A QoS Architecture for Future Wireless IP Networks

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Abstract

This paper presents a QoS architecture framework with preliminary protocol specifications for next generation wireless IP networks. The architecture is based on differentiated services, in that traffic are aggregated and forwarded in backbone network based on per hop behaviors; however, it is also offers a dynamic per session QoS negotiation which is needed to efficiently support roaming users. The proposed architecture has at least one global server and many dumb local nodes in each administrative domain. The server is referred to as the QoS Global Server (or QGS), and local nodes are referred to as QoS local nodes (or QLN). QLNs are ingress nodes of the DS (Differentiated Service) domain which police traffic for agreement with the Service Level Specification (SLS). The mobile nodes do not do any negotiation with the dumb QLNs; rather they negotiate with the QGS. The QGS is basically a dynamic version of a differentiated services bandwidth broker, which stores global information of the whole domain. The QGS informs the QLNs what to do when traffic comes in. By retaining the global information in central server and separating control and transport, the architecture is flexible, easy to add new services, and efficient for mobile environment.

Keywords: wireless and mobile QoS architecture, wireless diffserv, wireless IP networks.

1 Introduction

The current wisdom is that the existing circuit switched wired networks and 2G (second generation) wireless systems will eventually evolve into an end-to-end IP platform that provides ubiquitous real-time as well as non-real-time services. There are two major forces driving the trend towards third generation (and beyond) wireless IP technology. First, the users' demand for perpetual ubiquitous access to the Internet. Second, providers desire to deploy a flexible wireless and wireline IP platform that supports heterogeneous services economically, which will allow them to capture a share of this growing market.

ITSUMO[1](Internet Technologies Supporting Universal Mobile Operation) [1] is a research project that focuses on the design of next generation wireless IP networks. It envisions an end-to-end wireless/wireline IP platform for supporting real-time and non-real-time multimedia services in the future. Its goal is to use IP and next generation wireless technologies to design a wireless platform that allows mobile users to access all services on a next generation Internet.

The objective of this paper is to present a QoS (quality-of-service) architecture based on differentiated services (diffserv) [2] and ITSUMO architecture for next generation wireless IP networks, and present the preliminary specifications of the protocols built upon the proposed wireless and mobile QoS architecture. Although ITSUMO platform is the major consideration, we believe the proposed QoS architecture is general enough for other architectures. Four key characteristics of the architecture are: (1) allows dynamic (per session) QoS negotiation; (2) requires no renegotiation or signaling with the mobile after a move within a domain; (3) a flexible central server (bandwidth broker) which negotiates with the user based on up-to-date global information of the whole administrative domain; and (4) a dumb ingress nodes which polices users and feeds local information back to the central server. Based on these characteristics, we believe we can efficiently meet the QoS requirements in next generation mobile wireless environment. The architecture provides flexibility for different QoS session management and is easy to integrate with other protocols. This

[1] ITSUMO means “all the time, anytime” in Japanese.

paper presents the QoS architecture framework with high level view of the necessary protocols. The wireless IP testbed and implementation are depicted.

The rest of the paper is organized as follows. Section 2 describes the QoS architecture. Section 3 presents the preliminary protocol specifications. Section 4 states the testbed and initial implementation of the architecture and protocols. Section 5 summarizes the papers with concluding remarks.

2 Wireless QoS Architecture

Since the users in next generation wireless networks are expected to be highly mobile, the QoS architecture must support mobility efficiently. The QoS protocol should not cause high signaling overhead nor cause roaming users to experience sudden QoS degradation simply because of moving to a new subnet within the same domain. Although roaming users could move to any domain, an efficient solution requires that service be guaranteed in all possible domains. Given that it is possible for nodes to be highly unevenly distributed, some dynamic SLS (Service Level Specification) negotiation is needed to allow guarantees to be provided. For efficiency, the dynamic SLS must be able to be done per session. The services provided must not tie to a fixed path/location. It must also support tight end-to-end QoS guarantees for certain types of services, such as IP telephony or video conferencing. Besides, it must support certain types of critical services, such as E911, anytime anywhere for anyone. The QoS architecture and protocols must be interoperable and administrable between different service providers and with legacy networks as well. It must also be scalable.

Based on the these requirements, we proposed a QoS architecture for next generation wireless IP networks based on diffserv model. The proposed model is based on the ITSUMO architecture in which there is at least one global server and several local nodes in each administrative domain. The server is referred to as the QoS Global Server (or QGS), and local nodes are referred to as QoS local nodes (or QLN). QLNs are ingress nodes of the DS (Differentiated Service) domain. They reside generally in the edge of wired backbone networks. The QGS retains the global information of the domain, and informs QLNs what to do when traffic comes in. The mobile station (MS) has the QoS signaling with QGS. Once the QoS signaling is done, actual traffic generated by MS goes through QLNs. Therefore the QGS is in *control plane* and QLNs are in *transport plane*. By separating control and transport, the architecture is flexible, easy to add new services, and more efficient for mobile environment. The following section details the architecture components.

