A QoS-Enable Solution for Mobile Environments

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***Abstract*—This paper addresses the problem of designing a suitable Quality of Service (QoS) solution for mobile environments. The proposed solution deploys a dynamic QoS provisioning scheme able to deal with service protection during node mobility within a local domain, presenting extensions to deal with global mobility. The dynamic QoS provisioning encompasses a QoS architecture that uses explicit and implicit setup mechanisms to request resources from the network for the purpose of supporting control plane functions and optimizing resource allocation.**

For efficient resource allocation, the resource and mobility management schemes have been coupled resulting in a QoS/Mobility aware network architecture able to react proactively to mobility events. Both management schemes have been optimized to work together, in order to support seamless handovers for mobile users running real-time applications.

The analysis of performance improvement and the model parametrization of the proposed solution have been evaluated using simulation. Simulation results show that the solution avoids network congestion and also the starvation of less priority DiffServ classes. Moreover, the results also show that bandwidth utilization for priority classes is levered and that the QoS offered to Mobile Node's (MN's) applications, within each DiffServ class, is maintained in spite of MN mobility.

The proposed model is simple, easy to implement and takes into account the mobile Internet requirements. Simulation results show that this new methodology is effective and able to provide QoS services adapted to application requests.

***Index Terms*—Mobile IP, micro-mobility, QoS, Differentiated Services**

I. Introduction

In a communication world where user's expectations are continuously growing, adapting the current Internet infrastructure with new services, quality of service and mobility requires significant developments in network technologies. Today, users want to have simultaneously mobility, quality of service and be always connected to Internet. In order to satisfy these very demanding customers, the markets are imposing new challenges to 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.

However, Internet has been designed for providing application's services without quality guarantees. For this reason, in the last years several efforts have been made to endow Internet with QoS support. From the developed efforts had resulted two QoS paradigms: Integrated Services (IntServ) which offers the guaranteed service model, and the DiffServ which offers the predictive service model. Although, as these QoS models have been designed before the existence of mobile Internet they do not take into account the mobility issue. On the other hand, the current standard protocol for mobile Internet - Mobile IPv6 (MIPv6), reveals some limitations in scenarios where users are constantly moving to another point of attachment. In this type of scenarios, MIPv6 introduces latency times that are not sustainable for applications with more strict QoS requirements. All things considered, reveal the emerging need of adapt the current standard mobility protocol and QoS models to the today's mobile user's requirements.

For accomplishing this goal the present work proposes enhancements in the mobility management scheme of MIPv6 protocol and in the resource management of DiffServ QoS model. The former was enhanced for micro-mobility scenarios with a specific combination of FMIPv6 (Fast Mobile IPv6) and HMIPv6 (Hierarchical Mobile IPv6) protocols. Whereas, the latter was enhanced for mobile environments with dynamic and adaptive features by using QoS signalization and a distributed resource management. The mobility and resource management has been also coupled in the proposed solution with the objective of optimizing the resource utilization in a environment where the resources are typically scarce.

For this purpose, 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 in five sections. Section II describes the related work. Section III presents a brief description of the proposed QoS micro-mobility solution. Section IV describes a proposal to extend the QoS micro-mobility solution for global mobility. Section V presents the simulation model and some of the results obtained with the proposed QoS solution. The paper ends by remarking the most important conclusions.

II. Related work

Dynamic QoS provisioning architectures may be accomplished using signaling protocols and Admission Control (AC) policies. IntServ and Bandwidth Brokers (BBs) for DiffServ were the first dynamic QoS architecture proposals that arose for wired networks.

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The fact that IntServ was initially aimed to have a per-flow granularity made the framework inherently unscalable. Since IntServ has scalability problems in large scale scenarios [1], [2] same important enhancement proposals have been made in terms of core simplification (IntServ over DiffServ) and traffic aggregation (RSVP Aggregation) to turn IntServ more scalable. However, these enhancements had implementation difficulties which is why they are not widely deployed.

The use of policy-based management systems such as a centralized BB entity, for coordinating the network resources is one more element to add to the QoS architecture wherefore, it still needs a QoS model and a signaling protocol to communicate the policy information. Furthermore, BBs are centralized resource management entities. They are complex in terms of implementation because they congregate several features into a single entity, moreover in high dynamic networks such as wireless networks, rather than being a solution they may turn into the network bottleneck [3].

