Dynamic Decision Engine for Data Connections Routing

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***Abstract*—Companies nowadays are subscribing links to several Internet Service Providers (ISPs) for reliability, redundancy and better revenues underlying the service extension, while providing good Quality of Service (QoS). A dynamic decision-making framework is presented for SOCKS based data services over a multihomed platform that is primarily architectured for multimedia services. The decision engine takes multiple criteria (attributes from context of the request, platform's latest conditional parameters, business objectives of the company, etc.) into account while computing the routing decision. Two Multi-Criteria Decision Making (MCDM) methods, namely Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are used for weight calculation and decision-making respectively. The system supports outsourcing and provisioning decision enforcement modes. The proposed solution gives higher throughput and lower connection dropping probability with an add-on susceptible delay while fulfilling the desired goals, taking into account the multiple attributes for choosing the best alternative.**

***Index Terms*—Decision Engine, Multi-Criteria Decision Making (MCDM), Connection Dropping Probability, Throughput**

I. INTRODUCTION

Legacy network infrastructures and technologies cannot guarantee the Quality of Service (QoS), Quality of Experience (QoE) and performance requirements of voice/video and data services (FTP, Web, Mail) all together as they need diverse resources with varying set of QoS parameters. Companies use Internet to deliver these services with desired QoS. Traditionally, companies purchase multiple links to the Internet from different service providers (termed as multihoming) to address the versatile QoS requirement issue. Companies with mulihoming support also require the ability to ensure that connections in their networks are routed according to the optimal route to maximize their income and to ensure the required level of service performance. Although the primary purpose of multihoming is to enhance reliability of the network, it is also desirable to use multihoming for Load Balancing (LB) and latency reduction. However, intelligent route control/selection allows companies to take advantage of the path diversity that multihoming provides, to improve network performance while using the resources effectively and efficiently. Policy-based Border Gateway Protocol (BGP) [1] deployment is used to address the intelligent route control issue in multihomed environments. However, BGP deployment is costly and requires lots of administration effort and hence does not suit small-to-medium business. Decision-making in the intelligent route control/selection plays a crucial role in mulihomed systems. The system must take into account context of the request, platform's environmental conditions/parameters, state of the links, predefined routing rules and business objectives of the company. Multimedia sessions/connections (voice/video and other quadruple services) carry enough information about the context of the request during the signaling phase (e.g., Session Initiation Protocol (SIP) [2]) as opposed to data (FTP, Web, Email) connections. This information is exploited in decision-making for routing the request to an appropriate link in mulithomed network. The information availability with certain limitation can have an impact on dynamic decision-making for request routing in mulithomed environment.

The objective of this work is to provide a dynamic policy controlled decision-making framework (decision computation and its enforcement) for Transmission Control Protocol (TCP) based SOCKetS (SOCKS) [3] connections/session routing in consent with ongoing multimedia services over the same platform. There are mechanisms for controlling the traffic at private-public network border (e.g., Connection/Call Admission Control (CAC), Least Cost Routing (LCR), etc.). However, the decision-making mechanisms involved in these systems are usually static and/or semi-dynamic. Moreover, these systems take into account 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) etc.). It is important to mention here that the scope of an SLA is limited to exploit the relevant Service Level Specification (SLS) information extracted from the direct and/or reciprocal agreement between the company and service provider within Policy Server (PS) for decision computation.

The underlying information stated above (which has to be taken into account for request routing) comes from different sources with different dimensions, hence formulating a multi-criterion problem. The first challenge is to utilize the available information over the platform maximally, so that the final decision for link selection reflects dynamic control and effective resource utilization with good QoS. Another objective is to enforce the calculated decision using existing technologies (e.g., Network Address Translation (NAT)ing, Domain Name Service (DNS) Cycling, Hashing, Proxying etc.) without introducing overheads in the protocol stack. Multi Criteria Decision Making (MCDM) theory has been applied in order to use this multidimensional info for routing decision computation. Internet Engineering Task Force (IETF)

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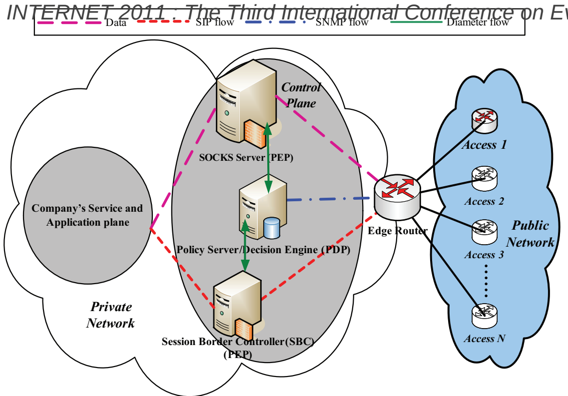

Fig. 1. Proposed Architecture.

conventional Policy-Based Network Management (PBNM) [4] framework involving Policy Decision Point (PDP), Policy Enforcement Point (PEP) and Local PDP (LPDP) is followed for decision enforcement in outsourcing and provisioning modes.

