QoS Support for an All-IP System Beyond 3G

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ABSTRACT

Mobile radio systems beyond the third generation will evolve into all-IP systems, integrating Internet and mobile system advantages. The BRAIN project is developing a system architecture which combines local coverage broadband radio access systems based on HIPERLAN/2 with several wider-coverage mobile radio systems, enabling full coverage of seamless IP-based services for users in hot spot areas and on the move. End-to-end QoS provision is one of the major challenges in the design of such a system and must be supported by the application, network, and wireless access layers. This article proposes a QoS system architecture, including the terminal architecture, the IP-based access network, and the main characteristics of the enhancements to the air interface based on HIPERLAN/2 focusing on its wireless QoS support.

INTRODUCTION

Third-generation (3G) mobile radio systems are evolving in their standardization process to provide more and more data transmission capabilities using the Internet model. The use of IP packets for both transport and signaling paves the way to a natural convergence of fixed and mobile networks. In this area, the IST Broadband Radio Access for IP-Based Networks (BRAIN) project aims to contribute to this convergence by specifying an all-IP architecture including cellular radio systems, fixed networks, and wireless LANs. We envisage users of beyond 3G systems having personal mobility — able to use any terminal on any access technology — but able to access the same services, suitably presented and adapted for the terminal and link bandwidth. End-to-end quality of service (QoS) is one of the main features that companies will demand for seamless services provision tuned to different customers' requirements. Two aspects of this QoS provision are the focus of this article: a new QoS model for applications called BRENATA, and the radio link improvements to support wireless IP QoS in the European Telecommunications Standards Institute (ETSI) high-performance LAN Type 2 (HIPERLAN2) system [1–3].

While systems beyond 3G will be commercially deployed this year in Europe, little consensus exists about the differential features of future generations. Nevertheless, it is a common view that there will not be a single radio air interface, but rather overlapping ones serving the same area. Our vision of beyond 3G systems considers the existence of different air interfaces like Universal Terrestrial Radio Access Network (UTRAN) Release 5, IEEE Wireless LAN, or ETSI HIPERLAN2. Each will offer different service in terms of coverage range, bandwidth, or delay. But they have in common grant access to a radio access network (RAN). We propose a radio access network, the Brain Access Network (BAN), which is fully IP-based. There are sever-
al reasons for this design choice. First, an IP-aware RAN can give better support to IP applications. Second, IP infrastructure will be widely available, reducing the cost of deployment, and IP-style engineering is faster and cheaper, as the Internet development has proved. And finally, considering the air interface an IP subnetwork facilitates the movement of terminals among RANs that use different air technologies.

On the other hand, the protocols serving such typical RAN functions as resource management and terminal mobility must be redesigned to use IP datagrams to communicate peer entities. Each element of the RAN and the user terminal must include the IP stack. To illustrate this, we will roughly describe here the BAN [4], its elements, and how it deals with terminal mobility support and QoS provision. This will provide a good framework to understand the contributions presented in the rest of the article.

The BAN uses HIPERLAN/2 as the air interface. It is used as the wireless link between the terminal and the Brain Access Router (BAR). The mobile terminal (MT), connected to the access point (AP), delivers IP datagrams that are transported inside the HIPERLAN/2 subnetwork to the BAR. The BAR is a standard IP-based router with one or more HIPERLAN/2 interfaces. The BAR will forward received IP datagrams using standard IP routing mechanisms. In order to increase the coverage of short-range HIPERLAN/2 cells, several BARs can be deployed. These BARs can be connected to each other using direct fixed links or through an intermediate IP-based router, but the final topology of the BAN will be an operator decision. There can be one or more routers connecting the BAN with other IP networks. These are called BRAIN mobility gateways (BMGs) due to their special function in mobility support. Figure 1 depicts these elements.

The ability to maintain connections in an all-IP system while the terminal is moving is divided into three levels. Mobility inside the wireless subnetwork (cells belonging to the same BAR) is handled by the wireless technology procedures and is unnoticed at the IP level. Serving mobility in a broadband radio access network that regards IP QoS requires tight integration of radio and network-specific mobility procedures (e.g., to reduce handover execution latency). HIPERLAN/2 provides basic functions to support fast local handovers without regarding specific network layers. IP mobility procedures support mobility across network elements, but end up with rather high handover execution latencies. Control functions are therefore defined for the IP convergence layer (CL) to integrate IP-aware and fast handover strategies at the radio interface with the supporting mechanisms in the network to allow mobility within and across BRAIN islands [5].

