

The protocol stack of the set-top box is as same as described in [6] with 3 new protocols. These protocols are:

1. SSP
2. ISP
3. VPMP

VPMP (Virtual Platform Management Protocol) defines the mechanism by which the Virtual Platform Manager (VPM) manages all the Virtual machines and provides APIs for underlying functionalities. Virtual Platform Management Protocol (VPMP) is a Client-Server based protocol, in which the Virtual Platform Manager (VPM) is the Server, which creates virtual managers (VMs) as clients and communicates with them using TCP based client-server message passing.

SSP (Service provider-to-Set-top box Protocol) is the communication protocol between the Service Provider and the set-top box, while ISP (ISMS-to-Set-top box Protocol) is for communication between the ISMS in IMS Control Layer and the management application at the set-top box.

The signaling between a service provider and the set-top box is initiated by a Session Initiation Protocol (SIP) INVITE message and the subsequent messages are carried by SIP INFO messages [24]. Each of the SIP INFO message contains one or more SSP body. An example of such message body is shown in **Fig. 4**. Session Initiation Protocol (SIP)-SSP messages are based on XML. The confidentiality of the SIP-SSP messaging can be ensured by using TLS (Transport Layer Security), which is supported by Session Initiation Protocol (SIP) protocol.

Session Initiation Protocol (SIP)-ISMS to Service provider (ISP) (SIP-ISP) works in a similar way and like SIP-SSP, its body is also based on XML schema. Both SIP-SSP and SIP-ISP are request-response protocols. An INFO message [24] is used for Request and a Response is sent back using another INFO message, as there is no response message to INFO message in SIP protocol, except ‘200 OK’ [23]. All the SIP based protocols are supported by the SIP module present in the set-top box.

4.3 Virtual Platform Manager (VPM)

Virtualization refers to providing a software environment on which programs and operating systems, can run as if on bare hardware. Such a software environment is called a virtual machine. Virtual machine is an efficient, isolated duplicate of the real machine. Two steps to construct a virtual machine are [20]:

1. Mapping of virtual resources or states to real resources in the underlying machine.
2. Using the real machine instructions and/or system calls to carry out the actions specified by virtual machine instructions and/or system calls.

The system virtual machines provide a complete system environment and support operating system along with its processes, while the process virtual machines supports individual processes. The virtualization software is placed over the operating system and hardware. This software emulates the user level instructions and the operative system calls.

Our set-top box supports process virtual machines. **Fig. 5** shows the virtualization environment designed within the set-top box. A Virtual Platform Manager (VPM) works as the overlay layer which provides multiple virtual machines (or platforms). Each of these virtual machines supports a separate application, which is controlled and managed by a service provider. For the applications, the VPM provides a single operating system environment using a System Abstraction Layer (SAL) such that a single (logical) set-top box is available for the applications running on each virtual machine.


```
<PerformanceControl>
  <SP_id>SIP:400@192.168.0.2:55312</SP_id>
  <STB_id>SIP:STB1@192.168.0.1:55314</STB_id>
   <Flow type = "voice">
    <Flow_id>3F2504E04F8911D39A0C0305E82C3301</Flow_id>
    <Delay_Value>29</Delay_Value>
    <Packet_Loss>0.5</Packet_Loss>
    <Jitter_Value>9</Jitter_Value>
  </Flow>
  <Flow type = "video">
    <Flow_id>3F2504E04F8911D39A0C0305E81C350F</Flow_id>
    <Delay_Value>26</Delay_Value>
    <Packet_Loss>0.3</Packet_Loss>
    <Jitter_Value>3</Jitter_Value>
  </Flow>
</PerformanceControl>
```


Fig. 4. Example of Session Iinitiation protocol-service provider to Set-top box protocol (SSP) body

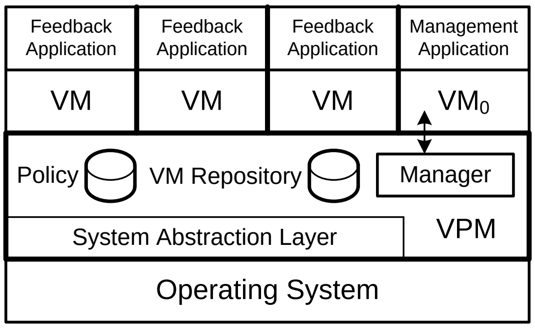


Fig. 5. Virtualization Platform design for enabling process virtual machine in the set-top box

