PROVISION OF QOS IN HETEROGENEOUS WIRELESS IP ACCESS NETWORKS

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Abstract - The Internet Protocol is being deployed at an ever-increasing pace to offer connectivity to support a wide range of applications. Current research is targeting mobile hosts, and numerous research projects are considering the technologies needed to support the nomadic user. The IST BRAIN and MIND projects have studied the problems using a top-down approach, from user requirements through the application layer all the way to link layer specific issues. This paper presents the results of the study of Quality of Service provision at the IP layer, to offer service differentiation to application data flows, even over wireless networks.

Keywords - IP, QoS, mobility, wireless, ad-hoc

I. INTRODUCTION

Current research on the Internet Protocol suite is aiming to extend its applicability to support delay-constrained and mission critical applications. This requires the provision of service differentiation. Service differentiation is particularly important, and difficult, in mobile networks because of the mobility of the users and the unpredictable nature of wireless links. The service received by users depends upon many elements - from operating systems, through IP networking protocol operations down to link specific issues.

In recent years, attempts have been made to bring together fixed IP and mobile networks together, with wireless networks providing a limited IP access service, for example WAP over GSM, GPRS and the forthcoming 3G networks. However, these networks do not provide a true IP network to users since they limit the supported services and protocols, and cannot be further integrated with multiple air interfaces to provide true fixed-mobile convergence. One of the goals of the BRAIN project [1] and its successor the MIND [2] project is to bring these two networks together using IP technology. The aim is to design, build and test a truly IP-based access network (AN) [3] that provides seamless mobility and Quality of Service (QoS) for different applications, ranging from best effort services to those with hard QoS requirements, such as IP telephony. Initially, such networks can complement 3G networks by using wireless LAN air interfaces in hot-spot areas. Longer term, the network technology would be suitable for an evolution of 3G networks themselves.

In this paper, we concentrate on how this network provides IP QoS to application flows. We first present the BRAIN QoS architecture and then discuss how the MIND project seeks to enhance this baseline architecture to support a wider range of network and user scenarios. This is still an area of active research. Finally, we describe the software and hardware testbed infrastructure that is being used to verify and refine the QoS architecture and concepts.

II. THE BRAIN NETWORK

The conceptual BRAIN network is presented in Fig. 1. In developing this model, the project considered the basic elements of QoS provisioning, and how these elements are affected by assumptions about wireless access and mobility. Issues considered included admission control to provide fairness and control resource usage, QoS allocation mechanisms in routers, signaling to request QoS, and handover management. The primary focus of the research was on the access network depicted in the middle lower part of the figure as having a HIPERLAN/2 wireless link. The access network is based on IPv6.

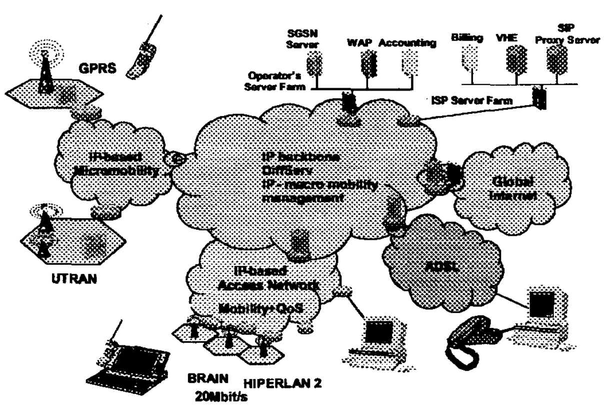


Fig. 1. The BRAIN network.

Mobility of IP hosts on a global scale can be supported with, for example, Mobile IP [4]. However, it is advantageous to minimize the use of Mobile IP and instead use localized mobility management to hide the movement of mobile hosts from correspondent nodes. For localised mobility management, the BRAIN project performed an in-depth analysis of existing protocols [5]. This resulted in a new local mobility management protocol called the BRAIN Candidate Mobility Protocol (BCMP) [6], which borrows most of the benefits of the existing protocols while minimizing their caveats. The fundamental goal in the host mobility management is to minimize the use of Mobile IP and instead make more use of localized mobility management in order to hide the actual movement of mobile hosts from correspondent nodes.

The provision of QoS in wireless access networks is very challenging because of the movement of the hosts and the characteristics and unpredictable nature of wireless links. The number of different transmission services and the requirements of multimedia applications further complicate the provision of QoS in a mobile access network.

The BRAIN QoS architecture is based on a combination of the IETF Integrated Services (IntServ) and RSVP [7] and Differentiated Services (DiffServ) [8] architectures. The fundamental concept is to use IntServ parameters and RSVP signalling to communicate application requirements trough the network, and to provide the actual packet handling with the DiffServ scheme [9] [10].