2.1 Architecture Components

Fig. 1 shows our overall architecture, with hosts (MSs) accessing a Global IP Network via Layer 2 Radio Access Networks (RANs). If the RAN provides QoS support we assume it is exploited, but we make no assumption about it in this paper. Fig. 1 shows the three major QoS components:

1. **MS (mobile station):** MS is the device that allows users to communicate, and also provides means of interaction between users and the networks. Traffic is generated/received by MS and may be dropped or queued in the MS while waiting for transmission/reception.

2. **QGS (QoS global server):** As shown in Fig. 1, there is one logical QGS in each administrative domain. The QGS has the global information of the resources available in the whole domain. The MS interacts with QGS, if necessary, when the MS requests certain degrees of QoS in this domain. The QGS is the entity for QoS negotiation and signaling between MS and the network control system, i.e. it is for QoS control. The QGS decides what services are available for each MS and sends the decisions to particular QLNs. Thus, the QGS is an intelligent entity residing in the control plane for QoS negotiation and signaling.

3. **QLN (QoS local node):** QLN is the ingress node of the DS domain. QLN generally resides in the edge of the network. Fig. 1 depicts that QLN could be part of edge router, or could reside in a component inside RAN (radio access network) such as BS (base station). QLN has the local information about the resources in the local domain. However QLN does not interact with MS directly for QoS negotiation and signaling. In stead, this local information is provided to QGS periodically. QLN maintains a table which is then updated by QGS periodically too. Based on this table, QLN will mark, police, shape, etc. the traffic going through it. It is the entity for transporting. Comparing to QGS, it is less intelligent.

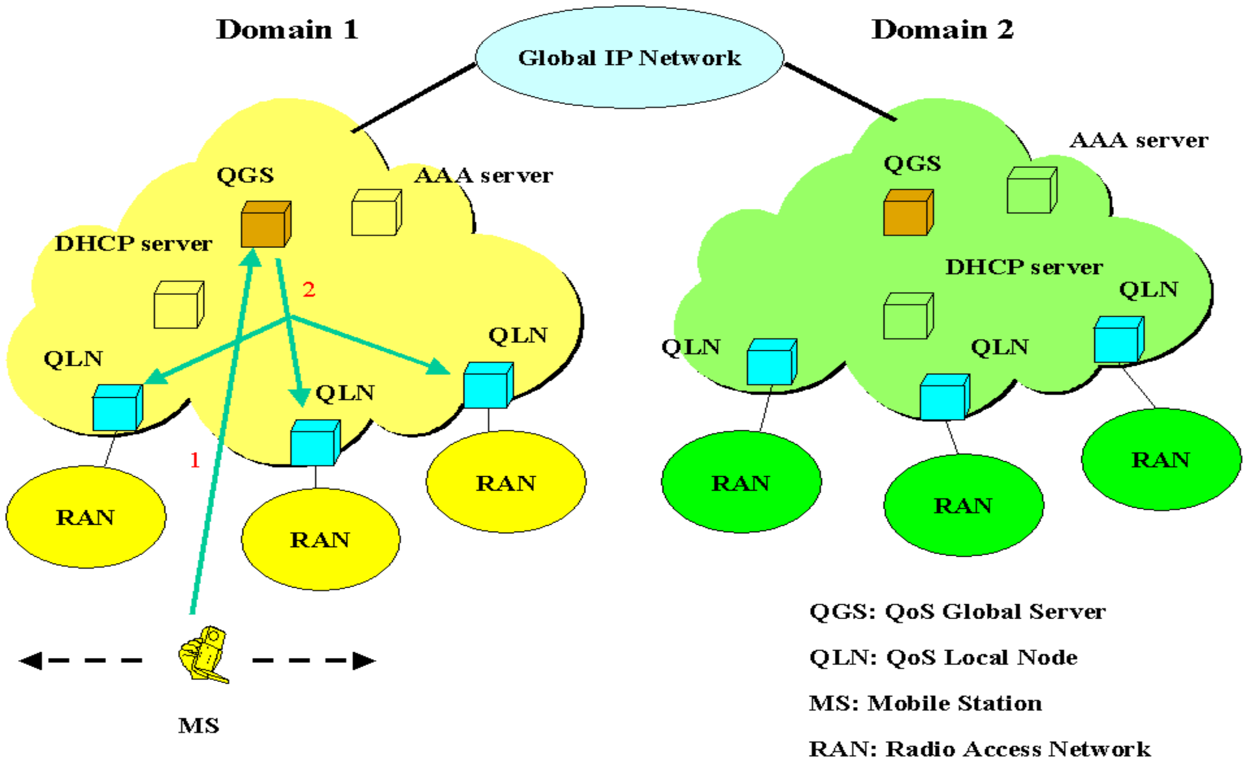

Figure 1: Wireless QoS architecture

Fig. 1 also shows two non-QoS components: the Dynamic Host Configuration Protocol (DHCP) server [3] (or a Dynamic Registration and Configuration Protocol (DRCP) server [4]) and the AAA server which provides Authentication, Authorization and Accounting services. The following section describes the protocols built upon this QoS architecture.

