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## Stochastic MCDM Framework Over Converged Infrastructure

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### Abstract

Service unification and application integration have brought about vendors, network operators, service providers, carriers, businesses and infrastructures over a platform while offering the business plans, presenting solution packages, proposing virtualization strategies and outsourcing the resources whereas promising an all Internet Protocol (IP) setup. Diverse business goals from distinctive providers alongside the technology merger and service unification in addition to dynamic border traffic management issues introduce more complexity over such platforms. A decision-making framework for handling the border traffic management issues at private public network with multi homing support is presented. Augmented Multi Criteria Decision Making (MCDM) theory addresses the qualitative entities while constructing the structural hierarchy of goals, criteria, sub criteria and alternatives. Inter/Intra-domain knowledge over different planes (service, control and transport) is modeled by using ontology. Blending ontology with Bayesian captures uncertainty over the planes. A simple use-case is presented over the test-bed to validate the proposed solution. The system offers higher throughput with lower call/session/request drop at the cost of an add-on delay.

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### 1. Introduction

Policy-based network control and management have risen to the forefronts of telecommunication industry and Information Technology (IT). Dynamic policy/rule-based management has emerged as a promising solution for the administration and control of heterogeneous and converged networks with multi homed infrastructure. The fundamental characteristics of such rule/policy-based frameworks are efficient and effective resource utilization over the infrastructure by accommodating flexibility, variability, frequent dynamics, service tearing down and application fusion, business logic variations and global/local change management. The ultimate goal is to adapt the behavior, context and variations dynamically without resetting/restarting/stopping and/or modifying/revamping the system. The aforementioned objectives are made possible by inheriting the corresponding local and global knowledge base from different domains/planes over the hybrid platform having multi dimensional business objectives correlated with diverse technological

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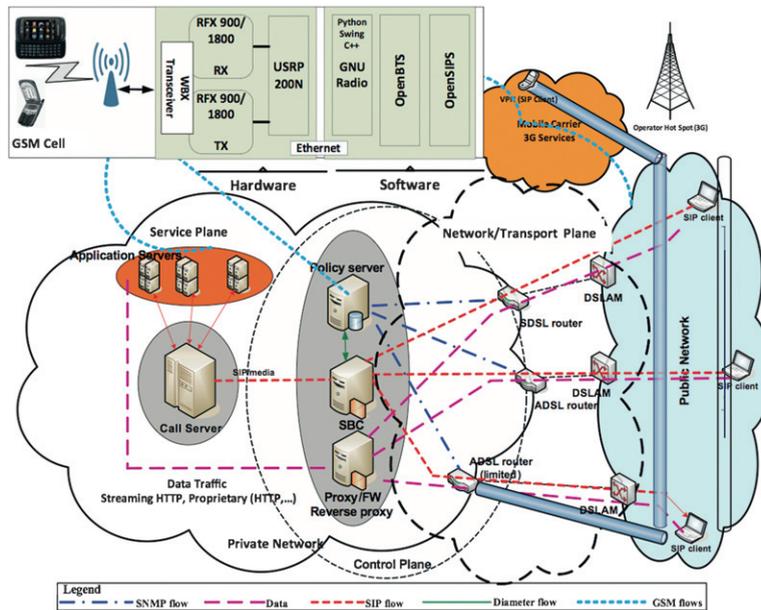


Fig. 1. Proposed Architecture

and physical span and scope. This multi-faceted knowledge base along with multiple business goals in addition to different set of administrative configurations over the heterogeneous platform has to be exploited for policy/decision/rule computation. These policies/decisions/rules are meant to govern the behavior of the communication infrastructure by enforcing these decisions at different granularity over the platform.