Mobility involving cells from different BARs is supported at the IP level using IP mobility protocols. Two levels of mobility are considered; macro mobility to handle mobility between different operators, and micro mobility to optimize mobility inside the same network operator. Since there will be different protocols supporting these two kinds of mobility, the BMG will act as a gateway between them. Applications will run in the terminal unaware of this mobility since the IP level will hide it.

The rest of the article is organized as follows. First, we describe the terminal architecture proposed to manage end-to-end QoS, including mobile end systems and IP-based wireless access networks (i.e., the BAN) in the transmission path; second, we describe enhancement of the ETSI HIPERLAN/2 system to support IP QoS provisioning, and we describe system simulation results on providing IP QoS over the BRAIN air interface; and finally, we summarize the most important contributions.

**QoS Management for Adaptable Services with Mobility Support**

Future end terminal architectures for systems beyond 3G are envisioned to provide applications with different levels of QoS, and to allow applications to adapt in front of degraded transmission quality in a predetermined way.
mission quality in a predetermining way. In order to do so, all the peers participating in a given telecommunication session shall coordinate their efforts in:

- Deciding how to deal with service degradation/disruption
- Managing the overall resources (i.e., not only the local ones) accordingly

According to this rationale, one of the main goals of the BRAIN project has been to investigate how to provide wireless connectivity with QoS enhancements to both sedentary and nomadic users, who will access services according to QoS contracts negotiated with service providers. Based on such contracts, applications can request QoS and react to any violation of the terms set forth in such contracts.

To this extent, BRAIN has developed an innovative architecture called BRAIN end terminal architecture [6] (BRENITA) for providing applications and services with QoS adaptation functionality, through the stepwise induction of a middleware solution above the transport layer. The foundation of BRENITA is the Enhanced Socket Interface (ESI), which services and applications can use for accessing QoS control and signaling functionality at the transport layer and below (Fig. 2). This section describes the key elements of the proposed architecture concerning systems beyond 3G.

THE EXTENDED SOCKET INTERFACE

The ESI is a generic interface, which is independent of any platform, QoS mechanisms, or transport service provider. In addition to the standard transport primitives (e.g., open, close, listen, connect), the ESI provides several new primitives to allow applications to specify their QoS requirements. QoS-aware applications can thus be implemented against this interface, which also hides mobility-related aspects. With the ESI, legacy applications can still use standard send/receive calls, whereas QoS-aware applications can request, renegotiate, and release QoS for network-related operations.

The Extended Socket Layer (ESL) maps the ESI primitives and parameters to those of any available transport/QoS service providers. For instance, a dedicated QoS service provider (QoSSP) would implement the local management and control mechanisms necessary to provide QoS, that is, configure the local network stack to set up adequate queuing disciplines to provide resources at the end system. Additionally, such a QoSSP could use signaling primitives (based, e.g., on RSVP) to reserve network resources along the path inside the network. The mapping between ESI primitives and the transport/QoS service...
provider ones depends on the terminal implementation and the transport/QoS service provider itself. Assuming the mobile terminal is equipped with an RSVP-like QoSPP, the mapping can be subject to one of the ESI’s QoS parameters, the service type. If an application requests Guaranteed Service as service type, the ESL maps the ESI’s QoS abstract definitions into valid TSpec and RSpec. The benefit of mapping QoS parameters and primitives is that if at some time the QoSPP were changed (e.g., due to handover), only the mapping should be adapted, without affecting the applications.

**Local Management Interface** — Additionally, a local management interface is used for local configuration, which is necessary for supporting vertical handoff, say, whenever AAA functionality is necessary, or for selecting terminal traffic control functionality (e.g., influencing the classification, queuing, and scheduling at the IP layer). By using the functions of the QoSPP, one can set up QoS for legacy applications. For instance, a configuration application could trigger the association of a certain differentiated services codepoint (DSCP) with a dedicated flow (i.e., associate high priority and low packet dropping for all IP packets destined to Web servers). Lower layers would recognize the request for premium service for the dedicated flow and use the proper queuing and scheduling discipline.