3 Protocols

Based on the architecture defined above, this section first describes the *Dynamic SLS Negotiation Protocol* (DSNP), then describes the use of this protocol in different scenarios.

3.1 Dynamic SLS Negotiation Protocol (DSNP)

The SLS is usually agreed by both the user and the service provider when a user signs up with a service provider. To change the SLS in wired network, usually a user has to contact with the authority of the service provider, which manually enters SLS changes. Once the negotiation is done, the user can utilize the new SLS. As we mentioned above we believe it is important to not only automate the process of changing SLS, but to be able to do so at a per session basis. In addition, the change in SLS should be known by all ingress nodes (QLNs) in the domain so that the user can fully utilize the new SLS without exchanging any new messages while roaming.

Since the QGS has global information, dynamic SLS can be achieved easily and efficiently in our architecture. With the global information, the QGS allows MS dynamically negotiate SLS with it. The QGS may need to consult with home QGS and/or other servers, such as AAA, etc. Once the negotiation between the MS and the QGS is done, the QGS multicasts the decision to all QLNs in the same administrative domain. The MS therefore is capable of utilizing the new SLS anywhere while it is moving within the same administration domain. Thus, dynamic SLS for mobile environment is achieved with only one negotiation in the same administrative domain. After that, all QLNs know the new QoS profile. This saves the wireless band-

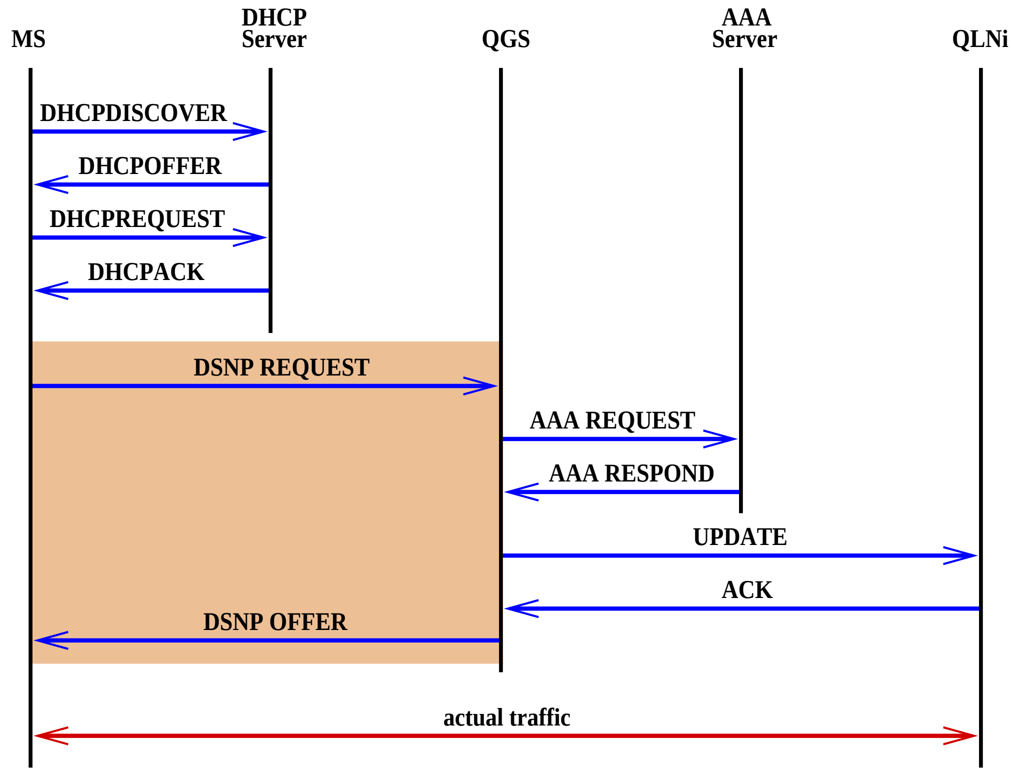

Figure 2: Example flow for first power-on or moving into a new domain

width significantly. This dynamic SLS can also be done in different granularity, for example, per session, per hour, or per day, etc.

