

Over-provisioning Centric Network Resource Control in Future Internet Systems

S. Jardim¹, A. Neto^{2,4}, J. Castillo Lema^{2,3}, E. Cerqueira⁵, F. Silva⁶

¹Informatics Institute, Federal University of Goiás, Goiânia-GO, Brazil

²Teleinformatics Engineering, Federal University of Ceará, Fortaleza-CE, Brazil

³Computer Engineering, University of Coruña, Coruña, Spain

⁴Institute of Telecommunications, University of Aveiro, Aveiro, Portugal

⁵Computer Engineering, Federal University of Para (UFPA), Belém-PA, Brazil

⁶Federal University of Rio Grande do Norte (UFRN), Natal-RN, Brazil

sandinojardim@inf.ufg.br, augusto.deti@ufc.br, jose.castillo@udc.es, cerqueira@ufpa.br, fdantas@ppgsc.ufrn.br

Abstract— Envisioning to meet the expectations arising from the *Future Internet*, and specifically to provide efficient *Quality of Service* (QoS) support for multimedia multi-user sessions, the attempts by the research community have resulted in mechanisms such as *Multi-User Aggregated Resource Allocation* (MARA). The MARA mechanism adopts an over-provisioning centric strategy to control surplus class-based bandwidth reservations and aggregate IP multicast trees, which allows to significantly improve network performance through a signaling-constrained approach. The results of MARA have been promising, mainly because it drastically reduces signaling and processing overhead. Although MARA has emerged as a promising QoS control mechanism, it was designed exclusively for single-ingress scenarios, thus restricting its applicability in today's and future networks that mostly adopt multi-ingress capabilities. Therefore, this paper proposes the *Multi-User Aggregated Resource Allocation – Multi Ingress* (MARA-MI), whose main extension can be found in a new architecture that is able to correlate aggregate IP multicast trees and to assist the adaptation of the over-reservation patterns in multi-ingress scenarios without the possibility of QoS violations and waste of resources occurrence. The overcoming of the main limitations of previous MARA, confirmed by results, qualifies MARA-MI as a promising tool for today's and future IP-based network systems.

Keywords— component – QoS, Over-provisioning, future IP-based network systems, Multi-user communications.

I. INTRODUCTION

The inability of current Internet to fulfill the rigorous Quality of Service (QoS) requirements of multimedia sessions, such as audio/video conference, (web) IPTV, immersive video and video surveillance has led the research community to define innovative mechanisms for the architecture of the Future Internet. Among others ultimate capabilities, the proposals foresees support for multimedia multi-user sessions with QoS guaranteed over a period of time.

Proposed to provide enhanced networking in the Future Internet, *Multi-user Aggregated Resource Allocation* (MARA) [1] deploys an innovative over-provisioning centric approach by seeking dynamic control of per-class surplus bandwidth reservations (over-reservations) and aggregated IP multicast trees. The architecture of MARA (henceforth called Legacy MARA) was designed by adopting a signaling-constrained

approach, which only allows the system to be signaled in two situations: (i) to bootstrap the network resources at the system boot-up; (ii) and when it is required to adapt the over-reservation patterns, to provision over-reservations and admit multiple flows without instant signaling events. The previous evaluation results of Legacy MARA [2] confirmed that it outperforms related (including standard) solutions, mainly by improving the bandwidth use that is influenced by the signaling-constrained approach, while drastically optimizing the overall network performance (e.g., CPU/memory overhead, and energy consumption, among others).

Despite the benefits described above, Legacy MARA was architecturally designed for systems hosting a unique ingress router, which allows complete control of all available data paths without the need for concern about other control nodes. However, current ISPs host multiple ingress routers in their systems, which drastically restrict Legacy MARA's deployment. This limitation has led us to adapt Legacy MARA to the systems mentioned above, as well as to the Future Internet, since we believe that the over-provisioning strategy is a promising approach that allows efficient support for multimedia multi-user sessions, while drastically optimizing the network performance at the same time.