As an alternative, the configuration application could initiate RSVP messages to set up resource reservation in the network transparent to the application for reserving, say, 64 kb/s peak and 32 kb/s sustainable bandwidth for the downlink of an Internet connection with a maximum delay of 100 ms. Thus, standard legacy applications (e.g., Web browsers or ftp clients) would provide more predictable services without changing the application code. If no QoS is provisioned, the given legacy application would still be able to operate as usual, but without QoS support.

**The BRAIN End Terminal Architecture**

BRENTA is based on the following design principles that we expect will be the bases for building successful systems beyond 3G:

- **Modularity** — Guarantees that existing applications can immediately be used, whereas more complex middleware solutions can be gracefully introduced later as soon as they become available.

- **Openness** — Allows BRENTA to be interoperable with other architectures. Furthermore, since BRENTA is mostly designed based on Internet Engineering Task Force (IETF) protocols and software components, its openness and modularity guarantee that future emerging IETF protocols providing more refined support for mobility and QoS may easily be integrated.

- **Flexibility** — Allows coping with different media types by, for example, supporting downloadable codes. Furthermore, QoS-enabling components featuring standardized interfaces may also be downloaded from a server during runtime to enhance the system.

Attending these design principles to address both existing and future applications, BRENTA introduces a classification of applications based on the degree of QoS awareness featured. Then specialized software interfaces are provided in the terminal to address the particular needs of each application type.

**Type A** applications are legacy ones (e-mail, ftp, Web browsing), which typically access IP services through legacy transport layer interfaces (application programming interface, API 0 in Fig. 2). Some legacy applications may also use proprietary QoS-enabled transport interfaces (e.g., Microsoft’s QoS), or even the ESI directly.

Type B applications are able to deal with session layer protocols (e.g., H.323, SIP, RTSP) across API B. Since type B applications autonomously manage QoS- and mobility-related issues, they only use standard protocols (e.g., IETF protocols), enhanced with mobility-related functionality.

Moving a step further, component-based architectures such as Common Object Request Broker Architecture (CORBA), Java Enterprise Beans, and DCOM are expected to emerge in the midterm and thus reduce the development time for sophisticated applications and services. Given the need to outfit applications with adaptation mechanisms in order to cope with QoS contract violations, shifting such mechanisms from the applications to a flexible middleware that features QoS- and mobility-related functions greatly simplifies the development of applications for mobile environments. To this extent, BRENTA type C applications leverage existing implementations of protocol and multimedia functionality (e.g., frame grabbers, codecs, packetizers, renderers) and resource management functionality through BRENTA API C, which is offered by a set of software components. However, the QoS adaptation logic still resides within the applications. IETF protocols can also be encapsulated in components to provide compatibility and flexibility (e.g., the session manager, SM, maps session protocols such as SIP, H.323 and RTSP to an abstract API). BRENTA also allows dynamic downloading of key components (e.g., for updating codecs or protocol objects) through the component coordinator (CC) functionality.

Finally, we foresee future applications (type D) that will totally rely on an external entity, the QoS broker, via API D. Based on user QoS profiles or application-supplied policies, the QoS broker coordinates local, network, and remote (peer’s) resources in order to provide end-to-end QoS and cope with QoS violations. Type D applications may also be XML-based, which interpret XML documents (e.g., SMIL) describing the business logic on a declarative basis.

BRENTA is split into two major planes: the usual data networking plane, and a QoS and resource management one [1]. The former deals with data handling through the use of multimedia components (e.g., codecs) and ESI sockets. The latter deals with data networking plane management — including the coordination of local, network, and peer resource management — in order to achieve given QoS levels.

The basic QoS adaptation strategy consists of the selection of predefined alternate QoS specifications, corresponding to well-defined QoS changes, as monitored by the overall middle-
The quality of a radio connection depends on the position/movement of mobile users, radio environments (indoor/outdoor), and the burstiness of co-channel interference, and may change either smoothly or rapidly.