Fig. 5 also depicts two repositories; one for the virtual managers and one for holding the policies. The defined policies are used by the Manager component to manage the virtual machines. VM_0 is a default machine at the set-top box, which provides connection to the ISMS server of the IP Multimedia Subsystem (IMS). It provides the basic management application for the set-top box. ISMS remains in contact with every set-top box using this application, deploying policies and capturing performance and management data. Detailed discussion of how platform virtualization works is provided in the next section and the implementation aspects are discussed in the simulation section.

5. Set-top Box Mechanism

Along with the basic functionalities of a set-top box, i.e. decoding the video and voice channels etc., our set-top box design contributes to many new options. The proposed set-top box can work as a home network gateway (home network manager), as a Session Initiation Protocol (SIP) Session Manager (SIP server and client for establishing session calls) and, as an end-to-end QoS enabler, as discussed in [6]. But the most outstanding functionality provided by our set-top box is the support for multiple service providers using virtual managers (VM) or logical set-top boxes.

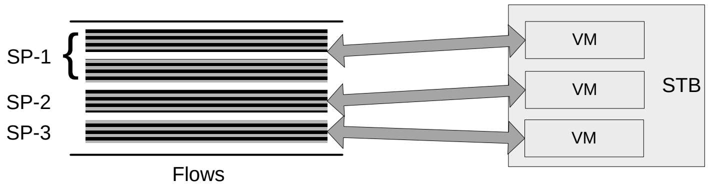


Fig. 6. Conceptual diagram showing that each service provider managing its own flows using virtual managers at the set-top box.

Here, a question arises that if more than one service providers are supported then who would own the set-top box. We believe that in the near future although the set-top box would be provided by one service provider but it would have the ability to allow the consumer to avail the services from other service and content providers also. As the Service provider who provides the set-top box has more control on the set-top box, hence, its services can have better quality than other 3rd party Service Providers (SPs).

Because of the many functionalities provided by a single set-top box, the power management at the set-top box is very important. The dotted line in **Fig. 3** shows logical division of the set-top box in two parts. The left part which is mostly concerned with the network connection and home gateway is always in 'on' mode. While the modules shown on the right side are tuned 'on' when only the multimedia streaming is accessed using the set-top box. This power management is necessary for the efficiency of the device; however most of the modules shown on the right side are software based. Hence the concerned hardware are storage based (volatile and non-volatile), which can be turned off using simple Operating System power management commands for turning off Hard Disk and memory, etc.

5.1 Virtual Machine Management

A Virtual Platform Manager (VPM) manages all the virtual managers, such as; initiating a virtual manager when a new service provider is connected to the set-top box, registering the services and monitoring the virtual machines to avoid conflict of resource access. **Fig. 6** shows the basic ideology of the mechanism by which each service provider manages its flows. virtual machine is provided on the basis of a connecting service provider, not on the basis of flows. Hence, more than one flows of a service provider are managed by a single virtual manager.

When a Session Initiation Protocol (SIP) client at the set-top box sends an invite message to the service provider, using the SIP INVITE message, the service provider communicates with the Virtual Platform Manager (VPM) at the set-top box. The VPM checks for a virtual manager (in its VM repository) for the concerned service provider. If that service provider was already provided with a virtual machine, the connection to that virtual platform is made. Otherwise, a new virtual machine is created and a corresponding virtual manager's information is added to the VM repository. For each virtual machine, sessions are saved in the session repository and the parameters related to each flow are saved in the MIB repository.

Each virtual manager supports a feedback application, which is controlled by its associated service provider using SIP-SSP. This application monitors the state of all multimedia flows associated with the service provider, the performance they are achieving (calculations are shown in next section), and the resource they are using. It provides the performance parameters of each flow as the feedback to the service provider, so that it can fine tune the resources of the flows and guarantees the QoS according to the SLA.

The SIP-SSP is used to request and query virtual platforms at the Virtual Platform Manager (VPM) by the service provider. This protocol is not an entirely new protocol but is based on SIP INFO messages. As the session is established using SIP INVITE messages, the service provider and the set-top box are authorized (by each other). As the session is secured so is the protocol used by a virtual manager and a service provider.

