A QoS/Mobility-Aware Model for Mobile Internet

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***Abstract*—This paper proposes a QoS micro-mobility solution capable of providing QoS support for global mobility.**

The solution comprises enhancements with regards to the mobility management of Mobile IPv6 (MIPv6) and in the resource management of the Differentiated Services (DiffServ) QoS model.

The mobility management of MIPv6 was extended with fast and local handovers in order to improve its efficiency in high dynamic micro-mobility scenarios.

The DiffServ resource management was extended with adaptive and dynamic QoS provisioning in order to improve resource utilization in mobile IP networks.

Furthermore, to improve resource utilization, the mobility and QoS messages have been coupled so that resource management able to proactively react to mobility events can be attained.

The performance improvement of the proposed solution in addition to the model parametrization have been evaluated using a simulation model. Simulation results indicate that the solution avoids network congestion as well as the starvation of DiffServ classes of a lesser priority. Moreover, the results also indicate that bandwidth utilization for priority classes increased. The QoS offered to MN's applications, in each DiffServ class, remained unchanged with MN mobility.

***Index Terms*—Mobile IP, Admission Control, QoS, Differentiated Services**

I. Introduction

Users want mobility, QoS and a permanent connection to the internet simultaneously. In order to satisfy these very demanding customers, markets are imposing new challenges on wireless networks by demanding heterogeneity in terms of wireless access technologies, new services, suited QoS levels to real-time applications, high usability and improved performance.

The heterogeneity is an important issue as a result of the complementary characteristics between different access technologies. The advantage of Third Generation (3G) cellular networks, such as Universal Mobile Telecommunication System (UMTS) and Evolution-Data Only/Data Voice (EV-DO/DAV) comes from their global coverage while their disadvantages lie in low bandwidth capacity and elevated operational costs.

On the contrary to 3G cellular networks, Wireless Local Area Networks (WLANs) exhibit higher bandwidth with reduced operational costs and coverage area. It is undisputable that mobile devices have technologically evolved to a new paradigm in order to support different radio access technologies.

These new mobility paradigms brought the opportunity to emerge new multimedia services due to increased usability and improved connectivity conditions offered by mobile networks. However, some of these new multimedia services will require QoS support thus leading to the necessity of QoS provisioning in wireless networks.

To achieve this purpose, the scientific community is making all sorts of efforts to provide end-to-end QoS in the Third Generation Partnership Project (3GPP/3GPP2) and in the Internet Engineering Task Force (IETF) standards, towards their convergence into the Next Generation or Fourth Generation of Wireless Networks (NGWN/4G).

The principle of the incoming Fourth Generation (4G) wireless networks is to embrace all wireless network technologies and all interoperability mechanisms enabling the mobile user to have seamless movement over different access networks technologies, while maintaining Internet connectivity with desired service quality for multimedia applications.

The manner in which different access networks must be inter-connected towards embracing heterogeneity in future networks must be defined in order to select the most appropriate mechanisms for resource and mobility management. There seems to be a general consensus that the inter-connectivity protocol will be based on the Mobile Internet Protocol (MIP) mainly due to the fact that Internet Protocol (IP) is being widely deployed in the Internet [1]. The standard IPv6 protocol only offers the Best-Effort (BE) service model. Therefore, in the last years two distinct philosophical currents within IETF have been developed in order to empower IPv6 with traffic differentiation. The first lies in Integrated Services (IntServ) which offer a guaranteed service model, and the second resides in a DiffServ which offers a predictive service model. However, these two QoS model proposals were designed before the existence of the MIPv6 protocol. Hence, they did not take mobility requirements into account.

On the other hand, the current MIPv6 standard also lacks scalability. The MIPv6 protocol is generally considered a macro-mobility solution that is not really effective in handling micro-mobility scenarios, where cell size is small and frequent handovers are common. In addition to this, it is well known that mobile networks predominantly have a local scope [2]. Thus, to overcome MIPv6 inefficiency in micro-mobility scenarios, a few proposals for micro-mobility connectivity improvements, such as Hierarchical MIPv6 (HMIPv6) [3], Fast Handover for MIPv6 (FMIPv6) [4], Cellular IP [5] and Handoff-Aware Wireless Access Internet Infrastructure (HAWAII) [6], have emerged. Micro-mobility protocols aim to enhance MIPv6 with fast, seamless and local handover control, although similarly to MIPv6, they do not supply QoS. The micro-mobility mechanisms introduced by these approaches help reduce packet losses and registration time in turn improving the overall network QoS. However they do not

Manuscript received January 13, 2011; revised May 13, 2011.

Nuno V. Lopes is supported by a FCT Grant (SFRH/BD/35245/2007).

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provide QoS support for multimedia applications intrinsically.

Therefore, in this work a dynamic QoS provisioning solution for local mobility as well as its extensibility for global mobility is proposed. For this, two enhancements have been introduced: the first enhancement is a specific combination of FMIPv6 and HMIPv6 (F-HMIPv6) to improve handover latency and reduce MIPv6 protocol registration time; the second enhancement is the coupling of a mobility management scheme with a specific Resource Management Function (RMF). The mobility management scheme is based on F-HMIPv6 and RMF is based on a new DiffServ RMF. As, in the standard DiffServ model resources are statically provisioned, the RMF of standard DiffServ has been enhanced to support adaptive and dynamic QoS provisioning.

In order to accomplish this goal, a combination of Fast and Hierarchical Handovers, in-band signaling, DiffServ resource management, QoS context transfer and a Measurement-Based Admission Control (MBAC) algorithm have been integrated to design a QoS framework solution for mobile environments. This symbiotic combination of components has been optimized to work together in order to support seamless handovers with suited QoS requirements for mobile users running multimedia applications.

The remainder of the paper is organized into five sections. Section II presents the challenges and requirements in supporting QoS in mobile environments. Section III describes the related work. Section IV presents a description of the proposed QoS micro-mobility solution. Section V describes a proposal to extend the QoS micro-mobility solution for global mobility. Section VI presents the simulation model as well as the results obtained with the proposed QoS solution. The paper ends by remarking the most important conclusions.

II. QoS in Mobility: Challenges and Requirements

To endow the Internet with QoS support, all the layers in the Internet protocol stack must be involved. Starting by application entities such as Session Initiation Protocol (SIP)[1], or H.323[2], passing through IP QoS solutions such as IntServ or DiffServ and ending in layer 2 QoS provisioning such as 802.1q [7] or 802.16 [8]. As, a QoS based handover management carried out at layer-2 demands a specific strategy suited for each type of wireless access network and one of the objectives of the present research work is to have an independent QoS solution of up/down layers, the QoS handover management will be managed at layer-3. Hence, the present work is only concerned with QoS solutions at IP level.

As stated previously, the Mobile IP solution was found to be non-optimal in supporting regional mobility within one domain. This is why several efforts to shorten handover delay have been made by means of micro-mobility protocols. However, currently, handover schemes such as Fast Handover[3], Smooth Handover[4] and Seamless Handover[5], provided by micro-mobility protocols treat different applications the same way, without any type of traffic differentiation. Moreover, the existing QoS models take no account of mobile users. Consequently, QoS support during the handover period remains unresolved. Supporting QoS during handovers is very challenging due to changing routes between endpoints and varying link characteristics when connecting to different access points. Providing dynamic QoS provisioning during handover in such critical conditions imposes a re-negotiation of QoS parameters in the new access router with an architecture that is aware of current context of mobility and QoS. The QoS context could be transfered to the new access router so that it can be subject to some resource management by means of contexts transfers [9], notwithstanding, mobility and QoS management schemes still remain working independently producing non-optimal solutions in terms of signaling and processing load, and handover latency. Context transfers are a very useful functionality in providing support to QoS handovers in IP networks. This functionality is very helpful in supporting seamless handovers because it allows the QoS re-establishment in the new access router by transfering MN QoS context from one router to another without needing to establish the QoS in the new router from scratch.