However, defining Legacy MARA's architecture is not a simple matter, as is revealed in the following section. On the one hand, Legacy MARA processes the adaptation of over-reservation patterns by overlooking path correlations and only taking account of the current QoS capabilities of the bottleneck link for the selected data path. The problem is that multi-ingress hosting support certainly introduces correlations between on-path routers (perhaps more than one) and their associated ingress nodes. In light of this situation, Legacy MARA's over-reservation pattern adaptation mechanism needs awareness of the current QoS conditions of at least all the correlating on-path routers, rather than solely the capabilities at the bottleneck link in order to avoid QoS violations [3]. On the other hand, Legacy MARA only bootstraps the entire system once, at the network boot-up, which requires the entire system to be manually re-booted whenever the topology changes.

In light of these factors, this paper proposes *Multi-user Aggregated Resource Allocation – Multi Ingress* (MARA-MI), which re-architects Legacy MARA to cope with the multi-ingress hosting capabilities of current and future Internet

systems. The main extensions consist in designing a decision point, aimed at enabling the selection of best aggregate multicast trees by path correlation awareness, in order to allow demanding multi-user sessions to be established efficiently. Moreover, the decision point maintains knowledge of the QoS capabilities of all the on-path routers of the available aggregate multicast trees. This assists in the adaptation of the over-reservation patterns at all the ingress nodes to avoid the possibility of a QoS violation occurrence. Finally, MARA-MI keeps track of changes in the topology, so that the system automatically converges, without the need of a manual reboot. Simulations were carried out as part of a performance evaluation to examine the benefits of MARA-MI compared with Legacy MARA. The results confirmed that MARA-MI outperforms Legacy MARA, improving bandwidth use while keeping multi-user sessions with an acceptable degree of quality over time.

The paper is structured as follows. Section 2 provides a related work study of existing over-provisioning centric attempts. Section 3 provides an overview of Legacy MARA. A detailed description of MARA-MI is outlined in Section 4. The results and analysis of the performance evaluation are given in Section 5. Finally, Section 6 concludes this paper with a summary of our findings.

II. RELATED WORKS

Over-provisioning centric resource allocation has been addressed in the literature, although a small number of proposals can be found. The *Border Gateway Reservation Protocol* (BGRP) [4] and the *Shared segment Inter-domain Control Aggregation Protocol* (SICAP) [5] use a similar two-pass receiver-driven signaling schema to control surplus bandwidth. Both BGRP and SICAP are not suitable for the dynamicity expected for the future Internet, since they follow a static bandwidth over-provisioning approach, by applying a pre-assigned fixed factor to change over-reservation patterns (i.e., double, triple and so on) without take into account conditions, such as current capabilities of the network bandwidth usage.

The *Dynamic Aggregation of Reservations for Internet Services* (DARIS) [6] is a fully centralized mechanism which uses knowledge of the internal topology, resource capacities and current selected routes to over-provision network resources. The fully centralized approach deployed by DARIS compromises the system performance and fault tolerance since it requires excessive control operations in a single node. The *Self-Organizing Multiple Edge Nodes* (SOMEN) [7] is a signaling mechanism aimed at allowing the design of totally decentralized over-reservation control approaches, by enabling multiple decision points to jointly exploit control data inside a network. The SOMEN mechanism requires the association with other mechanisms to effectively deploy resource management following the over-provisioning paradigm.

The limitations of the above related work enforce the use of the over-provisioning centric capabilities of Legacy MARA. However, redefining Legacy MARA architecture to cope with multi-ingress scenario is no simple matter, as is revealed in the following. On the one hand, Legacy MARA processes the adaptation of over-reservation patterns by overlooking path correlations and only taking into account the current QoS capabilities of the bottleneck link for the selected data path.

The problem is that multi-ingress hosting support certainly introduces correlations between on-path routers (perhaps more than one) and their associated ingress nodes. Therefore, the over-reservation pattern adaptation mechanism deployed in Legacy MARA needs awareness of the current QoS conditions of at least all the correlating on-path routers, rather than solely the capabilities at the bottleneck link, in order to avoid QoS violations. On the other hand, Legacy MARA only bootstraps the entire system once, at network boot-up. This is a critical networking behavior since it requires the entire system to be manually re-booted whenever the topology is changed (e.g. when new nodes are added) in order to converge to the new network topology. This is not a feasible task, since it jeopardizes system dependability, (causing instability by QoS violations) and affects user satisfaction.

