Network Management and Control Framework for Hybrid Converged Environment

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***Abstract*—Companies nowadays are approaching towards an all IP paradigm by subscribing to different access technology links from several service providers for reliability, redundancy and availability while providing good Quality of Service (QoS). A framework for rule-based converged hybrid network management in multihoming environment is presented. Diversity and dimensionality of the platform's service, control, transport and access planes along with multiple objectives over the platform has led us to use Multi Criteria Decision Making (MCDM) technique. A simple use-case involving the dynamic decision-based routing at private-public network border is presented to validate the proposed solution. The decision engine takes multiple criteria into account while computing the routing decisions (attributes from context of the request, platforms latest conditional parameters, business objectives of the company etc.). The system supports outsourcing and provisioning decision computation and enforcement modes. The system gives higher throughput and lower call dropping probability with an add-on susceptible delay offering good QoS.**

I. Introduction

Unified Communication promises an all Internet Protocol (IP) solution. Access technology convergence with heterogeneous network infrastructure is a step forward towards this goal. Access network convergence brings forth the challenge of resource allocation for applications with varying Quality of Service (Qos) requirements over networks having time variant and heterogeneous characteristics. Multimedia applications have been a main driving force behind the efforts targeted towards architectures, industrial standards, and polices for convergence. Companies nowadays are subscribing to different access technology links from several service providers in order to fullfil the diverse resource requirement over the converged platform. These mulihomed setups also require the ability to route the connections to the optimal links/routes in order to maximize their income and to ensure reliability, redundancy and availability with required level of service performance.

Network Management and control in these multihomed heterogeneous environments has always been a challenging task especially within an all IP converged infrastructure. Traffic mix, heterogeneous wireline/wireless technology, fixed-to-mobile and vice versa convergence difficulties, versatile data representation, diverse QoS requirements and variations/dynamics over the network are some of the main complexities involved for network administration and control over these platforms. Legacy network management/control techniques and technologies cannot guarantee the required QoS and desired Quality of Experience (QoE) requirements for voice/video and data services (FTP, Web, Mail) all together as they need diverse resources with varying set of QoS parameters.

QoS-centered architecture shown in Fig. I integrates different services, binds versatile control interfaces, combines a number of protocols in addition to unification of transport and access technologies which are unified over a single platform. Voice, video, triple-play, quadruple services over the platform are being offered by different service providers requiring diverse resources with varying set of QoS parameters. Rule based network control is needed over the proposed multihomed converged architecture for effective and efficient resource management.

Application, control and network information are to be shared within those distinct domains and across these planes for network management. The attributes and parameters related to resources, profiles, services and dynamics taking place over those planes are disseminated and exchanged via different interfaces and protocols. The information sharing and exploitation process becomes more delicate when its control and management has to be performed under the dictation of certain set of pre-configured rules. There are some frameworks [1], [2], [3] for rule-based management and control but they are static and/or semi-dynamic and are limited to device level configuration and control with different granularity. Moreover, in heterogeneous unified communication systems, there are vendor-specific concepts and implementation dependencies with different means of information representation and processing. These systems take into account a few information among the set of available parameters over the platform, while computing the rules (service profile, reliability information, time of the day, business objectives of the company, latest state of the links, user profiles and Service Level Agreement (SLA)). Moreover, a system capable of taking into account Service Level Specifications (SLS), e.g. susceptible delay, jitter and packet loss may not accommodate the technology specific information. Systems considering user, service and QoS profiles do not compensate for dynamic context of the request.

The information stated above for rule-based network management and control comes from different sources with different dimensions, hence formulating a multicriteria problem. The first challenge is to utilize the available information over the platform maximally so that the network management reflects dynamic control and effective resource utilization with good QoS and QoE. Moreover, the objective is to capture the dynamics over these distinct domains (inter-domain and intra-

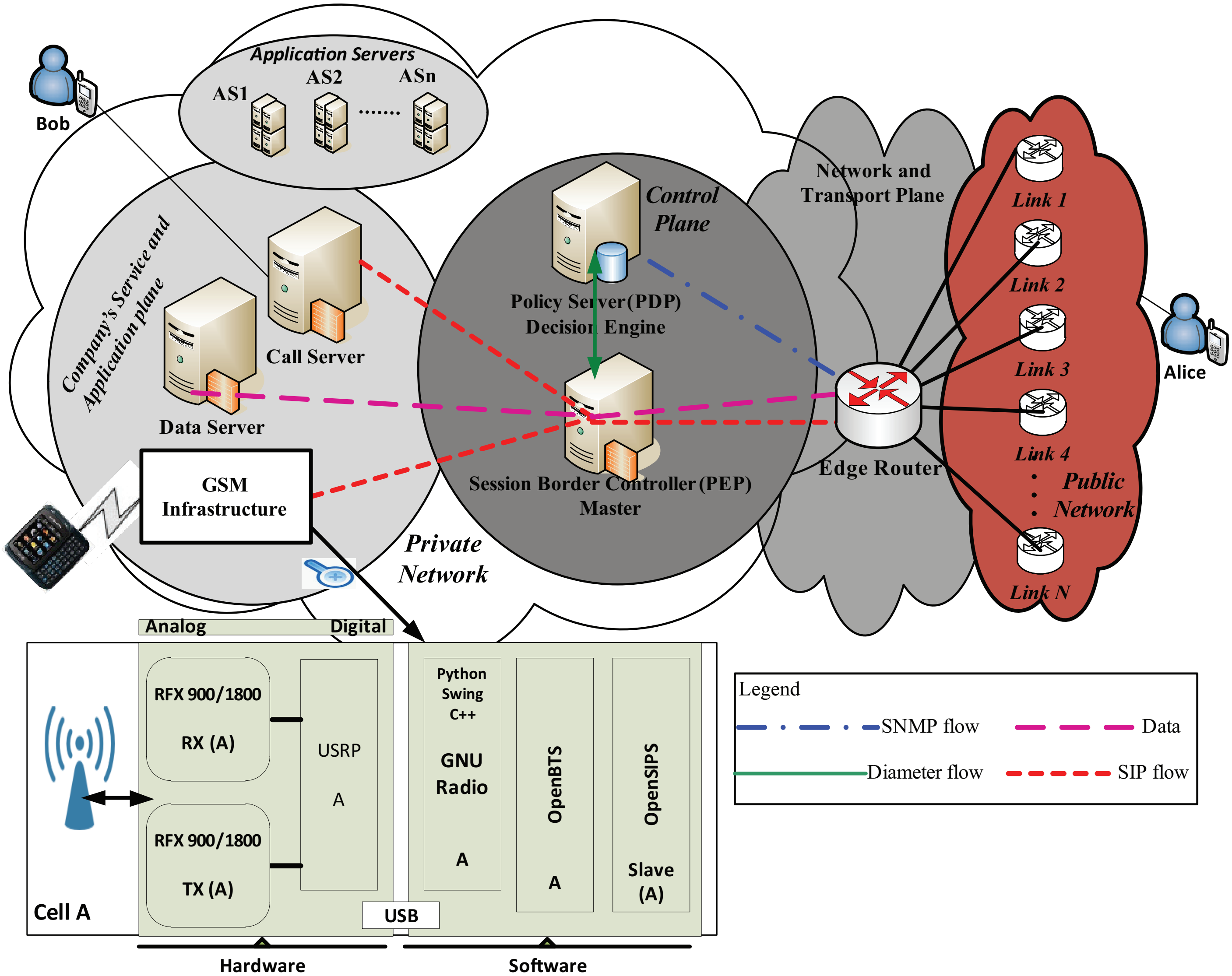

Fig. 1. Proposed Architecture.

domain) with all the variations in order to avoid the conflicts and overlapping. Finally, the use of existing technologies (e.g. Network Address Translation (NAT)ing, Domain Name Service (DNS) Cycling, Hashing, Proxying etc.) without introducing overheads in the protocol stack for policy enforcement is another aim over the unified converged platform.