Another important issue in QoS for mobile environments is the type of service model. For instance, in QoS architectures based on the guaranteed service model, whenever an MN moves to a new location, it must release the previously allocated resources in the old path and make new resource reservations in the new path resulting in extra signaling overhead and heavy processing and state load. If the handovers are very frequent, large signaling loads of mobility and QoS will be created in the access networks. Consequently, significant scalability problems arise with this service model. Moreover, given the unpredictable nature of wireless links, it is hardly possible to provide absolute guarantees in mobile networks.

On the other hand, if the QoS architecture is based on a predicted service model, additional features such as dynamic QoS funcionalities for resource management and adaptive resource management must be implemented in order to provide an efficient resource management for high dynamic mobile networks. Thus, traffic management mechanisms such as admission control that decide whether the router is capable of accepting or rejecting the flow, bandwidth reallocation and signaling protocols are necessary.

When speaking of admission control, in fixed networks, the admission control decision only applies to new flows, whereas in wireless networks the decision is made for new flows and handover flows. Since forced call termination due to handover have a profound impact on network reliability and user quality perception, the admission control policies should take into account the specificities of handover flows.

In order to enable QoS handover support to MIPv6, an optimized mobility management scheme with Fast and Smooth handovers is mandatory. The Fast handover scheme provides

[1]SIP is a signaling protocol used for controlling multimedia communication sessions such as voice and video streaming over IP

[2]H.323 defines the protocols to provide audio-visual communication sessions on any packet network. It is a recommendation from the ITU Telecommunication Standardization Sector (ITU-T)

[3]It is a handover that can comply strict delay bounds

[4]It is a handover that minimizes the lost packets

[5]It is a handover with minimum perceptible degradation of services

the anticipation of layer 3 handover allowing data traffic to be efficiently redirected to a new access router before it moves there. The hierarchical mobility management model permits the performance enhancement of Mobile IPv6 with local bindings, while using Fast Handovers helps MNs to achieve seamless mobility.

Another important feature for a QoS framework solution in mobile environments is its adaptation capacity to changeable nature of wireless networks. The wireless networks have a more dynamic behavior and cell resource availability is constantly changing due to incoming or outgoing handovers. For this reason, the user mobility requires a QoS signalization for dynamic resource provisioning in order to supply adequate QoS levels to MNs on a given cell. As a consequence, this involves the use of two important mechanisms: the admission control mechanisms which avoids data excess, and signaling protocols, which request the desired service and inform the requesters about the network elements decision/conditions.

III. Related work

The HMIPv6, FMIPv6 and F-HMIPv6 micro mobility approaches were evaluated and compared to Mobile IPv6 in [10]. Authors claim that FMIPv6 is capable of reducing MIPV6 handover latency by 15 times. The HMIPv6 is also capable of reducing by 8 times the handover latency of MIPv6. It is also important to note that FMIPv6 and HMIPv6 combined can reduce the overall handover latency by 18 times when compared to the standard MIPv6. Similar studies regarding MIPv6, HMIPv6, FMIPv6 and F-HMIPv6 performance, as seen in [11], [12], [13], also presented very similar results. Our proposed integration of FMIPv6 and HMIPv6 follows the implementation used by those works except in the proceeding of Handover Initiate (HI) and Handover Acknowledgment (HAck) messages which is maintained between the previous access router and the new access router as seen in the FMIPv6 protocol (see Figure 2).

Dynamic resource allocation architectures can be accomplished with signaling protocols and admission control policies. IntServ and Bandwidth Brokers for DiffServ were the main dynamic QoS architectures proposals for wired networks. These architectures are not suited for scenarios containing mobility, where bandwidth is limited and the operating conditions are non-deterministic therefore, they have been adapted with few improvements and adjustments for mobile reality. The Resource Reservation Protocol (RSVP) which is the signaling protocol of the IntServ model has been improved for mobile scenarios in the several works. In [14] the authors proposed the Mobile RSVP (MRSVP) in order to make advanced reservations at multiple locations where a MN may possibly visit. Thus, when an MN moves to a new location, the resources are reserved in advance. However, advanced resource reservations has a problem in creating excessive resource reservations resulting in the significant waste of resources and poor network performance.

In [15] authors combined Mobile RSVP with Hierarchical MIP (HMRSVP) where the main differences between MRSVP and HMRSVP reside in the local registration of MN and the advanced resource reservation which are only made when the MN proceeds an inter-domain handover, contrary to MRSVP which establishes reservations on all the MN's surrounding cells. This solution reduces the impact of Mobile RSVP's problems but still inherits the same framework problems of significant processing burden and resource waste. Moreover, the solution is restricted to HMIPv6 networks therefore, it does not inter-operate with other mobility protocols such as MIPv6 or FMIPv6.

In [16] the authors proposed the QoS-Conditionalized Handoff for MIPv6. The key idea is to employ the QoS hop-by-hop option, piggybacked in a mobility management binding message in order to provide theQoS signaling support to handovers based on resource availability along the new data path towards nAR. This scheme is built over Hierarchical MIPv6 in order to be suitable for micro-mobility scenarios but has the disadvantage that all nodes needed to be modified in order to implement the required functionality.

In [17] the authors introduce a Crossover Router (CR) entity to reduce tunnel distance between Previous Access Router (pAR) and nAR created by the FMIPv6 protocol. The CR is responsible for intercepting the packets to MN's previous Care-of-Address (CoA) and forwarding them to the nAR. With regards to QoS guarantees, they extend Fast Binding Update (FBU) and Handover Initiate (HI) messages to inform the nAR of the MN's QoS requirements and then make an advanced reservation on the common data path. The authors claim that their solution outperforms MRSVP in terms of signaling cost, reservation re-establishment delay, and bandwidth requirements.

In [18] the authors develop a modified RSVP called Mobility-Aware Resource Reservation Protocol (MARSVP). The main idea is to convey the binding update and the binding acknowledgment messages in two newly RSVP objects that should be embedded in the standard RSVP messages.

Since IntServ possesses scalability problems in large scale scenarios, the DiffServ model appeared with some important enhancements in terms of core simplification and traffic aggregation in order to become more scalable. The IntServ model is based on a flow reservation basis, whereas DiffServ is based on a packet priority basis. In the IntServ model, the service commitments are made to individual flows. These service commitments are mainly focused on delay requirements whereas in the DiffServ model, the service commitments are made to a class of traffic by policing the aggregated bandwidth distributed among the classes, according to a set of specified thresholds shares. In [19] the authors proposed a QoS framework for end-to-end differentiated services in Mobile IPv6. For this purpose, they used the Common Open Policy Service - Service Level Specification (COPS-SLS) protocol to make inter-domain SLS dynamic negotiations, and a new scheme for end-to-end DiffServ context transfer over MIPv6. The context is used to re-establish DiffServ context in a new data path and thus, avoids the re-initiate COPS-SLS signaling from scratch.

In spite of the unquestionable enhancements of the proposed QoS solutions for mobility, they are based on deterministic resource reservations for a guaranteed service model. When enforced on mobile networks, these QoS will introduce extra signaling overhead due to required QoS renegotiation in a new data path when a handover occurs. Consequently, significant scalability problems may arise due to simultaneous QoS and mobility signaling messages caused by handovers that may be excessive in high dynamic mobile networks. Besides that, the guaranteed service model also requires state information maintenance in all routers along the data path which may also result in scalability problems.