The architecture shown in Fig. 1 is proposed in Companym@ges [5] 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. PEP functionality for multimedia and data services is splitted and is being performed at two distinct locations (i-e., SBC and SOCKS server respectively). Data connections are routed to the external links by PEP, i-e., SOCKS server while taking into account business intelligence of the company, dynamics about the resources, network issues etc. Admission Control (AC) function has LCR objective and is split into profile and resource based AC and is distributed among PEP and PDP i-e., PS respectively. Communication between PDP and PEP is carried out over IMS 'Gq' [6] interface using Diameter [7] protocol. The private-public traffic management issues at the border-line regarding multimedia services are addressed in our previous work [8], [9]. The present paper is an extension to this work for data traffic. The proposed framework proposes an efficient solution by enhancing and extending the existing standards. Dynamic decision engine computes decisions by taking multiple criteria into account. In this context, tweaking of SOCKS server to act as PEP, support for decision enforcement in outsourcing (on-the-fly) and provisioning modes (off-line) respectively and the introduction of MCDM theory to solve the multi-criterion network problem are the main contributions from our side. It is an ultra lightweight solution for dynamic LCR implementation in SOCKS communication framework under the control of policy decisions.

The remainder of this paper is organized as follows. In the following Section, we describe the proposed architecture. Section III elaborates the decision theory and the application of MCDM methods. Section IV presents realization of the framework, its functionality, tools tweaked and the decision enforcement modes. In Section V, the test bed for the validity of the proposed solution is presented. Section VI outlines related work. Finally, in Section VII, concluding remarks are made while outlining the future work.

II. SYSTEM ARCHITECTURE

QoS-centered architecture integrates devices and modules from different vendors over a single platform while offering multimedia and data services for public and private (local) networks. One of the objectives of the proposed architecture shown in Fig. 1 is the accommodation of dynamic modifications/variations into the decision-making criteria for request routing to different links by using enhanced general methods/techniques. Service, control and transfer planes issues posing a multi-criteria problem are handled together without affecting the standard mechanisms and classical layered approach. The platform supports the enhanced standard protocols (e.g SIP) [2], SOCKS [3], Diameter [7], etc.) without employing overheads while the dynamics over those three planes are taken into account in decision-making.

A SOCKS based framework for the control and management in multihoming scenario is presented in order to provide better than Best Effort (BE) QoS for data services. The underlying Companym@ges [5] project stems from competitivity cluster for handling traffic management issues at the private-public network border. Components of this platform (Fig. 1) are provided by partners: the platform's service and application plane is realized by modules from Alcatel-Lucent whereas SBC, PS and SOCKS server are/will be developed and tweaked by two different teams at TELECOM Bretagne Brest. Moreover, these modules can be integrated in a single box; however, there are different teams/partners involved in this project with their dedicated solutions/packages (stand-alone boxes).

Policy Server (PS) is the main controller in the proposed architecture. It acts as a PDP. It computes all the decisions by taking into account the static configurations and dynamics taking place over the platform, in addition to the policy enforcement supervision. Decision engine proposed here while using MCDM theory partly constitutes the core of PS. It is worthwhile to mention here that functional decision engine is embedded within the architecture but PS is in development phase, so the rules are entered manually via web-based front end. Session Border Controller (SBC) in the offered framework is primarily dedicated to multimedia communication. It provides a number of vendor specific functionalities depending on the requirements and its deployment. More details are available in [8], [9].

SOCKS server is implemented in the application layer while the client is a shim-layer between application and transport layer (TCP/IP Layer Model). It allows hosts located on one side of a SOCKS server to gain controlled access to hosts located on the other side with configured rules and policies. It acts as a TCP forwarder on demand. The control, management and rule administration/application is static but we introduce dynamicity in decision-making for link selection by taking into account various parameters and attributes (user profile, QoS profile, latest state of the links/SLAs associated with these links, predefined configuration over the platform). TCP based SOCKS data connections are targeted here in this work (User Datagram Protocol (UDP) support is available in SOCKS5).

