Infrastructured Mobility Management Approach for Future Internet ETArch Networks

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***Abstract*—Among the current proposals for Future Internet new architectures, the Entity Title Architecture (ETArch) stands out because of its innovative approach. This system is able to integrate new features through an information-centric network that makes use of the Software Defined Networking (SDN) paradigm, exceeding the capacity of current IP-based infrastructures. However, the mechanisms adopted by ETArch for the Quality of Service (QoS) and mobility control were not designed in an integrated manner, which means they are unable to keep users well connected to mobility demands. In light of this, this paper proposes extensions to the legacy ETArch Mobility Manager which, when integrated to the QoS Manager, is able to support the following operations: *(i)* network-initiated mobility control to allow improved resource allocation; *(ii)* quality-oriented access point selection for the maintenance of best-connected mobile nodes; *(iii)* mobility load balancing, to maximize admissions of mobile nodes in conditions of congestion; and *(iv)* IEEE 802.21 compliant infrastructured handover setup. The resulting mobility control ecosystem benefits the ETArch by allowing a maximized admission of mobile sessions experiencing congestion, by means of a maximized transport capacity. The evaluations were carried out on a testbed that considered real events, and provided evidence that the proposal outperforms legacy ETArch mobility control functionalities.**

I. Introduction

Among the current initiatives for the *Future Internet* (FI), the *Entity Title Architecture* (ETArch) [1], stands out as a promising architecture since it makes use of the content-oriented paradigm, and employs a new naming and addressing scheme based on the Title. It is a realization of the *Entity Title Model* [2], and envisages how the entities should be able to semantically specify their requirements and capabilities so that they can communicate with each other. ETArch can inherently support mobile group-communication based on the OpenFlow [3] substrate within the Workspace, which is a channel that is able to bring together two or more communicating participants.

The mobility control functions of ETArch are based on the IEEE 802.21 standard (MIH – *Media Independent Handover*) [4], and are mainly designed for an exchange of access points (PoA – *Point of Attachment*).

Despite its innovative approach, ETArch was not designed to take account of important aspects of Future Internet concepts. This in particular applies to the dismissal of control mechanisms that have the capacity to establish workspaces that can support a transport model that goes beyond the current *best effort* delivery of the Internet. In other words, ETArch does not support mechanisms that allocate sufficient bandwidth to accommodate high-demand sessions with *Quality of Service* (QoS) to obtain minimum rates of loss, delay and variations in delay overtime. In addition, the ETArch mobility management model is absolutely user-centric, which means that the user is responsible for making an explicit request for a move to another PoA.

Recent work by our research group [5] has improved the ETArch ecosystem with the QoS Manager, a new control component that allows applications to semantically express quality requirements (flow, tolerance to losses and delays, codecs, etc.). In addition, the QoS Manager is responsible for allocating network resources (for class bandwidth and workspaces) dynamically and systematically, as well as accommodating sessions in line with quality requirements, especially for those with high demands (such as video streaming and voice). Figure 1 shows the integration of the QoS Manager with the ETArch framework.

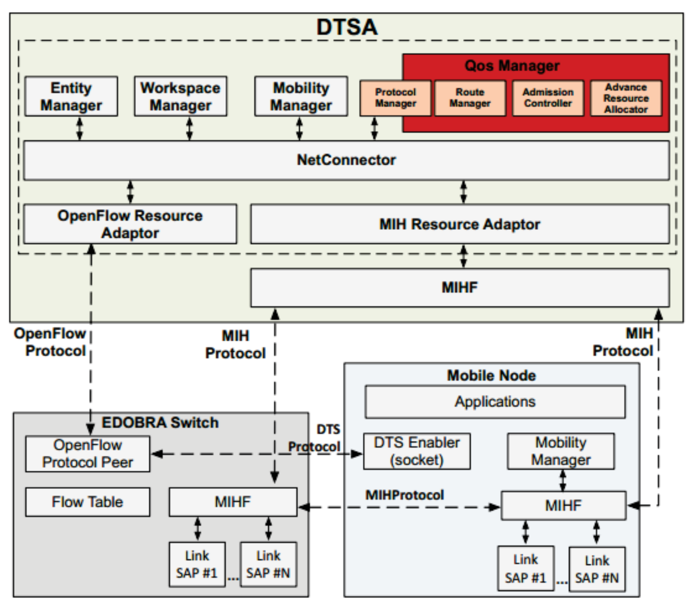


Figure 1: Integration of QoS Manager within the ETARch framework

The QoS Manager orchestrates the admission control functions and resource allocation in intra-domain links of ETArch wired networks. It is based on the dynamic control of an oversized resources strategy [6], to allow the admission control to be able to accommodate multiple sessions in the same workspace. This only has signaling in specific nodes (edge nodes), unlike the classic per flow model, where all of the selected path must be reconfigured to meet the demands of the new session. The strategy consists of making oversized workspaces during the system bootstrap, and aiming to make available a significant amount of workspaces in advance with an oversized bandwidth at each interface of the network nodes in each workspace.