III. LEGACY MARA OVERVIEW

Legacy MARA was proposed as a potential tool to overcome the scalability limitations caused by per-flow QoS signaling solutions, such as the IP standard *Resource Reservation Protocol* (RSVP) [8] and the Next Steps in Signaling (NSIS) [9], adopting a signaling-constrained approach to assist the combined over-provisioning control of QoS (per-class over-reservations) and connectivity (aggregate IP multicast trees) network resources. This over-provisioning centric approach allows Legacy MARA to establish multiple multi-user sessions without instant per session request signaling events.

The Legacy MARA approach allows the following functionalities to occur: (i) the system bootstrap initializes the QoS and Connectivity resources at system boot-up time; (ii) the over-provisioning centric admission control is responsible for admitting multiple multi-user sessions without instant per-flow signaling events; (iii) the over-provisioning centric adaptation patterns of the *Class of Services* (CoS) bandwidth seeks to re-adjust the over-reservations of demanding paths to provision bandwidth to assist the admission control; (iv) The over-provisioning centric connectivity control deals with the problem of providing fast resilience for the architecture, by re-routing sessions affected by network events (e.g. link break, congestion, etc.) to other aggregation multicast trees.

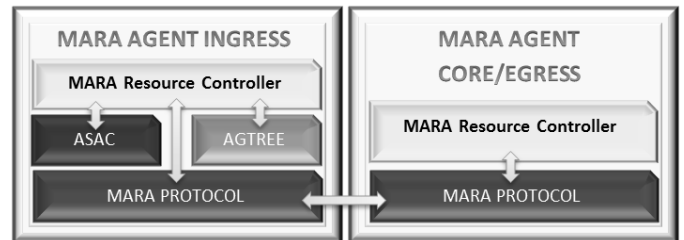


Figure 1. Architecture of Legacy MARA

A. MARA Protocol

The signaling approach used in Legacy MARA is employed using the MARA Protocol (MARA-P). MARA-P allows an exchange of control information to assist network resource enforcement at network nodes, following an ingress-driven single-pass signaling scheme. MARA-P specifies only two messages to ensure a low degree of complexity: RESERVE and RESPONSE. When combined with different flags, the RESERVE message is used to allocate, modify, refresh or

release QoS and connectivity resources in a unicast signaling. The RESPONSE message is used mainly to give feedback related to a previous RESERVE message and to generate network alarm events for resilience.

B. Advanced QoS Resource Allocation

The *Advanced QoS Resource Allocation* (ASAC) is a subcomponent aimed to control the over-provisioning of the CoS bandwidth, operating on the basis of a dynamic over-reservation approach to control the allocation of surplus QoS resources. Each supported CoS has assigned a *Maximum* and a *Committed Reservation Threshold* (MRth and CRth), which is combined with an *Initialization Index* (idx) configured by the network administrator (specified in percentage of link capacity). The obtained value determines the initial amount of bandwidth over-reserved to each CoS and is propagated at system bootstrap during system initialization.

ASAC avoids wasting resources, by re-adjusting the QoS resources to the current demands for network capacity assisted by equations, aiming enable Legacy MARA capabilities to admit multiple user sessions without need of signaling.

Equation (1) given below is invoked by admission control when there is a request for a flow of a required multi-user session.

$$Bw_{rq}(i) \geq Bw_{rv}(i) - Bw_u(i) \quad (1)$$

where:

Bw_{rq} – Bandwidth required by CoS i , derived from request triggering

Bw_u – Bandwidth currently used by CoS i

Bw_{rv} – Bandwidth currently reserved by CoS i

If (1) is satisfied, the request is instantly accepted and the state of the Bw_u is updated. Otherwise, this indicates the need for either a readjustment to the bandwidth reserves of the desired CoS, or a re-sizing of its MRth with the sum of the bandwidth available in the MRth of the remaining classes, determined by equation (2).

$$B_{ov}(i) = \frac{Bw_u(i)}{MR_{th}(i)} * (MR_{th}(i) - Bw_u(i) - Bw_{rq}(i)) \quad (2)$$

where:

$B_{ov}(i)$ – Over-reservation bandwidth of CoS i

Equation (2) takes into account the utilization ratio between the bandwidth used by the CoS i (the required class in the user request), and its MRth, as well as the amount of bandwidth which will be available after the admission of the request. If positive, it indicates that the over-reservation pattern can be enlarged, without reaching its MRth, then the value of B_{ov} is worked out to Bw_{rq} and added to CoS i .

$$Brl_{MRth(j)} = \left(\frac{B_{idx(j)} + Th_{idx(x)}}{2} \right) * (MR_{th}(j) - B_{ref}(j)) \quad (3)$$

$$MR_{th}(i) \leftarrow \sum_{j=1}^n Brl_{MRth}(j) \quad (4)$$

Where:

$Brl_{MRth}(j)$ – amount of bandwidth to reduce the current MRth of the remaining class j uninvolvement in operation.

$B_{idx(j)}$ – Bandwidth index of CoS j : the ratio between the amount of bandwidth that is currently reserved and used by CoS j in the bottleneck link of the associated communication path.

$Th_{idx(x)}$ – Threshold index of CoS j : the ratio between the $Mrth(j)$ and $B_{ref}(j)$ (that can be either Bw reserved or CRth, when the former is bigger than latter, or vice versa)

Otherwise, the negative value of (2) indicates the need for re-sizing the MRth, in order to accommodate future requests without signaling. Hence, for each CoS that is not involved in the operation, Brl_{MRth} will be released (equation 3), based on the average use of its respective bandwidths, limited by CRth and added to the involved class (equation 4). After both readjustments, the request is reprocessed by recalculating (1). If even after the readjustments (1) is not satisfied, the request is denied.

C. Advanced Aggregation Tree Allocation

The *Advanced Aggregation Tree Allocation* (AGTree) subcomponent implements the Multicast aggregation concept [10] to deal with scalability issues of legacy IP Multicast. AGTree is designed to over-provision Aggregate IP Multicast Trees and control the connectivity of flows.

The choice of IP Multicast by MARA depends on the low consumption of bandwidth caused by packet replications through distributed trees but only at points where the branches have active leaves joining the content. To avoid scalability problems in large-scale clusters (increasing state storage with the number of active flows), MARA creates Multicast aggregation techniques and allocate surplus aggregation trees in advance, forcing multiple flows to share the same aggregation tree.

To generate branched multicast aggregation trees, combinatorial sequences between branchless paths discovered during system initialization are generated and filtered to reduce the large number of incidents that can occur in this scheme (like having branching points closer to the root). After this, each branched multicast generated by sequences is signaled in order to install the multicast channel. At the end of all this process, surplus Aggregate IP Multicast Tree information is available in advance, and can be allocated without any signaling event.

D. MARA Resource Controller

The MARA Resource Controller (MARA RC) mechanism is responsible for cross-layer interactions with other network components to enforce operations, such as QoS schedulers and packet replicators, in order to correctly setup per-class bandwidth over-reservation and multicast distribution trees. MARA-P messages carry information to assist MARA RC behavior.

IV. MARA MULTI-INGRESS PROPOSAL

The main goal of MARA-MI is to expand the opportunity of using MARA in networks with multiple ingress nodes, thus benefiting current and Future Internet systems with efficient and scalable resource provisioning support. The architecture and signaling approach of Legacy MARA were totally restructured to achieve this goal. As a result, MARA-MI follows a hybrid approach with centralized and decentralized modules, as depicted in Fig. 2.

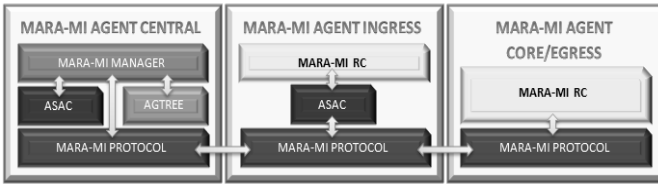


Figure 2. Architecture of MARA-MI

As can be noted in Fig. 2, the over-provisioning centric complexity of the MARA-MI suite is pushed to the software Agent hosted in the central node. In contrast to the Legacy MARA architecture (see Fig. 1), the network routers remain simple, mainly in charge of reacting upon receiving enforcement invocations.