Figs. 2-4 depicts example flows for DSNP. In Fig. 2, the MS asks DHCP to get an IP address to be used in this subnet in the initial set-up. It then make a DSNP request for the real-time session with the QGS. The QGS will make the decision based on several factors then decides to admit the request or not. Fig. 2 shows that the QGS decides to admit the request. The QGS informs the related QLNs, and sends the DSNP offer to the MS. In any time if the MS wants to change the SLS, Fig. 3 indicates that the MS updates the SLS with the QGS. Fig. 4 shows the flow when the MS roams to a new subnet within the same domain. Since all related QLNs already have the QoS profile of the MS, no QoS signaling and negotiation is necessary unless the MS wants to change the SLS. In Figs. 2-4, QLNi generally represent the QLNs that the QGS multicasts the new SLS to. However QLNi means only the QLN(s) the actual traffic goes through when the MS transmits/receives the actual data. Also, messages with all capital letters are traffic in control plan, other messages are traffic in transport plan. Shade areas represent the QoS control messages over the wireless link.

3.2 Mission Critical Traffic

Mission critical traffic is a class of traffic which cannot be lost or delayed. The amount of this kind of traffic is usually predictable and is among a small portion of the total bandwidth. Since it is critical, there is no admission or connection control for it. Since it is predictable and the amount is small, we reserve a specific portion of bandwidth for it. The bandwidth reserved is much larger than the predicted traffic. Therefore, it is reasonable to assume that the bandwidth for mission critical traffic is never exhausted. The reserved bandwidth can be adjusted dynamically, and the unused bandwidth for this class can be allocated to other classes of traffic in temporary basis.

As mentioned above, there is a global QGS and many local QLNs. QLN has the local information about the resources in local domain, and this local information is provided to QGS periodically. Based on the local information and the mobility pattern, the QGS envisions how much bandwidth should be reserved in each QLN for this class of traffic. QGS then sends this information to QLN. As described before, the bandwidth

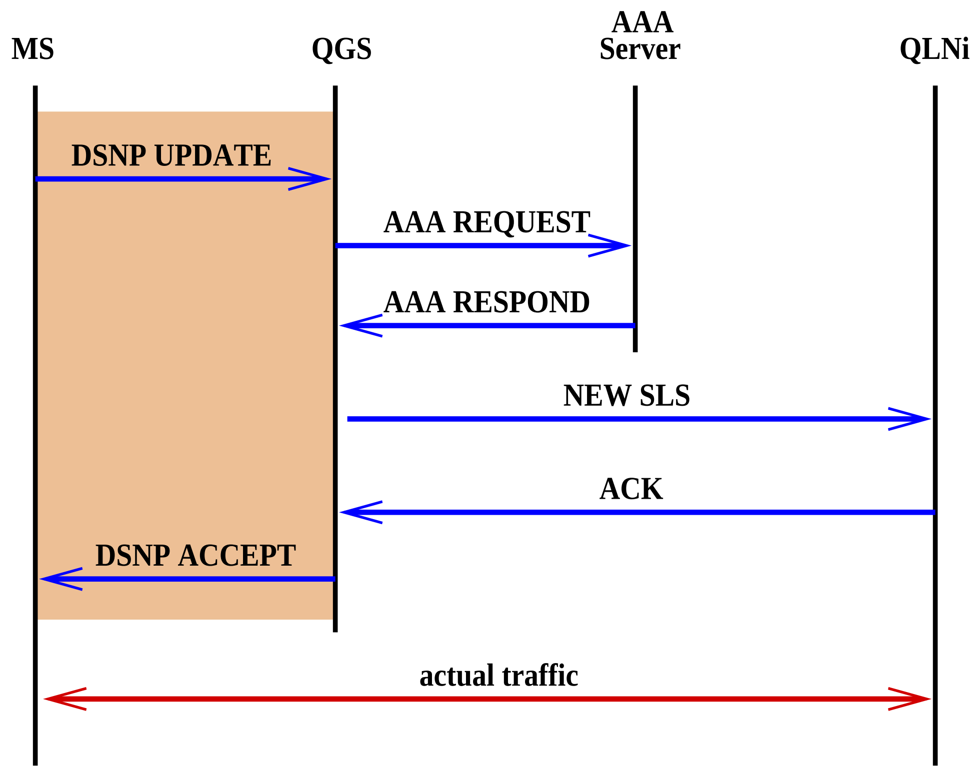

Figure 3: Example flow for dynamic SLS

reserved is much larger than the expected traffic. When a MS pops up, it first performs registration and configuration to get an IP address. This can be done, for example, by DHCP or DRCP. When it wants to send mission critical traffic, it does not perform QoS negotiation and signaling with QGS. There is no admission or connection control. The traffic can always go through QLN directly to enter the DS domain. When the MS moves to other local domain of QLN, it gets a new IP address, if necessary. The traffic can go through the new QLN without any QoS negotiation and signaling as that in previous QLN.

3.3 Real-Time Traffic – Pre-reservation

Real-time services usually require low delay. The loss of packet could be either low or moderate depending on the nature of the traffic.