In this manner, the QoS Manager makes local decisions in advance about the available information (without classical instantaneous collection), and only configures the flow tables of the edge nodes in the selected workspace, either to aggregate (i.e. join the workspace) or disaggregate (i.e. leave the workspace for another network) the flow packets of the demanded session.

The QoS Manager is able to accommodate multiple sessions with *Quality of Experience* (QoE) that meet their QoS requirements, while at the same time, maintaining good levels of network performance and scalability.

The admission control is activated in two situations: *(i)* during the establishment of a new session; *(ii)* or in response to the explicit request of a MN handover. This non-transparent mobility strategy that relies on an explicit request for handover (without mobility prediction), in addition to the lack of knowledge of the QoS Manager in the system mobility patterns, enables it to accommodate mobile sessions until the limit of the resources of the oversized reserves. Under conditions of resource exhaustion, the QoS Manager rejects the admission of the mobile session. In fact, this admission control behavior of mobile sessions is natural.

However, we believe in an approach that involves maximizing the admission rates of mobile sessions in congested PoAs (and without any the likelihood of increasing the depleted resources) through integrating the QoS Manager functions with an improved Mobility Manager. This hypothesis is based on the ability to make the Mobility Manager capable of moving connected sessions to a highly desired PoA (selected as the best or only alternative for moving sessions) to another PoA. The purpose of this is to release resources and thus accept the mobile session, since, currently, the QoS Manager denies access to the sessions because it is impossible to release resources (which only occurs at the end of sessions). As a result of this release of resources in response to handover, the moving sessions can be accommodated in the desired PoA, and have continuity. Furthermore, this model justifies its application in resilience and load balancing scenarios in response to dynamic network anomalies (PoA failure).

For this reason, this paper proposes making an extension to the legacy ETArch Mobility Manager, called *Quality-oriented Mobility Management Approach* (QoMMA), to support network-initiated quality-oriented handover management. Moreover, the Mobility Manager operates together with the QoS Manager in order to deploy mobility-based load balancing, and allows the admission of sessions affected by mobility patterns to be maximized by means of moving sessions in the demanding PoA to others with a greater capacity for accommodation. The proposal makes contributions in the following areas: *(i)* network-initiated mobility prediction; *(ii)* quality-oriented PoA selection; *(iii)* mobility load balancing; *(iv)* IEEE 802.21 compliant infrastructured handover control. The evaluation was carried out in a real testbed scenario consisting of OpenFlow/802.11 access points that consider real events.

The remainder of the document is structured as follows: Section II presents the background for this work, highlighting not only the supporting technologies, but also other related approaches. Section III provides an overview of the QoMMA proposal. Section IV outlines the basic operations of QoMMA. Section V shows the results of the evaluations in the control plane. Finally, Section VI offers some concluding remarks and makes suggestions for future work.

II. Background

The popularity of wireless networks requires the development of mobility control mechanisms to support the different traffic characteristics and needs of mobile users in various infrastructural conditions [7]. The increasing demand for real-time content and services require the wireless networks management systems to provide mechanisms that support different traffic features at different levels of quality [8]. In essence, the mobility management process consists of ensuring the mobile user is *Always Best Connected* (ABC), and is responsible for offering connectivity alternatives that best suit the user's needs.

For since many years, a number of strategies have been proposed as solutions to improve the mobility management and to support the growing requirements of mobile users. The main strategies adopted in designing mobility management solutions include the use of *Received Signal Strength* (RSS) monitoring, *Multiple Attribute Decision Making* (MADM) [9] methods and Fuzzy Logic [10]. These strategies are based on the principle of PoA selection as an alternative to connectivity, and in some cases, estimates the level of quality in the network as a condition for triggering the mobility procedures.