SOCKS is an application independent transport-level forwarder offering Authentication, Authorization (AA). It works in client-server mode and provides NAT/Port Address Translation (PAT) traversal and firewall services. SOCKS native AA

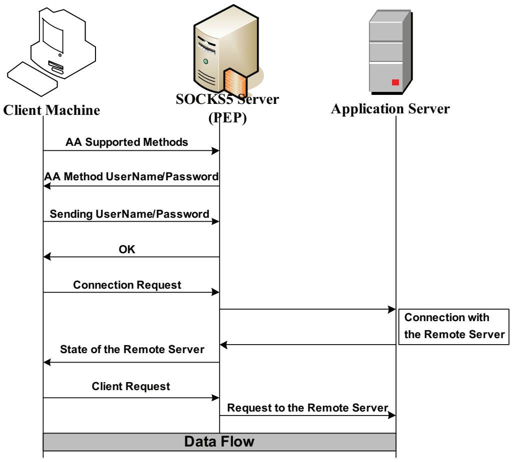

Fig. 2. SOCKS (Client, Server) Communication with Application Server.

functionality and its bi-directional proxy characteristics facilitates CAC but with static implementation. Its firewall traversal capability complements the routing at higher layers (Open System Interconnection (OSI) Application, Session layers) but with static rules and configurations. Typical communication between SOCKS (Client-Server) and the application server is shown in Fig. 2. After the AA mechanism, the connection established from client to SOCKS server carries client data to be forwarded by the SOCKS server to the application server through a simple TCP connection.

SOCKS is chosen for the introduction of dynamic decision-making framework due to the fact as network application stacks may integrate SOCKS capabilities for managing TCP connections (e.g., web browser, but some of the most popular ones lacks AA mechanism). If they don't facilitate SOCKS client then we may use a wrapper to insert SOCKS request at the top of TCP connection between the application and transport layer (TCP/IP layer model). For each socksified client request, there will be a decision to be enforced at SOCKS Server while routing the request to an appropriate link. The aforementioned data connection routing mechanism at network layer can be made workable by configuring the routers manually (access-list, route-map, static routing, etc.). However, this is not an elegant and efficient way due to its static nature and performance issues. Conventional proxy (Web) working above network layer is performing almost the similar functionality but the rules and policy enforcement are the same for all the traffic (unless a manual change is carried out), and are dedicated to web applications. There are some SOCKS proxy solutions available (e.g., Dante [10], one of the most sophisticated) but they do not take into account the latest dynamics of the platform from application, control and network point of view.

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 large number of pending requests. Common Open Policy Service (COPS) [11], a strong candidate for PBNM 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 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 [12]. SNMP-based information in our system is exploited to gauge the QoS parameters of access router interfaces. In case of communication failure between PDP and PEP, pre computed default rules are enforced depending on the context of the request offering ordinary QoS.

This paper addresses the private-public border traffic management issues for request routing decisions at the application layer (OSI). It supports dynamicity by using Multi-Criteria Decision Making (MCDM) theory. The calculated decisions are enforced in outsourcing and provisioning modes by using existing mechanisms mentioned subsequently.

III. Multi-Criteria Decision Making Theory and its Application in Dynamic Routing

MCDM involves choosing the best alternative, given a set of alternatives (available links here in the architecture) and a set of criteria (context of the request and predefined configurations/settings over the proposed platform). These alternatives are 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 [13], [14]. 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 technique and its impact on the decision-making is not within the scope of this work and reader is referred to [15] for an overview of this particular domain. However the abnormal behavior shown by certain MCDM methods for particular scenarios and the complexity involved in those methods complements our choice of the presented method for the posed problem. The targeted objectives in the multi-criteria decision-making problems might sometimes be conflicting and/or overlapping. In the underlying problem, SLA includes Delay (one-way delay is computed by dividing the round-trip delay by 2), Jitter (computed by polling the trapped values in SNMP MIB tables) and Packet Loss (calculated by counting the number of retransmissions in a particular session) (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 (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 due to space limitations.

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 (connection/session/packet level) obsession, cost, etc). The criteria are assigned different weights according to context of the 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, MCDM is chosen. Two MCDM methods have been chosen to address the problem. Analytical Hierarchy Process (AHP) [16] is used to calculate the corresponding weights of the attributes (termed as criteria in terms of MCDM) involved decision-making. The calculated weight values illustrate the relative importance of each attribute and they are used in the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank the links (alternatives). These ranked links will be used to route the SOCKS connections in consent with the business objectives of the company, user profile and platform's configurations/conditions.

A. Problem Formulation and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) MCDM Method

TOPSIS was developed by Yoon and Hwang [17]. It is an alternative to ELECTRE [18] 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 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 is that it will rank/grade the available alternatives (links) whenever applied by taking all the variations/dynamics and static configurations of the platform into account. Moreover, TOPSIS is extended to be applied on interval data (i.e. lower and upper values of an attribute) over the proposed architecture. Moreover, TOPSIS is extended to be applied in the scenario when the exact value of an attribute is not known, then these bounds (upper and lower) are used. 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. Due to space limitations and to avoid the complexity, TOPSIS is applied using the standard approach.