Other works underlying DiffServ architecture without dynamic resource allocation have also been proposed. In [20] the authors propose a QoS framework based on DiffServ and HMIPv6 micro-mobility protocol. In order to advertise resource availability on an access router to an MN, the authors extended the Router Advertisement (RA) message with this information. The MN uses this information as criteria for choosing the most suitable nAR for its QoS requirements.

In [21] the authors develop an algorithm for handover flows that intends to maintain the QoS level of the existing flows and handover flows during MN handover in a DiffServ-enable wireless access network. The authors only considered two service levels in the network: Assured Forwarding (AF) and BE. The algorithm measures the bandwidth utilization of an AF1 class and when sufficient bandwidth is unavailable for handover flows, it downgrades their service to an AF2 class. The algorithm also employs a penalty mechanism when both service classes , AF1 and AF2, do not have available bandwidth to satisfy the bandwidth requirements of the handover flow.

In high dynamic environments such as mobile networks, the extension of the DiffServ model for admission control and on-demand resource reservation in order to optimize the network utilization is necessary however, these two last proposals do not provide dynamic resource allocation.

IV. Proposed Model

The main objective of the proposed model is to define a micro Mobility/QoS-aware network with dynamic QoS funcionalities, adaptive resource management and seamless handovers. Another stated goal is to deal with potential scalability problems in situations where handovers are frequent, reducing signaling overhead, processing and state information load.

In order to overcome the inefficiency of MIPv6 in micro-mobility scenarios, the proposed model enhances the MIPv6 protocol with a specific integration of FMIPv6 and HMIPv6 (F-HMIPv6). The F-HMIPv6 enhances the MIPv6 mobility with seamless handovers and local handover registrations. The integration follows the recommendations of RFC 4140, except in the procedure of HI and Handover Acknowledgment (HAck) messages which is maintained between the pAR and nAR, as in the FMIPv6 protocol (see Fig. 2). In this sense, the integration of FMIPv6 and HMIPv6 differs from the previously proposed combination [13] in the procedure of HI and HAck messages. The Mobile Anchor Point (MAP) mobility agent of HMIPv6, which acts as a Home Agent (HA) in MIPv6, is located in the ingress node of the domain [3].

With regards to QoS architecture, the proposed model extends the RMF of DiffServ in the edge routers with an MBAC mechanism. The transparency of DiffServ packets caused by IP tunneling has been solved with the propagation of DiffServ Code Point (DSCP) information in the packet header to the outer IP header as recommended in [22]. The new RMF handles the QoS input parameters contained in QoS signaling messages. In the Access Routers (ARs) the RMF contains an additional element called the dynamic allocator which improves network utilization with an adaptive resource management. The RMF comprises the DiffServ QoS mechanisms (policer, congestion avoidance and scheduling) and an MBAC mechanism (estimator and AC algorithm).

In what respects QoS signaling, the proposed model uses a simple signaling protocol in order to allow new flows to make their QoS requests and uses the HI/HAck messages which are F-HMIPv6 mobility management messages. These messages convey the MN's QoS context in order to enable handover flows to request the desired QoS from the new router.

The use of mobility messages to convey MN'S QoS context allows the coupling of mobility management and QoS management thus, levering the possibility of optimizing both managements.

Similar to the NSIS framework the QoS signaling protocol used by new flows to request their services is decoupled from the RMF [23]. Therefore, a distinction is made between the signaling protocol operation and the RMF signifying that the RMF operability is autonomous from the adopted signaling protocol.

In summary, the model proposes an extension of MIPv6 mobility protocol with F-HMIPv6 and an extension of the DiffServ QoS model with QoS signaling and a MBAC.

These model components and the way they are interconnected are explained in the next sections.

A. Resource Management Function

In the DiffServ model, resources are allocated statically to a specific DiffServ class or allocated dynamically by means of a Bandwidth Broker (BB). A BB has the role of configuring DiffServ QoS mechanisms in the edge routers to a specific DiffServ class according to QoS requirements contained in an SLS. However, a BB is a centralized entity designed for fixed networks which only makes admission control for new flows that enter in the domain thereby when an MN moves to a new location the BB must always be informed to perform the admission control for handover flows and the associated edge router configuration. Furthermore, a resource management solely based on a centralized BB demands that each MN movement needs to be signaled, stated and processed in this central entity. Therefore, the BB can become the bottleneck in the resource allocation of edge routers.

On the other hand, standard DiffServ mechanisms such as PRI scheduling are not limited to a threshold of the amount of allocated resources that a priority DiffServ class can obtain. As a consequence, the lower priority classes can enter starvation if the higher priority classes´ traffic saturate the link capacity. Furthermore, a DiffServ queue management such as Random Early Detection (RED) is also insufficient in avoiding link congestion.

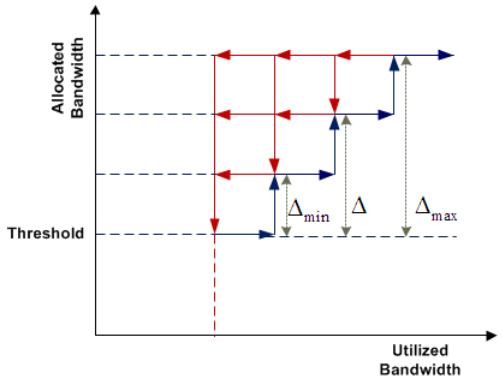


Figure 1: The Reallocation Mechanisms with Hysteresis of Dynamic Allocator

For these reasons, the resource management of standard DiffServ has been extended with explicit setup mechanisms to request resources from the network for the purpose of supporting class admission control in ingress and ARs. For admission control purposes a new MBAC has been used. The new class MBAC contains a rate estimator and an Admissiom Control (AC) algorithm/policy. The rate estimator is a Time Sliding Window Estimator (TSWE) that measures the actual class bandwidth load (associated with wired part of AR) and MN's QoS context which is its DiffServ context in the pAR. The MN's QoS context is the measured bandwidth in use in each DiffServ class on the pAR by MN in other words, the MN's QoS context is the measurement of the aggregated traffic being used by an MN in each individual DiffServ class.

In order to decide whether to admit or reject a flow, a measure rate sum algorithm has been used. For new flows, the decision is made on the ingress router and AR, and is based on inputs from a traffic descriptor and traffic class measurements. For intra-domain handover flows, the decision is made only on nAR, and for inter-domain handovers flows the decision is made on new ingress router and on nAR. The decision for handover flows is based on inputs from MN's QoS context and on traffic class measurements in the nAR at the time of handover.

The AC algorithm implemented in the ARs has been extended with a reallocation mechanism based on the hysteresis method, called "dynamic allocator". The dynamic allocator's main objective is to achieve better resource utilization and simultaneously increase the number of accepted MN classes meeting the required QoS. The dynamic allocator can induce the increase of the accepted handover flows by reducing the bandwidth allocated for BE traffic in favor of priority classes. Figure 1 illustrates the reallocation mechanism of the dynamic allocator which has been implemented using the hysteresis method. Equations 1 and 2 present the policy defined by the dynamic allocator to share the uncommitted bandwidth of the BE class.

$$0 \le \Delta Class_i \le \Delta_{max_i} \tag{1}$$

where $\triangle class_i$ is the bandwidth variation of class i and $\triangle max_i$ is the maximum bandwidth variation of class i.

$$\Delta BE_{min} \le \sum_{i=1}^{D-1} \Delta Class_i \le \Delta BE_{max} \tag{2}$$

Where D is the number of DiffServ classes.