The work in [11] employs a combination of the AHP and TOPSIS MADM methods to form a decision-making mechanism, where the considered criteria are RSS, available bandwidth and the network load. Although it yields results based on simulations, the work has limited value, since no additions were suggested to the existing methods. [12] establishes and evaluates a mobility control framework based on an IEEE 802.21 standard. The evaluation was conducted in a physical SDN testbed consisting of one OpenFlow Controller and 802.11 Openflow-enabled switches. Although it clearly demonstrates the benefits of its performance compared with other related approaches, the solution does not take into account qualitative factors, and the decision process is guided solely by the RSS of the candidate networks. [13] set out a handover decision mechanism which is based on fuzzy logic, and uses RSS prediction (PRSS – *Predicted RSS*), available bandwidth and user preferences as input parameters. The strategy does not use the actual value of the RSS but depends on a prediction, which can lead to inaccuracy in the decision-making process. Furthermore, the mobility decision is executed by the MN, and is thus unsuitable for devices with energy constraints.

Many of the proposed solutions for dealing with mobility management lacks some features of the network in terms of efficiency and Quality of Service [Silva et al. 2014]. One of the longstanding challenges in the design of mobile systems is the provision of QoS guarantees that are required by the applications in a diverse networking infrastructure [14]. Furthermore, another critical problem is the complexity involved in managing all the mobility information regarding a large number of MNs as well as the signaling overhead that is needed to control their common mobility procedures. This is an issue that can be easily be overcome as a result of the flexibility provided by the SDN framework, where network functions, including mobility and quality of service, can be simply deployed (such as the software in the control plane without computational overhead and updates to the network devices) [15].

Although several studies have explored the quality-oriented mobility control field extensively, there are extremely few which have addressed this question within the framework of a Future Internet integrated architecture. In addition, few studies are explicitly concerned with the mobility control in an integrated architecture that makes use of the SDN paradigm.

In the next session, we provide an overview of the proposed solution, by describing the new features and their relationship with the others components of the ETArch framework.

III. Overview of the QoMMA Proposal

The QoMMA proposal is composed by three main components: Decision Maker, QAMC and E2BS. The proposed extensions were developed and integrated into the DTSA, which acts as the SDN Controller, and thus enables mobility procedures to be managed in the network. The following subsections detail its subcomponents.

A. Decision Maker

This is the central core element of the decision-making mechanism. It is responsible for mediating the different requests to the other sub-components, such as: *(i)* changing the status of the monitoring and data collection system (QAMC) (within predefined limits), increasing efficiency (in critical situations), in processing the data collected, such as the MN moving; *(ii)* mapping the CoS to which a particular session belongs and, as a result, determining the importance of the values (weights) of the attributes, through the MADM AHP method [16], and where necessary using the E2BS subcomponent; *(iii)* sending the information with the decision of the new network to the MIHF, in cases where the handover is needed.

B. QAMC

The *Quality Attribute Monitoring and Collector* (QAMC) is responsible for monitoring and collecting the parameters that trigger: *(i)* the occurrence or need for mobility, loss or reduction of RSS (which show that the MN is moving) and; *(ii)* network quality level, through the QoS parameters. The collected data will be used by the E2BS network selection mechanism, which is outlined in the following section.

The QAMC monitoring interval is adjusted to the system status, defined by the Decision Maker:

- **Regular** – Every 15 seconds, to obtain network quality parameters and every 5 seconds, to obtain RSS;
- **Alert** – Every 2 seconds, to obtain network quality parameters and every second, to obtain RSS.

The regular monitoring is the default mode. In this case, the collecting is performed every 15 seconds, to obtain the network quality parameters and every 5 seconds, to obtain the RSS between the PoA and the MN. If the RSS between a PoA and MN exceeds the threshold that has been previously configured, the system runs in alert mode, which leads to an imminent disconnection of the MN. Thus, the data collecting interval will be reduced, and this will allow the decision-making system to immediately identify alternatives (selection of a new PoA), if these limits are exceeded again, which indicates the sudden need for mobility.

C. E2BS

In our previous work [7] , we proposed the *Extended Elitism for Best Selection* (E2BS), a handover decision method inspired by the Elitist Selection Strategy [17], and combined with MADM features to enable efficient quality-oriented mobility decisions. Its main goal is to meet both the quality requirements of active mobile session flows and to match the current quality standards of neighbouring PoA candidates.

The elitist strategy employed by E2BS is based on a multi-attribute evaluation of the QoS candidate networks. In our model, the population is represented by a set of PoAs and their attributes. This technique is used to select the PoA which offers the best criteria for connection. Assessing the QoS offered by the various PoA to select the best one is carried out by measuring the similarity [18] between the attributes of the elite individual, represented by the reference PoA, and the other candidates. The reference PoA is considered to be the one that has the ideal values, (i.e. attributes like delay and jitter should have values close to zero).

E2BS was based on the MADM approach and designed to deal with the attribute importance (i.e. weight) of diverse applications by means of different traffic classes with distinct requirements [19].

In [7] we carried out a performance evaluation of E2BS which confirmed that the capacity of the proposed solution was superior to that of the alternative methods currently available.