The system is capable of accommodating large number of links (n) with enormous set of attributes associated to those alternatives (links). But, for brevity and to avoid the complexity of stringent mathematics, 5 attributes are chosen

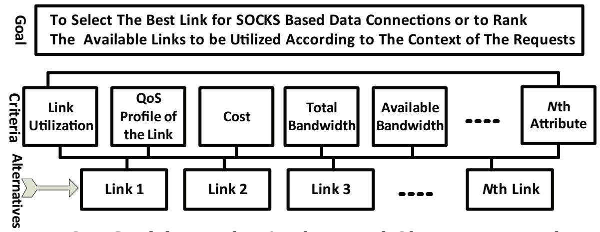

Fig. 3. Candidate Links, Attributes and Objectives Hierarchy.

for the application of MCDM methods on 4 alternative links. Figure 3 illustrates the hierarchy of the desired goal, the criteria and the available alternative links. There are four links L_1, L_2, L_3 and L_4 and for the sake of simplicity, Decision Matrix (DM) contains 5 attributes (link Utilization (U), QoS Profile of the Link (QPL), Cost (C), Total Bandwidth (TB) and Allowed Bandwidth (AB)).

$$DM = \begin{array}{c} \begin{bmatrix} U_1 & QPL_1 & C_1 & TB_1 & AB_1 \\ U_2 & QPL_2 & C_2 & TB_2 & AB_2 \\ U_3 & QPL_3 & C_3 & TB_3 & AB_3 \\ U_4 & QPL_4 & C_4 & TB_4 & AB_4 \end{bmatrix} \end{array} \begin{array}{c} L_1 \\ L_2 \\ L_3 \\ L_4 \end{array} \quad (1)$$

The values of these attributes are obtained from the SNMP traps and the SLAs of the corresponding links over the platform. Moreover the QoS Profile of the link is dependent on DJPL and it is computed by following a predefined criterion embedded by the administrator of 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., U represented in %age) is divided by the smallest value in the corresponding column vector. The normalized Decision Matrix is given by

$$\widetilde{DM} = \begin{bmatrix} \widetilde{U_1} & \widetilde{QPL_1} & \widetilde{C_1} & \widetilde{TB_1} & \widetilde{AB_1} \\ \widetilde{U_2} & \widetilde{QPL_2} & \widetilde{C_2} & \widetilde{TB_2} & \widetilde{AB_2} \\ \widetilde{U_3} & \widetilde{QPL_3} & \widetilde{C_2} & \widetilde{TB_3} & \widetilde{AB_3} \\ \widetilde{U_4} & \widetilde{QPL_4} & \widetilde{C_4} & \widetilde{TB_4} & \widetilde{AB_4} \end{bmatrix} \begin{array}{c} L_1 \\ L_2 \\ L_3 \\ L_4 \end{array} \quad (2)$$

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. AHP is used to calculate the weight of the corresponding column vector (laying out the criteria) representing an attribute column in the DM. AHP is a MCDM methodology in itself. But its ability to elicit accurate ratio scale measurements and combine them across multiple criteria has led us to use it in conjunction with TOPSIS for ranking the links (alternatives) dynamically. The integration of AHP and TOPSIS is illustrated in Fig. 4. The weighted normalized entities in the DM are represented by subscript wn (e.g., for U will be U_{wn})

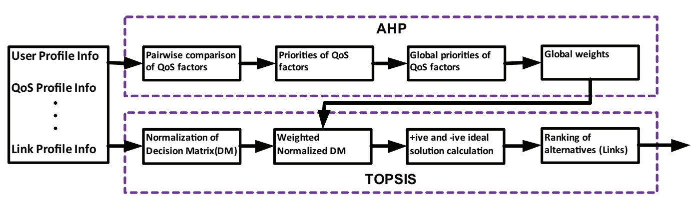

Fig. 4. TOPSIS and AHP Integration for Ranking of Candidate Links.

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., link Utilization, U)

$$U^{+} = \left(Max\left(U_{w-norm}\right)_i\right) \parallel \left(Min\left(U_{w-norm}\right)_i\right), i = 1,2,3,4 \quad (3)$$

and

$$U^{-} = \left(Min\left(U_{w-norm}\right)_i\right) \parallel \left(Max\left(U_{w-norm}\right)_i\right), i = 1,2,3,4 \quad (4)$$

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

$$S_i^{+} = \sqrt{\begin{array}{c}\left((U_{wn})_i - U^{+}\right)^2 + \left((QPL_{wn})_i - QPL^{+}\right)^2 + \left((C_{wn})_i - C^{+}\right)^2 + \\ \left((TB_{wn})_i - TB^{+}\right)^2 + \left((AB_{wn})_i - AB^{+}\right)^2\end{array}} \quad (5)$$

and

$$S_i^{-} = \sqrt{\begin{array}{c}\left((U_{wn})_i - U^{-}\right)^2 + \left((QPL_{wn})_i - QPL^{-}\right)^2 + \left((C_{wn})_i - C^{-}\right)^2 + \\ + \left((TB_{wn})_i - TB^{-}\right)^2 + \left((AB_{wn})_i - AB^{-}\right)^2\end{array}} \quad (6)$$