A. MARA-MI Components

The components that compose the MARA-MI architecture and the hosting node are described in detail in the next subsections.

1) MARA-MI Protocol

MARA-MI Protocol (MARA-MI-P) is the signaling approach used in MARA-MI to provide the centralized component with information such of entire network topology as any existing links between the routers, and to carry out connectivity and resource reservation operations. Two messages are used: ENFORCE and RESPONSE. The former will be used to trigger operations from the MARA-MI Manager module to ASAC in ingress routers and the latter will be usually used as feedback from a previous ENFORCE message.

The common heading of the MARA-P messages was extended to include new message-specific flags for asynchronous events (link break and addition of nodes - flag A) and to store and update QoS information between the links (flags L and S). The main operations of over-reserves and reserve readjustments will be carried, respectively, by flags RSV and RAD.

2) MARA-MI Manager

MARA-MI *Manager* (MNG) is the subcomponent responsible for exposing MARA-MI functionalities to external applications and mechanisms interested in establishing flows along the system. It is hosted in the central node and its statefull approach allows the full control of the entire MARA-MI enabled system. The operations deployed by MNG are described in next.

a) System bootstrap

MARA-MI follows the same principles of Legacy MARA to bootstrap the system in terms of deploying the controlled flooding and computing the QoS and Connectivity resources. The difference is that MNG starts the flooding process triggering each ingress router through an ENFORCE(I) message, after receiving acknowledgment messages (RESPONSE(A)) from each existing ingress routers. At the end of the flooding process, all reached egress routers send the messages to the central node so that MNG can bootstrap the over-provision of the Connectivity resources and book the QoS resources of all nodes.

b) Path Selection Mechanism

The MNG takes some functions provided by legacy ASAC to assist in its path selection mechanism. The priority in making a path selection will always be that which satisfies equation (1) described in Section 2, i.e., paths that do not need any signaling, since they already support the request. In this case, the path will be selected from those whose egresses are the same as the one to which the user is attached, and which have a maximum remaining bandwidth if the session is admitted, according to Equation 4 described below:

$$\text{MAX}[Bw_{rv}(i) - (Bw_u(i) + Bw_{rq}(i))] \quad (4)$$

Otherwise, if any path satisfies (1), MNG proceeds by first selecting a path with a maximum probability of acceptance by means of ASAC in the ingress router (triggered by an ENFORCE(RSV) message), without the need to readjust its MR_{th} (Equation (5)) or a path with maximum acceptance probability of MR_{th} readjustment (ENFORCE(RAD)), with less used bandwidth relative to its MR_{th} (Equation (6))

$$\text{MAX}[MR_{th}(i) - Bw_{rv}(i)] \quad (5)$$

$$\text{min}[MR_{th}(i) - (MR_{th}(i) - Bw_u(i))] \quad (6)$$

Figure 3 will be used to describe the exchange of messages between modules to meet a request for a multi-user session, assuming that there is no path with enough resources to accommodate (based on Equation (1)).

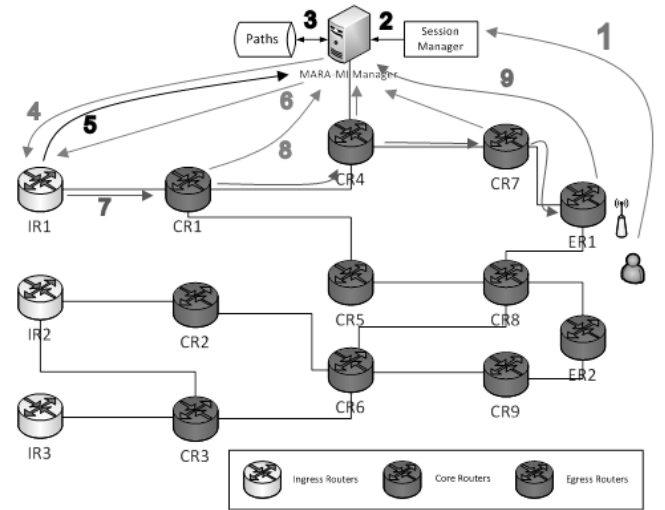


Figure 3. Exchange of messages during a reserve

Whenever a user is interested in receiving content (event 1), an existing session manager triggers the MARA-MI Manager (event 2) to start the path selection process (event 3). Considering the assumption cited above, the Manager will select a path for ASAC to make a new reserve. An ENFORCE(RSV) message is composed, supplied with an IP address from each router which composes the path, and sent to the linked ingress router (event 4).