For this class of traffic, the MS must perform the QoS signaling with QGS for QoS request. The MS first performs configuration with DHCP to get an IP address when it pops up. Before the MS sends actual traffic, it initiates the QoS signaling with the QGS. This QoS signaling may be part of SIP [5] or AAA protocol. The QGS will also interact with AAA or other servers if necessary. Based on the interaction with other servers, the global information in QGS, mobility pattern, and the service level agreement and specification, the QGS will either admit or reject the QoS request. Since the QGS has the global information (bandwidth in each QLN, mobility pattern, etc.), the QGS will admit the request only when the bandwidth in potential QLNs the MS will roam to is available. Depending on mobility pattern and how strong the guarantee is required, the QGS will decide how many QLNs should be included in the initial set of potential QLNs. Typically, potential QLNs the MS will roam to while still maintains the same real-time session are the adjacent QLNs of current QLN. The MS is admitted only when there are bandwidths available in potential QLNs. The decision made by the QGS is multicast to current QLN and all potential QLNs.

When the MS is roaming inside the same administration domain, i.e., the domain serving by the same QGS, the MS only needs to get a new IP address if changing subnet. It does not need to have any QoS signaling since the decision made by the QGS has been sent to all potential QLNs. Since the interaction between QGS and QLNs are updated periodically. The set of potential QLNs may be changed dynamically while the MS is moving. Thus the MS can transmit/receive real-time traffic through QLNs without initiating

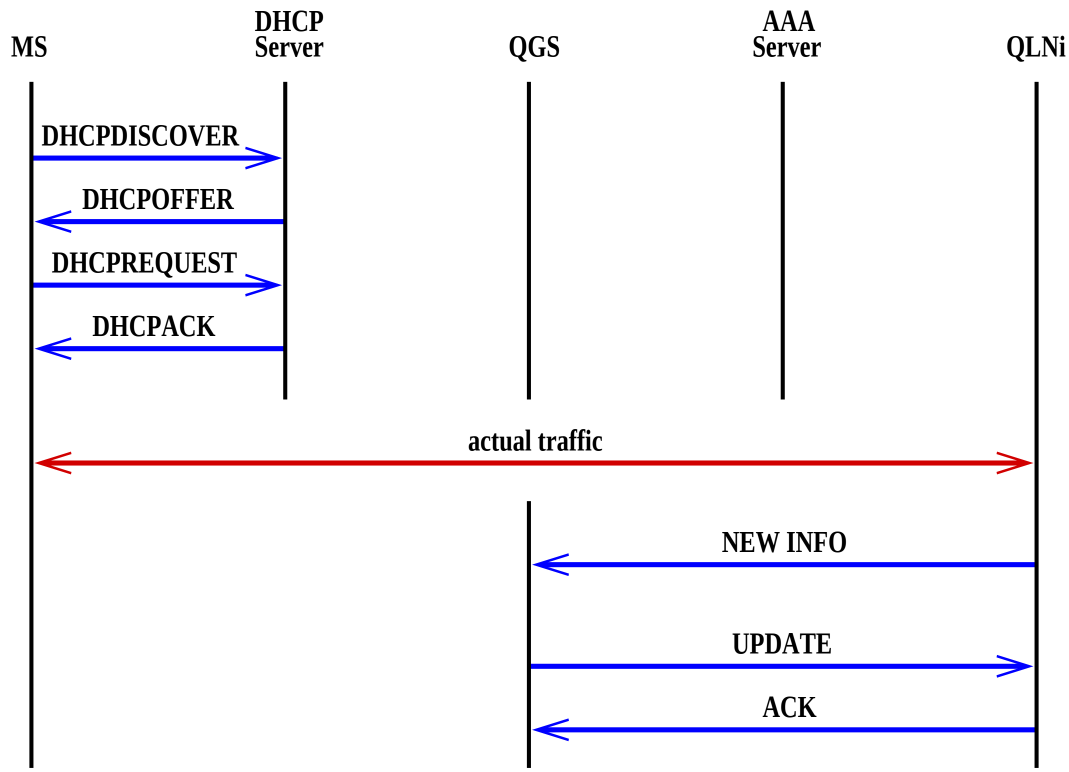

Figure 4: Example flow for moving into a new subnet within the same domain

new QoS signaling while it is moving within the same administration domain. This saves the wireless bandwidth. Please note the bandwidth reserved ahead for real-time traffic in QLNs can be allocated to other classes of traffic in temporary basis as that in mission critical traffic.

When the MS moves to a new administrative domain, it must initiate the QoS signaling with the new QGS. The new QGS may consult with the new AAA server, old AAA server, and the old QGS to decide whether it should admit or reject the QoS request. After that, it is similar to what described above.