By making bandwidth reallocations in fixed step sizes, the implemented algorithm conducts to a very predictable and stable behavior of the reallocation mechanism (see equation 3).

$$\#steps_i = int\left(\frac{(Class_i + ClassCntxt_i) - T_i}{\triangle min_i}\right) + 1 \tag{3}$$

The admission control algorithm accepts MN's handover flows until the maximum bandwidth variation for a given class i be reached ($\triangle max_i$). For instance, assuming that an MN starts with handover procedure to move to a new AR and at that moment the number of steps which are necessary to reallocate is 3 ($3 = \#steps_i$). In this scenario, the dynamic allocator will reallocate the following bandwidth

$$\triangle Class_i = 3 \times \triangle min_i.$$

if and only if $3 \times \triangle min_i \le \triangle max_i$.

The reallocated bandwidth is released in fixed step sizes accordingly to measure bandwidth utilization in the class i. The release of the reallocated bandwidth stops when the measure bandwidth utilization is less than or equal to the bandwidth initially allocated for $Class_i$ (T_i).

B. QoS signaling

A two-way signaling protocol is used so that new applications express their service requests to the network. Service requests contain a traffic descriptor describing the worst case application traffic behavior and the required DiffServ class.

Signaling protocol lets edge routers Signaling Agents (SAs) know the traffic and service specification of an incoming flow (see Fig. 3). To signal new flows, the Correspondent Node (CN) uses its SA to request services from the network; this SA is responsible for the delivery of all service request messages. Signaling Request (SA-REQ) messages sent by CN contain the traffic description which will be the RMF input. The message contains two parameters: Desired Bandwidth and Class. The Signaling Agent sets the desired bandwidth and class so that each SA on path is able to read and pass those parameters to the RMF. If one of the edge routers in the path fails to satisfy the desired QoS, the receiving Signaling Agent generates a negative Signaling Confirmation (SA_CONF) message to the SA initiator (the CN) with a negative decision and the flow is aborted. Otherwise, the receiving Signaling Agent generates an SA_CONF with a positive decision and the flow may continue with its traffic transmission.

For intra-domain handovers, the MN's QoS Context in pAR is conveyed by HI messages to nAR. The HI messages will be handled by the RMF of nAR. The HI handover signaling message triggers the RMF in the nAR before the handover occurs resulting in a proactive behavior which allows the RMF to adapts its configuration for incoming handover flows.

Figure 2 shows the signaling procedure for intra-domain handovers. Whenever an MN wants to change its point of

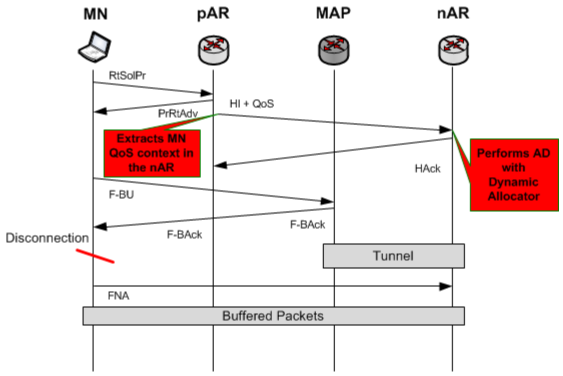


Figure 2: Intra-domain Handover Signaling Procedure

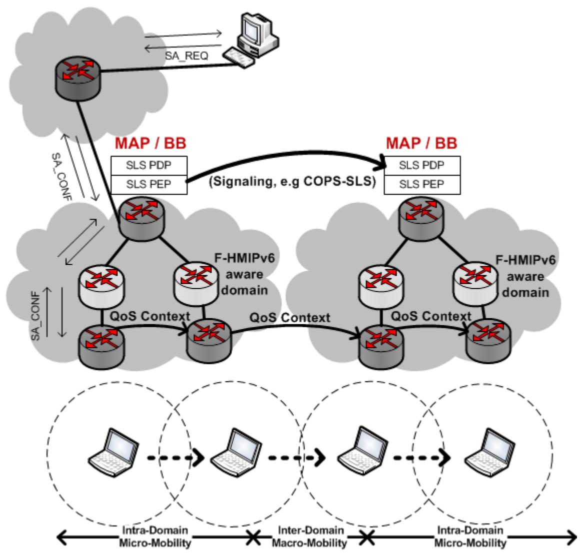


Figure 3: Major Components and Interactions

attachment, it must request a new CoA address from nAR by sending Router-Solicitation-for-Proxy (RtSolPro) message to pAR. The pARs receives the RtSolPro message and generates a Proxy-Router-Advertisement (PrRtAdv) message with a prospective new MN CoA and sends it to MN. The pAR also forms an HI message containing the nAR address and the MN's QoS context to send to nAR. The MN's QoS context in the pAR is extracted with the rate estimator of RMF which measures each DiffServ class bandwidth in use on the pAR by MN at that time. This per-Class state information (MN's QoS context) is stored in the mobility options field of the HI message. The nAR receives the HI message and processes mobility and RMF. The RMF then decides which MN's DiffServ classes can be accepted. Also, if necessary, the RMF dynamic allocator element fetches more bandwidth for classes with more strict QoS requirements to accommodate flows belonging to those priority classes.

Next, it forms a valid CoA or validates the prospective new CoA and places the CoA and the AC decision on a HAck message returning it to the pAR. The pAR receives the HAck, validates the new CoA address and sends a negative decision on a SA_CONF message (the message is not illustrated in the Figure) of the rejected flows to CN. Then MN sends a Fast Binding Update (F-BU), via pAR, to MAP for binding its previous CoA to new CoA. MAP receives F-BU message and sends a F-BAck message to MN and to nAR. The MN needs to wait for F-BAck message before makes handover because this message indicates that MAP is prepared to make the tunneling of the packets to the nAR. When the MN receives F-BAck message, first it disconnects from the pAR and then re-attaches to the nAR. Once in the nAR, MN sends a Fast Neighbour Advertisement (FNA) message to receive the buffered packets in the nAR and registers its new CoA with HA and CNs by sending a binding update message.

V. An Extended Proposal For Global Mobility

Another objective of the model is to design a micro Mobility/QoS-aware network capable of being easily extended for global mobility. Figure 3 illustrates the network reference model for global mobility. In this scenario MAP should integrate the functions of ingress router, BB and inter-domain signaling entity. For inter-domain communication, a signaling entity such as a COPS-SLS's entity may be used. The BB´s job is to negotiate SLSs with the BBs of neighboring domains in order to provide users with end-to-end QoS. The BB translates MN's QoS Context into SLS and then negotiates SLS with its peer BB.

Therefore, when an MN moves towards a new access router in another domain its BB, as the responsible for managing the Diffserv router configuration in a Diffserv domain, must be informed as to the QoS to be provided in the new router. The proposed model´s BB is only responsible at the inter-domain level which includes the negotiation of QoS parameters as well as the setting up of bilateral agreements with neighboring domains. The neighboring domains should have a pre-negotiated mapping of their SLSs to avoid the reconfiguration of DiffServ routers to a new SLS. On an intra-domain level, the edge routers are responsible for the enforcement of resource allocation and admission control instead of the BB.

In this scenario, the handover flows should be subject to AC policies in the BB of the new domain and in the nAR. For inter-domain handovers, the following considerations have been assumed: a scenario where domains are F-HMIPv6 aware; and previous MAP are configured and authorized to forward packets to local CoA associated with the ARs in neighbor of MAP domain. The forwarding of packets to nAR, located in the new domain, allows the MN to continue receiving packets while it is simultaneously updating the bindings in the new MAP (nMAP) and in its home agent. Therefore, when an MN enters into a new MAP domain, it must configure the regional CoA (RCoA) address on the new MAP and local CoA (LCoA) address. The LCoA is configured with the network prefix of nAR and RCoA is configured with the network prefix of new MAP.