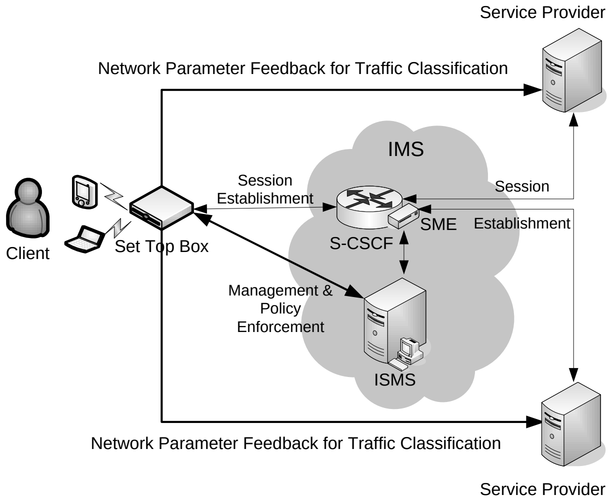


Fig. 7. Network feedback and signaling between the set-top box & ISMS (SME).

Now, as there can be more than one Service Providers (SPs) providing services so there are as many virtual machines at the set-top box. The Virtual Platform Manager avoids conflict of interest of all the virtual machines and separates the logical set-top boxes from each other. For this, the Virtual Platform Manager (VPM) monitors the resource sharing at the set-top box and optimizes the performance of the virtual platforms. This is enabled by the manager and service abstraction layer (SAL) at the Virtual Platform Manager (VPM). The SAL (software based) provides an interface for each virtual manager for accessing underlying resources, such as, operating system, repositories, queues, and other modules; while the manager controls the resource access and provides scheduling and resource sharing. Because the virtualization provided by SAL is software based and relies on authentication rights, therefore, there is no possibility of one virtual machine compromising another virtual machine using direct OS or hardware calls.

5.2 End-to-end QoS Enablement

When a session is started, the resources are assigned to a session by the IP Multimedia Subsystem (IMS) layer. First, IMS-SDP Management Server (ISMS) creates policies according to the required resources and flow performance and these policies are sent to the concerned policy enforcement points, along with the set-top box, to make sure the flow gets appropriate resources.

With the change in design, the mechanism of QoS enhancement is also changed a little bit as compared to [6]. As each service provider is responsible for managing its own flows now; the network performance feedback is calculated at the set-top box and sent to the service provider; the service provider itself enables the improvement of the flow.

```
<ParameterControl>
  <ISMS_id>SIP:ISMS@192.168.0.0:55310</ISMS_id>
  <STB_id>SIP:STB1@192.168.0.1:55311</STB_id>
   <Parameters type = "Network">
    <Delay_weight>0.7</Delay_weight>
    <Packet_weight>0.7</Packet_weight>
    <Jitter_weight>0.4</Jitter_weight>
  </Parameters>
</ParameterControl>
```

Fig. 8. Example of SIP-ISP protocol body

The QoS enabler is utilized by the feedback application at the logical set-top box for monitoring the flows and their enhancements. The threshold values in the SLA are compared with the performance metrics on per flow basis for each service provider. When a certain flow experiences degraded services, the concerned service provider is notified. The service provider takes an action by utilizing MPLS based traffic classification techniques and prioritize the degraded flow as a high priority flow. This is done by increasing the traffic class for the flow traffic (such as from AF12 to AF11 and so on). The mechanism is depicted in **Fig. 7**. The feedback from the set-top box to the service provider is shown by bold arrows.

5.3 Management of the set-top box

The management of the set-top box is the responsibility of the IMS-SDP Management Server (ISMS). Each set-top box has a default virtual machine with its manager named VM_0, which coordinates with the ISMS for the management of the set-top box itself. **Fig. 7** shows the communication between the set-top box and the ISMS. The ISMS uses SIP-ISP protocol for communicating with the set-top box for deploying and editing policies, gathering set-top box's management data, and monitoring the set-top box. Similar to SIP-SSP, SIP-ISP does not provide any security and the security of the signaling depends upon the security of the SIP protocol being used. **Fig. 8** shows a sample of SIP-ISP body for controlling the weighting factors used for the calculation of the network performance parameters (discussed in the next Section).