The architecture shown in Fig. I is proposed in Companym@ges [4] project which provides a platform where companies are linked to the rest of the world via two or more network accesses offering data and multimedia services. A framework for rule based network control and management has been presented. In order to avoid complexity, routing rules computation (taking into account all the knowledge from distinct information domains and the dynamics taking place over the presented platform) at private-public network border is focused on while emphasizing the multimedia communication (voice, video). Multi Criteria Decision Making (MCDM) theory has been applied to handle the multidimensional problem with multiple objectives in addition to varying set of attributes and parameters. Two MCDM methods are integrated in order to capture the inter and intra domain semantics and dynamics.

The posed problem without dynamicity reduces to simple Load Balancing system, which is already being examined and explored from the functionality and performance point of view in the community. The static and/or semi-dynamic nature of the decision-making mechanism in those systems leads to biased and ineffective resource utilization resulting in revenue loss with declined service quality. Moreover, these systems take into account a few attributes among the set of available parameters over the platform, while calculating the decision (service profile, reliability information, time of the day, business objectives of the company, latest state of the links, user profiles and Service Level Agreement (SLA)). A system capable of taking into account Service Level Specifications (SLS), e.g. susceptible delay, jitter and packet loss may not accommodate the technology specific information. Systems considering user, service and QoS profiles do not compensate for dynamic context of the request. The introduction of dynamicity by using Multi Criteria Decision Making (MCDM) theory while calculating the rules and the enforcement of the calculated decisions in two different modes without system reset/restart are one of the the main contributions from our side. The off-line (static) and on-the-fly (dynamic) information over the platform alongside the business rules of the company is used to extract the relevant attributes for MCDM application and the decision is enforced without revamping the existing protocol stack.

The rest of the paper is organized as follows: In the following Section, platform's architecture is described. Section III elaborates the MCDM theory, problem formulation regarding MCDM along with the application steps description of the chosen methods. In Section IV, the validity of the proposed solution is presented with comparisons. Section V outlines the related work. Finally, in Section VI, concluding remarks are given while outlining the future work.

II. Proposed Architecture

A. Telephony over IP Infrastructure

The QoS-centered architecture shown in Fig. I provides an all IP cost effective solution offering versatile technology convergence while highlighting network traffic unification. It integrates devices and modules from different vendors over a single platform while offering multimedia and data services for public and private (local) networks. The global objective is the accommodation of dynamic modifications/variations into the decision-making framework. Service, control and transfer planes issues posing a multi-criteria problem are handled together without affecting the standard mechanisms and classical layered approach. The underlying platform stems from competitivity cluster for handling traffic management issues at the network border in either direction (inbound and outbound traffic). It is worthwhile to mention here that we are targeting the Session Initiation Protocol (SIP) based multimedia communication over the platform

Policy Server (PS) is the main controller in the proposed architecture. It acts as a Policy Decision Point (PDP). It computes all the rules (decisions) by taking into account the static configurations and dynamics taking place over the platform, in addition to the policy enforcement supervision. The proposed dynamic decision engine partly constitutes the core of PS.

Session Border Controller (SBC) in the offered framework is primarily dedicated to multimedia communication. But it can also handle data services. SBC provides a number of vendor specific functionalities depending on the requirements and its deployment. In addition to its standard functionalities, SBC is tweaked to act as a Policy Enforcement Point (PEP) in the proposed architecture.

Call Server (CS) is an important component of IP-based PBX/Soft-switch. It supports proxy, registrar, redirect and location services. CS here provides registration, user profile management and service control mechanism. It is modified to handle the user profile based Call Admission Control (CAC) functionality.

B. Global System for Mobile communication (GSM) Infrastructure

An all open source real time module consisting of Universal Serial Radio Peripheral (USRP), GNU Radio, an extended OpenBTS and tweaked OpenSIPS constitutes the GSM infrastructure. Convergence of the ubiquitous GSM air interface with VoIP backhaul forms the basis of a new type of network that is deployed and operated at substantially lower cost (one tenth) than existing technologies, as the radical two-tier pricing would be disruptive for existing carriers. GSM components details are as follows:

The Universal Software Radio Peripheral (USRP) is designed as a general-purpose hardware subsystem for Software Defined Radio (SDR) having open source schematics and layouts [9]. It supports the simultaneous transmission and reception of four real or two complex channels in real-time. For reception, it utilizes four 12-bit Analog-to-Digital Converters (ADCs) operating at 64 MHz, and four Digital-Down Converters (DDCs) with programmable decimation rates. The transmit side of the USRP incorporates four 14-bit Digital-to-Analog Converters (DACs) that operate at 128MHz, and two Digital-Up-Converters (DUCs) with programmable interpolation rates. The on-board Altera Cyclone Field Programmable Gate Array (FPGA) is responsible for channelization, down-conversion and up-conversion. Data is transferred between the host computer and the USRP via a USB 2.0 interface, hence limiting the sustainable data rate to 32 MBps half-duplex. USRP here is used to present a GSM air interface ”Um” to a conventional GSM handset.

Different frequencies require different antennas and sometimes different signal processing, like amplifiers or filtering, to receive or transmit correctly. The USRP motherboard by itself does not provide direct Radio Frequency (RF) access; rather it utilizes an assortment of daughterboards to perform the RF-to-Intermediate Frequency (IF) translation. These daughterboards are plugged directly into the USRP motherboard. Some daughterboards are receive-only, some are transmit-only and some are transceiver devices that provide both receive and transmit functionality. RFX-1800 daughterboards (transceivers) are used in the proposed architecture.

GNU Radio [7] is an open source SDR. It is a software toolkit that provides a library of signal processing blocks that run on a host-processing platform. Algorithms implemented using GNU radio send/receive baseband data directly to/from the USRP, which is the hardware that provides RF access. The GNU library contains lots of standard signal processing functions. These functions, usually called blocks, are often divided into three categories: source blocks (USRP drivers, but also file readers and tone generators), sink blocks (USRP drivers, graphical sinks like an oscilloscope and sound-card drivers) and processing blocks (like filters, FFT and (de)modulators). The processing blocks are written in C++, and made callable from Python via SWIG (Simplified Wrapper and Interface Generator). Standard practice is to create a Python flowgraph by connecting the appropriate signal processing blocks. If a custom signal processing block is desired, it can be created in C++ and integrated into the GNU Radio development environment via SWIG.