3.4 Real-Time Traffic – Provisioning

The protocol presented above can potentially save the wireless bandwidth. This is because it does not need new QoS signaling when the MS is moving within the same domain once the request is admitted. In Section 3.3, the QoS signaling between MS and network is only limited to the initial set-up or when roaming to a new administrative domain. It also reduces the handoff blocking probability because the bandwidth in potential QLNs has been reserved before moving. It however may increase the connection blocking probability because the MS is admitted only when the bandwidth is available in potential QLNs. An alternative for real-time traffic based on the same QoS architecture is presented as follows.

Similar to that described in last section, the MS gets a new IP address and performs QoS signaling with QGS. The QGS makes the admission control only based on the local information provided by the serving QLN. Instead of admitting the request based on the bandwidths in all potential QLNs, the connection request is admitted only if the bandwidth in current serving QLN is available. The decision made by the QGS is sent to the serving QLN. All other QLNs have certain bandwidth reserved for potential traffic of this class handed over from adjacent QLNs. When the MS moves to a new QLN, the MS performs the new QoS signaling with QGS. The QGS admits the handoff to the new QLN only when the reserved bandwidth for handoff in the new QLN is still available. If not, the connection is lost.

The reserved bandwidth for handoff in QLNs can be carefully provisioned so that the handoff blocking probability can be minimized. Since QGS has the global information, it can decide the reserved bandwidth for handoff in each QLN more efficient. Similar to that in mission critical traffic, QGS can instruct the QLNs to dynamically change the reservation based on the global information. The merit of this protocol

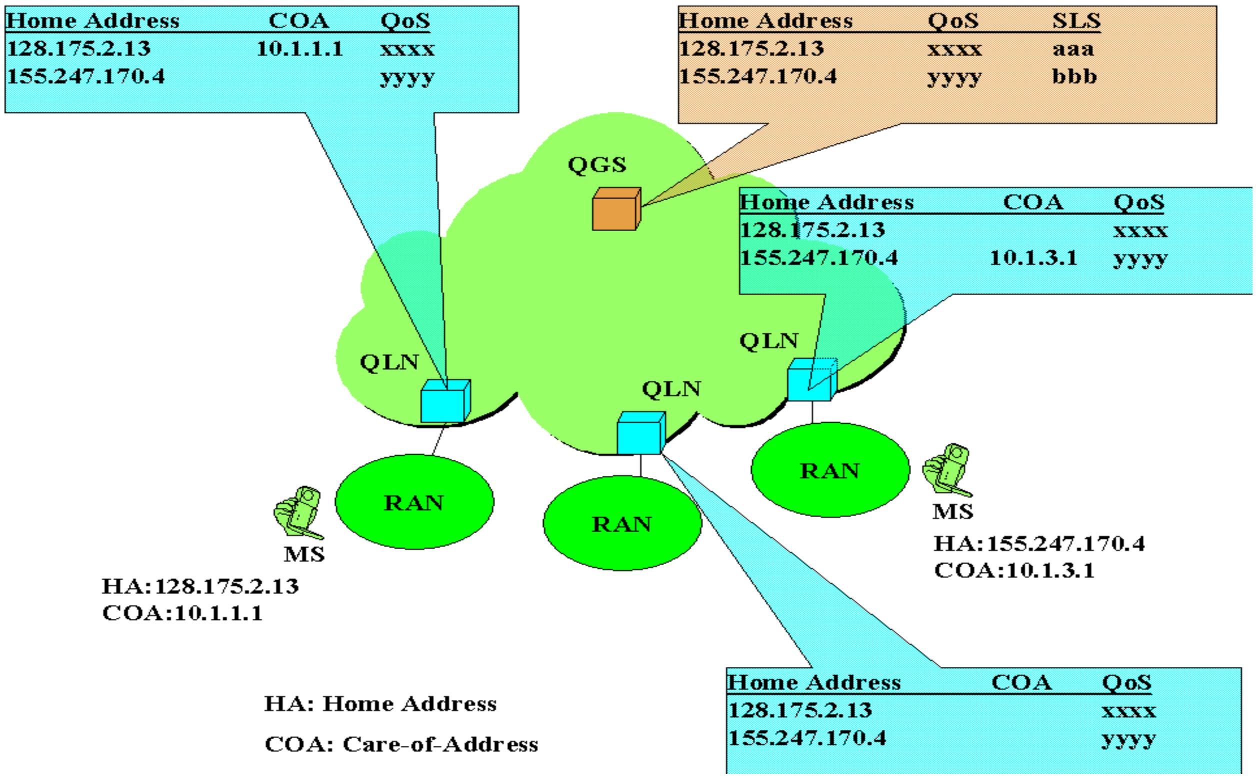

Figure 5: Implementation

is to reduce the connection blocking probability. It however increases the messages for QoS signaling and may increase the handoff blocking probability. Based on the SLS with the user, the QGS can decide which protocol to use for real-time traffic.