**Resource Management** — In the QoS and resource management plane, BRENTA features the following mechanisms:

- **Management of local resources** (CPU, memory, battery power, etc.): Centralized resource controllers (RCs), one per resource type, monitor and control resources on a system-wide basis. Sets of resource managers (RMs) provide resource management on a per-flow basis by interacting with the corresponding RC through an RC-specific API. An example is the CPU RC (CRC), which allows monitoring the task scheduler, reserving CPU time slices, and/or setting deadlines for a given task. The RCs actually abstract the basic functionality provided by lower-level functions like the OS. Some form of correlation may in fact affect the management mechanisms of different resources; for instance, memory swapping impacts power consumption. The ultimate goal of the RC/RM design pattern is to hide all these low-level details from applications.

- **Network resource management** provides a guaranteed amount of network resources (e.g., bandwidth) to mission-critical applications through the ESI. A stack manager (SM) can also be used to access link-level resource availability information in order to determine when QoS can be upgraded. Modulated according to the RC/RM design pattern, the SM is associated with one or multiple network resource managers (NRM).

- **Remote resource management** guarantees that the called parties can also provide the desired QoS level before reservation of any network resource.

- **QoS orchestration** mechanisms coordinate resource reservation and management in order to provide predictable end-to-end QoS, even in situations of multiple QoS tasks may be delegated to instances of the chain coordinator (ChC) component. Once provided a derived QoS contract, each ChC accordingly combines on a per-flow basis multimedia components and QoS sockets, and derives low-level access points (APs) for configuring them and for dealing with adaptation (using RM services). The media handler (MH) component is used as a CHC factory and supervisor. Additionally, peers can negotiate end-to-end APs and capabilities (e.g., codec types, bit rates) and manage distributed resource management using ad hoc extensions of specific session protocol layers, through the session manager [7].

**The QoS Broker** — The QoS broker will provide controlled and predictable QoS adaptation, based on QoS contracts and well-defined strategies for each subscribed service. To this extent, the QoS broker manages sets of active flows by:

- Deciding the distribution of resources among them
- Resolving any conflicts between flows whenever required resources are lacking
- Handling priorities in order to provide the optimal repartition according to the user privilege and application QoS

Adaptations can be triggered by either a user's change of profile, a peer's initiative, or upon detection of changes in network resource usage (e.g., radio propagation degradation or handover, a new flow accepted, or an old flow terminated). Enforcement of negotiated APs is achieved by using finite state machines (FSMs). Since some QoS specifications can be derived from low-level ones (reflecting the multiplicity of flows in multimedia applications and the various BRENTA layers), we can model APs as hierarchical FSMs.

Inputs to such FSMs are ESI primitives and/or the output of the QoS assessment function, which derives estimates [8] of the actual high-level QoS from QoS measurement information obtained from (hierarchically structured) monitors. This function then compares such estimates against the states of the hierarchical FSM representing the given AP, checking whether the currently enforced QoS contract (i.e., the currently active state) complies with the estimated QoS level, and to what extent. A compatibility factor and a time window are used for tuning the sensitivity of this algorithm. The goal is to determine whether a new QoS contract (out of the negotiated AP) better fits the estimated QoS level. Once a new QoS contract has been identified, the QoS broker delegates any low-level QoS adaptation task to ChCs, as described above.

**PROVIDING IP QoS OVER THE AIR INTERFACE**

In order to create an open architecture for IP-capable broadband radio access, several mechanisms for support of IP QoS over various underlying wireline or wireless technologies for mobile users must be defined. Currently, the IETF has identified several different service model approaches that should provide QoS for IP traffic. Our proposal is based on the idea that each network element has to serve the respective requirements on a per-hop basis. Wireless access networks may provide only one or two hops of an end-to-end traffic flow (i.e., wireless links on one or both sides of the IP network). Within the BRAIN radio access, the responsibility of maintaining IP QoS is divided between the AP and mobile terminal (MT). The AP is responsible for assigning the radio resources to fulfill the connection QoS required under the current radio conditions. The MT is responsible for associating itself to the best AP and providing channel measurements for the AP.