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

$$R_i = \frac{S_i^{+}}{S_i^{+} + S_i^{-}} \quad (7)$$

The links L_1, L_2, L_3 and L_4 characterized by attributes

	U	QPL	C	TB	AB
	%	1-10	Cost per byte(Cents)	Megabits per second(Mbps)	Mbps
L_1	66.65	5	0.50	100	65
L_2	53.84	7	0.25	100	71
L_3	81.81	6	0.30	100	81
L_4	25.00	9	0.15	100	46

TABLE I
LINKS WITH CORRESPONDING PARAMETRIC VALUES

link Utilization U , QoS Profile of the Link (QPL), Cost (C), Total Bandwidth (TB) and Available Bandwidth (AB) respectively are represented by the values shown in table I. For the application of TOPSIS on the links represented by the corresponding row vectors in table I, all the steps mentioned subsequently in this section are gone through in order. The links are ranked with R values as mentioned in table II.

	L_1	L_2	L_3	L_4
R Value	0.4025	0.5835	0.4605	0.6344
Rank	4	2	3	1

TABLE II
R VALUES AND THE CORRESPONDING GRADING OF LINKS

IV. COMMUNICATION FRAMEWORK AND ITS FUNCTIONING

A. Realization

An open source SOCKS proxy server is tweaked and enhanced to route data requests according to the context of external links, user information, and resource conditions under the control of decision engine. This article presents an add-on feature within the ongoing Companym@ges [5] project outlining the implementation of well known and existing mechanisms but with novel methodology framing the competitivity and dynamicity of the platform. Jsocks [19] is chosen as the base SOCKS package for modification and addition accordingly. It supports Internet Engineering Task Force's (IETF) SOCKS5 standard and in turn allows more adaptability, flexibility and compatibility. Moreover it requires small enough code analysis and modifications to meet the proof of concept requirements within the framework. Traffix OpenBlox [20] Diameter stack has been adapted to act as IMS Gq interface. It is an implementation of the IETF's Request For Comments (RFC) 3588. It is used for the communication between PS (Decision Engine) and SOCKS server. Diameter Attribute Value Pairs (AVPs) have been developed and used for the required mechanism following the standardized header format. However, the AVP numbers adopted here are non-registered, i-e., these AVPs are understandable onto the platform and within the partners environment only. This methodology has been adopted to avoid the delayed and long AVP registration and approval process however, in the near future, the administrative requirements will be followed. The communication between the Diameter client at SOCKS server and Diameter server within the PS is initiated by Capability Exchange Request (CER) and Capability Exchange Answer (CEA) messages. Negotiation for secured connection (TCL or IPSec) is then performed. The communication starts immediately after the negotiation using Diameter protocol over the Gq interface. WatchDog request/answer messages are often sent to check the keep-alive status of the Diameter client and server. The peers must disconnect formally by sending/receiving the Disconnect Peer Request/Answer (DPR/A). The communication flow graph is shown in Fig. 5. Non-standard AVP identifiers 2221, 2222 and 2223 are chosen for service IP, service port and username respectively. The triplet service IP, service port and username is the reference information for choosing the ranked links (graded by MCDM theory) at PS. The underlying decision is going to be enforced at SOCKS server while routing the request to external link.

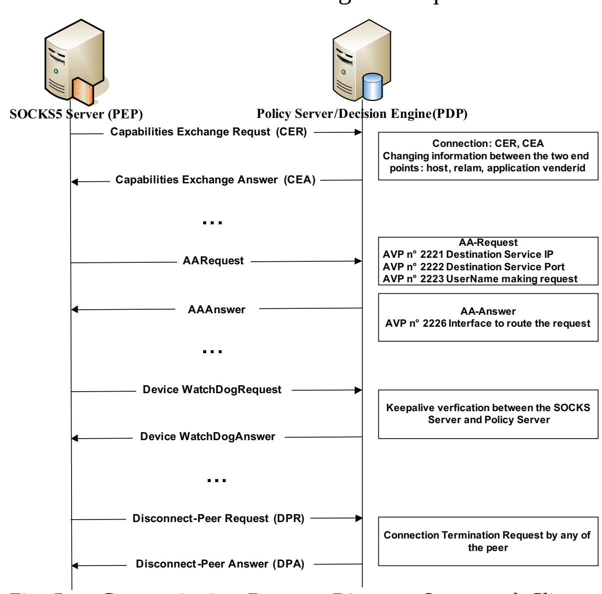

Fig. 5. Communication Between Diameter Server and Client at SOCKS Server and PS Respectively.