3.5 Non-Real-Time Traffic

For non-real-time traffic, there is no need for admission and/or connection control. When the MS first pops up, it performs configuration to get an IP address as described above. The QoS profile and SLS of the user have been stored in the home QGS and/or QLNs when the user subscribes to the service provider. The MS does not need to perform QoS negotiation with the QGS unless the user wants to change the SLS, which can be done by the protocol in Section 3.1. However, the MS needs to inform the QGS about its presence when it first appears in the domain. The QGS then multicasts the QoS profile of the MS to all QLNs in the same administration domain, if necessary. The MS then can transmit/receive traffic regardless where the MS is moving. By this way, the new QLN does not need to ask the QoS profile from previous QLN each time when the MS is moving. If the MS moves to a new administrative domain, the new QGS has to interact with the old QGS as that described in Section 3.3. Based on the SLS, the QLN will perform necessary mechanisms such as policing, shaping, etc. The traffic therefore may be queued or dropped.

4 Testbed and Implementation

The ITSUMO testbed consists of a number of laptops, base stations, and routers. The radio layer transport is carried over an IEEE 802.11 complaint WaveLAN system. Each MS also equips with a digital camera. The indoor testbed is composed of three distinct subnets. The OS running is Linux. Some important protocols and applications running in the testbed include DRCP [4] servers, MosquitoNet implementation of Mobile IP [6], SIP [5] user agents and SIP proxy/re-direct servers, IMT-2000 emulator which emulates the Packet Data Layer in the LAC (Link Access Control) sublayer of cdma2000, vic [7] with Toshiba's MPEG4 implementation, RAT [8] for audio applications, and whiteboard (WBD) [9] for collaborative shared file applications.

An initial implementation of the protocols covered in Section 3 has been developed to perform experiments. Some statistical results gathered from experiments will be presented in the final version of the paper. The following sub-sections provide the implementation details of each QoS architecture component.

4.1 MS

An MS is a user device which is used to transmit and receive data over the network. Because it is an end user device, it does not perform much QoS processing at all. The functionality of an MS consists of simply four requests: SLS update, mission critical traffic, real-time traffic, and non-real-time traffic. The other QoS architecture components carry out the task of processing the request.

4.2 QGS

The QGS has the responsibility of maintaining global information about the available resources in the whole domain and using this knowledge to process MS requests and delegate traffic shaping tasks to the QLNs in the domain. The result of each incoming request may affect the current status of available resources, and therefore, should not be processed concurrently. Instead, the QGS processes each request one at a time. This insures that all necessary data for processing a request is accurately available, allowing decisions to be made correctly.

Much of the processing that QGS performs involves communicating with other components in the architecture. While this is going on, new requests may be arriving as well. Hence, if all incoming messages arrive on the same port, both request and processing messages will be arbitrarily interleaved in the socket's queue. This would place additional burden on the QGS by requiring it to do some complex state maintenance and get involved in queuing new requests.

Our implementation avoids the additional complexity by having two separate ports. The QGS listens on port 2000 for new requests, while using port 2001 for all processing communication needed to handle requests. In this way, QGS is relieved of the burden mentioned above by allowing the existing queueing mechanism in the socket layer to queue new incoming requests. Additionally, internal state is more easily maintained, because at any given moment, the QGS knows the expected message type and from which port to expect it.

The current status of each MS in the domain is also needed by the QGS to process new requests appropriately. Fig. 5 shows the MS table that the QGS maintains. Each entry has the static home address, SLS information, and current QoS parameters for the MS. The following subsections explain how the various types of MS requests are processed and how the MS table aides in the process.

4.2.1 SLS Update

The Dynamic SLS protocol allows an MS to send an SLS update at any time to the QGS to change its SLS agreement. If the QGS decides to decline the update, then it simply does nothing else but reply to the MS with a deny message. However, if the update is accepted, the QGS must do some processing before it can reply to the MS. First, the new SLS information is copied into the MS' table entry. If the MS has a session in progress, then the current QoS parameters must be updated to reflect the updated SLS. To do so, not only is the table entry updated, but the QLNs need to be notified as well. Finally, the QGS may send the acceptance message to the MS.

4.2.2 QoS Request

The protocol for real-time traffic requires that an MS send the QGS a QoS request to begin a session. The purpose of the request is to reserve the resources needed to fulfill the SLS requirements for a real-time session.

The QGS extracts from the MS' SLS agreement the QoS parameters needed for a real-time session. Using these parameters, it determines if the resources can be reserved. If there are sufficient resources, the QGS will accept the request. This involves updating available domain resource information, modifying the MS table entry to reflect the current QoS parameters, multicasting those QoS parameters to the QLNs, and replying with an acceptance message to the MS.

4.2.3 MS Notice

All non-real-time traffic oriented sessions must begin by notifying the QGS of the MS' presence. Although there is no negotiation needed, much of the processing is similar to that of a QoS request.

