A QoS Architecture for Provisioning High Quality in Intelligent Transportation Services

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***Abstract*—A multi-homed vehicular mobile network uses different wireless and radio communication technologies to reach the Internet through multiple routing paths. Because of network mobility and lack of reliable quality-of-service (QoS) support in these communicating technologies, it is challenging to guarantee high quality in vehicle-to-infrastructure (V2I) communications. In this paper, we evaluate a novel policy to support resource reservation for mobile networks. We also define a probing mechanism based on IPv6 messages and traffic load estimation at mobile routers and home agent to enable NEMOs choose the most optimal egress routing path to reach Internet. Intelligent transportation service providers (ITSPs) can deploy this proposed QoS architecture to realize Service Level Agreements (SLAs) based on QoS negotiation with NEMOs or quality in provisioned multimedia services for on-board users.**

I. Introduction

The drivers and passengers were very happy to be able to listen to AM radio news along their travel, but now they demand more communication services such as watching video and listening to on-line music. For security and safety reasons, vehicles should be capable of sending voice alerts, video images or text messages to other neighboring vehicles to avoid accidents, or a transport traffic center for traffic management purposes. The quality in provisioned services measures the satisfaction of users on-board mobile networks and the success of intelligent transportation service providers (ITSPs) in provisioning services for vehicular mobile networks (NEMOs).

In this paper, we will analyze the required QoS mechanisms to be integrated with NEtwork MObility Basic Support Protocol (NEMO-BSP) [1]. This protocol has provided a basic solution to a challenging problem: Managing the mobility of $IPv6$ [2] enabled and non enabled mobile nodes moving together in one entity, such as vehicles and aircrafts, so that they can be reached ubiquitously. This problem could be solved by adding one or more Mobile Routers (MRs) to manage the entire mobility of these *Mobile Network Nodes (MNNs)* which could be: sensors transmitting critical data to another NEMO (or server somewhere to analyze the data for safety purposes and fleet management), or users surfing the Internet or sending emails and communicating through their personal data assistants (PDAs) with other external users.

MNNs might be a group of doctors performing a surgical operation and getting assistance from others in a hospital while they are in an ambulance driving to the hospital. MNNs might be travelers listening to music and watching video in a bus or train.

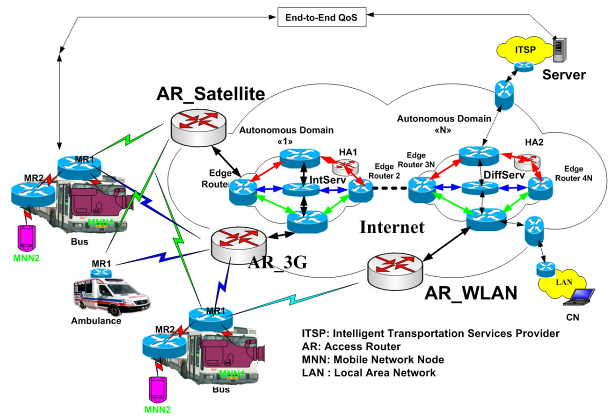

Fig. 1. Multihomed nested vehicular mobile internet networks.

When NEMO maintains multiple routing paths to the Internet, as shown in Fig. 1, it is said to be a *multi-homed* NEMO. This can be multi-homed through different configurations based on three parameters [3]: Number of root MRs 'X', number of home agents (HAs) serving NEMO 'Y', and number of mobile network prefixes (MNPs) advertised in NEMO 'Z'. In this paper, we will focus on the multi-homing configuration, (X=1,Y=1,Z=1) depicted in Fig. 1, with a single root multi-interfaced MR, single HA and single MNP. NEMO (MR_1) maintains transparent communication by establishing a bi-directional tunnel with the *HA*. While the MR acts as a gateway for MNNs, the *HA* forwards traffic packets destined to MNNs through the different egress interfaces of MR connected to Internet through access routers.

When a public transport bus, shown in Fig. 1, moves out of its station, home network, the NEMO-BSP starts executing the tracking process based on IPv6 [2], which is done through the configuration and registration processes. MR_1 configures a temporary address called *Care-of-Address (CoA)* for each egress interface. Then, it sends a *Binding Update (BU)* to its home agent to bind its Home-of-address (HA) with the configured CoA, which enables the HA to reach NEMO anywhere anytime. MNNs which are connected to the ingress interfaces of MR configure permanent addresses containing *the Mobile Network Prefix (MNP)* assigned previously to NEMO.