Furthermore, both dynamic QoS architectures are based on deterministic resource reservations for a guaranteed service model, the guaranteed service model requires the creation and maintenance of flows reservations states in all routers along the path. Thus, when an MN moves to a new location, the release of previously allocated resources in the old path is necessary and new resource reservations are made in the new path, resulting in extra signaling overhead, heavy processing and state load.

On the other hand, several extensions to standard Resource Reservation Protocol (RSVP) have been made in an attempt to enhance it for mobile networks. The first RSVP extension proposal was the Mobile RSVP (MRSVP) [4], a protocol that makes advanced reservations at multiple locations where an MN may possibly go. This solution has the problem of creating excessive resource reservations causing the waste of bandwidth and reducing the network performance.

The HMRSVP [5] combines Mobile RSVP with Hierarchical MIP (HMRSVP) to improve the MRSVP with local MN's registrations and advanced reservations only for inter-domain handovers but still has a significant processing burden and resource waste and is restricted to HMIPv6 networks.

Another MRSVP derived solution is proposed in [6] where the authors introduce a Crossover Router (CR) entity to reduce tunnel distance between previous access router and new access router created by the FMIPv6 protocol. The CR is responsible for intercepting all packets sent to MN's previous CoA and forward them to the new access router. To deliver the QoS requests, they extend Fast Binding Update (FBU) and Handover Initiate (HI) messages, which are used for informing the new access router of the MN's QoS requirements. With the information of the MN's QoS requirements, the new access router can make an advanced reservation on the common data path. This solution is claimed to outperform MRSVP in terms of signaling cost, reservation re-establishment delay and bandwidth requirements. However, the solution introduces more signaling messages and complexity.

In a more recent proposal, [7] the authors deployed a modified RSVP called Mobility-Aware Resource Reservation Protocol (MARSVP) where the binding update and the binding acknowledgment messages are conveyed in two new RSVP objects, that must be added in the standard RSVP messages [8]. The solution implies modifications on MIPv6 and RSVP protocols, and on end nodes.

Due to the fact that the proposals mentioned above are based on the guaranteed service model when applied in high dynamic networks, such as wireless networks in micro-mobility scenarios, significant scalability problems may arise.

In conclusion, despite unquestionable improvements achieved by the above proposals, state information overhead, signaling overhead and processing load caused by frequent handovers are still not completely solved in the existing QoS solutions for mobile environments. Moreover, the non-deterministic nature of mobile networks makes QoS provisioning with absolute guarantees hardly possible.

III. 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 aim is to deal with scalability problems that may arise when handovers are frequent by reducing the signaling overhead, and the processing and state load.

For overcoming the inefficiency of MIPv6 in micro-mobility scenarios the proposed model enhances MIPv6 protocol with a specific integration of FMIPv6 and HMIPv6 (F-HMIPv6). The F-HMIPv6 enhances the MIPv6 mobility with seamless handovers and local handovers registrations. The integration follows the recommendations in RFC 4110, except in the proceeding of HI and Handover Acknowledgment (HAck) messages which are maintained between the previous access router and the new access router, like in FMIPv6 protocol.

Regarding to Mobile Anchor Point (MAP) placement, the adopted strategy was to place the MAP in a common crossover router for all Access Routers (ARs) in the domain. In hierarchical networks the crossover router is usually found above the ARs. Therefore, being the ingress node in a DiffServ stub domain, a common crossover router for all ARs is the best place to redirect traffic to any new data path. Further, for fast mobile nodes that perform frequent handovers it is important a more distant MAP for reducing the probability of having to change to a new MAP and informing all the CNs and the HA. However, other solutions for the placement of MAP and more than one MAP agent per DiffServ domain are also possible [9].

Regardless F-HMIPv6 connectivity improvement, it is also necessary to give a different treatment to incoming and existing traffic with special QoS requirements, and also to give QoS support to mobility by re-establishing the QoS context that MN had on the previous router on the new router whenever a handover occurs, in order to avoid the QoS context re-establishment from scratch. Hence, the Resource Management Function (RMF) in the new AR (nAR) would benefit from receiving QoS context in advance, by means of F-HMIPv6 handover layer-3 anticipation, i.e., before MN moves to there. By having the QoS context in advance the resource management function of the nAR can perform proactive actions accordingly with the received MN's QoS context requirements and AR's status. The QoS context received in advance allows deciding beforehand the admission of new handover flows only if the QoS requirements of the existing and the incoming flows are fulfilled. Since the establishment of QoS context on nARs is made before the handover takes place the re-establishment of MN's QoS context on nAR from scratch is avoided.