Per-flow state is only kept at the edge of the access network and the core of the access network forwards packets in DiffServ aggregates. Mapping of RSVP reservations to DiffServ Per-hop Behaviours (PHB) is done at the edges of the access network, at the access routers (AR) and the network gateways. The QoS architecture also permits Mobile Hosts (MH) to send and receive flows using pure DiffServ without RSVP signalling. This provides for a more flexible service provision, more suitable for certain dynamic applications. The combination of these architectures has the potential to minimize the scalability problems commonly associated with RSVP, whilst also improving the approximate service outcome of pure DiffServ. However, the DiffServ framework does not mandate that a DiffServ Code Point (DSCP) set at the sender must prevail up to the receiver; thus, the service outcome of pure DiffServ is dependent on the behaviour of the external IP networks, between the BRAIN access network and the correspondent node. Fig. 2 illustrates this concept.

Extensions to the basic QoS architecture have been designed to enable enhanced support for mobility, the Localized RSVP protocol (LRSVP) [11], coupling of mobility and QoS signalling [13], and the DiffServ handover PHBs. These solutions are discussed in more detail in the rest of this section.

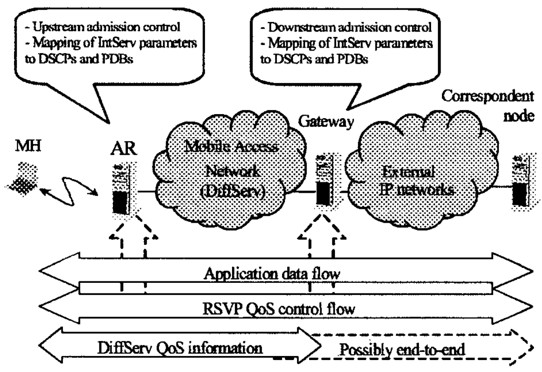


Fig. 2. The BRAIN QoS architecture.

The Localized RSVP concept is based on the fact that within the current Internet, end-to-end QoS is rarely available. Thus, especially in view of the unreliable wireless links and the hybrid traffic crossing the core of the access network, it would be beneficial if the application could request QoS from at least its own access network. The solution proposed requires a slight modification to the RSVP protocol and proxies, which intercept RSVP signalling packets and answer to the requests of mobile host for local resources. RSVP uses a Path message to indicate the resources required by a traffic flow, and a Resv message, sent in response to the Path message, to install the reservation. This exchange is usually carried out end-to-end between the sender and receiver of the traffic flow. In LRSVP, the LRSVP proxies respond to the Path message sent by a MH by sending an appropriate Resv message back towards the mobile. For downstream traffic flows, the MH can request resources by sending a new Path Request message towards the LRSVP proxies. This message causes the receiving proxy to send a Path message downstream towards the mobile with RSVP objects filled with information received in the Path Request [11]. Most of the other standard RSVP operation remains the same.

During and after handover, however, any reservation will be disrupted. Solutions to these problems, coupling of mobility and QoS signalling, and DiffServ handover markings, have been identified. When there is loose coupling between the mobility and QoS protocols then as soon as a handover occurs, the affected nodes are immediately notified and can initiate an RSVP local path repair by exchanging appropriate Path/Path Request and Resv messages. This constrains RSVP message propagation to the area affected by handover, and also there is no need to wait for a scheduled RSVP refresh message to refresh the reservation state on the new path [12] [13].

The handover marking is based on the use of dedicated guard bands. These guard bands are portions of bandwidth that are reserved for use by traffic during and after handover until the reservations have been re-established [3]. Within the network this can be implemented through the use of special DiffServ classes reserved for handover traffic. This process must be initiated by identification of mobility events, for example using the coupling described before. Thus, during handover some QoS can be maintained until the resources for the new path have been installed.

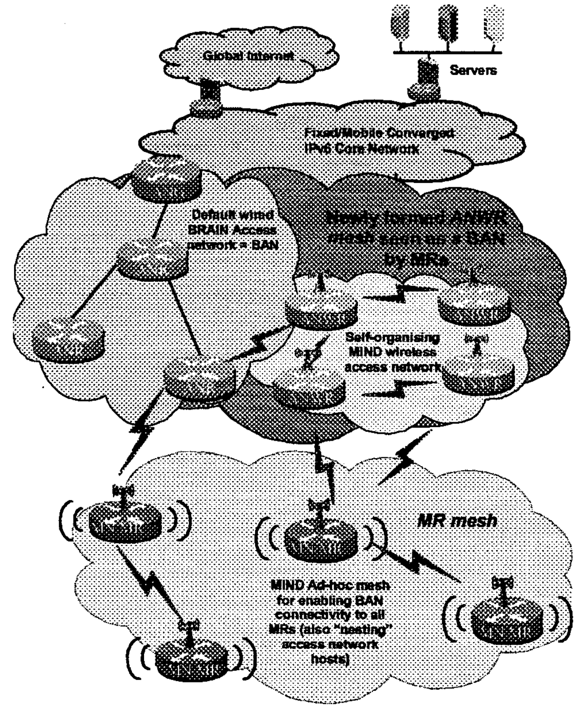
III. MIND EXTENSIONS TO THE BRAIN NETWORK