When a user wishes to access the service over the SOCKS communication platform, a query is sent to the SOCKS server inquiring about the supported methods (Authentication and Authorization (AA) methods. After getting the response, the user then uses an appropriate method for sending the user name and password for AA process to take place at the SOCKS server. A response (an OK) is sent back to the client. The client is now eligible to send the data connection request with the triplet (service type, service IP and service port) info. This info is extracted by the Diameter client at the SOCKS server and is then sent to the PS (Diameter server). In response, the PS sends the decision (one of the ranked links is picked) in consent with the user info and the platform's configurational parameters. Enforcement of the decision takes place to be at SOCKS server. The data connection request is routed to the remote server using that particular interface number (link). The information communication and message exchange between different entities is shown Fig. 6. The remote server answers to the SOCKS server. SOCKS server informs the client about the status of the remote machine. In case it is an OK message, the client then initiates the connection request, which is being routed over the same interface sent previously by the PS in response to the former request.

B. Policy Enforcement Modes

The framework supports two decision enforcement modes namely provisioning and outsourcing. The System however functions in outsourcing mode by default. Whenever a request arrives at the SOCKS server, it extracts the required information and sends this information to Local Policy Decision Point (LPDP) situated at SOCKS server. An appropriate rule from the rule base is mapped and one of ranked links (already available at PEP) is chosen for routing the request in provisioning enforcement mode. It is up to the administrator of the platform to choose either provisioning or outsourcing enforcement mode. However, the policy enforcement irrespective of the two modes is ultimately done at SOCKS server (PEP). In provisioning mode, the pre-computed rules and the

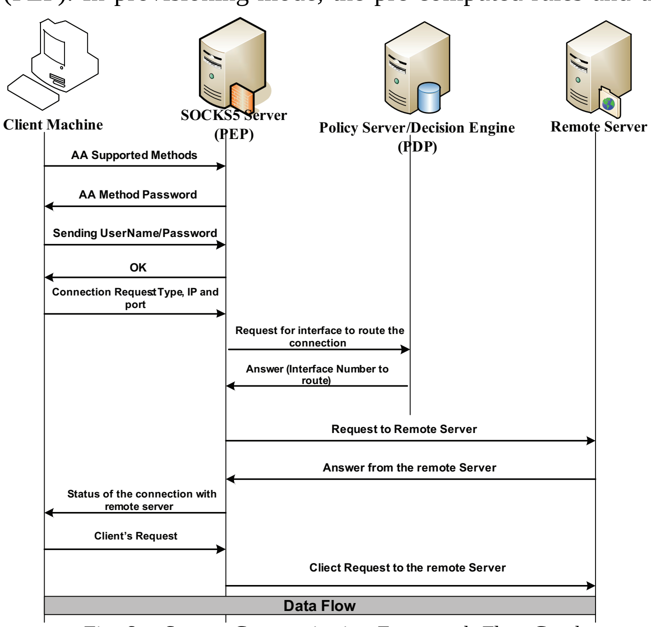

Fig. 6. SOCKS Communication Framework Flow Graph.

ranked links are available at SOCKS server. In outsourcing mode, the extracted information from the pending request is fetched to the PS (PDP) using Diameter Gq interface. PS, in outsourcing mode is delegated to compute/use online/off-line policy/decision depending on the request and the system configuration and conditions (system state). List of ranked links in the provisioning mode are fetched at SOCKS server, a-priori irrespective of online or off-line policy computation. The two enforcement mechanisms are in contrast with each other but they are not mutually exclusive. The policy-based management system is capable of handling both data and multimedia services. However, we are explaining the two policy enforcement modes while considering TCP based SOCKS data connections. The self-explanatory flow graphs give an illusion of the two enforcement modes in Figs. 7 and 8 representing provisioning and outsourcing mode respectively.

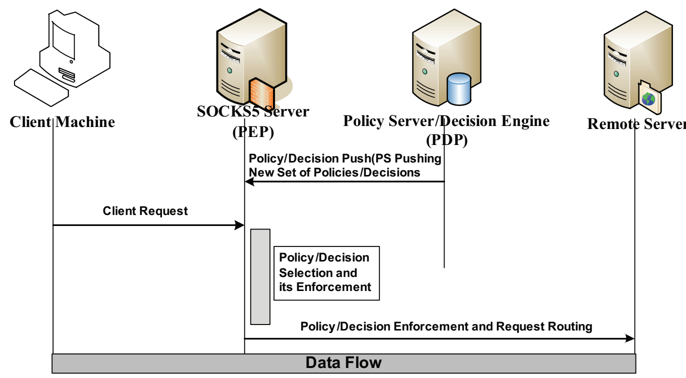

Fig. 7. Policy Decision and Enforcement in Provisioning Mode.