Regarding to QoS architecture the proposed model extends the RMF of DiffServ in the edge routers with a Measurement-Based Admission Control (MBAC) mechanism. By taking into account the workload of performing admission control in all network nodes regarding the changes and overhead introduced, admission control should be left for critical points. As stated in [10], [11] the edge links are considered the most probable critical points in the domain whereas intermediate routers are over-provisioned. Was assumed that interior nodes are engineered by taking into account the routing behavior, and the maximum aggregated traffic injected inside domain through the ingress router. As in wireless networks the most critical points are the ARs on account of wireless link constraints the admission control in such routers are made for new and handover flows whereas the ingress router only makes admission control for new flows entering in domain.

In relation to QoS signaling the proposed model uses a simple signaling protocol for new flows make their QoS requests to the network. And uses the HI/HAck messages, which are mobility management messages of F-HMIPv6, to convey MN's QoS context in order to handover flows make their QoS requests by means of these messages to the new access router.

The use of the mobility messages to convey MN'S QoS context allows to couple the mobility management and QoS management granting the possibility of optimize both managements.

Similar to NSIS framework the QoS signaling protocol for new flows request their services is decoupled of RMF [12]. Therefore, a distinction is made between the operation of signaling protocol and RMF which meaning that the RMF operability is independent of the adopted signaling protocol.

Relating to state information overhead, signaling overhead and processing load problems caused by guaranteed service model our approach effort has been to overcome this problems with more relaxed QoS requirements i.e., with the predictive service model of the DiffServ QoS model. Further, as the admission control scheme chosen is based on class traffic measurements the processing load and state overhead caused by this mechanism are not critical [13]. The main advantage of using measurements for admission control is the fact that this scheme does not have to maintain any reservation states by means of a signaling protocol. Once an admission decision is made no record of the decision needs to be stored, thereby it does not require a pre-reservation state nor an explicit release of reservation.

The transparency of DiffServ packets caused by IP tunneling has been solved with propagation of DiffServ Code Point (DSCP) information in the packet header to the outer IP header as recommended in [14].

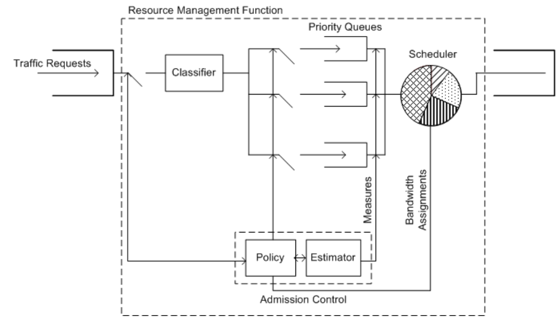


Figure 1: Resource Management Function

The new RMF handles the QoS input parameters contained in QoS signaling messages. In the Access Routers (ARs) the RMF has an additional element, called dynamic allocator, to improve the network utilization with an adaptive resource management. The RMF comprises the DiffServ QoS mechanisms (policer, congestion avoidance and scheduling) and a MBAC mechanism (estimator and AC algorithm). The major design issues in the implementation of the new resource management were: using DiffServ mechanism as the QoS model; selecting the AR as the most critical point in the end-to-end path; and defining edge routers as lower state information entities. Figure 1 shows the proposed resource management function.

Basically, the RMF in the ARs consists in three components: 1) QoS model - Diffserv QoS mechanisms to give a different treatment to priority traffic; 2) Admission Control - Admission control to determine whether a node has sufficient resources to support the requested QoS and; 3) Dynamic Allocator - Reallocation mechanism to reallocate more bandwidth for handover flows belonging to priority classes.

Figure 3 illustrates the four main functions of the RMF (Measure, Estimate, Police and Reallocate bandwidth). Estimators implement measurement mechanisms in order to determine the current network load in terms of DiffServ class bandwidth and DiffServ class bandwidth per MN (which is the MN's QoS Context).

The policer runs an algorithm for deciding whether to admit, or reject flows. For new flows the decision is based on inputs from traffic descriptor and on measurements of DiffServ class bandwidth against a given class threshold (which is the allocated bandwidth for that class). Whereas, for handover flows the decision is based on inputs from MN's QoS context in pAR and on measurements of DiffServ classes bandwidth per MN in nAR at the time of handover, against a given class threshold.