A universal SDR structure with the specific software (GNU

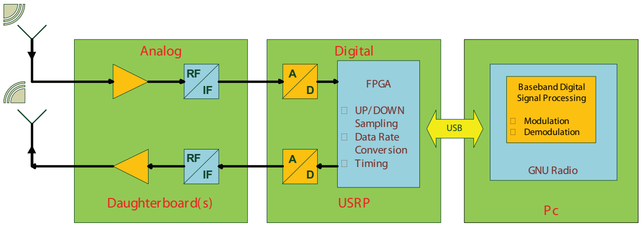

Fig. 2. Software Defined Radio Block Diagram.

Radio) and hardware (USRP) is shown in Fig. 2. The left hand side forming the RF front-end of the hardware serves as an interface to the analog RF domain. In the middle block, the intelligence of the hardware part is implemented, forming the interface between the digital and the analog world. The whole signal processing is done in the right hand side block in Fig. 2. Digital Signal Processing (DSP) chips are very expensive and are flexible to certain limits for customization while targeting a particular application. The combination of GNU Radio and USRP along with daughterboards offers flexibility with efficient customization for signal processing applications. This fully open source and cost effective solution is being used/developed by a large and diverse community (research, academia and industry). The stumbling bottleneck in moving towards software defined radio is the availability of high speed analog to digital and vice-versa (ADC/DAC) Convertors. SDRs invariably require parallel and sequential partitioning of algorithms to get the required processing power so yet another issue is the computational power of the host machine. The motivation behind using USRP with GNU radio is the performance of ADC/DAC modules over USRP kit and the flexible/modular approach adopted in GNU radio (C++ is used for core and the modules are glued using python). The idea here is to perform most of the DSP specific hardware based processing using conventional computation (PC). Another objective is to transfer the complexity of the radio system, design from hardware to software while moving the software as close as possible to the antenna.

OpenBTS [8] is an open source linux-based application that uses USRP to present GSM air interface (Um) to standard GSM handsets (mobile phones). OpenBTS makes it possible to create a GSM network without using the networks of the various service providers. Its architecture completely differs from the conventional GSM hierarchical architecture. OpenBTS replaces the traditional GSM operator network switching subsystem infrastructure, from the Base Transceiver Station (BTS) upwards. Instead of forwarding call to an operator's Mobile Switching Centre (MSC), the calls are terminated on the same box by forwarding the data onto the Asterisk using SIP.

OpenSIPS [10], an open source SIP server is tweaked to act as Back-2-Back User Agent (B2BUA) and slave Session SBC. Moreover, the Master OpenSIPS is extended to act as Policy Enforcement Point (PEP) for enforcing the decisions. It is built around the core that is responsible for the basic processing and handling of SIP messages. The modules developed around its core are responsible for the majority of OpenSIPS functionalities. Its scalability and modular design provides a number of functionalities (registrar, router/proxy (LCR, dynamic routing, dial-plan features), redirect server, B2BUA etc). OpenBTS emulates the mobile handsets as the SIP endpoint and these handsets are treated as SIP extensions while registering to Slave OpenSIPS. After the initial registration and authentication, SIP request is then forwarded to Master SBC (OpenSIPS) for routing the call/text messages to the appropriate link in consent with the decision calculated on the basis of platform's conditional parameters, link state, business objectives of the company and context of the request. Moreover, the Slave and Master OpenSIPS servers share and exchange relevant information for Horizontal Handover (HH) decision-making during ongoing call (System offers this provision using the same decision engine used for routing the requests to different links but dynamic routing is focussed in this work).

All these open-source modules are integrated over a single platform to present the multihomed converged framework and a use case for inbound and outbound dynamic call/request/session routing at the private-public network border is presented . The Decision Engine within the PS takes into account multiple criteria (Service Level Agreement (SLA), service profile, reliability information of the links, user profile, time of the day, static configuration over the platform, mobility within the GSM cells (in case of HH), dynamic variations over the platform) and uses MCDM theory for decision computation.

C. Control Plane Infrastructure and Protocols

The protocol chosen to communicate the information/decisions between PDP and PEP is Diameter with newly defined and developed Attribute Value Pairs (AVPs). Diameter is natively an Authentication Authorization Accounting (AAA) protocol. Due to its AAA characteristics, its enhancement orientations are becoming natural for decision-based network management. It has large AVP space and supports a large number of pending requests. Common Open Policy Service (COPS) [3], a strong candidate for Policy Based Network Management (PBNM) [11], has not been chosen for decision (policy) provisioning and dissemination, as it is specifically designed for device-level configuration and management. However, dynamic session/call/data-connection management and handover support is required while taking into account the variations and latest dynamics. SNMP has sometimes been proposed in the literature to be a candidate for PBNM [2]. SNMP-based information in our system is exploited to gauge the QoS parameters of access links (router interfaces). This paper addresses the private-public border traffic management issues for request routing decisions at the application layer (OSI). The mobility management and cell load issues within the GSM cells can be resolved by handover mechanism (not addressed in this work). The framework supports dynamicity by using MCDM theory. The calculated decisions are enforced in outsourcing (on-the-fly) and provisioning (off-line) modes (more details about information sharing and its exploitation are available in [5], [6]) by using existing standards and mechanisms, without introducing overheads in the protocol stack. It is worthwhile to mention here that outbound dynamic call routing is emphasized here due to the following factors: cost (International and Long Distance Routing of Mobile through VoIP), access technology convergence providing unified communication at the private-public network border, multiple criteria including large number of attributes involved in the outbound routing decision-making, and finally this scenario represents an ongoing and existing business model experienced by different companies.

III. Multi-Criteria Decision Making Theory and its Application

The process of decision-making involves choosing the best alternative, given a set of alternatives (available external links and various GSM cells in case of HH in our scenario) and a set of criteria (context of the request and predefined configurations/settings over the proposed platform). These alternatives can also be ranked on the basis of multiple criteria using some specific MCDM method. MCDM methods have been used to help solve a wide variety of problems in many different applications such as telecommunications, manufacturing, transportation and software engineering [12],[13]. Experiences show that there is not a single MCDM technique to deal with all multi-criteria problems. Indeed each situation requires a specific MCDM technique. The choice of the technique and its impact on the decision-making is not within the scope of this work and the reader is referred to [14] for an overview of this particular domain. The targeted objectives in the multi-criteria decision-making problems might sometimes be conflicting and/or overlapping. In the posed routing problem, SLA includes Delay, Jitter and Packet Loss (DJPL) which falls under the business objectives of the company when they sign the direct or reciprocal agreements with partners or companies. However, the same sets of parameters (DJPL) are used to grade the QoS of the available links (when a link has to be chosen). The triplet (DJPL) can be used to gauge the authorization and authentication of a particular user class (e.g., Gold user must have the best QoS profile, while Silver can be assigned either a good or a satisfactory QoS profile) while executing the context of the request. There are various approaches to deal with such sort of problems, each having its pros and cons but we will not address this issue here. Two MCDM methods have been chosen to address the problem of dynamic call/request/session routing on the basis of multiple criteria, while making decisions for the best link in outsourcing and provisioning modes respectively.

Each MCDM problem is associated with multiple attributes. These attributes are linked to the goals and are referred to as decision criteria. Since different criteria represent different dimensions of alternatives, they may conflict with each other (e.g., cumulative bandwidth may be confused with total bandwidth, traffic measurements, granularity (call/connection-/session level) mania, cost, etc.). The criteria are assigned different weights according to the context of request and the rules defined over the platform.