C. Provisioning and Outsourcing Mode Comparison

Data traffic is more immune to delay as compared to delay sensitive real time multimedia traffic. So susceptible delay in the two enforcement modes might not make any difference. More resources and computational power are required in outsourcing mode as opposed to provisioning mode. The former mode introduces higher delay than the latter one. Outsourcing mode takes latest platform conditions and network information into account. Provisioning mode, on the other hand, may have conflicts with the platform conditions and/or resource info due to the fluent dynamics onto the platform. Outsourcing mode supports both online and off-line policy/decision computation while provisioning mode has to rely on pre-ranked links.

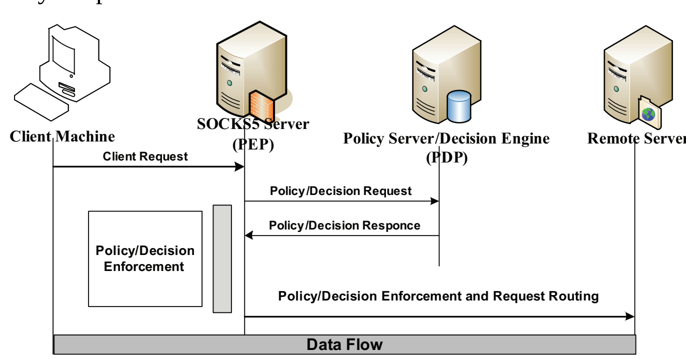

Fig. 8. Policy Decision and Enforcement in Outsourcing Mode.

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V. Test and Solution validity

The test environment for validating the proposed framework is shown in Fig. 9. The SOCKS server has four interfaces ranging from 1 to 4 for connection to the public network (external links). It has one internal interface for intercommunication within the platform. The proxy server (SOCKS server which is connected to four external interfaces marked as 1, 2, 3 and 4 as shown in Fig. 9) has four different IP subnets. Web Client on the left hand side of the Fig. 9 is connected having IP addresses from those mentioned four subnets. BitTwist [21], an open source traffic generator is used to generate extensive Ethernet-based traffic for stress testing and analysis. It is designed to compliment tcpdump or wireshark packet captures supporting captured file replay. PS is configured to listen to all the requests from SOCKS server on an interface as we are emulating the outsourcing enforcement mode. The links (4 interfaces) are ranked by using the combination of TOPSIS and AHP as explained earlier and the appropriate ranked link (interface) is chosen by following a predefined set of criteria and is ultimately disseminated to the SOCKS server. The remote web server, which is configured to listen on all those interfaces, (linked with SOCKS), displays a webpage showing the IP address of the chosen link. We then calculated the delay

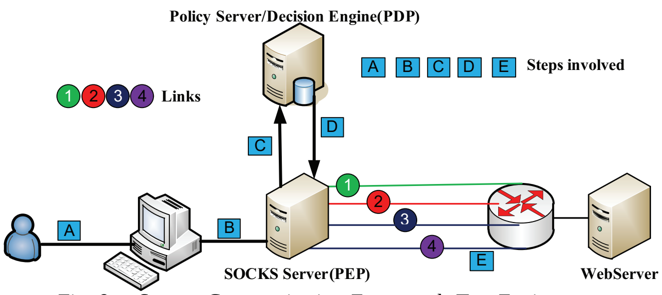

Fig. 9. SOCKS Communication Framework Test Environment.

introduced by the system with and without decision engine. The graph shown in Fig. 10 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. The delay increases almost linearly as the number of connections increases and the delay is small enough having very little impact on services due to delay-prone and sustainable nature of data traffic. The factors involved in this minor delay are: firstly decision engine is not populated with complete data sets, so the decision computation introduces negligibly small delay, secondly the TCP also contributes to this delay due to its native connection oriented approach. Thirdly, the test is performed using Personal Computers (PCs) with 100 Megabits per second (Mbps) Ethernet interfaces, so the carrier grade hardware with giga speed inter-communication interfaces/channels can make a difference. Finally, the information extraction from the request at SOCKS server which is going to be sent to the PS for decision-making and the policy enforcement mechanism also contributes to this delay. The testing of the same platform while using UDP may be an interesting future work. Throughput of each link is plotted with and without decision engine as shown in Fig. 11 It is observed that there is

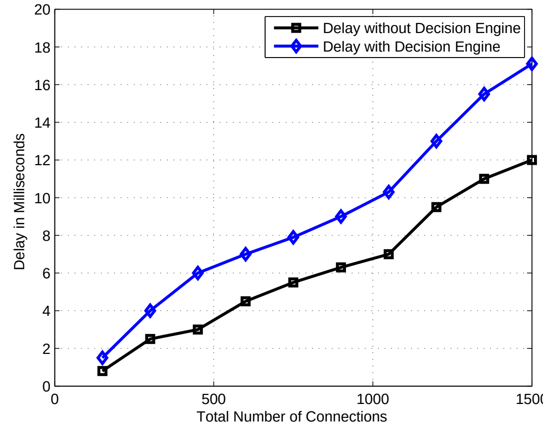

Fig. 10. Delay (Millisecond) Introduced by the System with and without Decision Engine.