Additionally, if necessary, the dynamic allocator, which acts as bandwidth reallocation mechanisms, dynamically redistributes the allocated bandwidth for best-effort traffic among the DiffServ classes with more strict QoS requirements in order to accommodate more incoming handover flows in higher priority DiffServ classes. Figure 2 illustrates the reallocation mechanism of the dynamic allocator which has been implemented with the hysteresis method. Equations 1 and 2 present the policy defined by the dynamic allocator to share the uncommitted bandwidth of the Best-Effort (BE) class.

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

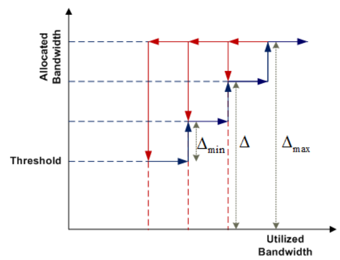


Figure 2: The Reallocation Mechanisms with Hysteresis of Dynamic Allocator

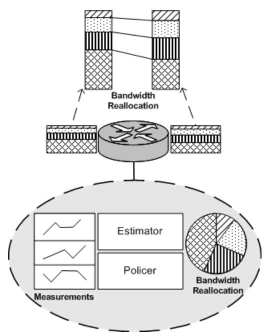


Figure 3: Resource Management Main Functions

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

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

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 AC algorithm always accepts MN's handover flows whenever there is available bandwidth to reallocate in the required class ($\triangle max_i$). The RMF can use the reallocation mechanism until the maximum variation ($\triangle max_i$) for the class be reached. The reallocated bandwidth is released in fixed step sizes accordingly to measure bandwidth utilization in the class. The RMF stops with the releasing bandwidth process when the measure bandwidth utilization ($Class_i$) is less or equal than the initially allocated bandwidth for the class (T_i). This proactive (before MN moves to a new location) and adaptive (adjusting the allocated bandwidth for a class to accommodate handover flows) behavior of RMF can provide a seamless mobility by maintaining always the same MN's QoS level across ARs.

Summarizing, the model proposes to extend MIPv6 mobility protocol with F-HMIPv6 and to extend DiffServ QoS model with QoS signaling and an enhanced MBAC.

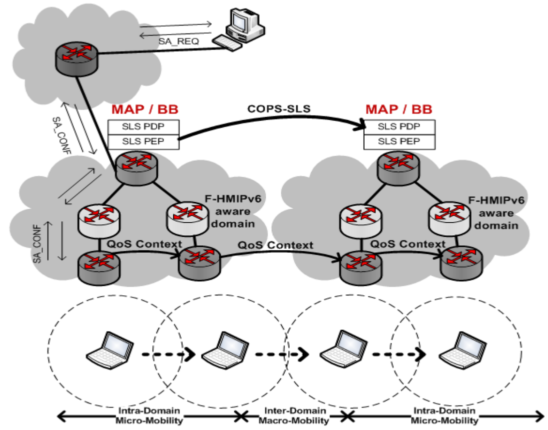


Figure 4: Major Components and Interactions

IV. An Extended Proposal For Global Mobility

Another objective of the model is designing a micro Mobility/QoS-aware network capable of being easily extended for global mobility. Figure 4 illustrates the network reference model for global mobility. In this scenario MAP should integrates the functions of ingress router, BB and inter-domain signaling entity. For inter-domain communication a signaling entity such as Common Open Policy Service- Service Level Specification's (COPS-SLS's) may be used. The job of BB is to negotiate SLSs with BBs of neighboring domains in order to provide QoS to the users even in case of inter-domains handovers occur. The BB translates MN's QoS Context into SLS and then negotiates SLS with its peer BB. Therefore, when a MN moves towards a nAR in another domain the BB, as responsible for managing the Diffserv router configuration in its DiffServ domain, needs to be informed about the QoS to be provided in the new router. The BB of the proposed model only has responsibilities at inter-domain level which include the negotiation of QoS parameters and setting up 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 intra-domain level the ARs routers are responsible to enforce 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, it has been assumed the following considerations: 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 a MN enters in a new MAP domain, it needs to 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.