The quality of a radio connection depends on the position/movement of mobile users, radio environments (indoor/outdoor), and the burstiness of co-channel interference, and may change either smoothly or rapidly. Therefore, to control radio link quality in a mobile environment, thus adapting the radio QoS to the required IP QoS, several mechanisms are used and coordinated in the AP [9, 10]. The scheduler in the AP utilizes
the radio channel capacity in the optimal way according to the connection's capacity requirements. QoS-related link layer parameters such as data rate, transmission delay, and protocol data unit (PDU) error rate (PER) are optimized using the powerful link control mechanisms, such as automatic repeat request (ARQ), discarding of PDUs, and link adaptation (LA). ARQ is used to react to transmission errors by retransmission. However, for a poor radio link, ARQ increases the transmission delay and signaling overhead. Discarding of PDUs represents a QoS policy especially used for differentiated services (DiffServ) with an allowed dropping rate that skips retransmission of specific PDUs when due dates expire in order to maximize overall system throughput.

In HIPERLAN/2 multiple coding and modulation schemes have been specified on the physical layer. For poor link quality the radio transmission mode chosen for PDUs can be adapted to a more robust one. This process is LA. An LA scheme is useful and efficient only if the measurement is reliable and able to provide enough state information on radio channels. Figure 3a shows the system throughput for different radio transmission modes. These results are derived from simulations of the BRAIN air interface regarding physical transmission (i.e., PER) and analytical estimations of the impact of medium access control protocol and ARQ retransmissions. With decreasing carrier-to-interference ratio (C/I), the ARQ retransmission overhead increases, so the system throughput will be reduced. However, the system throughput can reach the maximum in different C/I values if the transmission modes are changed at the switching points. Figure 3b shows the resulting maximum downlink transmission delay due to retransmission for various radio transmission modes. These analytically estimated figures show the delay bound experienced by 99 percent of the transmitted PDUs in the downlink direction. Considering these results, the transmission delay is mainly determined by the radio transmission mode selected. From the delay aspect the switching points in Fig. 3a are not valid in Fig. 3b. If C/I is larger than 20 dB, the system throughput can be increased significantly if the 54 Mb/s mode is selected for further transmissions. However, in that situation the transmission delay can be kept minimal if the 27 Mb/s mode is used. Therefore, for IP applications with different QoS (e.g., maximum peak data rate or minimum transmission delay), we can use different link adaptation mechanisms based on Fig. 3 to control data rate and transmission delay, respectively.

In order to simultaneously support integrated services (IntServ) and DiffServ best effort (BE) QoS in the DLC layer, both priority- and reservation-based scheduling have to be supported. To meet this challenge a two-staged scheduling strategy is constructed. In the first stage priority-based scheduling is performed for BE and DiffServ classes with higher priorities for the DiffServ classes, while IntServ traffic is passed through to the second stage. In the second stage reservation-based scheduling is carried out where specific amounts of capacity are allocated for the IntServ traffic flows. The remaining capacity is used by the traffic resulting from the first stage. Call admission control takes care that sufficient resources are available for DiffServ and IntServ.

For a broadband radio access terminal, local mobility is a key requirement; thus, mobility management must support IP QoS as well. For that purpose radio resource control (RRC) functions in the DLC layer provide procedures to support terminal mobility within the service area of one AP and between APs. Three types of handover are distinguished: sector, radio, and network. Fast handover signaling procedures have been elaborated in order to minimize packet loss and transmission delay performance figures. More detail results are given in [5, 10]. Validation of this model has been provided by means of simulations described in the next section.

**SIMULATING IP QoS OVER THE BRAIN AIR INTERFACE**

The simulations are focused on the QoS scheduling strategies; meanwhile, they also include ARQ, discarding of PDUs, LA, and handovers. In addition to the theoretical IP QoS scheduling scheme in Fig. 4, the real DLC scheduling algorithm must also take HIPERLAN/2 constraints into account. These constraints include the DLC layer retransmission protocol, and the combining of all QoS and control flows of a user terminal.
into a single transmission. The scheduler was realized using the following rules: first priority is for control broadcast, second for link level retransmissions and other control, third for IntServ flows having a reservation for the current MAC frame, fourth for all non-BE flows, and fifth for BE flows. A TCP/IP packet is discarded if not delivered within 400 ms. The IntServ reservations are executed by the DLC level admission policy.