Conventional algorithms used for link selection in multihomed networks are either user-centric or motivated for efficient resource utilization over the platform and/or they are centered towards application optimization for desired QoS. However, to cope with all these multi-criteria goals and objectives, the choice of MCDM is indispensable. Hence two MCDM methods, Grey Relational Analysis (GRA) [15] and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [16] for outsourcing and provisioning enforcement modes respectively are picked among the number of available methods to be applied to our problem of decision-making.

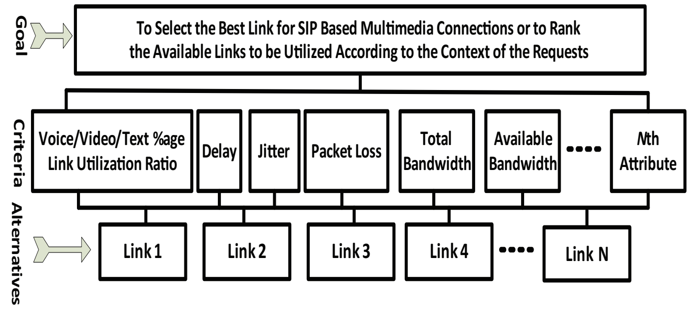

Fig. 3. Candidate Links, Attributes and Objectives Hierarchy.

A. Problem Formulation and GRA Application

For brevity and to avoid the complexity of stringent mathematics, 6 attributes are chosen for the application of MCDM methods on 4 alternative links for routing the multimedia sessions (voice and video communication is emphasized here due to resource and QoS requirements). Fig. 3 illustrates the hierarchy of the desired goal, the criteria and the available alternative links. As mentioned earlier that SIP based multimedia communication is focussed, so let us have the QoS requirements for these services as follows:

Video Call: It requires a higher bandwidth than voice so the available bandwidth, transport cost and current utilization are important factors. Its ability to buffer a longer duration data before playback makes it less vulnerable to delay and jitter than voice.

Voice Call: It is very sensitive to delay and jitter, requiring low bandwidth but this service is susceptible to packet losses to some extent. Because of its low bandwidth usage, the transport cost factor is considered negligible. Total bandwidth and available bandwidth are not significant factors due to low bandwidth requirements. Since there is some correlation of utilization with jitter and delay, it is preferred to have a low utilization for the selected network.

There are four links L_1, L_2, L_3 and L_4 and for the sake of simplicity, 6 attributes: Utilization Ratio of a link (UR), Delay (D), Jitter (J), Packet Loss (PL), Total Bandwidth (TB) and Available Bandwidth (AB) respectively are considered for the application of MCDM. Two user Bob (local) and Alice (remote) are supposed to communicate (outgoing SIP communication) with each other by using the available resources on the platform as shown in Fig. I. Bob initiates the communication and sends an initial INVITE to the SBC at the border of the platform to start a voice call with Alice. SBC extracts the information from the request and constructs the reference for decision making by taking into account the platform's pre-defined set of objectives for different services and users. At minimum, user and communication types (more details available in [6]) have to be known. This information is sent to the PS and the corresponding user, application and QoS profiles are loaded from the profile base. The information from the context of the request is bundled with the link latest information to construct the reference vector as follows:

$$Ref\,(L) = \left[\begin{array}{cccccc} UR & D & J & PL & TB & AB \end{array}\right] \quad (1)$$

The candidate link attributes constituting the Decision Matrix (DM) is given as follows:

$$DM = \left[\begin{array}{cccccc} UR_1 & D_1 & J_1 & PL_1 & TB_1 & AB_1 \\ UR_2 & D_2 & J_2 & PL_2 & TB_2 & AB_2 \\ UR_3 & D_3 & J_3 & PL_3 & TB_3 & AB_3 \\ UR_4 & D_4 & J_4 & PL_4 & TB_4 & AB_4 \end{array}\right] \begin{array}{c} L_1 \\ L_2 \\ L_3 \\ L_4 \end{array} \quad (2)$$

The values of these attributes are obtained from the SNMP traps and the Service Level Agreements (SLAs) of the corresponding links over the platform. As the parameters involved in the DM come from different sources, the units representing the values are different. We need to normalize these parameters in order to make them unit-less. The attributes having bigger values (e.g., TB is in Mega) are divided by the largest value in the corresponding column vector, while the smaller range attribute (e.g., D is in milliseconds) is divided by the smallest value in the corresponding column vector. The normalized Decision Matrix is given by

$$D\widetilde{M} = \left[\begin{array}{cccccc} \widetilde{UR}_1 & \widetilde{D}_1 & \widetilde{J}_1 & \widetilde{PL}_1 & T\widetilde{B}_1 & A\widetilde{B}_1 \\ \widetilde{UR}_2 & \widetilde{D}_2 & \widetilde{J}_2 & \widetilde{PL}_2 & T\widetilde{B}_2 & A\widetilde{B}_2 \\ \widetilde{UR}_3 & \widetilde{D}_3 & \widetilde{J}_2 & \widetilde{PL}_3 & T\widetilde{B}_3 & A\widetilde{B}_3 \\ \widetilde{UR}_4 & \widetilde{D}_4 & \widetilde{J}_4 & \widetilde{PL}_4 & T\widetilde{B}_4 & A\widetilde{B}_4 \end{array}\right] \begin{array}{c} L_1 \\ L_2 \\ L_3 \\ L_4 \end{array} \quad (3)$$

The normalized reference vector is given by

$$Ref\left(\widetilde{L}\right) = \left[\begin{array}{cccccc} \widetilde{UR} & \widetilde{D} & \widetilde{J} & \widetilde{PL} & T\widetilde{B} & A\widetilde{B} \end{array}\right] \quad (4)$$

Now the distance between the corresponding normalized reference vector entities and the normalized Decision Matrix entities is calculated as follows:

$$\Delta_{UR_i} = \left|\widetilde{UR} - \widetilde{UR}_i\right|, i = 1, 2, 3, 4 \quad (5)$$

The Δ Decision Matrix is obtained by applying Eq. 5 to the corresponding entities in the normalized Decision Matrix and the normalized reference vector:

$$\Delta_{DM} = \left[\begin{array}{cccccc} \Delta_{UR_1} & \Delta_{D_1} & \Delta_{J_1} & \Delta_{PL_1} & \Delta_{TB_1} & \Delta_{AB_1} \\ \Delta_{UR_2} & \Delta_{D_2} & \Delta_{J_2} & \Delta_{PL_2} & \Delta_{TB_2} & \Delta_{AB_2} \\ \Delta_{UR_3} & \Delta_{D_3} & \Delta_{J_3} & \Delta_{PL_3} & \Delta_{TB_3} & \Delta_{AB_3} \\ \Delta_{UR_4} & \Delta_{D_4} & \Delta_{J_4} & \Delta_{PL_4} & \Delta_{TB_4} & \Delta_{AB_4} \end{array}\right] \begin{array}{c} L_1 \\ L_2 \\ L_3 \\ L_4 \end{array} \quad (6)$$