IV. QoMMA basic operation

This section provides a detailed account of the interaction between ETArch features and the new proposed operations supported by the Mobility Manager that makes use of the QoMMA functionalities.

A. System bootstrap

The system bootstrap is designed to boot the system with oversized network resources. In this case, the PoAs are configured with over-reservation resources, and this information is recorded in the state table of DTSA. Since this information will be available in advance, the Mobility Manager will be able to make admission decisions in several sessions without any signaling events either for consultation or to set up a ground of resources in the PoA.

In case there is any change in the network topology caused by the entry of a new PoA, the system bootstrap mechanism is triggered for this device. In this way, the QoS Manager sends an OpenFlow message to the new PoA, and sets the CoS over-provisioning patterns, in a way that is compatible with the underlying QoS approach (for instance, by configuring the priorities for packet scheduling).

At this stage, with the support of QAMC, the Mobility Manager will be able to identify the conditions (available bandwidth per CoS, delay, jitter, loss, RSS etc.) of each registered PoA. This information will be used by the E2BS to give priority to the candidate PoA classification.

B. Mobile session setup

This process is triggered whenever: *(i)* the DTSA receives a request from a MN to be attached to a PoA or when; *(ii)* the Mobility Manager detects the need for the mobility of a MN owing to the loss or reduction of RSS, which is mainly caused by its movement.

If the first case occurs, the requester MN must register itself at DTSA, by stating the communication requirements (required bandwidth, delay/jitter/loss tolerance etc.). If this process was triggered because of the need for mobility (which is identified by the Mobility Manager), this information will be available in advance at the DTSA state table (in this case, the MN is already registered in the DTSA).

On the basis of this information, the QoS Manager will use the admission control mechanism to check whether the candidate PoA has capacity to accommodate the requester MN session at the desired CoS. If not, new over-reservation patterns will be applied to meet the MN request.

The new over-reservation patterns are carried out by making readjustments to the limits of each traffic class until the *Maximum Reservation Threshold* ($MRth$) or, if there is availability, through the provision of available resources in other classes to a congested class.

Figure 2 shows a generic scenario, from the system bootstrap to the requester MN handover setup in a new PoA, that displays the events and their respective signaling messages:

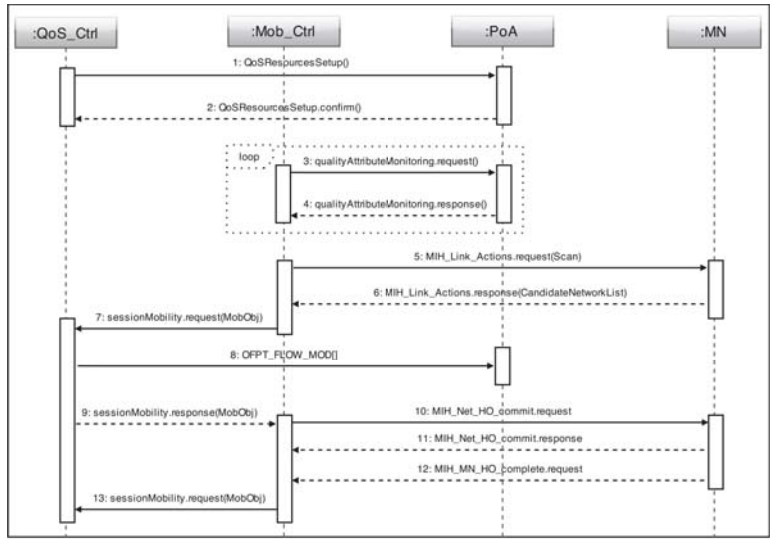


Figure 2: Generic mobility scenario

1) The process starts with the over-reservation PoA configuration.
2) After processing the bootstrap settings, the PoA sends a confirmation message to the QoS Manager.
3) This process is undertaken by the QAMC, and is performed by requesting information about parameters that identify the occurrence of mobility (monitoring of RSS) and of the network quality level (through SNMP and OpenFlow queue queries).
4) The query answer, consisting of a continuous process of monitoring and collecting, is sent to the Mobility Manager so that it can be used by decision methods, when necessary.
5) In the occurrence of an event, e.g. a MN is about to lose connection with the current PoA, the Mobility Manager starts the handover process by sending a notice through a *MIH_Link_Actions.request(Scan)* message, and then the MN detects candidate networks in its coverage area.
6) Through a *MIH_Link_Actions.response* message, the MN sends to the Mobility Manager a list of candidate networks. This enables it to sort the viable networks, by priority, using the E2BS method.
7) The Mobility Manager then informs the QoS Manager about the candidate networks, in order of priority, so that admission checks can be performed. If any of them has compatible resources with the MN needs, its attachment will be allowed.
8) Once the MN's admission to the network has been authorized, the QoS Manager provides the necessary resources to the target PoA.
9) The QoS Manager then notifies the Mobility Manager about the admission of the MN, so that it can setup the handover to the new network.
10) Through a *MIH_Net_HO_commit.request message*, the Mobility Manager instructs the MN to perform the handover for the selected network.
11) The MN performs the association procedure for the new PoA and informs the Mobility Manager about this operation, by sending a *MIH_Net_HO_Commit.response* message.
12) At the end of the handover procedure, the MN notifies the Mobility Manager by sending a *MIH_MN_HO_complete.request* message.
13) At this stage, the Mobility Manager knows that the MN is no longer associated with the old network and requests the QoS Manager to release all the associated resouces, in the old PoA.

C. Mobility load balancing

If the admission possibilities provided by the over-reservation mechanism are not sufficient to accommodate new mobile sessions, and shows a lack of resources in the PoA, the Mobility Manager will release resources through a mobility load balancing operation, that reduces the effects of this scarcity, and as a result, the rejection of new mobile session requests.

This process consists of moving already associated MNs in the required PoA to another feasible PoA that is within its coverage area and provide available resources. Through this operation, it is possible to maximize admissions to the network, by always keeping the MNs well connected.

On receiving a request from a MN that wishes to be associated with a PoA where the CoS does not have sufficient resources to carry out the over-reservation procedures, the Mobility Manager will identify other MNs that are already connected to this PoA that can be moved. Hence, there will be a release of sufficient resources for the admission of the requester mobile session.

The process for selecting the candidate MN to handover consists, initially, of identifying the MNs where the mobility results in a likelihood of a higher admission of the requester MN. This means that an individual analysis will be conducted of the alternative forms of connectivity for candidate MN that comply with certain criteria, such as: *(i)* low priority CoS; *(ii)* largest amount of reserved resources; *(iii)* equivalent reserved resources to that required by the requester MN, among others. The analysis of alternative forms of connectivity is carried out by giving priority to candidate networks in each MN coverage area, through the E2BS decision method. Each available network will be checked by the admission control process, and this will identify whether it is able to accommodate the candidate MN mobile session in the respective CoS. If so, the required resources for the candidate MN mobile session admission will be provided and then it will be transferred to the new PoA. Finally, all the reserved resources associated with the transferred MN are released and will be available for the mobile session of the requester MN.

The mobility load balancing operation is described in Algorithm 1.

Algorithm 1: Mobility load balancing description

Retrieve QoS_{req} of the MN_r attachment in PoA_t;
for *each* $MN_c(i)$ *in* PoA_t **do**
    Order available networks (PoA_c) in $MN_c(i)$ range by priority (using E2BS);
    for *each* $PoA_c(j)$ *in* $MN_c(i)$ *range* **do**
        Perform admission control verifications in $PoA_c(j)$;
        if $PoA_c(j)$ *is able to acommodate* $MN_c(i)$ QoS_{req} **then**
            Prepare required resources for MN_c in $PoA_c(j)$ (OpenFlow);
            Move $MN_c(i)$ to $PoA_c(j)$ (using 802.21);
            Release all $MN_c(i)$ associated resources in PoA_t (using OpenFlow);
            Prepare required resources for MN_r in PoA_t (OpenFlow);
            Allow MN_r attachment in PoA_t;
            break;
Reject the MN_r attachment;

Where:

- QoS_{req}: QoS requirements;
- MN_r: Requester MN;
- PoA_t: Target PoA;
- MN_c: Connected MN;
- PoA_c: Candidate PoA.

If the mobility load balancing operation cannot release the necessary resources to accommodate the requester mobile session, it will be rejected.

V. Performance evaluation

In seeking to evaluate the feasibility of our proposal, we extended the ETArch Mobility Manager implementation with the QoMMA architecture in accordance with the guidelines outlined in Section III. The aim of this evaluation was to compare the performance of the ETArch admission control strategy (without QoMMA) and QoMMA-enabled Mobility Manager, with load balancing functionalities by means of the network admission capacity of mobile sessions.