The MIND project is a follow-up to BRAIN and has adopted as its basic framework the network architecture and protocols envisaged in BRAIN. MIND has extended this work to include support for ad-hoc networks, and in particular investigating issues associated with the connection of ad-hoc networks to access networks. This greatly increases the range of uses for such ad-hoc networks - for example, extending network coverage to increase capacity temporarily for a major event, or building low cost networks within universities or on a business campus. A number of different configurations of the MIND network are possible - these can be distinguished by the degree of mobility and the nature of trust relationships [2].

From the network architecture point of view, Fig. 3, the extensions to BRAIN are that the access network can be fully or partially built with wireless links in an ad-hoc manner, known as an operated ANWR mesh, and that whole mobile networks, rather than single hosts, can connect to the access network and request services – the MR mesh.

Within the MIND scenarios, the design choices about QoS are affected by the dynamic, wireless nature of the envisaged networks. For example, the topology of the resultant network is dynamic, and consists of multiple, wireless links with variable characteristics, such as capacity and error rates. Thus, in addition to the basic QoS issues studied under BRAIN, the further issues of radio resource management, QoS inter-working mechanisms, and QoS routing need to be considered in the ad-hoc environment. In ad-hoc networks, allocation of resources for flows must occur rapidly with minimum overhead, whilst reacting adequately to changes in topology and removing allocations as soon as the session is finished. Further, in the ad-hoc environment, signaling should aid application adaptation through suitable, fast feedback of network state information.

QoS information between application and network can be separated from the data flows, as with RSVP, or in the data packets, as in DiffServ. The former can provide more precise information and so lead to better service, but it is less responsive to the mobility of hosts, consumes some portion of bandwidth, and so affects power consumption. Because the QoS information is in every packet, the latter approach is more flexible in supporting mobile hosts and ad-hoc networks. Further, by using the DSCP bits already available in the IP header we can avoid adding overhead to each data packet, so minimizing bandwidth and power consumption. The caveat is that the limited information carried may produce a more approximate service.



ANR – Access Network Router
ANWR – Access Network Wireless Routers

Fig. 3. The MIND extensions.

Since a flow of datagrams may cross several ad-hoc and traditional network domains, each having its own internal QoS mechanisms, interworking of the QoS mechanisms to offer end-to-end service is essential. RSVP is the only feasible end-to-end protocol and, so both the RSVP messages and DSCPs must be mapped to the domain specific mechanism. In an optimal configuration, end-to-end QoS between applications would be unaffected by local QoS solutions, even if different domains – represented by the shaded clouds in Fig. 3 – use different QoS mechanisms. Proper handling of DSCPs is especially critical, since the DiffServ framework allows for much freedom in the packet handling and re-marking in each domain. This is illustrated in Fig. 4.

In addition, QoS routing plays an important role in the ad-hoc networks. In QoS routing the next hop for a packet is chosen based on the quality of alternative routes. The additional QoS information used in routing decisions can be expressed as bandwidth availability, size of queues in routers or the signal-to-noise ratio of wireless links. The information needed by QoS routing can be added to all types of routing protocols – even OSPF routing protocol can

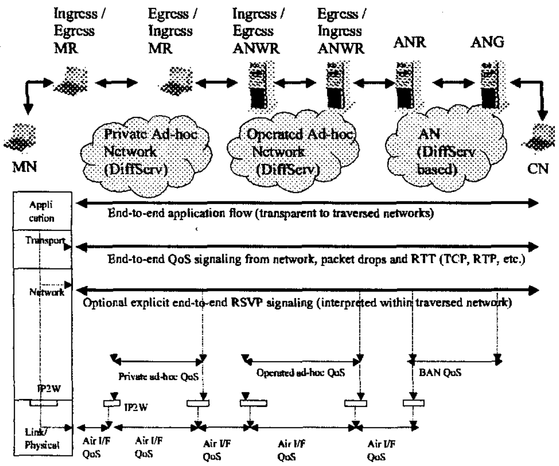


Fig. 4. End-to-end QoS in the MIND network.

support QoS routing [16]. The biggest problem is that the dynamic nature of the environment will mean that the QoS routing information will often be stale regardless of the routing protocol.

Since the network topology of the ANWR-mesh is relatively static it is likely that a proactive, table building routing solution, that includes QoS information on links, will be most suitable for basic datagram forwarding. The dynamic topology of the MR mesh will probably require a different routing solution - a reactive solution where the route to a node is determined when required.