Grey Relation Coefficients (GRCs) representing the measurement of similarity of an attribute to its reference are calculated (e.g. for voice/video Utilization Ratio of a link UR) as follows:

$$GRC_{UR_i} = \frac{\Delta_{\min} + \alpha\Delta_{\max}}{\Delta_{UR_i} + \alpha\Delta_{\max}}, i = 1, 2, 3, 4 \quad (7)$$

where $\alpha \in [0, 1]$; $\Delta_{\min}$ and $\Delta_{\max}$ are calculated as follows:

$$\Delta_{\max} = \max_i \left(\Delta_{UR_i} + \Delta_{D_i} + \Delta_{J_i} + \Delta_{PL_i} + \Delta_{TB_i} + \Delta_{AB_i}\right) \quad (8)$$

$$\Delta_{\min} = \min_i \left(\Delta_{UR_i} + \Delta_{D_i} + \Delta_{J_i} + \Delta_{PL_i} + \Delta_{TB_i} + \Delta_{AB_i}\right) \quad (9)$$

As we are emphasizing on voice communication (outbound calls) and to meet the QoS requirements of voice, (Delay and Jitter are given more weight), we choose the weights corresponding to each attribute in the Decision Matrix. The available bandwidth is coupled with user profile loaded from the profile base (in case of gold profile, it is highly desirable to choose the link with good available bandwidth so AB and U will also be given suitable weight values). These assigned weights illustrate the relative importance of each attribute in Decision Matrix such that:

$$W = W_{UR} + W_D + W_J + W_{PL} + W_{TB} + W_{AB} = 1 \quad (10)$$

The weighted GRC coefficient representing an attribute column is given by:

$$GRC_{wUR_i} = W_{UR} * GRC_{UR_i}, i = 1, 2, 3, 4 \quad (11)$$

The resulting weighted GRC matrix is given by equation 12 The GRC value for individual link is calculated as follows:

$$Coef\,(GRC)_i = GRC_{wUR_i} + GRC_{wD_i} + GRC_{wJ_i} + GRC_{wPL_i} + GRC_{wTB_i} + GRC_{wABi}, i = 1, 2, 3, 4. \quad (13)$$

The Candidate Link with the highest GRC coefficient value is the final decision, i.e., the best link for the request. There are two possibilities for calculating/declaring the reference attribute vector: the first is to compute the reference attribute vector before the request arrives and the second is to calculate it on the fly (discussed above in the GRA method). The susceptible QoS set of parameters are well defined and known for voice and video. The range of required bandwidth for different codecs (used by the end points during the multimedia communication) is also well documented. The attribute, available bandwidth is calculated by keeping the track of number of ongoing calls/requests on a particular link (i.e., Available Bandwidth=Total Bandwidth - Used Bandwidth). It is important to mention that the presented GRA includes the simplest possible case. Embedding the reference vector beforehand can be tedious and complex as the number of links and attributes increases. The business objectives of an enterprise might change (e.g., voice might be given priority over video, the silver profile might use gold profile service during night (free hours), etc.), the user profile priorities/authentication/authorization parameter (QoS profile corresponding to a user profile) may go through modification, or the link resources might go through up-gradation/downgrading. Although this complexity can be handled but it requires extensive administrative efforts. The objective however, is to minimize these efforts at minimal while taking into account the dynamicity that the manual system is not able to accommodate. GRA method is applied in the outsourcing enforcement mode over the converged platform offering provision to compute the decisions on the fly and off-line depending on the platform's operational rules.

B. TOPSIS MCDM Method

TOPSIS was developed by Yoon and Hwang [16]. It is an alternative to ELECTRE [17] and is considered to be one of its variants. It is known as a double standard method that evaluates alternatives through two basic criteria. First, the

$$GRC_{wDM} = \begin{bmatrix} GRC_{wUR_1} & GRC_{wD_1} & GRC_{wJ_1} & GRC_{wPL_1} & GRC_{wTB_1} & GRC_{wAB_1} \\ GRC_{wUR_2} & GRC_{wD_2} & GRC_{wJ_2} & GRC_{wPL_2} & GRC_{wTB_2} & GRC_{wAB_2} \\ GRC_{wUR_3} & GRC_{wD_3} & GRC_{wJ_3} & GRC_{wPL_3} & GRC_{wTB_3} & GRC_{wAB_3} \\ GRC_{wUR_4} & GRC_{wD_4} & GRC_{wJ_4} & GRC_{wPL_4} & GRC_{wTB_4} & GRC_{wAB_4} \end{bmatrix} \begin{matrix} L_1 \\ L_2 \\ L_3 \\ L_4 \end{matrix} \quad (12)$$

chosen alternative should have the shortest distance from the positive ideal solution and secondly it must be farthest from the negative-ideal solution for a MCDM problem. The perceived positive and negative ideal solutions are based on the range of attribute values available for the alternatives. The distances are measured in Euclidean terms. The Euclidean distance approach is proposed to evaluate the relative closeness of the alternatives to the ideal solution. The reason for choosing TOPSIS in provisioning enforcement mode (i.e., pre-computed decisions are available at PEP in this mode, which is described in detail in [5]) is that it will rank/grade the available alternatives (links) whenever applied. Moreover, TOPSIS is extended to be applied on interval data (i.e. lower and upper values of an attribute) for the provisioning enforcement mode over the proposed architecture. In provisioning mode, the decision engine is not very much interactive with the platform's variations especially at the arrival of a new request so it provides half hearted dynamicity. Hence if the exact value of an attribute is not known, then these bounds (upper and lower) are used for the application of an extended TOPSIS. The best link among the available alternative links (ranked by the application of an extended TOPSIS) is assigned to request by following the predefined set of criteria. To avoid complexity, only the Decision Matrix is expressed with lower and upper bounds while considering the same set of 6 attributes and 4 links in equation 14

C. TOPSIS MCDM Method Application Steps

TOPSIS method is explained and applied here by using the standard approach to avoid rigorous mathematics in the following steps.

1) Normalize the Decision Matrix containing the link attributes: the process is to transform different scales and units among various criteria into common measurable units in order to allow comparisons across the criteria. As the parameters involved in the DM come from different sources, the units representing the values are different. Normalization of these parameters is required in order to make them unit-less. The attributes having bigger values (e.g., TB is in Mega) are divided by the largest value in the corresponding column vector while the smaller range attribute (e.g., D, which is in milliseconds) is divided by the smallest value in the corresponding column vector. The normalized Decision Matrix is given by

$$D\widetilde{M} = \begin{bmatrix} \widetilde{UR}_1 & \widetilde{D}_1 & \widetilde{J}_1 & \widetilde{PL}_1 & T\widetilde{B}_1 & A\widetilde{B}_1 \\ \widetilde{UR}_2 & \widetilde{D}_2 & \widetilde{J}_2 & \widetilde{PL}_2 & T\widetilde{B}_2 & A\widetilde{B}_2 \\ \widetilde{UR}_3 & \widetilde{D}_3 & \widetilde{J}_3 & \widetilde{PL}_3 & T\widetilde{B}_3 & A\widetilde{B}_3 \\ \widetilde{UR}_4 & \widetilde{D}_4 & \widetilde{J}_4 & \widetilde{PL}_4 & T\widetilde{B}_4 & A\widetilde{B}_4 \end{bmatrix} \begin{matrix} L_1 \\ L_2 \\ L_3 \\ L_4 \end{matrix} \quad (15)$$