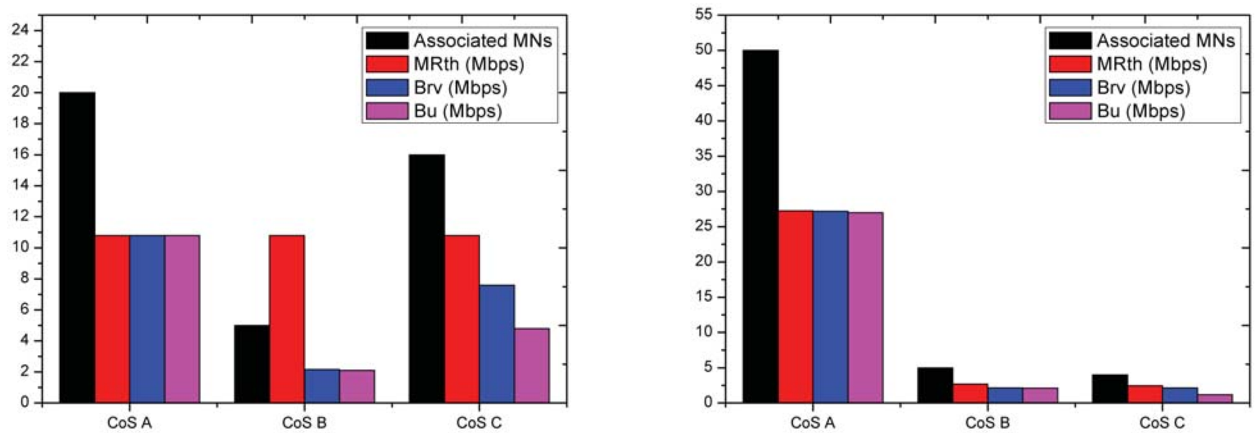
A. Evaluation Scenario

The experiments were carried out in a real testbed composed by three TP-Link TLWR1043ND routers embedding EDOBRA Switch Configuration [20], to support both IEEE 802.21 and QoS-aided OpenFlow v1.0 (queuing control) facilities. The wireless configuration of EDOBRA switches were set at in 802.11g mode. A Network Server hosts the DTSA OpenFlow Controller by implementing ETArch features with the facilities provided by the new Mobility Manager extensions. The testbed described above was used to perform the evaluation in the control plane, and a wide range of mobile sessions requests were considered with varying constant bitrate requirements of 450, 350 and 250 kbps [21], linked to three CoS (A, B and C), respectively.

In this scenario, we initialized each CoS over-reservation with 20% of total bandwidth, i.e., 10.8 Mbps. After the system bootstrap, all the session requests were triggered to the same AP, namely AP1. Figure 3a shows the information about each CoS of AP1 before the readjustment between the CoS was carried out.

In this case, the CoS A carried out mobile session admissions until the Maximum Reservation Threshold ($MRth$) capacity (initially configured at 20% of the total bandwidth) and took account of both the *Reserved Bandwidth* (Brv) and the *Used Bandwidth* (Bu). At this point, AP1 accomodates 20 MNs in CoS A, 5 MNs in CoS B and 16 MNs in CoS C. The graph in Figure 3a shows that the Brv of the CoS C is not aligned with the respective Bu, because following the Cisco guidelines for implementing QoS provisioning [22], the QoS Manager reserves 20% beyond the actual bitrate required. Before it could perform new mobile session admissions in CoS A, the Mobility Manager had to ask the QoS Manager to make some readjustments between the other CoS. Figure 3b shows the AP1 CoS A state after the readjustments as a result of which it was possible to admit 30 new requester MNs.

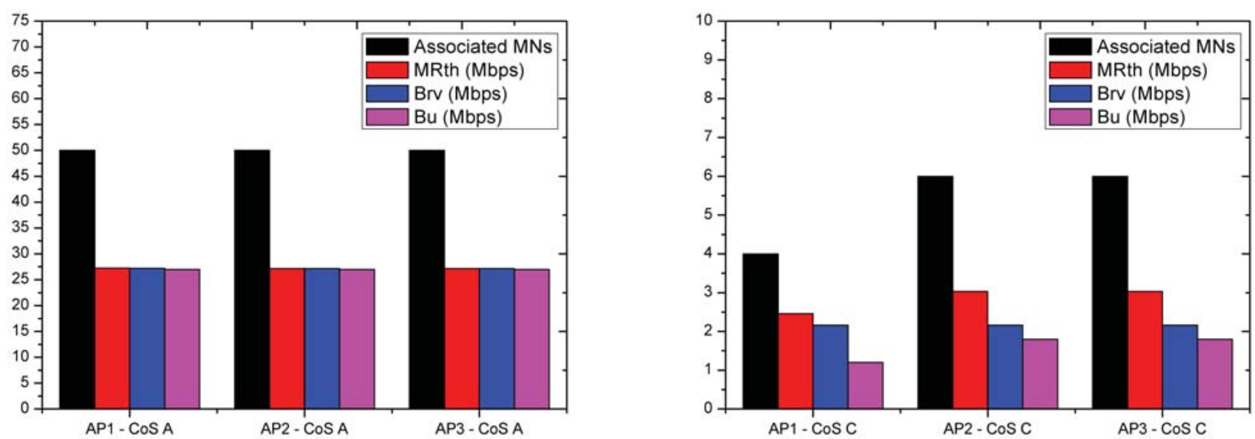
At this point the AP1 is no longer capable of accommodating new mobile session requests in CoS A until the mobility load balancing procedure has been executed, and new resources released.