Figure 4 illustrates an inter-domain handover signaling procedure. Thus, when an MN enters a new domain it receives link-layer information from the available access points. The MN may discover an available access point using link-layer WLAN scan mechanisms and then request sub-net information corresponding from the access point. After, the MN sends a RtSolPr message to pAR to resolve the identifier associated to the found access point. The pAR performs the prefix information match of the access point (provided in RtSolPr) with its prefix list of neighboring ARs in order to formulate a prospective new CoA. The resolution of the identifier is a tuple containing the nAR prefix, IP address and L2 address.

The pAR responds to the MN's solicitation with a PrRtAdv message containing the prospective new CoA (nCoA). The MN obtains the prospective nCoA when is still connected to pAR, thus eliminating the need to discover the new prefix after the attachment in new subnet link.

After the MN receives the PrRtAdv message, it sends an F-BU message to the previous MAP (pMAP). The MN should wait for an F-BAck message sent by the pMAP in response to F-BU, before disconnecting from its current sub-net link. As stated previosuly, the F-BAck message indicates that pMAP is prepared to tunnel the packets to nAR. The pAR also generates an HI message containing the MN's QoS context and sends it to nAR. When the HI message arrives at pMAP through a common routing process, its BB translates the MN's QoS context to SLS information and establishes a secure connection with its peer BB to negotiate a rate and a service class. If the request is accepted by the peer BB/MAP, the MAP of current MN's domain is authorized to forward the MN's QoS context in the HI message to nAR.

The nAR verifies whether or not the nCoA present in HI is already in use if so, it forms a new and valid CoA and then checks its capabilities for receiving the MN's traffic using the RMF. Additionally, the nAR can dynamically adapt its configuration in order to accommodate the incoming handover flows belonging to priority classes. Then, in response to the HI message, the nAR sends back a HAck message containing the AC decision.

In the new domain, after L2 handover, the MN sends an FNA message to nAR to receive the buffered packets in the nAR. After that, the MN performs the registration procedures with nMAP and HA. Regarding to the Correspondent Nodes (CNs) the MN may send a Binding Update with its LCoA instead of RCoA for receiving the packets directly from CN.

VI. Simulation Model and Results

This section presents several simulation results regarding model performance and parametrization. The objective of the simulation model is to assess the performance improvement achieved when implementing the proposed QoS solution in mobile environments and also to evaluate the model parametrization. The model has been implemented in the network simulator version two (ns-2), patched with IEEE 802.21, HMIPv6 and FMIPv6 extensions [24], [25].

Figure 5 shows the simulated topology for an intra-domain scenario. The simulation scenario includes ten CNs and MN's HA in the global Internet, and a DiffServ domain F-HMIPv6 aware with two ARs and ten MNs. The QoS mechanisms of standard DiffServ have been configured with four DiffServ classes that have been set up according to QoS requirements of UMTS classes [26].

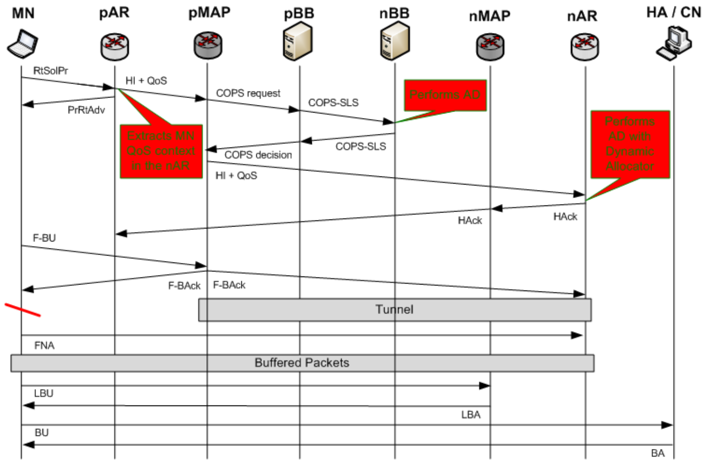


Figure 4: Inter-domain Handover Signaling Between Different Administrative Domains

The highest priority class (class 1) has been configured for Expedited Forward (EF) service, the lowest priority class (class 4) has been configured for BE service and the other two classes (class 2 and 3) have been configured for AF service.

MNs are receiving Constant Bit Rate (CBR) flows from CNs located at another DiffServ domain in the global Internet in a one to one relation CN→MN. Each CN is generating four CBR flows each one marked with a different DSCP. Therefore, forty flows have been generated in total. As the bottleneck is in the last hop (wireless link) all the flows will be accepted by precedent posts of AC until the AR.

Eight MNs are initially located in pAR and two MNs are fixed in nAR (see Fig. 5). One MN in pAR is moving at fixed time (60 seconds) and the others start moving randomly in a time range between 50 and 100 seconds to nAR. Only intra-domain handovers are considered in this simulation environment. The network load on nAR after MNs handovers is 132%.

A. *Model Performance*

Four distinct scenarios have been designed in order to assess the performance improvement of the proposed QoS solution. Scenario A has been implemented with the proposed combination of FMIPv6 and HMIPv6. Scenario B aims to show the solution of IP tunnels problem, therefore has been implemented on F-HMIPv6 mobility scheme the DiffServ over tunnels. Scenario C represents proposed dynamic QoS provisioning, in this scenario the QoS signaling and the AC scheme have been added to the standard DiffServ RMF. Scenario D has one more element than scenario C. To illustrate the adaptive behavior of the proposed RMF, the dynamic allocator element has been added to scenario D. Summarizing:

Scenario A - F-HMIPv6;
Scenario B - Scenario A + DiffServ over Tunnels;
Scenario C - Scenario B + Admission Control;
Scenario D - Scenario C + Dynamic Allocator.

Figures 6 illustrates class 1 mean throughput distribution and the mean delay distribution and their associated standard

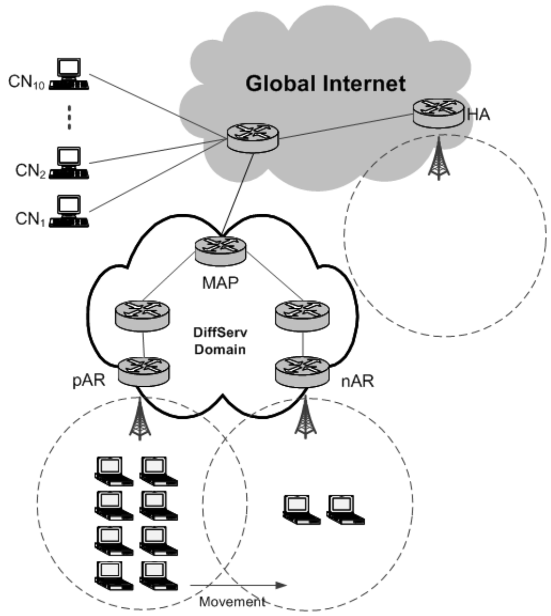
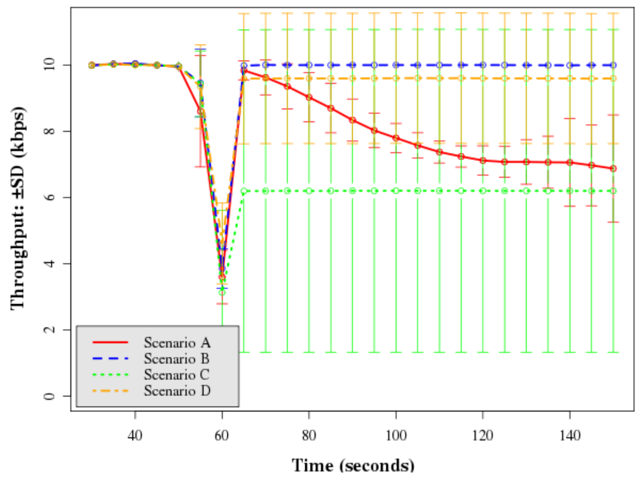