2) The next step is to construct the weighted normalized DM: it cannot be assumed that each evaluation criterion is of equal importance because the evaluation criteria have various meanings. As we are emphasizing over voice communication (an outbound call in the presented use-case), the Delay and Jitter are given more importance to meet QoS requirements and hence, the weights corresponding to each attribute in the DM are chosen according to the context. The available bandwidth is coupled with the user profile loaded from the profile base (in the case of a gold profile, it is highly desirable to choose the link with good available bandwidth so AB and U will also be given appropriate weight values). Business objectives of the platform and the preconfigured configurations over the architecture are pivotal indicators for suitable weight values. These assigned weights illustrate the relative importance of each attribute in the DM such that:

$$W = W_{UR} + W_D + W_J + W_{PL} + W_{TB} + W_{AB} = 1 \quad (16)$$

The corresponding weighted normalized entities in the DM are represented by subscript wn (e.g. for UR will be UR_{wn}). Now positive and negative ideal solutions for each attribute are computed: the positive ideal solution indicates the most preferable alternative and the negative ideal solution indicates the least preferable alternative as follows (e.g. voice/video link Utilization Ratio, UR):

$$UR^+ = \left(Max\,(UR_{wn})_i\right) \parallel \left(Min\,(UR_{wn})_i\right), i = 1,2,3,4 \quad (17)$$

and

$$UR^- = \left(Min\,(UR_{wn})_i\right) \parallel \left(Max\,(UR_{wn})_i\right), i = 1,2,3,4 \quad (18)$$

3) The Euclidean distance method is applied to measure the separation from the positive and negative ideal for each alternative

$$S_i^+ = \sqrt{\begin{matrix} \left((UR_{wn})_i - UR^+\right)^2 + \left((D_{wn})_i - D^+\right)^2 + \left((J_{wn})_i - J^+\right)^2 + \\ \left((PL_{wn})_i - PL^+\right)^2 + \left((TB_{wn})_i - TB^+\right)^2 + \left((AB_{wn})_i - AB^+\right)^2 \end{matrix}} \quad (19)$$

and

$$S_i^- = \sqrt{\begin{matrix} \left((UR_{wn})_i - UR^-\right)^2 + \left((D_{wn})_i - D^-\right)^2 + \left((J_{wn})_i - J^-\right)^2 + \\ \left((PL_{wn})_i - PL^-\right)^2 + \left((TB_{wn})_i - TB^-\right)^2 + \left((AB_{wn})_i - AB^-\right)^2 \end{matrix}} \quad (20)$$

4) Finally, the candidate links are ranked by measuring the relative closeness of an alternative (candidate links L_1, L_2, L_3 and L_4 under consideration represented by a row vector in the Decision Matrix) to the ideal solution S^+ as follows:

$$R_i = \frac{S_i^+}{S_i^+ + S_i^-} \quad (21)$$

$$DM = \begin{bmatrix} (UR_1^L, UR_1^U) & (D_1^L, D_1^U) & (J_1^L, J_1^U) & (PL_1^L, PL_1^U) & (TB_1^L, TB_1^U) & (AB_1^L, AB_1^U) \\ (UR_2^L, UR_2^U) & (D_2^L, D_2^U) & (J_2^L, J_2^U) & (PL_2^L, PL_2^U) & (TB_2^L, TB_2^U) & (AB_2^L, AB_2^U) \\ (UR_3^L, UR_3^U) & (D_3^L, D_3^U) & (J_3^L, J_3^U) & (PL_3^L, PL_3^U) & (TB_3^L, TB_3^U) & (AB_3^L, AB_3^U) \\ (UR_4^L, UR_4^U) & (D_4^L, D_4^U) & (J_4^L, J_4^U) & (PL_4^L, PL_4^U) & (TB_4^L, TB_4^U) & (AB_4^L, AB_4^U) \end{bmatrix} \begin{matrix} L_1 \\ L_2 \\ L_3 \\ L_4 \end{matrix} \tag{14}$$

	UR	D	J	PL	TB	AB
	%age	Milliseconds (ms)	ms	%age	Megabits per second (Mbps)	Mbps
L_1	49.65	210	35	36	100	68
L_2	30.84	200	25	25	100	71
L_3	20.81	100	15	10	100	81
L_4	15.00	150	30	30	100	46

TABLE I
LINKS WITH CORRESPONDING PARAMETRIC VALUES

	L_1	L_2	L_3	L_4
R Value	0.0698	0.4088	0.8163	0.4846
Rank	4	3	1	2

TABLE II
R VALUES AND THE CORRESPONDING GRADING OF LINKS USING TOPSIS.

The links L_1, L_2, L_3 and L_4 characterized by attributes voice/video Utilization Ratio UR, Delay (D), Jitter (J) Packet Loss (PL), Total Bandwidth (TB) and Available Bandwidth (AB) respectively are represented by the values shown in Table I. D, J and PL are given higher weights due to voice call (outgoing) while keeping in view the required bandwidth judged from the codec negotiated during the call setup. For the application of TOPSIS on the links represented by the corresponding row vectors in Table I, all the steps are gone through in the order stated above in this section. The links are ranked with R values as mentioned in Table II.

IV. TESTBED AND EXPERIMENTAL SETUP

Dynamic SIP-based call routing decision-making at private-public network border under the control of Decision Engine is investigated to validate the framework. The system offers the provision of on-the-fly and off-line decision computation depending on the chosen enforcement mode and system settings. Test bed used for the proof of concept is shown in Fig. 4. SIPp [18] is used to generate extensive SIP requests (INVITE messages). It is a configurable traffic generator and is extensible via a simple XML configuration language. Call model with User Agent Client (UAC) at slave OpenSIPS sends an INVITE to SIP server (same machine) that adds the resource priority tag and forwards the request to Master OpenSIPS (tweaked to act as SBC). Master OpenSIPS analyzes the request to judge its communication type and pairs it with the resource priority tag sent by the slave OpenSIPS. Resource priority type and communication type tuple is mapped to an appropriate user profile from central profile base at PS. It is important to mention here that a random number is generated to send the codec information along with the SIP message. The bandwidth requirement of the call is judged from the codec information and the request is forwarded to an appropriate link (decision can be computed on-the-fly by following the criteria in sections III-A. MCDM method (GRA) in outsourcing mode is executed three times; in the first iteration, all four links are ranked according to their corresponding GRC values, lowest ranking alternative (link) is removed before performing the second iteration and then finally GRA is implemented after eliminating the top ranked link. It is observed that the removal of the top order alternative does not change the ranking; however, the elimination of the candidate link at the bottom (lowest ranked) reverses the ranking of the two alternatives other than the top most link (top ranked link during first and second iterations), as shown in Table III. GRA therefore does not exhibit ideal behavior, however it is capable of overcoming ranking inconsistencies when used to select the top candidate. However, in the presented architecture, the business objectives of the company may be translated to rules for bottom line link allocation to certain profiles. It is observed after extensive simulations that the ranking of the alternatives is influenced by weight computation and its allocation to the attributes involved in the Decision Matrix. The mentioned problem is addressed by the application of Analytical Hierarchy Process (AHP) [19] to calculate the corresponding weights of the attributes involved in the DM.