Conventional decision-making systems take into account the technology specific and technology independent information solely (devices, interfaces, protocols, architecture, topology etc.) related to the network infrastructure while computing the management and control decisions. Application specific data sets, corresponding attributes over the service plane, control oriented metrics and the business objectives over the platform are not considered and/or they are taken into account partially. However the systems meditating the business objectives may not be able to capture the required granularity. The specific solutions considering the control and network layer metrics are ignoring the border traffic management problems/concerns at higher layers. The systems accommodating the services information have to be handled in an abstracted way regarding the service scalability and extensibility. Above all, the latest systems targeting the aforementioned issues might not be able to provide required dynamicity for effective control and efficient management over such converged and hybrid systems with multi-homing support. Furthermore platform's multidisciplinary and multivariate information domains (layers/planes) are Globally Asynchronous and they are Locally Synchronous while forming the GALS system. Inter/Intra/Cross domain, planer and layered static and dynamic information over the unified infrastructure are characterized by extrinsic and intrinsic info. The subsequently mentioned distinct info sources present a multi-criterion problem while reflecting the multiple objectives globally and locally. It is therefore indispensable to alleviate and accommodate the accumulative multiple dimensions, disparate criteria, diverse goals and varying application/service/business logics over the GALS infrastructure. Moreover the information sources over the distinctive planes (Application, Service, Control and Transport planes) are structured and synchronized (intra-planer and inter-domain) locally. But global view of the same information infrastructure reflects highly unstructured and asynchronous representation (inter-domain inter-planer). Authentication/Authorization/Accounting information, application tearing down methodology, service logic, link profiles, global business objectives over the infrastructure, frequent dynamics over the unified platform and traffic management concerns at private public network edge represent a multi-disciplinary problem. The information coming from distinctive sources with diverse dimensions illustrates the density of the problem.

There are certain classical and typical modules that accommodate such problems over these converged environments with multi-homing infrastructure. But they are either user-centric or motivated towards effective resource utilization over the platform and/or they are centered towards application optimization for required Quality of Service (QoS) and desired Quality of Experience (QoE). However to cope with user authorization/authentication profiles, business objectives of the different companies offering their services and resources over the platform, straight and/or reciprocal SLAs with corresponding carriers, technology

dependent and technology independent information over the converged platform; an adequate, efficient and dynamic decision-making system is required. Moreover, the continual and continuous variations over the underlying infrastructure with core network traffic control problems in addition to the in-bound/out-bound border traffic handling all together can only be resolved with a competitive, capable and adepted decision-making framework. Furthermore, the scalability, extensibility and performance of the said decision-making platform must be taken into account even though the granularity over the Companym@ges<sup>1</sup> architecture shown in Fig. 1 deals with calls/sessions/requests rather than individual packets. The convergence at service, control, access/transport and network level requires modification/addition and updation of multi-disciplinary data sets with multiple objectives. Diversity and dimensionality of the criteria and/or sub-criteria extracted on the basis of contextual information and platform conditions, multifaceted goals deduced from the service/application/business logic and finally multiple objectives associated with the alternatives over the platform require Multi Criteria Decision Making (MCDM) theory in order to accommodate the diversified former and latter info for decision making.

The ingredients of the framework range from raw data collection to information model construction while leading towards semantics capturing mechanism. Behavioral, communicational and functional modules/components are tied up globally and locally keeping in view the planer isolation. Management and control of the layered infrastructure is carried out by revamping the sole signaling protocols (e.g. Diameter [1], SNMP [2] and Session Initiation Protocol (SIP) [3]). The language over the platform that is deeply rooted inside the platform sticks all the constructs, macro/micro rules, business logic, global and local objectives and administrative policies over the platform. Decision-making and its enforcement regarding the call/request/session routing at the private public network border is emphasized solely here due to space limitation.

The paper from now onward is organized as follows: In the following section, related work is presented. Section 3 outlines the platform's architecture. Section 4 elaborates the requirements of MCDM theory and its deployment over the proposed architecture. Test bed for the validity and proof of the concept over the proposed infrastructure is presented in section 5. Section 6, includes the concluding remarks in addition to future work.