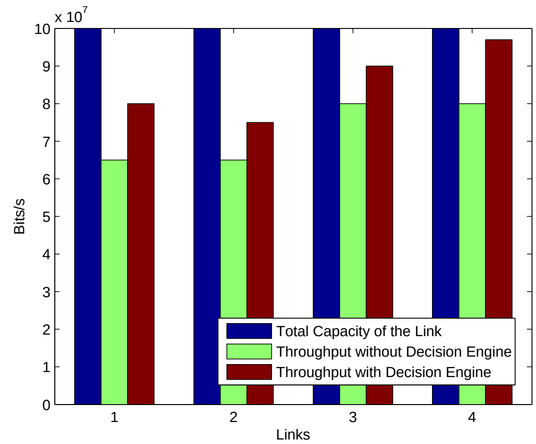

Fig. 11. Throughput of each Link with and without Decision Engine.

a significant improvement in the throughput for each link with decision engine. This improvement illustrates the effective and efficient utilization of resources by decision system by taking all the dynamics and variations along with business rules of the platform. Decision system supports connection level granularity so the connection dropping probability is also plotted with and without the underlying Decision Engine. It is observed that the aggregated connection dropping probability with decision engine of the four links has lower value than without it as shown in Fig. 12. The presented decision engine is relatively simple and easy to realize the computer programming so can be easily embedded into systems with little complexity.

VI. Related Work

Currently there are growing number of research and proprietary efforts related to Multimedia Load Balancing focusing SIP [22], [23]. The core design and lower-level functionality are hidden because of commercial implications. Some vendors offer partial dynamicity with limited controls, while others are enforcing static decisions/rules [24]. A dynamic framework for load balancing in multi-homing scenario is presented by taking into account multiple criteria involving the service, control and network issues all together. MCDM theory is used to address the issue of dynamic variations and configuration from different planes with different set of objectives. This

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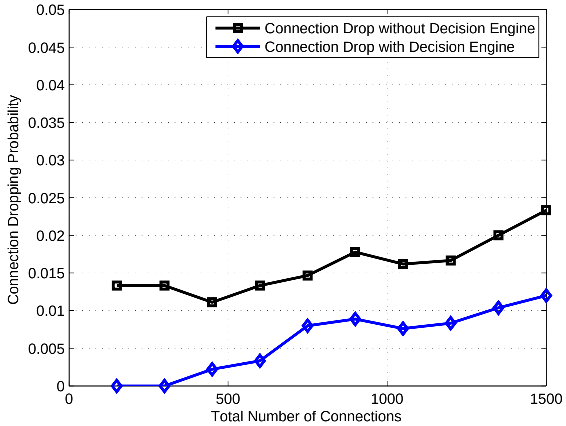

Fig. 12. Connection Dropping Probability with and without Decision Engine.

theory is used for access network technology (UMTS, GSM, WLAN etc) selection during the handoff based on user preferences [25]. A user priority scheme for admission control using Analytic Hierarchy Process (AHP) is proposed in [26]. Two MCDM methods namely AHP and TOPSIS are used in this framework for weight calculation and ranking of candidate link in multihomed network.

VII. Conclusion

QoS profile of the links, user authentication and authorization profiles, business objectives of the company and fluent dynamics over the multihomed platform constitutes a multidisciplinary problem. 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 multidimensional and multidisciplinary information. Conventional algorithms used for dynamic routing at higher layers in multihoming setups are either application oriented or are service dependent. Performance optimization is the ultimate goal in some cases while the others are technology specific. To address all these multi-facet goals in addition to the dynamics and fluctuations over the platform, MCDM methodology is required. A dynamic decision engine for SOCKS-based routing is presented. The system is capable of accommodating the fluent dynamics while handling a large set of attributes representing the underlying criteria in MCDM. Analytical Hierarchy Process (AHP) is used to calculate the weight of the corresponding attributes. These weight values are exploited in Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank the alternatives (links). The system supports two decision enforcement modes. Decisions are computed on-the-fly in outsourcing mode while one of the pre-ranked links is chosen to route the request in provisioning mode (off-line). Existing standards and mechanisms are followed without involving overheads in the protocol stack. A test bed is developed to validate the solution. Throughput of the individual links improved significantly mentioning that the resources are being used efficiently and effectively at the cost of susceptible delay. Aggregated connection dropping probability has lower values than without the Decision Engine. Future work includes the interconnection of MCDM and conventional Policy-Based Network Management through the development of an automated linguistics in order to specify goals, criteria and alternatives.

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