(a) AP1 CoS utilization before readjustment

(b) Readjustment between CoS in AP1

Figure 3: AP1 state before load balancing



(a) CoS A utilization

(b) CoS C utilization

Figure 4: CoS utilization after load balancing

As can be seen in Figure 5, new mobile session requests were admited through the mobility load balancing procedure until it reached the full capacity of the available resources of the network devices. The sessions accommodated in the CoS A of AP1 before, were transferred to AP2 and AP3, and resources in AP1 released, so that new mobile sessions could be received. The same ocurred with the sessions accommodated in the CoS C of AP1. Before the load balancing process (as displayed in Figure 3a), there were 16 sessions in CoS C. Figure 4b shows the scenario after this process, where AP1, AP2 and AP3 accomodates 4, 6 and 6 mobile sessions, respectively.

The results of Figure 5 reveal the maximization of the admissions of the mobile sessions which could be obtained from the facilities provided by the QoMMA proposal. It is well-know that after the QoMMA mobility procedures, it was possible to reconfigure the network, and thus, to some extent, avoid the rejection of new mobile sessions. In total, there were made 172 requests for association to AP1, and 107 of them were rejected by the approach without QoMMA and only 1 by QoMMA.

The numerical analysis confirms this behavior, and shows that QoMMA increased the mobile session admission optimization at a rate of approximately 163%, for this scenario, compared with the previous admission control strategy.

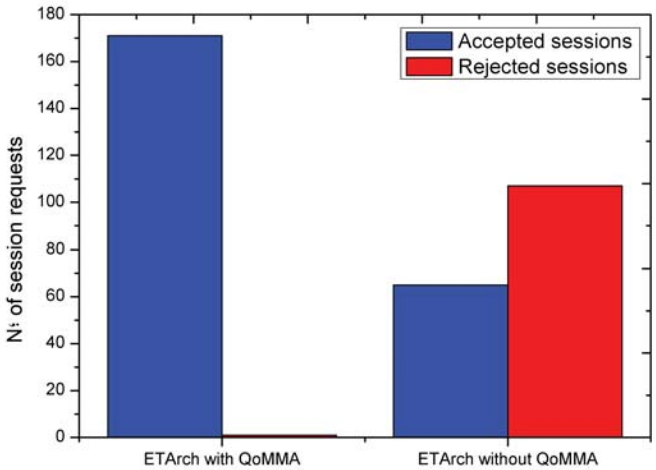


Figure 5: Admission rate with QoMMA and without QoMMA

VI. Conclusion and Future Works

In this paper, there has been an investigation of the Quality-oriented Mobility Management Approach (QoMMA) as an additions to ETArch, to support quality-oriented mobility procedures in the network (as in the case of mobility prediction operations). The proposed extensions follow a dynamic control of an always best connected principle, that aimed at keeping the MNs with higher QoS guarantees. It allows a dynamic and preemptive reconfiguration of the network by providing a better use of resources and the maximization of mobile session admissions. The results of the evaluation confirm these benefits while, at the same time, keeping best-connected mobile nodes. The next stage of this work is to evaluate the extensions of the proposal in a data plane and also estimate the benefits of the application perspective through different benchmarks. The objective is to confirm all the QoMMA capabilities in terms of QoS and QoE.

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References

[1] F. Silva, M. Goncalves, J. Pereira, R. Pasquini, P. Rosa, and S. Kofuji, "On the analysis of multicast traffic over the entity title architecture," in *Networks (ICON), 2012 18th IEEE International Conference on*, pp. 30–35, 2012.

[2] J. H. de Souza Pereira, F. O. Silva, E. L. Filho, S. T. Kofuji, and P. F. Rosa, "Title model ontology for future internet networks.," in *Future Internet Assembly* (J. Domingue, A. Galis, A. Gavras, T. Zahariadis, D. Lambert, F. Cleary, P. Daras, S. Krco, H. Müller, M.-S. Li, H. Schaffers, V. Lotz, F. Alvarez, B. Stiller, S. Karnouskos, S. Avessta, and M. Nilsson, eds.), vol. 6656 of *Lecture Notes in Computer Science*, pp. 103–116, Springer, 2011.