## 2. Related Work

Policy Based Network Management (PBNM) and control frameworks have been proposed by numerous authors and forums [4, 5, 6, 7]. The disintegration of PBNM working group leads to the characterization of distinctive forums and standard bodies. The solutions proposed by some working groups (i.e. Autol by EU FP7 IST, IMS by 3GPP, ETSI, ITU, FOCALE etc.) [8, 9] are specific while targeting the particular architecture. To the best of our knowledge there is no general-purpose and/or technology independent solution that accommodates the diversity, dynamicity, heterogeneity and dimensionality. The known layered methodologies and mechanisms at the services, applications, control, transport layers and network infrastructure work at different granularity (packet level). The proposed solution offers service, application and technology unification with access plane convergence while capturing the dynamic variations and frequent fluctuations. Specific techniques (ontology), subjects (MCDM) and tools (Bayesian) are revamped and integrated in order to propose the multi-faceted solution. Ontology [10] and MCDM [11] have been used for rule-based network management and control individually and exclusively. There are numerous efforts that have been done for PBNM [12, 13] with static and/or partially dynamic network management and control. IMS works on the basis of layered approach at fine granularity while producing huge signaling traffic in addition to fact that it is still in its evolution phase. The proposed solution in this work overcomes the subsequently mentioned issues as it works at call/session/request level granularity. It provides decision-making and its enforcement at higher OSI layers (Application and/or Session layer).

## 3. Proposed Infrastructure and Framework Requirements

Companies nowadays are approaching towards unified communication paradigm by leasing and subscribing different access technologies from different carriers and providers for availability, reliability and redundancy in order to provide 24/7 service up time while providing good QoS and QoE. Dimensionality and diversity of the company's service, control and transport planes in addition to multiple objectives over

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<sup>1</sup>Companym@ages is a FUI project, led by Alcatel Lucent. The partners of the project are Telecom Bretagne France and Comverse.

these planes having multi-homing support to give rise the challenge of formulating a framework for such hybrid and heterogeneous environment where services and solutions have to be unified. Access technology merger, network infrastructure change management, service integration, applications fusion and concentrated control and management mechanisms at the core and edge are the key driving forces towards this unified framework with an all IP infrastructure. The convergence of data, voice, video, triple play and quadruple services over the company's platform requires carrier grade performance with resilience. Moreover, the infrastructure must provide promising and effective QoS to ensure that delay and jitter sensitive multimedia traffic is getting enough resources even during congestion and heavy traffic load time spans. This is what is targeted in one of the modules (Policy Server; prioritized in the present work) in Company@ges project. It integrates distinctive services, binds corresponding control interfaces, stacks a number of signaling, control, access and transport protocols in addition to blending of network access technologies. Distinct service providers over the underlying architecture while providing number of services are interfaced to the global service, application and technology village (public network) via different network accesses (links). Registered users over the platform can even access the underlying services in a nomadic manner. It is therefore vital to enable the company (providing the infrastructure and platform) to implement the rule-based optimization of the underlying access links while emphasizing the private public network border traffic control and management matters. Proliferation of diverse networks, vendors and providers (heterogeneity of networks and increasing number of services, vulnerabilities etc.) highlights the imperative role of traffic management and control problems at the edge. Convergence, unification and heterogeneity orientation of the multifaceted domains with distinctive knowledge-base require dynamic management and control.

QoS-oriented converged infrastructure shown in Fig. 1 provides a resourceful, well-organized and cost effective platform highlighting the service unification while emphasizing/answering private public network border traffic management issues/questions. It integrates components, devices and modules from corresponding vendors over the platform while integrating different services/applications over the public (internet) and private (local) networks. The prime and global objective is the accommodation of fluent modifications and frequent variations during the decision-computation (decision-making) by integrating, enhancing and tweaking the conventional mechanisms and techniques without introducing the overheads. Service, control, network/transport problems and local/global routing problems constitute a multi-criteria problem and they are handled together by adopting the classical layered approach.