IV. INTERACTIONS WITH IP AND LOWER LAYERS

IP protocols make minimal assumptions about the underlying link layers - a simple FIFO packet transmission is mostly enough. Lately, attempts have been made to include QoS features in link layer MAC functions, for example in the Hiperlan/2 standard [14]. If not co-ordinated correctly, there is a major risk that the QoS mechanisms on the IP and link layers can work against each other.

The BRAIN project defined a convergence layer between the link layer and the IP layer called the IP-to-Wireless convergence layer (IP2W) [3]. This convergence layer is responsible for co-ordinating efficiently functions such as address management, handover and QoS. For QoS, the primary purpose is to provide information about link layer features to the IP layer so that IP packets can be provided to the link layer together with enough information to allow for more efficient resource usage and enhanced QoS [15]. The work on IP2W is continued in the MIND project.

Furthermore, in ad-hoc radio networks, Radio Resource Management (RRM) is important. RRM is responsible for managing wireless link resources and allocating air interface resources to traffic flows. In traditional mobile environments, where a mobile is attached to the access network via a single wireless link, RRM functions reside at the link layer performing local measurement, resource allocation and admission control decisions. A centralized RRM server may also be present to co-ordinate resources across multiple cells. However, in the dynamic ad-hoc environment a centralized RRM server is not a feasible solution; RRM functionality must be placed in the network layer with mechanisms to support inter-RRM communication.

Moreover, ad-hoc networks may consist of multihomed terminals. RRM entities must monitor the load on all air interfaces supported by a terminal device in order to determine whether a traffic flow can be supported and what QoS can be provided. This overview of all interfaces can only be maintained above the link layer. Furthermore, the capacity and resource availability of neighbouring cells, and potentially cells a few hops away, must be monitored to support handover, QoS routing and admission control. Finally, the provisioning of resources at the link layer must be coordinated across multiple hops to avoid interference between cells.

V. TRIALS

Several testbeds have been developed in the framework of MIND, on which the QoS concepts described above are being implemented and evaluated. A simplified version of the QoS testbed is described in Fig. 5. Wireless LAN technology is used to provide access to the network. Three Linux-based access routers (AR) are set up at the edge of the AN in order to demonstrate different handover scenarios. Two gateways connect the access network to external IP networks.

A range of different test scenarios have been envisaged. During these tests, in addition to demonstration of applications, factors such as packet delay, delay variation (jitter), packet loss rates and throughput during handover will be measured. Test scenarios include:

- The effect on QoS of changing the relative depth of the IntServ and DS network segments and the mapping between these two QoS mechanisms, and
- Handovers that only change the serving AR, handovers that change the network interface of the gateway, and finally handovers that change the gateway.

A key result of the trials will be an understanding of how well an IP solution to QoS supports applications over the wireless network. In addition, simulations will also be carried out to validate new concepts, particularly for the ad-

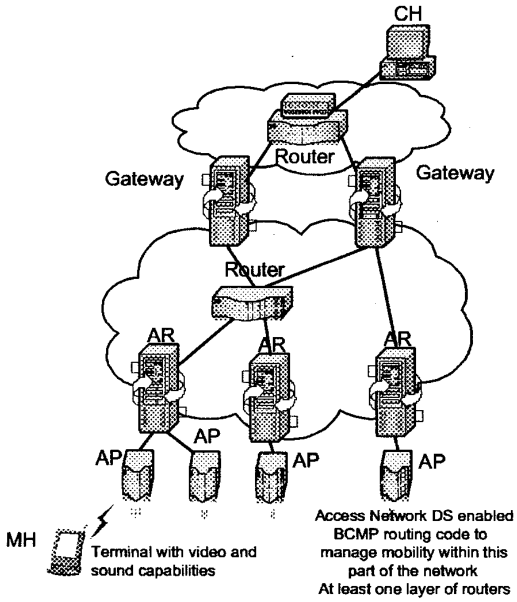


Fig. 5. Structure of the testbed.

hoc networks. Of key interest here are the various ways to perform QoS routing in the wireless part of the access network.

VI. CONCLUSIONS

In this paper the vision of the BRAIN project on QoS provision in IP-based mobile and wireless networks was presented. The scheme is based on a combination of RSVP signalling and DiffServ flow aggregation. Several extensions to the baseline QoS architecture seek to provide more seamless mobility as seen by the user and their applications. The MIND project has further extended these concepts to include support for wireless ad-hoc access networks and mobile networks.

At the time of writing, the definition of the QoS and mobility mechanisms is been finalized and we are building testbeds to demonstrate the presented concepts. Results of these tests will be available during the autumn of 2002.

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