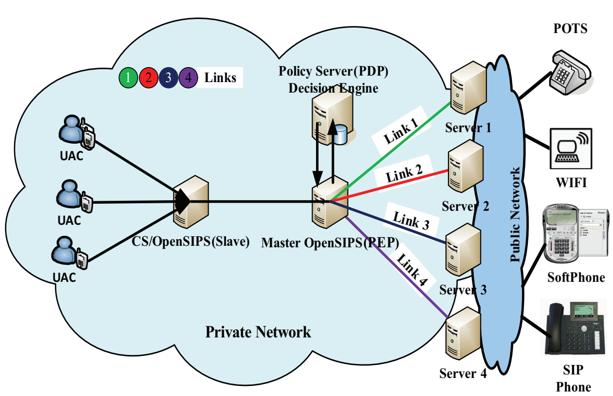

Fig. 4. Test Bed With 4 Links

	L_1	L_2	L_3	L_4	Iteration
GRC Value	0.4726	0.4005	0.8003	0.3781	1
Rank	2	3	1	4	1
GRC Value	0.3347	0.3467	0.8566	—	2
Rank	3	2	1	—	2
GRC Value	0.4615	0.4586	—	0.4501	3
Rank	2	3	—	4	3

TABLE III
GRC VALUES AND THE CORRESPONDING GRADING OF LINKS AFTER EACH ITERATION USING GRA.

A. Analytical Hierarchy Process (AHP)

AHP is used to calculate the weight of the corresponding column vector (laying out the criteria), representing an attribute column in the DM. AHP can fragment a problem into a hierarchy of simpler and manageable sub-problems. Scoring the alternatives under each criterion, weighing the criterion, calculating the final score and the final decision standings are the four step involved for the application of AHP. It is a MCDM methodology in itself. However, its ability to elicit accurate ratio scale measurements and combine them across multiple criteria has led us to use it in conjunction with GRA for ranking the links (alternatives) dynamically. The integration of AHP and GRA is illustrated in Fig. 5. Inconsistent behavior shown by GRA during iterative decision-making process motivated us to explore the method. It is observed that the method suffers from problems related to the weighting. A hybrid method consisting of GRA and AHP shown in Fig. 5 is proposed to resolve the ranking abnormality.

Two weighting classes have been devised using Saaty's

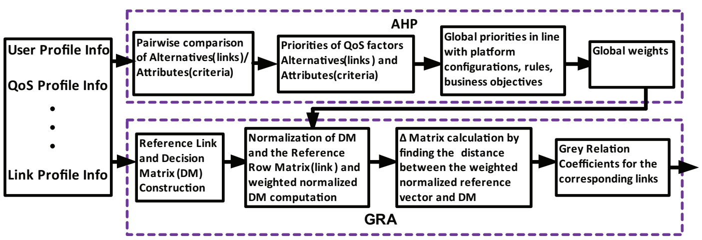

Fig. 5. GRA and AHP Integration for Candidate Links Grading.

scale: the first class formulates the global priorities of the alternatives (links) illustrating the degree of importance of those candidate links and the second class is conceived by the pairwise comparison of the attributes involved in the DM using the same scale as shown in Table IV. Decision computation for the request routing at private-public multihomed network border (GRA) by using the weights, computed by pairwise comparison of the attributes (AHP) fixes the inconsistent behavior. The candidate links (alternatives) ranking remains the same with the exclusion of top and bottom ranked links after a number of iterations.

Network Address Translation (NAT) is enabled at master SBC

Relative Importance of Corresponding Elements in a Class	Saaty's Scale
Equally Important	1
Moderately Important	3
Strongly Important	5
Very Strongly Important	7
Extremely Important	9
Intermediate Values	2, 4, 6, 8
Reciprocal Values	1/2, 1/3, ., 1/9

TABLE IV
RELATIVE IMPORTANCE OF THE ATTRIBUTES AND THEIR CORRESPONDING VALUES USED FOR PAIRWISE COMPARISON.

and the decision is enforced during NAT implementation. The Remote SIP server (Asterisk) responds with 100 TRYING, 180 RINGING and 200 OK. UAC then sends an ACK and the call is established. The UAC closes the communication after a pause of variable duration by sending a BYE which is acknowledged by the SIP server with 200 OK. Wireshark [20] is used to capture the traffic at different interfaces (links). OriginLab [21] is used for data analysis from the captured file. Throughput of each link is plotted with and without decision engine (i.e. using built-in LB in SBC) as shown in Fig. 6. It is observed that there is a significant improvement in the throughput for each link with decision engine while performing SIP-based call routing.

The retransmission mechanism within SIPp is turned off when

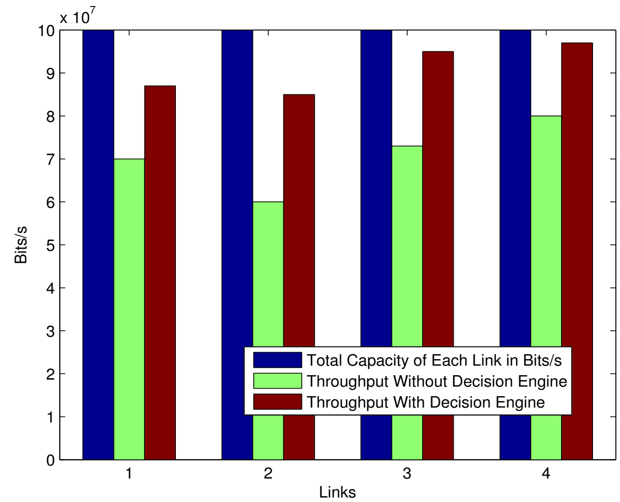

Fig. 6. Throughput of Each Link With and Without Decision Engine.

INVITE messages are sent in order to know that a call has been dropped. The aggregated call dropping probability (for the 4 links shown in Fig. 4) with the proposed decision engine has lower value than the ordinary SBC's LB as shown in Fig. 7.

The delay introduced by the system with and without Decision

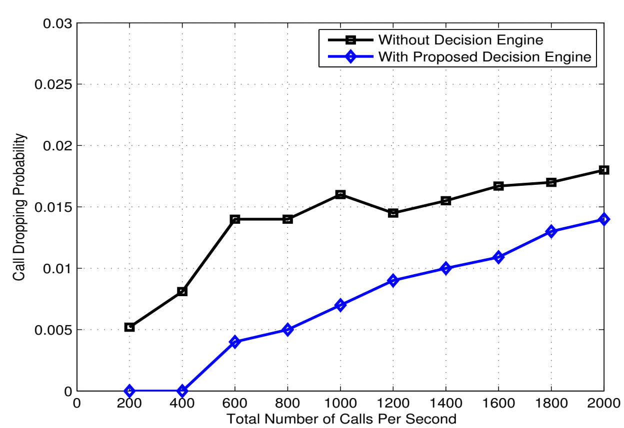

Fig. 7. Call Dropping Probability With and Without Decision Engine.

Engine is also calculated over the same test bed. The graph shown in Fig. 8 indicates that addition of Decision Engine in the system introduces a minor overhead (delay). This calculation is performed in outsourcing enforcement mode due to more dynamics involved in that particular mode (for detailed functionality, information sharing and communication between different devices over the presented architecture in outsourcing and provisioning modes respectively, the reader is referred to [5], [6]). The delay increases almost linearly as the number of calls/requests increases and is small enough having very little impact on services. It is due to the fact that the decisions are being executed and enforced during call/connection setup time.