Part of the GSM cell and Application Servers (AS) constitutes the service plane, Call Servers (CSs) over the GSM cell and fixed infrastructure respectively, proxy server, Session Border Controller (SBC), Policy Server (PS) forms the control plane and wire-line/wireless distinctive access technologies at the private public network border incorporates the network/transport plane. However some of the functional and behavioral mechanisms and procedures of these planer constituent building blocks are shared and overlapping. More details about the modules, sub-modules and the components, sub-components, their inter-communication and their behavior over the proposed architecture are available in [14].

The policy system supports multi-service and multi-vendor environment having diverse technology convergence with high variability while isolating the service, control and network/transport planes. The decoupling of the three planes results in CAC functionality distribution into profile and resource related functions that are being carried out at two distinct points; CS and SBC respectively. The policy/decision computation takes SLAs, business objectives, routing rules, services information, QoS of the accesses (links) and profiles into account. The SNMP [15] flows presented in figure 1. are used by the policy server to gauge the QoS of the external links by performing statistical analysis on captured metrics (delay, packet loss etc). Diameter [1, 16, 17]; a native Authentication, Authorization and Accounting (AAA) protocol is modified accordingly in order to communicate/disseminate the information/decisions/rules between PS and SBC. New Attribute Value Pairs (AVPs) are defined and developed over the infrastructure. Diameter has a large AVP space offering pending request and flexibility support while working in Peer to Peer (P2P) mode. But it can also be tweaked for additional client-server side applications. Its native AAA orientations and enhancement characteristics complement its choice over the decision-making framework.

Space limitation restricts the focus exclusively on routing-rule computation (by taking into account the knowledge-base from different information domains and the fluent dynamics occurring over the presented platform) at core-edge network boundary while highlighting the multimedia traffic. Multi Criteria Decision

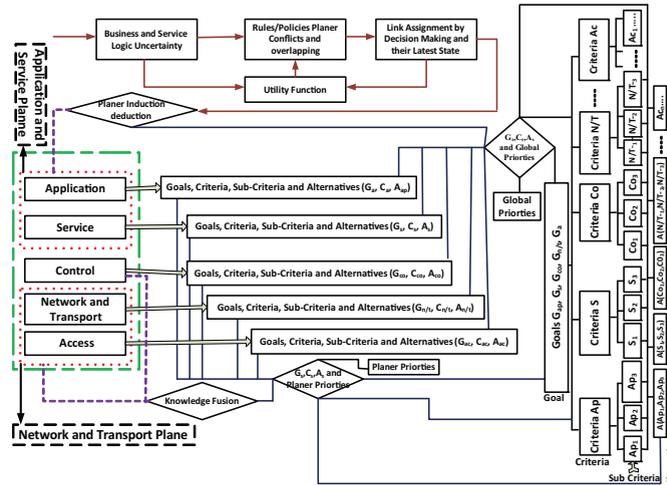


Fig. 2. Frameworks Layered and Planer Stack With the Corresponding Mapping of Goals, Criteria and Alternatives Hierarchy.

Making (MCDM) theory is exploited to handle the multidimensional orientations with multiple objectives in addition to varying set of attributes and parameters. Inter/Intra-domain knowledge over distinct planes (service, control and transport) is modeled by using ontology. But ontologies are not capable of capturing the uncertainties involved over the aforementioned distinctive planes (service, control and transport planes over the proposed architecture). Uncertainties over the infrastructure are captured by integrating ontology with Bayesian.

**4. Multi Criteria Decision Making Deployment Over the Architecture**

MCDM over the platform involves choosing the best alternative (best link), given a set of alternatives (multi-homed available links for simple use-case) and the criteria/sub-criteria (contextual info of the request and a-priori infrastructure knowledge and the set of global configurations/settings). Business logic over the platform, service and application profiles, link states, straight and reciprocal SLAs, layer 2 (OSI model) technology convergence and distinctive user profiles has to be dealt qualitatively and quantitatively. The variables and metrics extracted over the service, control and transport planes in addition to the former issues establish a multi-disciplinary problem with multiple goals. However to address the multi-dimensional characteristics of attributes and parameters (reflecting the multiple diversity) that are induced/deduced over multifaceted service, control, transport, network and access planes, MCDM methods are revamped and integrated. Framework’s layered stack and the corresponding planer/domain information with consequent mapping of different parameters/attributes (metrics) is presented in Fig. 2. The Goals (G’s), Criteria (C’s) and Alternatives (A’s) with the explicit subscripts over these distinct layers present the relevant and corresponding information. The underlying mapping of G’s, C’s and A’s in coordination with the planer info assists in hierarchy construction by declaring the corresponding goals, setting the criteria/sub-criteria and finalizing the alternatives.