6. Calculation of Network Parameters

In our previous design, the system was designed to provide feedback of packet delay, jitter, packet loss, and throughput attained by the flow. The calculations of these parameters were done at the set-top box as shown in [6]. For increase the effectiveness of the performance in our new system, we use weighted averages for delay, jitter and packet loss. It helps in studying the overall behavior of the flows and sudden changes in the values are ignored; thus avoiding the useless feedback and traffic classifications.

6.1 Packet Loss

Packet loss ratio δ is defined as the number of packets lost divided by the number of packet expected. It is calculated as shown in [6]. The weighted packet loss $\bar{\delta}_W$ is calculated as shown in (3).

$$\bar{\delta}_W = (\gamma)\delta + (1-\gamma)\bar{\delta}_{W_{OLD}} \tag{3}$$

Here, $\bar{\delta}_{W_{OLD}}$ is the previously calculated weighted average of packet loss, and δ is the newly calculated packet loss, and γ is the weighting factor.

6.2 Delay

Delay is calculated as the round trip delay sustained by a packet and its response. The set-top box calculates the round trip delay as shown in [6] and then calculates the weighted delay $\bar{D}_W$ as in (1);

$$\bar{D}_W = (\alpha)D + (1-\alpha)\bar{D}_{W_{OLD}} \tag{1}$$

Here, D is the newly calculated delay, $\bar{D}_{W_{OLD}}$ is the old weighted average of delay and α is the weighting factor.

6.3 Inter-arrival Jitter

Jitter is the time variation in the packet arrival at the set-top box. Jitter is calculated for each data packet, as it is received by the set-top box, as shown in [6]. The weighted Jitter $\bar{\Delta}_W$ is calculates as in (2);

$$\bar{\Delta}_W = (\beta)\Delta + (1-\beta)\bar{\Delta}_{W_{OLD}} \tag{2}$$

Here, Δ is the newly calculated value of jitter, $\bar{\Delta}_{W_{OLD}}$ is the old weighted average of jitter, and β is the weighting factor.

7. Hardware & Software aspects

Designing of a set-top box typically involves

- Set-top box prototyping using reference kits
- Schematic and printed circuit board layout design
- Embedded software development
- Set-top box middleware integration
- CAS/CAM support
- Tuner & Front-panel development
- Set-top box Test software for mass-production, customization to manufacturing process
- CAD 3D drafting and enclosure design

Our set-top box, which is in the first phase of designing and prototyping, has been evaluated on a desktop PC hardware. The hardware equipment required consists of:

- An Intel motherboard featuring an Atom processor
- 7200rpm laptop drive
- 2GB RAM stick
- Miniature 'PicoPSU' 90W power supply
- Mini-ITX M350 case

- USB Wi-Fi adapter - for wireless internet access
- Network Adapter (for WAN)
- TV Tuner adapter

The system is installed with an Ubuntu OS with running Java Virtual Machine (JVM) for the process virtualization support and other software based modules for further features. The cost of the system can be imagined to be more than a usual set-top box, but if an embedded system is used with similar hardware equipment functionality then the cost could be reduced and comparable to the set-top boxes in the market taking in consideration the intelligence that it supports. According to a report by IP Multimedia Subsystem (IMS) research [25], the cost of the set-top box would increase in the near future due to the provided intelligence.

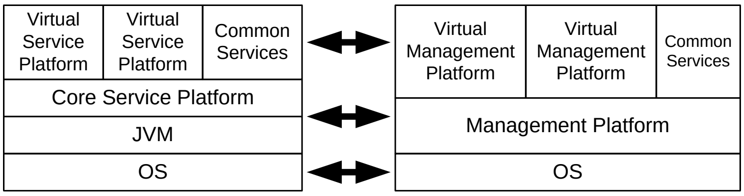


Fig 9. Process Virtualization, as designed in [11] (left) and evaluated in our simulation (right).

Also Linux based real-time OS promise to be the OS for these set-top boxes [25].

The software based features of the set-top box are: security (authentication service), encryption provider (certificates), shell & user interface (command processor & console window), multimedia components, network user interface, network utilities (IfConfig, Ping, Route), codecs and renderers, power management, multimedia waveform, audio, XML core, Session Initiation Protocol (SIP), WAN (Wide Area Network), wired LAN (Local Area Network), and wireless LAN.