On receiving the message, ASAC calculates the B_{ov} (Eq. 2). Assuming that there are not sufficient QoS resources to support the request, (2) will return a negative number and the MARA-MI Agent will send a RESPONSE(ACK) message

reporting the failure (event 5). In the event of the remaining paths also not meeting the requirements, MARA-MI Manager will now select a path in accordance with equation (6). The selected path is added to RSVPATH of an ENFORCE(RAD) composed message and sent to the over-provisioning mechanism located at the linked ingress router (event 6).

After ASAC calculates the amount of MRth to be released from uninvolved classes in request (Eq. 3) and add this value to required CoS (Eq. 4), it triggers MARA-MI RC that enforces the new thresholds to all supported CoS in the cluster and composes an ENFORCE(RAD) message to send over the path to update the MRth of each class (event 7).

On each visited router, (in addition to the threshold update), a RESPONSE(S) message is composed with QoS specifications about the link and sent to the MNG (event 8) which updates the information in the associated link. On reaching an egress router, after it has carried out the update, a RESPONSE(ACK) message is sent to MARA-MI Manager confirming the operation, and updating its 'statefull' tables about the entire path (event 9). Upon concluding this process, the request for the session is reprocessed, recalculating Eq. 5.

V. PERFORMANCE EVALUATION OF MARA-MI

As a means of evaluating the benefits of MARA-MI, a simulation model was implemented in the Network Simulator v2 (NS-2) [11]. The methodology applied to evaluate MARA-MI consists in comparing its behavior against the Legacy MARA architectures with identical scenarios and configurations concerning queue scheduling, traffic policies and bandwidth links. The reason for adopting this methodology is that the Legacy MARA approach was evaluated in our previous works against other standard Internet-based solutions, namely RSVP and NSIS, with results demonstrating the superiority of Legacy MARA to improve networking performance. Thus, it is not suitable to compare MARA-MI against other existing proposals beyond the Legacy MARA.

A network topology generated by BRITE [12] was used with simulation parameters that took into account the real conditions and events obtained from previous Legacy MARA test scenarios [1] [2]. Three users are linked to all the three different APs to exhibit multi-homing capacities. The core network links randomly vary their values of delay, between 1ms and 2ms, and bandwidth, from 5Mb/s to 7 Mb/s, for congestion experience. Each AP supports a total of 1 Mb of traffic, and causes a delay of 10 ms. Flow generators are hosted at three session sources, and configured with 100 kb/s and 125 kb/s of Constant Bit Rate (CBR) and Exponential (EXP) traffic patterns respectively. The session setup request events are scheduled for the MARA-MI Manager following a Poisson distribution (taking a simulation time of 120 seconds to consider long- time duration), to initiate the whole selection process. Six users are linked to the three different APs to exhibit multi-homing capacities. The core network links give values of delay and bandwidth at random. The simulations comprise 10 experiments with a varying number of sessions with scheduled setup request events following a Poisson distribution, to initiate the whole selection process. The experiments were repeated 20 times to obtain a confident interval of 95%. The methodology applied in the evaluation defined two sets of experiments.

A. Experiments Set A

On the one hand, the set of experiments *A* considers the mean throughput (data and signaling) and latency over the varying number of sessions as measures to evaluate the impact that mechanisms of both configurations take in the overall network performance, in terms of bandwidth use and processing overhead, respectively. As can be seen in Figure 4, the results reveal that the mean throughput resulted from using both Legacy MARA and MARA-MI average 71.8 Mbps and 39.3 Mbps respectively at all experiments. Hence, it is significant that MARA-MI improves the throughput of Legacy MARA to be optimized at 45%.