V. Simulation Model and Results

The simulation model has been implemented in the network simulator version 2 (ns-2), patched with IEEE 802.21, HMIPv6 and FMIPv6 extensions [15], [16]. The aim of the simulation model has been to assess the following achievements: 1) to choose the best rate estimator for the model's architecture [17]; 2) the evaluation of the model in order to assess the class traffic behavior during MN's handover and influence of the handover traffic in the existing traffic [18], and; 3) to assay the model performance under different parametrization values in order to choose the best values based on objective criteria [19].

In this section is only presented some simulations results regarding model performance. To assess the performance improvement of the proposed QoS solution four distinct scenarios have been designed. Scenario A has been implemented with the proposed combination of FMIPv6 and HMIPv6. Scenario B aims to show the adopted solution for the IP tunnels problem, therefore has been implemented on F-HMIPv6 mobility scheme the DiffServ over tunnels. Scenario C represents the 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 the 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.

Figure 5 shows the simulated topology for intra-domain scenario. The simulation scenario includes ten CNs and the 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 [20]. 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 others two classes (class 2 and 3) have been configured for Assured Forward (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 and each one marked with a different DSCP. Therefore, forty flows have been generated in the total. As the bottleneck is in the last hop (wireless link) all the flows will be accepted by precedents 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%.

Figures 6 illustrate the class 1 mean throughput and delay distributions and their associated standard deviation around the mean. It should be noted that in order to simplify the

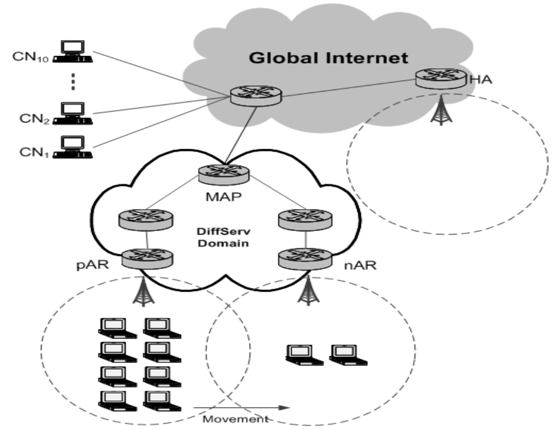


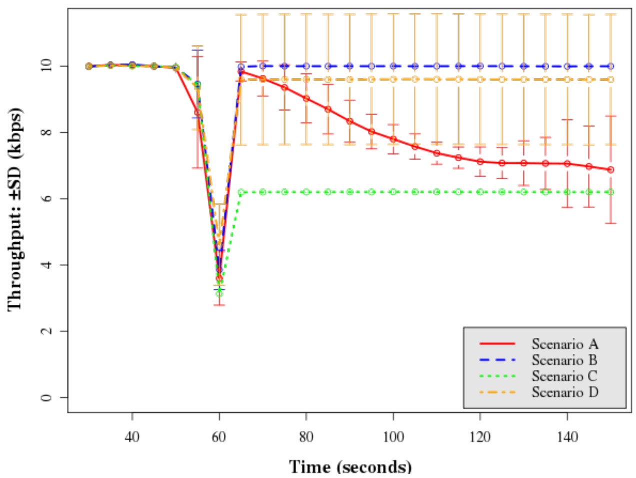
Figure 5: Simulation Model

interpretation of Figs. 6 and 7, the scenario D standard deviation 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. Moreover, to facilitate the analysis, the traffic flows in Scenario A have been aggregated in the same manner as in the DiffServ configurations, even though they do not have any differentiated treatment in this scenario