As Ubuntu has a performance overhead when compared to Microsoft based Operating System (OS) [26], we also considered the Platform builder for embedded system based on Windows CE.Net, which could be used on an emulator. Although, the cost of this system would be more than the open source OS but it gives an edge on performance.

8. Simulation & Results

We have evaluated the design of our set-top box as a simulation for the purpose of testing and evaluation of our proposed design. In [20], the authors have provided an efficient way of implementing virtualization using Process Virtual Machine. They have used OSGi platform in a multiple provider environment using Multi-Tasking Virtual Machine (MVM), a multi-platform support based on Java Virtual Machine (JVM). Our set-top box is simulated on an embedded system emulator running Windows CE.Net, while the rest of the entities in our simulation are built using C#.Net. The whole simulation is running on a Microsoft Windows XP environment. **Fig. 9** shows the modular designs of [20] and our simulation. The client is another application connected to the emulator using a socket connection.

We have designed an application which works as the Virtual Platform Manager (VPM) over the OS layer and supports multiple virtual manager applications. Each virtual manager application works independently, and uses the service calls provided by the VPM for accessing the set-top box system. System Abstraction Layer (SAL) is responsible for providing a façade for these system calls. When a Service Provider connects to the set-top box (the manager in the VPM) a new instance of virtual manager application is created and a connection between the service provider and a virtual manager is made using .Net sockets. There is a default management application named (Virtual Manager 'zero') VM_0, which is in connection with the ISMS entity for downloading policies and management of the set-top box itself.

The simulation environment is depicted in **Fig. 10**. We have included typical nodes of the IP Multimedia Subsystem (IMS) architecture such as; Proxy, Serving, and Interrogating Call Session & Control Functions. Along with these nodes, we have also enabled the functionalities of the IMS-SDP Management System (ISMS) [22]. Moreover, many router nodes are included in the simulation for creating background traffic.

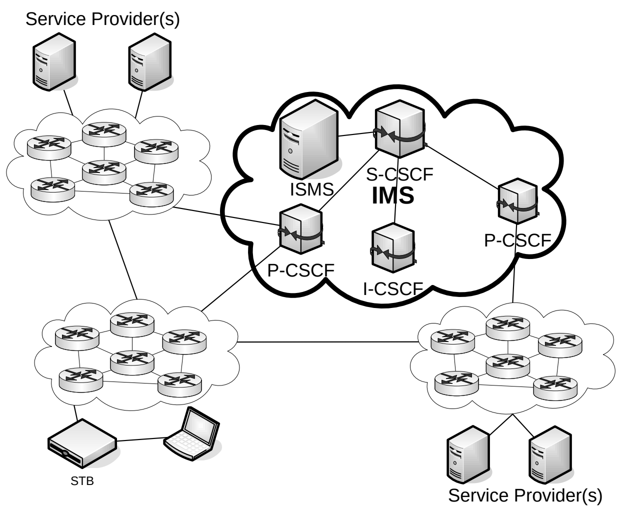


Fig. 10. Simulation environment, with Client connected to set-top box and Video service is provided by the service providers' servers.

These router nodes use static routes for maintaining routing tables and interconnectivity. These router nodes are for simulating the Internet environment such that it is crafted as an imitation of a real scenario.