[3] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, "Openflow: enabling innovation in campus networks," *SIGCOMM Comput. Commun. Rev.*, vol. 38, pp. 69–74, Mar. 2008.

[4] D. Corujo, C. Guimãraes, B. Santos, and R. L. Aguiar, "Using an open-source ieee 802.21 implementation for network-based localized mobility management.," *IEEE Communications Magazine*, vol. 49, no. 9, pp. 114–123, 2011.

[5] J. Castillo-Lema, F. Silva, F. Silva, P. R. Rosa, C. G. Guimarães, D. Corujo, and R. L. Aguiar, "Evolving future internet clean-slate entity title architecture with quality-oriented control plane extensions," in *Advanced International Conference on Telecommunications (AICT 2014)*, pp. 161–167, July 2014.

[6] A. Neto, E. Cerqueira, M. Curado, P. Mendes, and E. Monteiro, "Scalable multimedia group communications through the over-provisioning of network resources," in *Management of Converged Multimedia Networks and Services, 11th IFIP/IEEE International Conference on Management of Multimedia and Mobile Networks and Services, MMNS 2008, Samos Island, Greece, September 22-26, 2008. Proceedings*.

[7] F. Silva, J. Castillo-Lema, A. Neto, F. Silva, P. Rosa, D. Corujo, C. Guimaraes, and R. Aguiar, "Entity title architecture extensions towards advanced quality-oriented mobility control capabilities," in *Computers and Communication (ISCC), 2014 IEEE Symposium on*, pp. 1–6, June 2014.

[8] J. Sen, "Mobility and handoff management in wireless networks," in *Trends in Telecommunications Technologies*, 2010.

[9] P. K. Yoon, C.-L. Hwang, and K. Yoon, *Multiple Attribute Decision Making: An Introduction (Quantitative Applications in the Social Sciences)*. Sage Pubn Inc, Mar. 1995.

[10] M. Zekri, B. Jouaber, and D. Zeghlache, "A review on mobility management and vertical handover solutions over heterogeneous wireless networks," *Comput. Commun.*, vol. 35, pp. 2055–2068, Oct. 2012.

[11] M. Sharma, "Multi network handover decision using extended multi criteria decision making technique," *IU-Journal of Electrical & Electronics Engineering*, vol. 14, no. 1, 2014.

[12] C. Guimaraes, D. Corujo, R. Aguiar, F. Silva, and P. Frosi, "Empowering software defined wireless networks through media independent handover management," in *Global Communications Conference (GLOBECOM), 2013 IEEE*, pp. 2204–2209, Dec 2013.

[13] M. Sharma and D. K. Khola, "Fuzzy logic based handover decision system," *Wireless Communication*, vol. 4, no. 13, 2012.

[14] J. Chan and A. Seneviratne, "A practical user mobility prediction algorithm for supporting adaptive qos in wireless networks," in *Networks, 1999. (ICON '99) Proceedings. IEEE International Conference on*, pp. 104–111, Sept 1999.

[15] K.-H. Lee, "Mobility management framework in software defined networks," *International Journal of Software Engineering and Its Applications (IJSEIA)*, vol. 8, no. 8, 2014.

[16] S. Dhar, R. Bera, and A. Ray, "Design and simulation of vertical handover algorithm for vehicular communication," *International Journal of Engineering Science and Technology*, vol. 2, no. 10, pp. 5509–5525, 2010.

[17] A. P. Engelbrecht, *Computational Intelligence: An Introduction*. Wiley Publishing, 2nd ed., 2007.

[18] Z. Tang, Y. Zhu, G. Wei, and J. Zhu, "An elitist selection adaptive genetic algorithm for resource allocation in multiuser packet-based ofdm systems.," *JCM*, vol. 3, no. 3, pp. 27–32, 2008.

[19] 3GPP, *QoS Concepts and Architecture: TS 23.107, 3rd Generation Partneship Project (3GPP)*. 2009.

[20] EDOBRA, "Edobra switch os - odtone openwrt," 2013. Available at: https://github.com/ATNoG/odtone-openwrt. Acessed 4 December 2014.

[21] Microsoft, "Lync server 2013 network bandwidth requirements for media traffic," 2013. Available at: https://technet.microsoft.com/en-us/library/jj688118.aspx. Acessed 14 May 2015.

[22] Cisco, "Cisco visual networking index: Global mobile data traffic forecast update, 2012-2017," 2013. Available at: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html. Acessed 14 December 2014.