The general structure of the dynamic simulation study is as follows. First the reference simulations consisting only of the BE scheduling at the DLC layer are made. Next the obtained reference performance is compared to the simulations where DiffServ and IntServ/RVS information is utilized. In the DiffServ and IntServ simulations it is assumed that half the flows are stumped as higher QoS class and the other half as lower QoS class.

The simulation environment is an exhibition hall environment. The traffic model is ftp transfers of 10 Mb; the average offered bit rate from the IP layer to the link layer is 2.36 Mb/s. The packet size is 1500 bytes except the two 40-byte packets at the beginning. The key simulation parameters are: exhibition hall size 250 × 250 m, number of APs 16, frequency reuse 8, propagation exponent 2.4, std. of slow fading 6 dB, channel model ETSI/BRAN D, suppression of the adjacent channel interference 28 dB, and RF front-end noise figure 7 dB. The simulation setup is further specified in [11].

The used Poisson arrival rate of 1.4 flows/s/ AP results in mean through put of 14 Mb/s/ AP in the reference case. The used parameterization creates a network where the performance is mainly bounded by the hardware limitation but, in addition, some packets are lost due to interference or insufficient signal strength at the receiver. As can be seen in Fig. 5, performance is greatly improved when IP QoS mapping is utilized. In the reference case only 40 percent of the flows experience mean packet delay below 50 ms, and 48 percent of the flows succeeded without packet losses before TCP retransmissions. Using DiffServ QoS mapping, the respective figures of the highest QoS class improve to 75 and 78 percent, and with IntServ the figures further improve to 91 and 92 percent.

Figure 6 presents detailed time serial behavior of a highest QoS class flow from the IntServ simulation. In terms of IP packet delay and loss, the best FTP flow of the worst decile is selected. At the top of Fig. 6 the one-way delay of every TCP/IP packet is presented. QoS deteriorates significantly 1.7 s after the beginning of the transmission. The middle of Fig. 6 illustrates the instant through put at the receiving IP layer, and on the bottom the concurrent received power of its own signal and the interference level are presented. The uplink transmit power is continuously at the maximum level due to the high distance-based signal attenuation. Therefore, the received power varies along the multipath fading. The fading dips correlate clearly with the throughput dips. Hence, fading dips around 1.7 s ultimately result in a significant increase in delay performance. After 3 s the received power level improves again, but due to the increased mean interference level the IP packet delays remain at a higher level than at the beginning of the ftp transfer.
CONCLUSIONS

Internet applications are beginning to appear in second-generation mobile systems and will be enhanced in third-generation mobile systems with a more flexible air interface and higher data rates. We believe that systems beyond 3G will have to incorporate a wider range of radio access technologies (e.g., GSM, UMTS, and HIPER-LAN/2) to provide seamless service for users with high mobility and support broadband local radio access up to 54 Mb/s and beyond. The BRAIN project was created to solve these key issues in moving beyond 3G. A flexible and open end system terminal architecture with adaptive services, support for QoS enhanced networking, and mobility has been developed. Through a well-defined service interface a clear separation of the actual network QoS implementation is possible, so the terminal architecture can be used not only in DiffServ and IntServ enabled networks but also in future new networks. BRAIN will be complementary to 3G by using the HIPERLAN/2 access technique to provide hot spot coverage with high bandwidth and QoS as in wired broadband networks. To efficiently support wireless QoS, powerful radio link and medium access control mechanisms have been investigated. Both the analysis and simulation show that link adaptation, scheduling, and admission control can improve overall radio transmission quality if IP QoS required by users is reflected and considered in the radio link control layer. However, to provide stable radio transmission quality the radio control mechanisms should also be efficient in the presence of interference and multipath fading.

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REFERENCES

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Hector Velayos received his engineering degree in telecommunication systems in 1998 at the Technical University of Madrid. Currently he is working toward his Ph.D. at the same university. During 1999 he worked full time as a networking researcher for the Technical University of Madrid, mainly working during this period was done for the SABA project, funded by the Spanish National Research Program. Since January 2000 he is working full time for Agora Systems as a systems engineer. His Ph.D. studies have been mentioned above. His R&D projects allowed him to develop skills in the design of multimedia applications, and the design and deployment of advanced networks including broadband and wireless technologies.

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