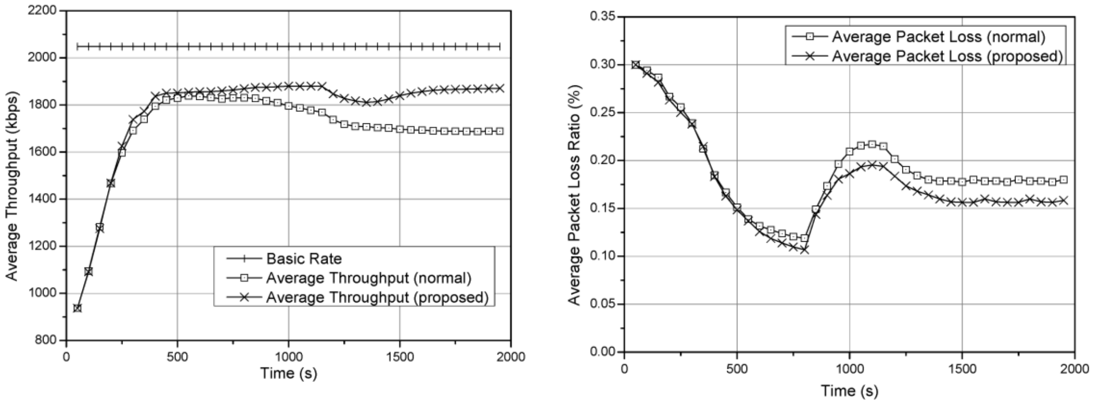
When a user connects to a service provider for example to access a video streaming, it communicates with the CSCF to start a session. CSCF in turn connects to the Service Provider and establish the session between the user and the service provider with already decided Service Level Agreement. As the sessions progress, the background traffic disturbs the network performance and the promised QoS is not accumulated at the user end.

The set-top box in the simulation monitors the session that is used by the client and compare the performance parameters to the values in the SLA and delivers them to the concerned service provider. When the service is not up to certain threshold, the set-top box communicates with the service provider and informs it about the problem i.e. to upgrade the QoS. If the service provider supports this functionality then it sets the priority of that session and puts it in a higher class till it achieves the required QoS. Typically, the network is supposed to support MPLS classes or some traffic prioritizing technique. A service provider just enhances (or sets the priority to high) the class of the concerned session's traffic, so that the session can be entertained by higher resources. Along with the traffic classification, policy creation, modification and enforcement are also performed.

The simulation has been performed with different number of flows with video, voice and the Internet (HTTP & FTP) traffic. Analysis and evaluation are performed on the basis of the simulation results. A client uses a multimedia service, with intermediate nodes having high rate of entropy for network delay and available bandwidth. These delays are generated at each node randomly with simulating different flows. With the help of QoS feedback, our set-top box, with the help of the service provider, is able to reserve better resources for each flow.

Fig. 11-(a) shows the average throughput achieved by a video flow from the service provider to the set-top box. Video flow generates two 1024 Kbits packets per second. We have compared the throughput in the normal case[1] and in the case of using our proposed scheme for end-to-end QoS enablement.

At the start, the throughput is low as there are small sized packets for session establishment.



(a) **(a)**

Fig. 11. (a) Simulation results for a multimedia stream with degrading Internet channel. **(b)** Simulation result showing the Packet Loss ratio at the set-top box for the data traffic between the service provider and the set-top box.

More packets with small size show less throughput than few packets of larger size (although the rate is same). After session establishment, we see an improvement in the throughput for the video flow. As the time progressed, we analyzed the throughput for the flow by increasing the background traffic. We created 2 voice channels and 4-5 HTTP channels, with a different service provider, for back ground traffic. Results shown in **Fig. 11-(a)**, confirm the higher throughput achieved by our scheme. Due to the feedback gathered from the set-top box, the video flow is classified as a higher prioritized flow. When the flow is lacking throughput, higher bandwidth is dedicated to the video flow as the service provider upgrades the priority of the flow and the throughput is enhanced.

Fig. 11-(b) shows the effect of the proposed scheme on the weighted average of packet loss rate of the traffic between the service provider and the set-top box. The value of γ is selected to be 0.7; which means the new value's effect would be 30% on the average. The use of weighted average of packet loss ratio helps in avoiding the spikes in the graph and temporary changes can be avoided. **Fig. 11-(b)** shows the packet loss as weighted average which is calculated as

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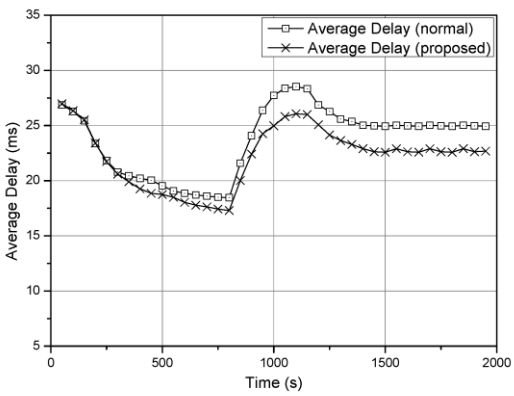
[1] Normal case is when the feedback based end-to-end QoS enabling mechanism is not applied.