For example, most of the public transport buses are equipped with a GPS, which is used to localize the buses on the different routes and to calculate the waiting times at every stop. To this end, a satellite connection would be necessary to monitor and manage transport traffic congestion on the different routes. Although public buses run through determined routes, some of these cross cities to reach rural places. Wireless and radio networks with various transmission ranges and capacities such as 3G and WLAN networks would be necessary to maintain uninterrupted access to Internet for users on-board these buses. However, the connections through 3G and WLAN communication networks are sensitive to network mobility and conditions of surrounding communication environment. Furthermore, wireless and radio networks suffer from scarce network resources and channel fading [4]. In this paper, we introduce a novel policy to support resource reservation for mobile networks. This policy is integrated with a routing path selection mechanism in a QoS scheme to enable a multi-homed vehicular mobile network to communicate ubiquitously with correspondent nodes while guaranteeing e2e quality in provisioned intelligent transportation services.

The rest of this paper is organized as follows. In Section II, we explain our policy for mobile network resource reservation. In Section III, we describe a probing mechanism for collecting link layer information. In Section IV, we describe the operations of call admission control and scheduling service discipline in MR and HA, then we explain our proposed QoS negotiation policy. In Section V, we evaluate the performance of the proposed policy for resource reservation. Finally, Section VI draws a conclusion to this paper.

II. Mobile Network Resource Reservation

A passenger sitting in the bus, shown in Fig. 1, should be able to check his emails and download some music from the Internet using his PDA. This could be the case for another passenger who uses his IPv6 camera to send live photos to his friends. The video configured on this bus should send images with a determined delay to a traffic or security center for transportation traffic control and security purposes. Traffic requiring various QoS requirements is generated by this NEMO; however, we will focus on guaranteeing the e2e QoS required for real-time IP multimedia flows like video traffic in this scenario. The network resource required for this traffic should be reserved along a selected routing path between MNN and CN or NEMO and ITSP so that the required e2e QoS can be guaranteed.

In the Integrated Services (IntServ) model [5], two aggregate reservations should be made, which correspond to the Guaranteed Services (GS) and Control load Services (CLS). The RSVP-TE is deployed to reserve network resources along the routing path connecting MNNs with CNs or NEMO with ITSPs. In our proposed mechanism, the MR_1 and HA represent the aggregate and de-aggregate points, respectively, so they assign the same DiffServ Code Point (DSCP) in the packets header belonging to the same aggregate reservation. Fig. 2 describes our mechanism, in which MNNs are passengers who would like to watch video-on-demand in Eurostar train. The e2e PATH messages generated by the CN are intercepted, aggregated and assigned a DSCP and tunneled by the HA to the MR_1. When this aggregated PATH message is received by the MR_1, it is decapsulated and sent to the MNNs which reply by sending RESV messages. These are intercepted, aggregated, assigned the same DSCP and tunneled by the MR_1 to the HA which uses tunnel reservation [6] to confirm the network resources reservation required by the aggregated RESV message. Afterwards, the HA decapsulates the aggregated RESV message and sends to the CNs. The following proposed policy manages and controls the bandwidth reservation for multimedia traffic aggregate along a selected routing path between MR_1 and HA:

- ***Traffic class based Stair Reservation Policy:*** In this, MR_1 adjusts dynamically in a static increment manner the network resources reserved for each traffic class. For example, MR_1 reserves initially 200kbps for a GS MNN and 130kbps for two CLS MNNs already connected to NEMO. When a new GS MNN joins NEMO, it reserves further 200kbps. When NEMO serves as a relay for another NEMO, it reserves 4×200kbps, depending on traffic class. However, the departure of only two CLS MNNs enables MR_1 to release 130kbps of the reserved bandwidth. This policy can provide high flexibility by altering the value of the static increment and therefore it can be deployed for NEMOs with high and low traffic load, such as buses.

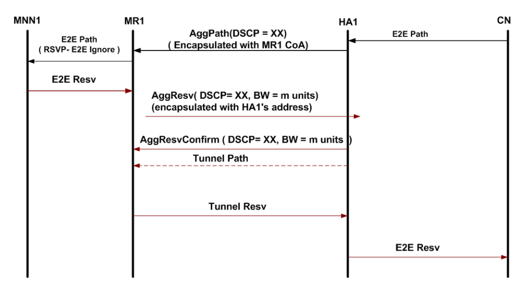

Fig. 2. Signaling flow during the aggregated RSVP.

Note that the performance of the Resource Reservation Protocol (RSVP) [5] relies on the quality of selected routing paths. Furthermore, it requires that all the nodes along this path to support RSVP unless they can guarantee the minimum network resources required for the aggregate of QoS-sensitive traffic flows. Various proactive RSVP mechanisms for mobile IP have been proposed to minimize the delay required for establishing again RSVP over a new routing path when mobile IP performs IP-handoff [7].