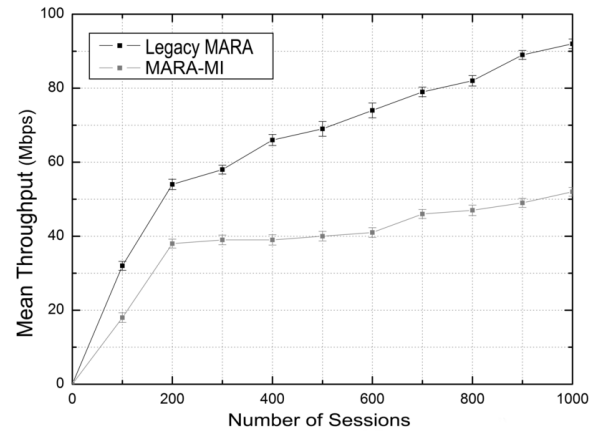


Figure 4. Mean throughput of Legacy MARA and MARA-MI

The signalling optimization of the MARA-MI experiments is achieved under the influence of the MARA-MI Protocol signalling-constrained approach, which only introduces signalling events in the network system when there is a need to both adapt over-reservation patterns and announce new node additions to the topology convergence system. Although it can be premised that the Legacy MARA Protocol approach is similar to the MARA-MI Protocol, by only signalling the event to adapt over-reservation patterns, MARA-MI introduces fewer signalling events (~104 kbps, less than 1% of the network capacity), that are influenced by the information of all the links of the selected path, which allows more over-reservation bandwidth to be computed than in Legacy MARA. Figure 5 depicts the latency measures in the simulations.

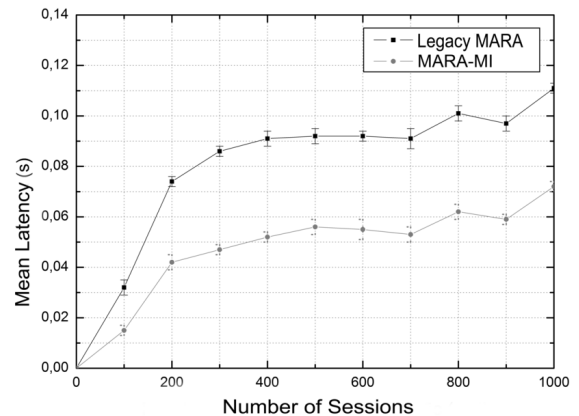


Figure 5. Latency experience in a varying number of sessions

As can be seen in Fig. 5, the improvement in latency allowed by MARA-MI is 40.9% (from 0.095 ms in Legacy MARA to 0.054 ms). As expected, the latency increases with the session setup demands in both experiments. However, the signalling-constrained scheme of MARA-MI allows setting up sessions to occur more rapidly than Legacy MARA due to the reduced operations to readjust the over-reservation patterns, which are deployed by Legacy MARA at each session setup event.

B. Experiments Set B

On the other hand, the experiments set B uses the behaviour of packet loss over the simulation to measure the impact of QoS control on the quality perceived by users in the Legacy MARA and the MARA-MI configurations of the simulation model, which is shown in Fig. 6.

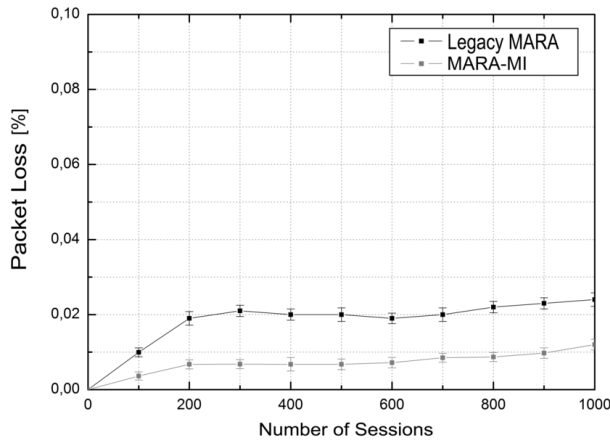


Figure 6. Packet Loss over number of sessions for Legacy MARA and MARA-MI

As can be seen in Fig. 6, there is a significant improvement in the packet loss, when the rate is improved from 0,019795% in Legacy MARA to 0,007683% (61.19% rate of improvement) in MARA-MI. The improvement in packet loss can be explained by the fact that MARA-MI selected the best paths, with autonomy and path correlation, that optimizes the networking processing throughout the network system.