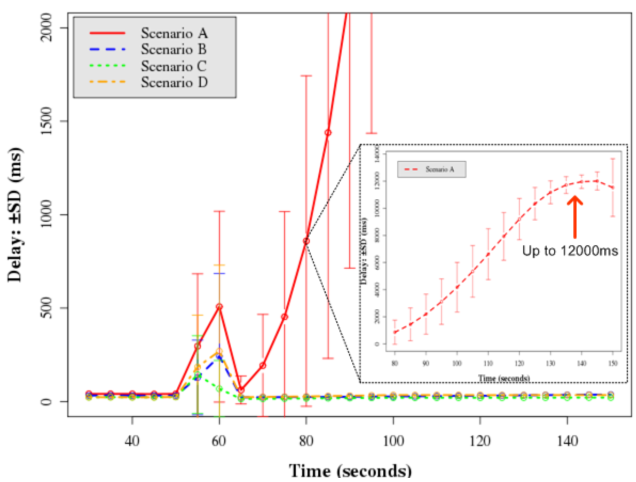
Figure 6a shows that after MN's handover (at instant 60 seconds) the scenario B was achieved the best mean throughput. This results from the fact of the standard DiffServ mechanisms do not have any class threshold limit resulting in the admission of all generated traffic. For Scenario C the Fig. 6a shows that after MN's handover the mean throughput decreases for almost half of its initial value (before handover). This is due to AC scheme that limits the amount of traffic in class 1 by rejecting the traffic in excess. Scenario D presents a slightly decrease in the initial mean throughput and a low standard deviation, after MN's handover. This is due to dynamic allocator that reallocates more bandwidth for class 1 in order to accommodate more traffic in this class, 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 of traffic be equally treated.

Figure 6b shows that in scenario A after MN's handover the mean delay and the associated standard deviation sharply increase due to 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, before and after handover.

Figure 7 illustrates the mean throughput and delay distributions for class 3 and their associated standard deviation. Fig. 7a shows that after MN handover in the scenarios B and D the MN can obtain approximately the same mean throughput that it had before handover. However, while in scenario D the mean throughput remains constant, in scenario B the mean throughput begins to decrease around 100 seconds because at that moment all MNs have been moved to the nAR, and as the class 3 is the less priority class, when the link begins to become saturated the less priority classes are affected by

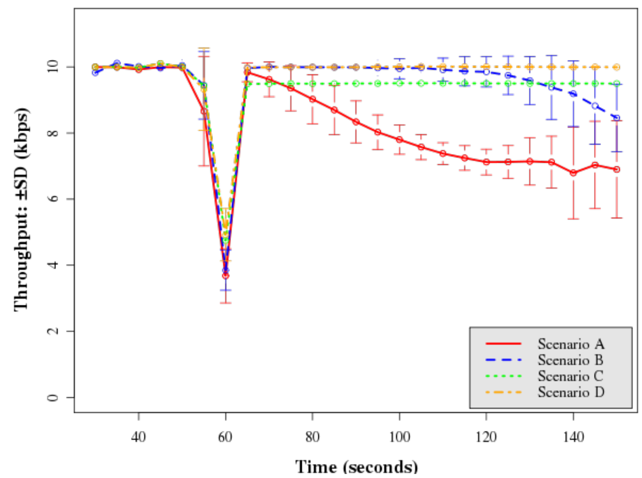


(a) Class 1 Mean Throughput and Standard Deviation

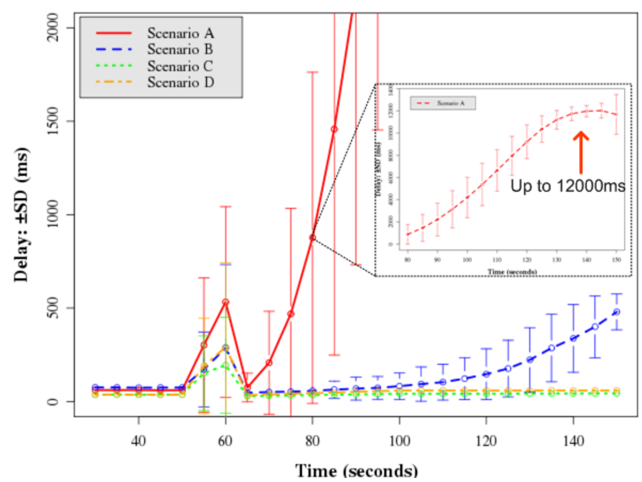


(b) Class 1 Mean Delay and Standard Deviation

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



(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

those with higher priority. Scenario C presents, after MN's handover, a slightly decrease in the mean throughput which derives from the fact of the AC scheme rejects 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 Fig. 6a.

Figure 7b shows that in the scenarios C and D the MN's delay in the class 3 is maintained during the 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 because in this scenario the traffic classes are equally treated.

VI. Conclusion

This research work proposes a model that enables dynamic QoS provisioning to local mobility. Further, the model can also be easily extended to global mobility. The proposed model aims to enhance micro and global mobility with QoS support and seamless handovers. 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, the 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 QoS 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. In future work, we intend to apply optimization functions to adjust the reallocation parameters in order to maximize the resource utilization.

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