III. Link Layer Information-Based Probing

The MR_1 and HA can estimate the upstream and downstream traffic along the different routing paths using one of the following methods [8]:

- **Locally measured load:** NEMO measures and compares the amount of traffic it has received or forwarded during a recent time window through its egress interfaces. The HA can also measure and compare the upstream and downstream traffic destined to NEMO. For example, during the last 15s, the average traffic load that MR_1 has received or forwarded through the WLAN egress interface is 400kbps, and through the 3G egress interface is 200kbps. However, the average traffic load that HA has received is 520kbps.
- **AP measured load:** Since all traffics should pass through one of the available APs, the load of all NEMOs connected to this AP can be estimated as the load at the AP. For example, during the last 15s AP_{WLAN} observes that it has forwarded 5Mbps of traffic, and AP_{3G} observes that it has forwarded 800kbps of traffic. NEMO can use this information as a basis for egress interface selection. However, this is not enough because it does not indicate how many hops a packet needs to travel.
- **AP-measured weighted load:** The load is measured at the AP, but it is weighted according to the hop distance from the AP to the destination. This can be used by NEMO to select the best AP. It can also be used by other NEMOs to choose better their relays to the available APs.

By exploiting the status information collected by HELLO packets and IPv6 messages regarding the link technologies, estimated traffic load at AP, MR and HA, information collected by RSVP-TE messages, MR_1 and HA can select better a routing path among the available ones. In our scenario, the reservation and probing are based on a specified policy: When NEMO is in a rural place or moves at a high speed, probing and network resource reservation should be done through the 3G egress interface; whereas, when it is in an urban environment, probing and reservation should be done through the WLAN egress interface.

IV. Traffic Admission and Scheduling Control

Based on the collected link information and RSVP messages, two coordinated Call Admission Control (CAC) mechanisms should be employed in the MR_1 and HA to control upstream and downstream traffic, respectively. When NEMO shown in Fig. 1 performs IP-handoff or one of its MR_1 egress interfaces fails, traffic flows should be transmitted through the other egress interfaces. However, it could happen that these do not have enough capacity to serve already admitted flows and those handing-off traffic flows, the employed CAC then decides which traffic flow should be admitted or rejected. This improves network resource utilization and eliminates the influence of Best Effort(BE) traffic on real-time IP traffic. Once a traffic flow is accepted by the CAC, the Class Based Queuing (CBQ) discipline serves traffic flows according to its traffic classes and applications. Due to the scarce capacity of wireless networks and eventual routing path change, downstream and upstream traffic packets may arrive out of order at MR and HA, respectively. A de-jitter algorithm should be coupled with the CBQ scheduling service discipline (SSD) to reorder these packets in their corresponding traffic flows to eliminate jitter.

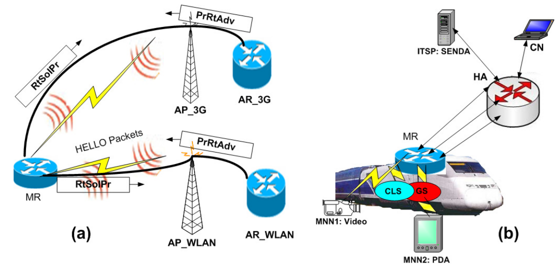

Fig. 3. (a) Active probing on link layer. (b) QoS negotiation in NEMO.

1) QoS Negotiation: By QoS guarantee [9], we mean that the type of guarantee envisaged in service level agreements, where performance targets are assured for traffic with given characteristics. Such SLAs are proposed in one form or another in the QoS architectures, IntServ and Differentiated Services (DiffServ) [5]. Fig. $3b$ depicts two types of SLA for offering Internet services proposed for passengers in Eurostar trains: Fixed and dynamic SLA. For example, MNN1 can connect to an Internet access point configured to offer QoS based on the supported service classes in the IETF service model implemented in NEMO. MNN2 can negotiate with MR_1 to establish a virtual Private Network (VPN) with a CN; however, MR_1 should negotiate with it and its HA to agree on the service level requirements. Thus, MR_1 can perform traffic admission control, traffic policing and shaping to accept the new SLA and satisfy the performance requirements.

V. Performance Evaluation and Results

To evaluate the performance of our proposed stair reservation policy and aggregated RSVP, we model the RSVP-TE process at MR_1 by $M/G/1/C_{Res_{max}}$ queuing model. In this we assume that the inter-arrival of reservation requests at MR_1 is exponentially distributed. Due to the varying amount of bandwidth which should be reserved by RSVP for the GS and CLS requests, the service time (reserved bandwidth) of this queuing system may have a large standard deviation relative to the mean value so we assume that the service time can be well approximated by Hyper-exponential distribution which is a special case of the general distribution [10]. We also assume that MR_1 does bandwidth reservation on a single routing path. The maximum amount of bandwidth $(C_{Res_{max}})$ which can be reserved by RSVP-TE for NEMO is upper bounded by the minimum available capacity (bottleneck capacity) along a selected routing path between the MR_1 and HA. By assuming that we can estimate the average amount of bandwidth that should be reserved for GS and CLS requests, we can compute the number of successful reservation requests K that can be done by RSVP-TE, so we replace $C_{Res_{max}}$ with K, thus we can model the RSVP-TE process at MR_1 by $M/G/1/K$.