Fig. 2 demonstrates a simple use-case containing distinct links and a set of attributes that are inferred and/or extracted over the framework (from service, application, control, network and transport planes in addition to the access technology set-up). Decision Matrix (DM) after the extraction, deduction and inference of the corresponding info for the application of MCDM method is given by eq. 1

$$DM = \begin{bmatrix} TA_1 & D_1 & J_1 & LR_1 & TB_1 & AB_1 & CS_1 \\ TA_2 & D_2 & J_2 & LR_2 & TB_2 & AB_2 & CS_2 \\ TA_3 & D_3 & J_3 & LR_3 & TB_3 & AB_3 & CS_3 \\ TA_4 & D_4 & J_4 & LR_4 & TB_4 & AB_4 & CS_4 \end{bmatrix} < -L_1 \dots -L_4 \tag{1}$$

Technology Attribute *TA*, Delay (*D*), Jitter (*J*), Loss Rate (*LR*), Total Bandwidth (*TB*), Available Bandwidth (*AB*) and Contextual Situation (*CS*) respectively represent the corresponding criteria illustrating the vertical column vectors within the DM. Horizontal row vectors characterize 4 alternative links *L*<sub>1</sub>, *L*<sub>2</sub>, *L*<sub>3</sub> and *L*<sub>4</sub> respectively within the DM. MCDM methods are modified and tweaked for their application accordingly and the alternative links are ranked for routing the call/session/request to one of the candidate links.

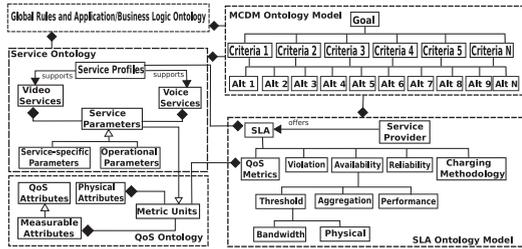


Fig. 3. Global Rules, Application/Business Logic, MCDM, SLA and Service/QoS Ontologies.

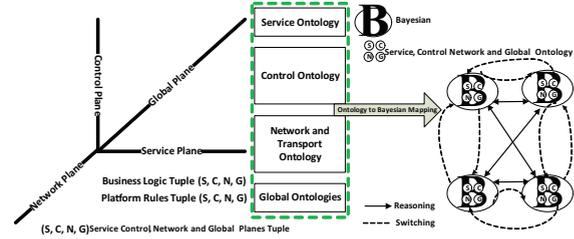


Fig. 4. Ontology Mapping By Bayesian.

These routing decisions are computed on the basis of ongoing contextual information, pre-configured rules, business logic, global objectives over the platform etc. Details about the modification, enhancement and application steps of different MCDM methods are available in [18].

MCDM theory over the framework can handle the multiple goals gathered globally and locally, diverse attributes/parameters/metrics emerging from distinct sources and inferred inter/intra planer data sets in addition to the contextual scenarios. The subsequently mentioned information sets reflect the disparate dimensionality. However the semantics variations, inter/intra-planer affiliations, knowledge inference and deduction while accommodating the frequent dynamics cannot be handled simply by deploying the MCDM theory. The underlying problem is addressed by integrating ontology with MCDM. Ontology design and development is not within the scope of this paper. Moreover it is almost impossible to show the ontology-space used in this work on a paper while reflecting a specific domain. However the snapshot of global rules, application/business logic, MCDM, SLA and Service/QoS Ontologies is shown in Fig. 3. But frequent dynamics over the platform, overlapping of the concepts among service, control and transport planes and uncertainty regarding the inter/intra domains/classes/instances can not be captured by ontology solely. This issue is handled by ontologies mapping by using bayesian [19, 20]. Blending ontology with bayesian for capturing the underlying uncertainty is shown in Fig. 4. Block diagram of the system illustrating the MCDM, ontology and Bayesian integration is shown in Fig. 5. Business logic and service logic are defined onto the platform a-priori. Arrival of each session/request/call triggers a novel context. Moreover change up to a predefined threshold over the service, control and transport planes are also considered as contextual variation and as a consequence new rule set is overloaded. Corresponding ontologies are overridden and inherited. Ontology feedback improves the structural hierarchy during the ontology overloading while the Bayesian feedback improves the stability while diminishing the node uncertainty to some extent. All components are interconnected via a trigger/control bus.