Figure 5: Simulation Model

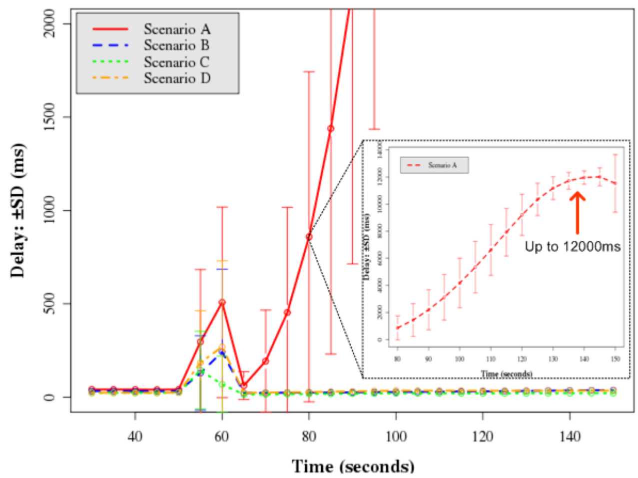
deviation around the mean. It should be noted that in order to simplify the interpretation of the Figs. 6 and 7, the standard deviation of scenario D is not shown. In this scenario the maximum flow rate corresponds to the peak rate of the admitted flows, and the minimum flow rate corresponds to the rejected flows, therefore is zero.

Figure 6a shows that at 60 seconds, after an MN's handover, scenario B achieved the best mean throughput. This results from the fact that the standard DiffServ mechanisms do not have any class threshold limit result in the admission of all generated traffic. After handover, Scenario C presents a mean throughput decrease of almost half of the initial mean throughput (before handover). This is due to the AC scheme that limits the amount of traffic in class 1 rejecting the surplus traffic. Scenario D presents a slight decrease in the initial mean throughput and a low standard deviation after handover. This is due to the dynamic allocator that reallocates more bandwidth for class 1 to accommodate more traffic in this class thus resulting in a small traffic rejection. Scenario A presents a gradual mean throughput decrease which is proportional to the link saturation. This derives from the fact that all traffic is equally treated in each of the four classes. With regards to delay behavior, Figure 6b shows that in scenario A the mean delay and the associated standard deviation increase sharply after MN's handover because of the link saturation caused by the MNs handovers. Whereas scenarios B, C and D present a very similar mean delay behavior where their mean delay and the associated standard deviation are nearly equal both before and after handover.

Figure 7 illustrates the class 3 mean throughput distribution and mean delay distribution and their associated standard deviation. Figure 7a shows that in the scenarios B and D, after MN handover, the MN can achieve approximately the same mean throughput it had before handover. However, while in scenario D, the mean throughput remains constant. In scenario



(a) Class 1 Mean Throughput and Standard Deviation

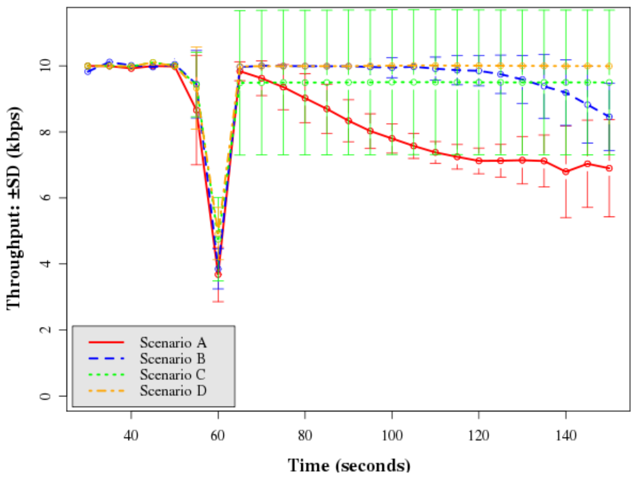


(b) Class 1 Mean Delay and Standard Deviation

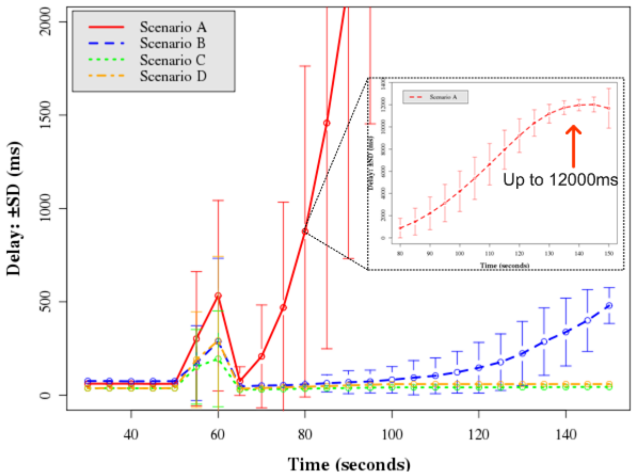
Figure 6: Class 1 Throughput and Delay with Standard Variation in the Four Scenarios

B the mean throughput starts to decrease around 100 seconds because at that moment all MNs have been moved to the nAR and being as class 3 is the class with decreased priority when the link starts to become saturated priority classes with decreased priority become affected by those with higher priority. Scenario C presents a mean throughput decrease after MN's handover which derives from the AC scheme rejecting some of the flows during the handover. Scenario A, as expected, presents a mean throughput distribution for class 3 very similar to the mean throughput distribution for class 1 presented in Figure 6a.

Regarding delay behavior, Figure 7b shows that in scenarios C and D, the MN's delay in class 3 is maintained during simulation time, while in scenario B the delay starts to increase, around 50 seconds, when MNs arrive at nAR. The mean delay distribution in scenario A of the Figs. 6b and 7b is very similar, resulting from traffic classes being equally treated.



(a) Class 3 Mean Throughput and Standard Deviation



(b) Class 3 Mean Delay and Standard Deviation

Figure 7: Class 3 Throughput and Delay with Standard Variation in the Four Scenarios

B. Model Parametrization

The model parametrization is made by setting up the following parameters: 1) $ClassBW_i$: the bandwidth initially allocated for class i; 2) $\triangle max_i$: the maximum bandwidth variation of class i; 3) $\triangle min_i$: the size of step unit.

The first two parameters values should be chosen by a network administrator based on the Internet Service Provider (ISP) policies and the knowledge of his network traffic, assigns the most appropriate values for his domain. The last parameter ($\triangle min$) determines the number of steps needed to achieve the $\triangle max$. The $\triangle min$ value infers in the QoS provided by the dynamic allocator and in the network stability, since frequent reallocations in a class can cause instability. Considering T_{BW} the total wireless link bandwidth, the first parameter $ClassBW_i$ which is the allocated bandwidth for each DiffServ class, has been set up with: 10% for class 1, 20% for class 2, 30% for class 3 and 40% for class 4.

The second parameter which is the maximum bandwidth variation of the class has been set up with: 50% for class 1, 40% for class 2 and 30% for class 3, the sum of these variations corresponds to 22% $(0.1T_{BW} \times 50\% + 0.2T_{BW} \times 30\% + 0.3T_{BW} \times 20\% = 0.22T_{BW})$ which is the maximum negative variation of class 4 (the class with BE traffic).