Again, the QoS parameters needed for a non-real-time session are extracted from the MS' SLS agreement. Since there is no negotiation, the response is an automatic acceptance. However, before replying to the MS, the QGS needs to update the available domain resource information, modify the MS table entry to reflect the current QoS parameters, and multicast those QoS parameters to the QLNs.

4.2.4 Bye

An MS should not terminate a session abruptly; notifying the QGS of a session termination, allows proper cleanup to be performed. Upon receiving a termination notification, the QGS frees up domain resources that were being used by the MS session and multicasts new traffic shaping information to the QLNs.

4.3 QLN

The responsibility of a QLN is to control the traffic flow of all MSs in its subnet. Each must be diffserv enabled to carry out its duty. Shaping traffic involves filtering all packets into separate queues and assigning QoS parameters to the different queues. To allow the QoS needs of each MS to be managed separately and dynamically, there is a queue maintained for each MS.

As shown in Fig. 5, each QLN also maintains an MS table for all the MSs in the domain which currently have a session running. Each entry has the static home address, the current care-of-address (only if the MS is in its domain), and current QoS parameters for the MS. The following subsections explain the use of the MS table in processing different messages types.

4.3.1 QoS Update

The QGS sends QLNs QoS update messages whenever there is a need to change QoS parameters. These update messages are used in the protocols for all three traffic types: mission critical, real-time, and non-real-time.

Each time a QLN receives a QoS update message, it updates the appropriate MS table entry to reflect the new parameters. It also checks if that particular MS is currently in its subnet. If so, it also updates the diffserv filters and queuing information to shape traffic appropriately.

4.3.2 Care-of-Address Update

A care-of-address update message is sent by an MS to notify a QLN its arrival to the subnet. For a session to continue smoothly while roaming to a new subnet, the new subnet's QLN must know the MS' new care-of-address. Without the care-of-address, a QLN cannot control the MS' traffic properly.

Upon receiving this message type, a QLN updates the MS table entry's care-of-address. Additionally, a diffserv filter and queue is set up to provide the MS traffic its QoS needs.

5 Summary and Concluding Remarks

This paper presents a QoS architecture and preliminary specifications to support mobility. Some of the QoS requirements for next generation wireless IP networks are identified. QoS architecture and protocols are presented. Example flows are shown. In addition to support mobility, the proposed model also significantly reduces the QoS signaling messages while the MS is moving. This also potentially reduces the handoff delay. If the amount of QoS signaling messages is not the major consideration and the MS can tolerate small percentage of handoff blocking rate, the model is flexible enough to use provisioning scheme to increase the number of admitted MS. Since the QGS has global information, dynamic SLS can be achieved easily and efficiently. The MS only needs to negotiate with the QGS once. After that, all QLNs will know the new QoS profile. In the proposed model, the dynamic SLS can be done in any granularity as well.

Because the proposed model is based on diffserv, it is interoperable and administrable for all service providers which deploy diffserv. To interoperate with legacy networks, the IP networks usually connect with legacy networks by *media gateway* (MG) which is controlled by *media gateway controller* (MGC). As that in MEGACO [10], the MG is for transport, and the MGC is for control. The proposed architecture fits this model well. By separating the control and transport, both QGS and QLN handle only part of the QoS functionality. Although all classes of transport traffic go through QLN, QLN should be able to handle them because each QLN only serves a local domain. The potential traffic going through QGS is the QoS signaling message. This QoS signaling may only need to be done once when the MS first pops up. Other traffic to QGS includes dynamic SLS negotiation and communications between QGS and QLN. If one QGS is not enough in an administrative domain, multiple QGS can be deployed. The scalability issue can be handled similarly to that in MG and MGC. The separation of control and transport also makes the mobility support easy to deploy and maintain. When new services are needed, only QGS needs to be upgraded. There usually is no need to upgrade all QLNs in the edge of the network. Since most of the intelligence is in the QGS, QLNs only need to be diagnosed after QGS if the QoS mechanism malfunctions.

The design of the proposed architecture and protocols is to provide an efficient and flexible way to support QoS in mobile environment. The QLN provides the local information to the central QGS, thus the QGS retains the global information of the domain. The merit of the architecture includes efficient mobility support, less QoS signaling message, flexibility for different protocols, easy to integrate with other protocols, and also easy to maintain and deploy. Future work includes detailed protocol specifications, and validation of the architecture and protocols by thorough analysis and implementation.

6 Acknowledgments

The authors wish to acknowledge the contributions of other members of the ITSUMO team from Telcordia Technologies (P. Agrawal, S. Das, A. Dutta, D. Famolari, S. Madhani, F. Vakil, H. Sherry, C. Stumpf, and R. Wolff) and Toshiba America Research Incorporated (T. Kodama, T. Maeda, N. Nakajima, S. Shiomotsuji, and Y. Shobatake).

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