VI. CONCLUSION

This paper introduces Multi-User Aggregated Resource Allocation – Multi Ingress (MARA-MI), which is an extension of MARA designed for use in multi-ingress scenarios, and for coping with the demands of Future Internet systems. MARA-MI follows a hybrid approach with centralized and decentralized components aiming a more distributed architecture, in contrast to Legacy MARA, envisioning the

benefits of a decentralized architecture, (e.g., with regard to scalability and availability). The simulation results that were obtained demonstrate the benefits in bandwidth use and its ability to maintain quality over time in multiple-user sessions. They also show evidence of better performance in throughput, latency and packet loss in comparison with Legacy MARA, which suggests that MARA-MI can possibly be adapted for use in distributed environments in both the current and Future Internet systems.

As suggestions for future works, a performance evaluation with the mentioned related works would confirm superiority of MARA-MI over multi-ingress scenarios. It is also planned a redesign of MARA-MI architecture to a distributed way, in order to avoid scalability issues in large scale environments.

REFERENCES

- [1] A. Neto, E. Cerqueira, M. Curado, P. Mendes and E. Monteiro, "Scalable Multimedia Group Communications through the Over-Provisioning of Network Resources," in *Proceedings of the 11th IFIP/IEEE international conference on Management of Multimedia Networks and Services: Management of Converged Multimedia Networks and Services*, Berlin, Heidelberg, 2008.
- [2] A. Neto, E. Cerqueira, E. Monteiro, M. Curado and P. Mendes, "Scalable Resource Provisioning for Multi-user Communications in Next Generation Networks," in *IEEE Global Communications Conference (GlobeCom) 2008 Next Generation Networks, Protocols, and Services Symposium*, New Orleans, LA, 2008.
- [3] A. Neto, S. Figueiredo, L. Marcal and R. L. Aguiar, "QoS-RRC: Integrated QoS routing and resource provisioning mechanism for future internet," in *Computers and Communications (ISCC), 2010 IEEE Symposium on*, 2010.
- [4] P. Pan, E. Hahne, and H. Schulzrinne, "BGRP: A Tree-Based Aggregation Protocol for Inter-domain Reservations", *Trans. of Communications and Networks Journal*, vol. 2, pp. 157-167, Jun. 2000.
- [5] R. Sofia, R. Guerin, and P. Veiga, "SICAP, a Shared-segment Interdomain Control Aggregation Protocol", in *Proc. Int. Conf. in High Performance Switching and Routing*, Turin, Italy, Jun. 2003.
- [6] R. Bless, "Dynamic Aggregation of Reservations for Internet Services", in *Proc. 10th Conf. on Telecommunication. Systems –Modeling and Analysis*, vol. 1, pp.26-38, Monterey - California, USA, Oct. 2002.
- [7] E. Logota, A. Neto and S. Sargento, "A New Strategy for Efficient Decentralized Network Control," in *Global Communications Conference (GLOBECOM)*, Miami, FL, USA, 2010.
- [8] R. Braden, L. Zhang, S. Berson, S. Herzog and S. Jamin, "Resource ReSerVation Protocol (RSVP) -- Version 1 Functional Specification," IETF RFC 2205, Jan 2001.
- [9] R. Hancock, G. Karagiannis, J. Loughney, S. Van Den Bosh, "Next Steps in Signaling (NSIS): Framework", IETF RFC 4080, Jun 2005.
- [10] D. Thaler and M. Handley, "On the Aggregatability of Multicast Forwarding State," *IEEE INFOCOM*, March 2000.
- [11] The Network Simulator - NS-2: <http://www.isi.edu/nsnam/ns/>
- [12] A. Medina, I. Matta and J. Byers, "BRITE: A Flexible Generator of Internet Topologies," Boston University, Boston, MA, USA, 2000.