Denoting the service time (reserved bandwidth) by μ, the requests arrival rate by λ and the reservation requests intensity by ρ. Then, our system can be described as $M/G/1$ RSVP queueing system with average arrival rate λ follows Poisson distribution, and service time characterized by a two-stage Hyper-exponential distribution. In this, the reservation requests arrive at the MR_1 with a probability α_{GS} for GS reservation requests requiring service time μ_{GS}, and a probability α_{CLS} for CLS reservation requests requiring service time μ_{CLS}.

In this context we can describe the problem as follows. RSVP-TE deployed at MR_1 receives reservation requests at a varying average rate, λ =[0.1 .. 0.9], every second; the reservation response time has a two-stage hyper-exponential distribution with α_{GS} =0.4, α_{CLS} = 0.6, $\mu_1 = 0.9s$, $\mu_2 = 0.75$; calculate the total delay, T_D, and throughput, γ, of traffic flows that sent a number of reservation requests, $N_{Res_{req}}$, to the MR_1, and therefore,

$$\overline{S(service,\ time)} = \frac{\alpha_{GS}}{\mu_{GS}} + \frac{\alpha_{CLS}}{\mu_{CLS}} \tag{1}$$

$$\overline{S^2} = \frac{2*\alpha_{GS}}{\mu_{GS}^2} + 2*\frac{\alpha_{CLS}}{\mu_{CLS}^2},\quad \rho = \lambda*\overline{S}$$

$$T_D = \frac{\lambda*\overline{S^2}}{2(1-\rho)} + \overline{S} \tag{2}$$

$$N_{Res_{Req}} = \lambda*T_D,\quad \gamma = \frac{\rho}{N} \tag{3}$$

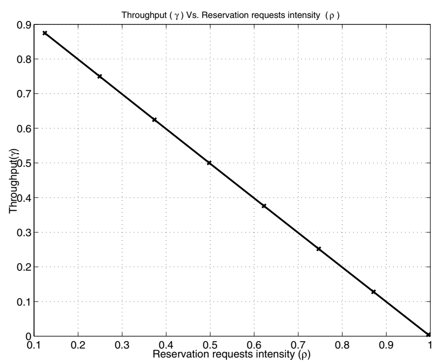

Fig. 4. Throughput Vs. reservation requests intensity.

By evaluating the above derived equations, we have obtained the results shown in Fig. 4 and 5. In Fig. 4, the throughput of the traffic flows depends on many parameters among which ρ, μ_{GS} and μ_{CLS}. In addition, this figure shows the bandwidth reservation is fairly distributed among GS and CLS reservation requests according to α_{GS}, α_{CLS}, μ_{GS} and μ_{CLS}. Fig. 5 illustrates a promising result where a high number of reservation requests have been accepted, proving the high accuracy of the proposed model.

VI. Conclusion

In this paper, we have introduced a QoS scheme to enable ITSPs to guarantee high quality in provisioned intelligent transportation services. Such a scheme will enable vehicular NEMO to utilize 3G, WLAN and satellite communication technologies together and to roam between them while maintaining persistent, seamless and real-time communication with

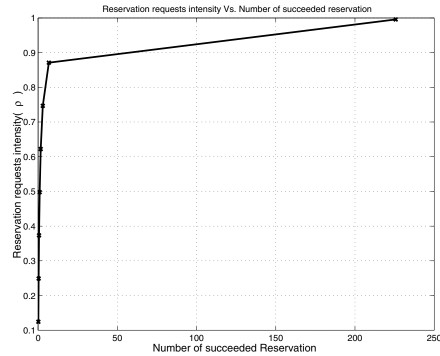

Fig. 5. Number of succeeded reservation requests.

CNs and ITSPs. This view is supported by the promising results which we have obtained on RSVP-TE reservation modeling at MR_1. However, vehicular NEMOs still require the Continuous Air-interface for Long and Medium Range communication (CALM) [11], [12] to reduce handover latency and guarantee seamless communication with CNs and ITSPs. In the future, we will integrate in our proposed QoS scheme a power control policy based on orthogonal frequency-division multiplexing (OFDM) [13] to efficiently support downlink channel of V2I communications.

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