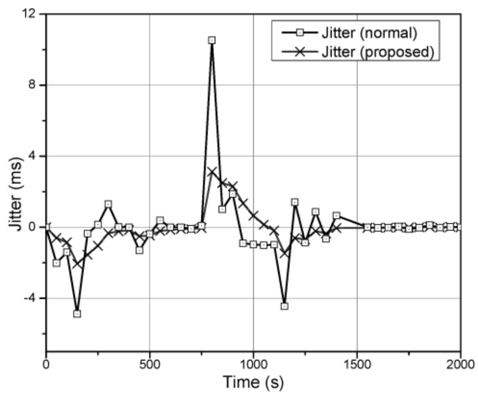
shown in (3). As with the throughput, the loss rate is high at the beginning at the set-top box. But after receiving the feedback from the set-top box, the service provider increases the priority of the flow for higher bandwidth. This decreases the value of weighted average of packet loss for the data traffic.

The increase in packet loss is due to the addition of a new simultaneous flow by another service provider. This again is due to the higher loss rate of smaller sized packets used for establishing the session. But as the time goes on, the packet loss decreases and after a while gets stable. In **Fig. 11-(b)**, it is clearly visible that the higher prioritization of the multimedia flows reduces the loss rate, although the difference is not much.

Fig. 12-(a) shows the effect of the proposed mechanism on the weighted average delay of packet delivery for the video flow. The value of α is selected to be 0.7 also; which means the new value's effect would be 30% on the average packet loss. Similar to packet loss ratio, the use of weighted average of delay helps in avoiding the spikes in the graph and temporary changes can be avoided. As showed in **Fig. 12-(a),** the proposed scheme is able to reduce delay of the delivered packets. This is by prioritizing the flow for high priority queues, thus the packets in the flow bare less delay at intermediate queues. The increase in delay is again due to the addition of a simultaneous flow by another service provider. This affects the average delay for the packets received by the set-top box and it calculates higher values of delay for the incoming packet. But as the second flow is also prioritized, the average delay for incoming traffic starts to decrease.



(a)



(b)

Fig. 12. (a) Simulation results for delay in milli-seconds calculated at the set-top box for the data traffic between the service provider and the set-top box. **(b)** Simulation results for Jitter in milli-seconds calculated at the set-top box.

Fig. 12-(b) shows the graph for the change in jitter value for the normal scenario and the proposed mechanism. Although there is no significant difference in jitter value, but the proposed system produced smaller variance in the jitter value, which is the desired goal. The porposed mechanism restricts the system from sudden changes in delay by dedicating better resources to the degrading flows. In te graph of **Fig. 12-(b)**, the two spikes showing the neagtive jitter are due to the improvement in the delay values, while the positive spike is due to the sudden increase in the delay due to the enterance of the new flow. It can be observed from the graph that our proposal tries to stabilize the performance and avoid sudden changes in delay.

From the results we got from the simulation, we can see that feedback mechanism shows the potential for improving the QoS in multimedia sessions, especially when more flows are added, the difference increases. After a while, the improvement of the scheme get to a constant (after achieving the maximum gain); this can be observed in **Fig. 11-(b)** and **Fig. 12-(a)**. After 1500 seconds, the curves for proposed system and the normal[2] system become almost parallel to each other, which shows that the maximum performance has been achieved by the scheme. This difference (between the curves) may get disturbed when a new flow is introduced into the scenario or a current flow is stopped. Other factors can also affect this difference, such as, a new network activity, link breakage, etc.

9. Conclusion

In this paper, we have presented the design and working of our set-top box, which works as a home network gateway (regional gateway), as well as enables end-to-end QoS in the IP Multimedia Subsystem (IMS) architecture. Our set-top box provides virtual platforms within the set-top box using process virtual machines. With this technology, the set-top box is able to provide a virtual manager (a logical set-top box) for each service provider, by which SPs are able to manage their own flows. This mechanism assures to assist in the end-to-end QoS provision mechanism by relieving the ISMS server and also reduces the number of messages passed between the service provider and the ISMS server in enabling the QoS management. The results achieved in simulation confirm the effectiveness of the mechanism.

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