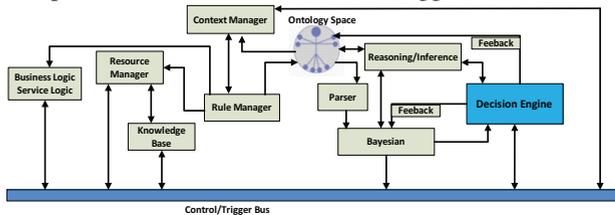


Fig. 5. System's Modular Diagram.

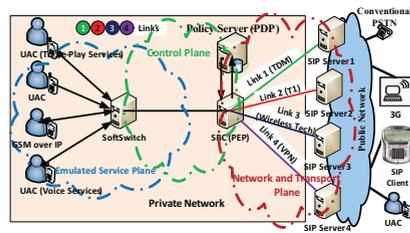


Fig. 6. Testbed for Solution Validation.

### 5. Experimental Setup for System Validation

Though the proposed system is capable of handing all sorts of traffic over the converged infrastructure. But due to space limitation only SIP-based multimedia traffic (voice, video) is targeted and the routing decision-making is enforced at private public network border for call/session/request routing dynamically. Testbed used for validating the proposed framework is shown in Fig. 6. SIPp [21]; a traffic generating tool for SIP protocol, is used to generate large number of SIP requests (INVITE, Re-INVITE etc.). OpenSIPS [22] is tweaked to act as B2BUA and SBC for slave and master deployments respectively. Master OpenSIPS, in addition to its native functionality is tweaked to function as Policy Enforcement Point (PEP) for decision enforcement. More details and information sharing over the framework in consent with dynamic routing decision-making at private public network border is available in [18]. Modified MCDM methods (Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [23], Extended TOPSIS and Grey Relational Analysis (GRA) [24] are integrated with AHP [25]) and then applied to the same use-case of 7

criteria and 4 alternative links (eq. 1) over the testbed shown in Fig. 6. PS acting as Policy Decision Point (PDP) has the provision of online and offline decision computation depending upon the administrative configuration over the platform.

Throughput, Call Dropping Probability (CDP) and Delay are plotted using the integrated MCDM methods and is shown in Fig. 7. It is observed that the throughput of the individual links is improved with significant decrease in aggregate call drop (Fig. 8). The substantial throughput increase and reasonable call drop is observed as the proposed decision system is now taking into account contextual information and fluent dynamics and variations. Moreover multiple objectives are being considered in addition to inter/intra-domain and inter/intra-plane dependencies. Semantic and relational dynamics are being captured. Additionally the linguistic quantification of the business objectives and other administrative and configurational parameters by using Saaty's scale (AHP integration with the 3 MCDM methods) helps in true numerical value translation and conversion with their inter/intra-dependence. There must be a clear distinction between TOPSIS and Extended TOPSIS in terms of aggregated CDP as Extended TOPSIS is supposed to accommodate the dynamics over the platform in addition to capturing uncertain and indefinite behavior of the corresponding attributes. But the curves for these two methods show almost identical behavior. The similarity and conduct of these two methods is due to the fact that the platform chosen reflects the simple use-case involving few attributes facing little dynamicity. It is thus foreseen and apprehended that addition of more links and attributes may draw a clear line between these two methods in terms of call dropping probability. GRA and integrated MCDM methods are forming another group regarding the CDP while the former method gives the lowest CDP; as GRA is taking the micro/macro contextual information into account by constructing the ideal reference link that has to be reused throughout the computation. The integrated method on the other hand is accommodating the semantics information while capturing the uncertainties. The cost of this