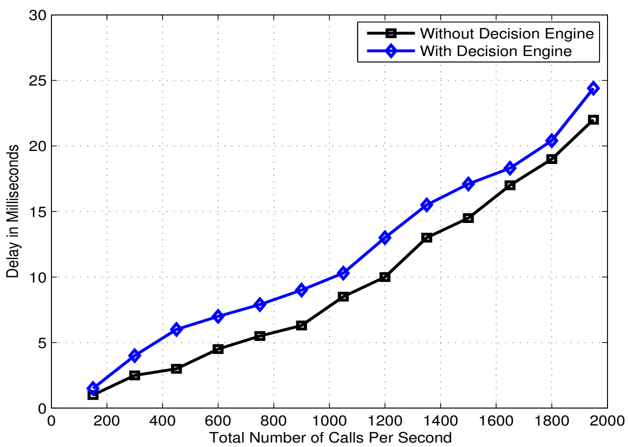

Fig. 8. Delay (Milliseconds) Introduced by the System With and without Decision Engine.

B. Outsourcing and Provisioning Mode Comparison

System validation is accomplished in outsourcing mode but the system supports two enforcement modes namely outsourcing and provisioning. The system performance is analyzed by calculating and comparing the delay and call dropping probability in these enforcement modes. As mentioned subsequently that multimedia traffic is focussed in the converged hybrid architecture with multihoming support. Moreover there are signaling protocols (SIP, H323, etc.) involved for connection/session setup before the actual data starts flowing. The supported outsourcing and provisioning enforcement modes are strongly correlated with signaling phase of multimedia communication. So the decisions/rules are enforced during the signaling procedure. Additionally the choice of the decision computation (on-line or off-line) is dependent upon the predefined rules entered by the administrator of the platform. Data services (Web, FTP, Mail) are not considered here as they are more immune to delay and connection dropping as compared to real time multimedia traffic which are more sensitive to delay, jitter and connection/session dropping while requiring good QoS. Delay introduced by the decision engine and the call dropping probability in outsourcing (online and off-line) and provisioning enforcement modes are shown in Figs. 9 and 10 respectively.

More resources are required in outsourcing mode than provisioning mode due to dynamics and variations involved during the former mode which has to be captured requiring intensive computation. Outsourcing mode take in to account the latest platform's conditional and environmental parameters, newest pre-configured rules and network information (external links latest state) while in provisioning mode the policies may have conflict with the platform conditions and/or resource info due to the frequent dynamics onto the platform, which might not be captured for decision making. Outsourcing mode supports both online and off-line decision computation while pre-computed decision is selected from local repository in provisioning mode.

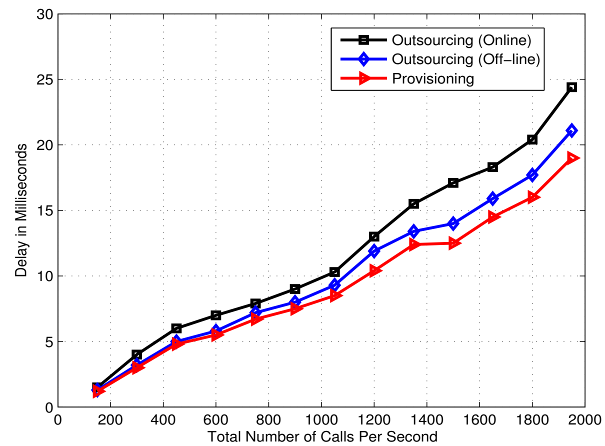

Fig. 9. Delay (Milliseconds) Introduced by the System in Outsourcing (Online and Off-line) and Provisioning Mode Respectively.

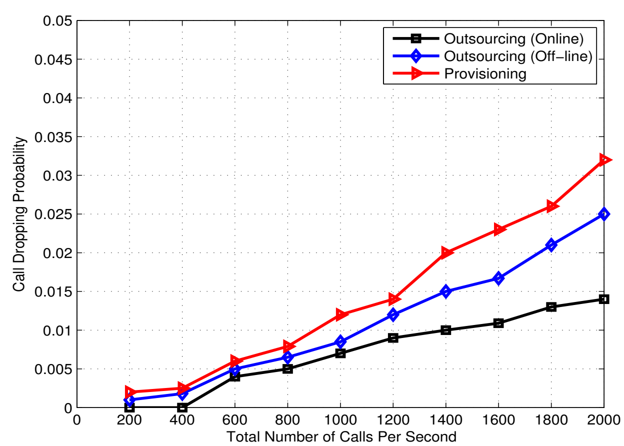

Fig. 10. Call Dropping Probability Introduced by the System in Outsourcing (Online and Off-line) and Provisioning Mode Respectively.

V. Related Work

MCDM [22], [23], [24] and PBNM [25], [26], [27] has been explored and used for rule-based network management and control independently. But the presented work here is motivated to integrate former and later theories/techniques to accomplish dynamic network management over a converged hybrid environment. There are commercial and proprietary solutions available for multimedia traffic management at higher layers (above OSI transport layer). Publicly available information does not reveal the decision-making mechanism and the LB algorithms. The core design and lower-level functionality are hidden because of commercial implications. However some vendors provide Software Development Kit (SDK) for customization of the specific solution with limited interaction and access to the core [28], [29]. Some products offer partial dynamicity with limited controls, while others are enforcing static decisions/rules. F5 networks [30] uses NAT for Load Balancing the SIP traffic to multiple links with static configurations. The proposed solution in this work accommodates the dynamic behavior of the platform and the context with the provision of provisioning mode (off-line) and outsourcing mode (on the fly or off-line) decision-making by integrating MCDM theory and PBNM.

VI. Conclusions

QoS profile of the links, user authentication/authorization profiles, business objectives of the company, reciprocal SLAs with providers, technology specific and technology independent information over converged platform, fluent dynamics over the multihomed platform and traffic management issues at private-public network border constitutes a multi-disciplinary problem. The scalability of the service, control and network/transport planes in hybrid network environment cannot be guaranteed without convergence of heterogeneous technologies. This convergence at service, control, access/transport and network level require modification/addition and updation of multi-disciplinary data sets with multiple objectives. The information coming from different sources with different dimensions reflects the complexity of the underlying problem when a single decision has to be taken on the basis of multi-dimensional information. A dynamic framework for converged multimedia network management is presented to overcome these issues. MCDM theory is used to address the multi-criteria and multidimensional facet of the problem. The proposed solution is tested for dynamic routing decision-making at the private-public network border (SIP-based multimedia traffic). The system supports two decision enforcement modes (outsourcing and provisioning). Abnormal behavior of the system is resolved by weight calculation using AHP. The system offer the provision of on line and off-line decision computation in outsourcing mode to overcome the performance issues. Existing standards and mechanisms are used for decision enforcement without introducing overheads in the protocol stack. Throughput of the individual links improved significantly where the resources are being used efficiently and effectively at the cost of susceptible delay. Aggregated call dropping probability with the proposed Decision Engine has lower values than the SBC's built-in load balancer for call routing. The same decision engine can be used for horizontal handover decision computation without system reset/restart (on the fly)

Future work includes the development of an automated lingua franca in order to specify goals, criteria, alternatives and policy rules.

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