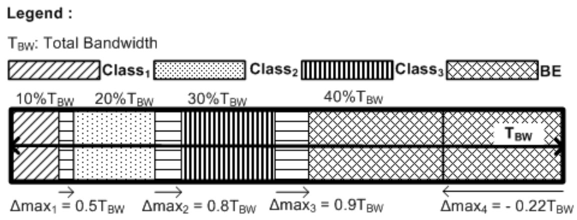


Figure 8: Defined Parameters

$\triangle Class_{min}$	$\#steps_i = \frac{\triangle Class}{\triangle Class_{min}}$
1%	100
2%	50
5%	20
10%	10
15%	7
20%	5
50%	2

Table I: Relation between $\triangle Class_{min}$ and $\#steps$

Figure 8 shows a representation of the defined parameters.

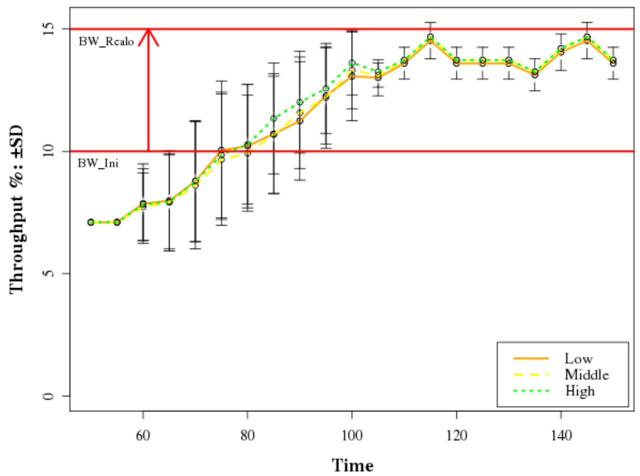
The $\triangle min$ value determines the number of steps needed to achieve the $\triangle max$ (see table I). To have a more stable network, the number of steps within each class should be the lowest possible. In order to evaluate the $\triangle min$ parameter influence, the network stability and maximum bandwidth utilization have been used as criteria.

For analyzing the influence that the choice of the $\triangle min$ has in the model architecture efficiency some graphics and results about class 1 throughput for different $\triangle min$ values are presented and discussed. The chosen values for $\triangle min$ have been 10% (or, bandwidth variation in 10 steps), 25% (or, 4 steps) and 50% (or, 2 steps), denominated as Low, Middle and High. The $\triangle min$ has been evaluated under two different scenarios of network load (see table II). The same topology and network configurations of the previous subsection have been used for simulation. The second scenario of network load is the same used in the previous subsection.

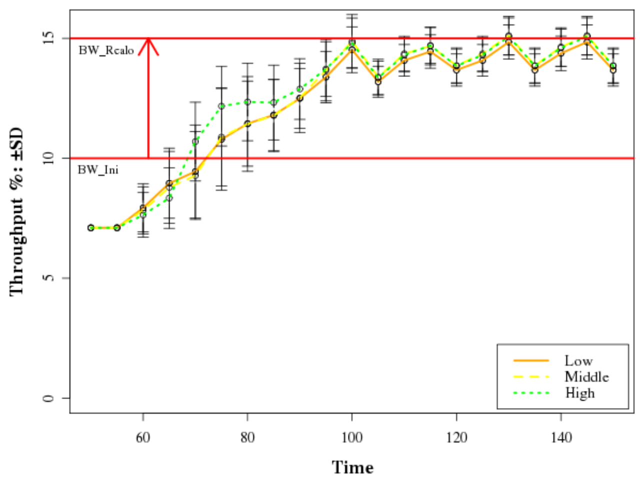
Table III shows the reallocated bandwidth in class 1. The table shows that the Middle $\triangle min$ has achieved a better bandwidth utilization for the priority class 1 in the tested scenarios, and one can observe that the $\triangle min$ has a considerable impact in bandwidth distribution among classes. It can be also theorized that the relation between data flow rate and $\triangle min$ influences the amount of reallocated bandwidth, i.e. if the flow rate and the $\triangle min$ step of a given class are closer, the reallocation mechanism achieves higher values of bandwidth utilization. For instance, in scenario S1 the flow rate in class 1 is $0.03T_{BW}$(Kbps) which represents a percentage utilization of 14.2% for a Middle $\triangle min$ with a step size

	Class 1	*Class 2*	*Class 3*	*Class 4*	*Total*
S1	*15.0%*	*30.0%*	*48.0%*	*36.0%*	*129.0%*
S2	*15.0%*	*30.0%*	*45.0%*	*42.0%*	*132.0%*

Table II: The Two Scenarios of Network Load in nAR



(a) Total Bandwidth Percentage Used by Class 1 Throughput in the Scenario S1



(b) Total Bandwidth Percentage Used by Class 1 Throughput in the Scenario S2

Figure 9: Class 1 Throughput For Distinct Values of $\triangle min$ (Low, Middle and High) in the Scenarios S1 and S2.

of $0.012.T_{BW}$, whereas in scenario S2 with a flow rate of $0.015T_{BW}$(kbps) a percentage utilization of 14.7% in the class 1 has been achieved . Furthermore, Figure 9 also shows that in this case, the reallocated bandwidth converges more quickly to the maximum variation value.

Equally important is the fact that despite in scenario S1, the traffic generated for class 4 (S1:36%, Tab. II) did not totally fill the allocated bandwidth for this class (40% of allocated bandwidth, Fig. 8) the reallocation mechanism takes advantage of the available bandwidth in class 4 in order to increase the allocated bandwidth of priority classes, thus increasing the bandwidth utilization to approximately its maximum capacity. Obviously, according to policies of AC algorithm, this improvement can also imply the decrease of BE throughput if the allocated bandwidth for this class is totally occupied. Therefore, based on the results obtained for the two scenarios, one can conclude that the Middle $\triangle min$ achieves a better bandwidth utilization percentage for the priority classes than the other two $\triangle min$ values, being Low $\triangle min$ the poorer.

	Low $Step \rightarrow 0.5\%T_{BW}$	*Middle* $Step \rightarrow 1.2\%T_{BW}$	*High* $Step \rightarrow 2.5\%T_{BW}$
S1	*14.0%*	*14.2%*	*14,2%*
S2	*14.4%*	*14.7%*	*14.5%*

Table III: Total Bandwidth Percentage Used By Class 1 in the Scenarios S1 and S2.

In this sense, one can argue that the best $\triangle min$ for the proposed model is the one that achieves a bandwidth utilization percentage closest to the $\triangle max$ value (15%). Thus, by analyzing the results presented and taking into account the criteria of network stability, one can verify that a $\triangle min = 25\%$ is the best choice. The $\triangle min = 50\%$ could also be a good choice if the option is to have a more stable network in detriment of bandwidth utilization.

VII. Conclusions

This research work proposes a model that enables dynamic QoS provisioning to local mobility which can be easily extended to global mobility.

The proposed model aims to enhance global mobility with efficient handovers and QoS. For this purpose two enhancements have been introduced. The first enhancement has been a specific integration of FMIPv6 and HMIPv6 (F-HMIPv6) to improve MIPv6 handover latency. The second enhancement has been the extension of the standard DiffServ resource management with dynamic and adaptive QoS provisioning.

The model uses explicit and implicit setup mechanisms to request resources from the network for the purpose of supporting admission control and optimizing resource allocation.

For better resource allocation, resource and the mobility managements have been coupled, resulting in a QoS/Mobility aware network architecture, able to have a proactive behavior to mobility events.

In order to avoid both signaling overhead and resorting to a complex bandwidth broker, the model offers end-to-end predicted services which provide high reliable services but without absolute guarantees.