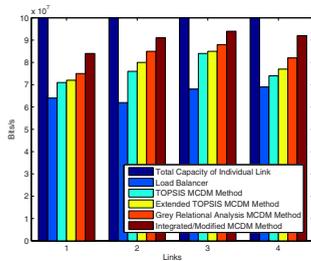


Fig. 7. Throughput of Links with Built-in Load Balancer (LB), TOPSIS, Extended TOPSIS, GRA and Integrated/Modified MCDM Method.

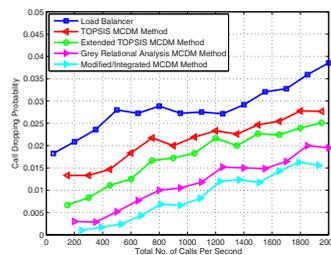


Fig. 8. Aggregated Call Dropping Probability By Using the Built-in LB, TOPSIS, Extended TOPSIS, GRA and Integrated/Modified MCDM Method.

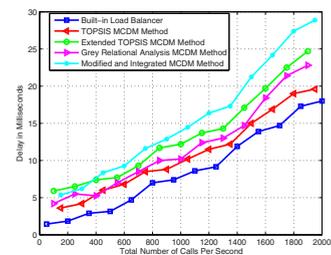


Fig. 9. Delay Offered By the System By Using the Built-in Load Balancer, TOPSIS, Extended TOPSIS, GRA and Integrated/Modified MCDM Method.

improvement is an add-on delay system has to bear while computing the decisions shown in Fig. 9. Semantics capturing via reasoning and inference, uncertainty accommodation and the contextual information deduction of the ongoing request/call are some of the main root causes of this additional delay. Moreover the intra-domain/plane correlations and associations may also be sources of this add-on delay. Linearity is observed among the number of calls/requests/sessions and the delay (i.e. delay increases almost linearly as the number of calls/requests increases). The add-on delay introduces a little and/or no impact on unified services as the decisions are computed and enforced during the call/session/request setup.

### 6. Conclusions

Stochastic MCDM framework with converged infrastructure while offering unified communication is presented. Inter/Intra/Cross-domain/plane static and dynamic information (macro and micro) around the GALS system is considered over the platform. Behavioral, communicational, functional, modular and component based global and local data sets over the architecture have been exploited for dynamic decision-making. Dynamic routing decision-computation of multimedia requests/calls/sessions at the border of the company is emphasized in this work. Diverse signaling protocols, stacks and suits are revamped and developed for adaptability, flexibility and compatibility by following the layered approach (application, service, control, network, transport and access technology planes). Different MCDM methods are tweaked and integrated accordingly. Inter/intra-domain/plane semantics variations over the system are captured by ontology development. Frequent variations, fluent dynamics, rapid business logic alterations and service/application

scalability/tearing-down cause uncertainties that are being captured and modeled by Bayesian mapping. Proposed solution supports on the fly and off-line decision computation. Developed test bed validates the proposed framework by evaluating certain metrics (throughput, call dropping probability, delay). Resources over the platform are being used efficiently and effectively as higher throughput of individual links (alternatives) is observed after deploying the system. Aggregated lower call drop illustrates that the routing decisions computed/enforced are in agreement with the infrastructure's latest conditional and environmental circumstances. The cost of the underlying improvement in shape of high throughput of individual links and lower aggregated call drop is vulnerable delay (having little impact as the decisions are being computed and enforced during call/session/request set-up). Development of dedicated language for the specification of global/local and planer/domain business logic, administrative rules, routing rules, MCDM ingredients, ontologies and the corresponding mappings is an ongoing as well as future work.

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