According to simulation results, the model has shown to be able to deal with network congestion to limit the amount of traffic within a class and to improve resource utilization, while maintaining QoS requirements of flows, within their DiffServ classes, unchanged.

This paper also indicates how the model should be parameterized; more specifically in what pertains to the $\triangle min$ parametrization, a study has been conducted in order to find the value with the best commitment between the criteria of network stability and maximum bandwidth utilization.

VIII. Future Work

Although a proposal for extending the model for global mobility has been presented in this research work, its implementation and evaluation in NS-2 still remains for future work. This implementation will allow the performance analysis of reallocation dynamics and stability in global mobility. Another intention is to support secure end-to-end QoS services for real-time applications accross heterogeneous domains. Therefore, it is intended to add a new element to the proposed model with an Authentication, Authorization, Accounting and Charging component (AAAC). The AAAC possesses the role of authenticating a user from a foreign domain, granting a given contracted service and controling the payment of the used resources.

Another development to be carried out is the analysis of the signaling overhead introduced by inter-domain handovers.

REFERENCES

[1] A.-E. Taha, H. Hassanein, and H. Mouftah, "Extensions for Internet QoS paradigms to mobile IP: a survey," *Communications Magazine, IEEE*, vol. 43, pp. 132–139, May 2005.

[2] A. T. Campbell, J. Gomez, S. Kim, Z. R. Turányi, A. G. Valkó, and C.-Y. Wan, "Internet micromobility," *J. High Speed Netw.*, vol. 11, no. 3-4, pp. 177–198, 2002.

[3] H. Soliman, C. Castelluccia, K. ElMalki, and L. Bellier, "Hierarchical Mobile IPv6 (HMIPv6) Mobility Management." RFC 5380 (Proposed Standard), 2008.

[4] R. Koodli, "Mobile IPv6 Fast Handovers." RFC 5568 (Proposed Standard), July 2009.

[5] A. Campbell, J. Gomez, S. Kim, A. Valko, C.-Y. Wan, and Z. Turanyi, "Design, implementation, and evaluation of cellular IP," *Personal Communications, IEEE*, vol. 7, pp. 42 –49, aug 2000.

[6] R. Ramjee, K. Varadhan, L. Salgarelli, S. R. Thuel, S.-Y. Wang, and T. La Porta, "HAWAII: a domain-based approach for supporting mobility in wide-area wireless networks," *IEEE/ACM Trans. Netw.*, vol. 10, no. 3, pp. 396–410, 2002.

[7] IEEE, "IEEE 802.1q: VLAN," tech. rep., November 2008. http://www.ieee802.org/1/pages/802.1Q.html (last visited 05/2011).

[8] I. of Electrical Electronics Engineers, "IEEE Standard for Local and Metropolitan Area Networks," tech. rep., 2009. http://standards.ieee.org/getieee802/download/802.16-2009.pdf (last visited 05/2011).

[9] J. Loughney, M. Nakhjiri, C. Perkins, and R. Koodli, "Context Transfer Protocol (CXTP)." RFC 4067 (Experimental), July 2005.

[10] R. Hsieh, A. Seneviratne, H. Soliman, and K. El-Malki, "Performance analysis on hierarchical Mobile IPv6 with fast-handoff over end-to-end TCP," in *Global Telecommunications Conference, 2002. GLOBECOM '02.*, vol. 3, pp. 2488–2492, 2002.

[11] N. Jordan and P. Reichl, "A Fast Handover System Evaluation in an All-IPv6 Mobility Management - Wireless Broadband Access based Hotspot Network Environment," in *International Conference on Networking, International Conference on Systems and International Conference on Mobile Communications and Learning Technologies, 2006. ICN/ICONS/MCL 2006.*, pp. 122–122, 2006.

[12] Z. Zhang, J. Fang, W. Wang, and S. Zhang, "Performance Comparison of Mobile IPv6 and Its Extensions," in *International Conference on Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007*, pp. 1805–1808, 2007.

[13] X. Pérez-Costa, M. Torrent-Moreno, and H. Hartenstein, "A performance comparison of Mobile IPv6, Hierarchical Mobile IPv6, fast handovers for Mobile IPv6 and their combination," *SIGMOBILE Mob. Comput. Commun. Rev.*, vol. 7, no. 4, pp. 5–19, 2003.

[14] D. Awduche and E. Agu, "Mobile extensions to RSVP," in *Proceedings of the Sixth International Conference on Computer Communications and Networks*, pp. 132–136, 1997.

[15] C.-C. Tseng, G.-C. Lee, R.-S. Liu, and T.-P. Wang, "HMRSVP: A Hierarchical Mobile RSVP Protocol," *Wireless Networks*, vol. 9, pp. 95–102, March 2003.

[16] X. Fu, H. Karl, and C. Kappler, "QoS-Conditionalized Handoff for Mobile IPv6," in *NETWORKING 2002: Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications* (E. Gregori, M. Conti, A. Campbell, G. Omidyar, and M. Zukerman, eds.), vol. 2345 of *Lecture Notes in Computer Science*, pp. 721–730, Springer Berlin / Heidelberg, 2006.

[17] Z. Wan, X. Pan, and L. Ping, "QoS Provisioning in an Enhanced FMIPv6 Architecture," in *International Conference on Computational Science and its Applications (ICCSA 2005)*, vol. 3481, pp. 704–713, May 2005.

[18] A. Belhoul, Y. A. Sekercioglu, and N. Mani, "Mobility-Aware RSVP: A framework for improving the performance of multimedia services over wireless IP-based mobile networks," *Computer Communications*, vol. 32, pp. 569–582, March 2009.

[19] C. Liu, Y. Liu, D. Qian, and M. Li, "An Approach of End-to-End DiffServ/MPLS QoS Context Transfer in HMIPv6 Net," in *Autonomous Decentralized Systems, 2007. ISADS '07. Eighth International Symposium on*, pp. 245 –254, march 2007.

[20] S. Mongkolluksamee and V. Visoottiviseth, "Diffserv Conditionalized Handover for HMIPv6," in *10th International Conference on Advanced Communication Technology, 2008. ICACT 2008.*, vol. 2, pp. 1401 –1406, 17-20 2008.

[21] L. Huang, M. Jaseemuddin, and H. El-Sayed, "QoS Assurance of Handover TCP Flows in a DiffServ-enabled Mobile Wireless Access Network," in *IEEE International Conference on Computer Systems and Applications, 2006*, pp. 37 – 44, March 2006.

[22] D. Black, "Differentiated Services and Tunnels." RFC 2983 (Informational), Oct. 2000.

[23] J. Manner, G. Karagianni, and A. McDonald, "NSIS Signaling Layer Protocol (NSLP) for Quality-of-Service Signaling." RFC 5974 (Proposed Standard), October 2010.

[24] NIST, *The Network Simulator NS-2 NIST add-on (IEEE 802.21 model).* National Institute of Standards and Technology, January 2007. http://w3.antd.nist.gov/seamlessandsecure/ (last visited 05/2011).

[25] R. Hsieh and A. Seneviratne, "A comparison of mechanisms for improving mobile IP handoff latency for end-to-end TCP," in *MobiCom '03: Proceedings of the 9th annual international conference on Mobile computing and networking*, (New York, NY, USA), pp. 29–41, ACM, 2003.

[26] N. Lopes, M. Nicolau, and A. Santos, "Efficiency of PRI and WRR DiffServ Scheduling Mechanisms for Real-Time Services on UMTS Environment," in *2nd IFIP International Conference on New Technologies, Mobility and Security, 2008. NTMS '08*, pp. 173–178, Nov 5-7 2008.

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