

A QoS Framework for Heterogeneous Wireless Networks using a Multiagent System

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Abstract: Heterogeneous wireless networks will converge into a single network, making the majority of services independent of the access technologies. Thus, current and emerging wireless technologies will belong to a multi-tier system that will interoperate with different wired backbone networks and will have to provide Quality of Service (QoS) guarantees. The asymmetrical nature of the traffic, the handover support, the different access devices and the sparse standardization of QoS parameters are some of the known problems in heterogeneous wireless networks. In this paper, we propose a multiagent system that will improve the mapping of parameters between heterogeneous networks, call admission control and handover management. The objective is to guarantee end-to-end QoS.

1. Introduction

The development of third generation cellular networks has turned out to be the beginning of a move toward a seamless integrated network to be accessed from anywhere by users with unlimited geographical mobility. The idea is that third generation cellular networks will be the core of a multi-tier wireless system composed of different wireless networks that have different infrastructures, protocols and parameters for achieving their own QoS.

Wireless networks (or technologies) can be classified according to the area of geographical coverage of the transmitter or base station, i.e. picocells, microcells, macrocells and megacells. This classification provides the basis for proposing a multi-tier system with a hierarchical architecture. In a cell, each access node has to allow the change of cell (same layer) or of network (upper or lower layer) of an ongoing call. The scenario supposes the implementation of specialized algorithms for call admission control, resource negotiation and QoS parameters mapping, in every network, in order to achieve the QoS required by the user.

The multi-tier wireless system will interoperate with different wired backbone networks, i.e. IP over Dense Wavelength Division Multiplexing (IP-DWDM) with Packet over Synchronous Optical Network (SONET). Another trend in the design of IP layers is to incorporate QoS parameters. In this way, the end-to-end QoS framework for Heterogeneous

Wireless Networks may consider the QoS mechanisms used by the wired network. With an analysis of the state of the art and the results of some exploratory work, we propose a Multiagent System (MAS) that combines local and distributed resource management and QoS negotiation in different levels by using mapping functions.

This paper is organized as follows: In Chapter 2, we present important related issues. Then, in Chapter 3, we discuss state-of-the-art QoS in heterogeneous wireless networks. In Chapter 4, we describe the concepts of a Multiagent System. In Chapter 5, we present the details of our proposal. Finally, in Chapter 6, we provide some concluding remarks and describe future work.

2. Background

2.1. Third Generation (3G) Cellular Networks

Third Generation (3G) cellular networks are designed to provide global mobility with a vast number of services such as telephony, paging, messaging, Internet and broadband data. Universal Mobile Telecommunication System (UMTS), as the European has been taken as the standard for 3G Cellular Networks. In order to provide the end-to-end service to users, a UMTS bearer service layered architecture has been specified by the Third Generation Partnership Project (3GPP). According to this architecture, the provisioning of the end-to-end service is borne over several networks and carried out by the interaction of the protocol layers. An end-to-end service may have a certain QoS which is provided for the user of a network service [1].

A bearer service should include all the features needed to ensure the provision of a contracted QoS, such as control signalling, user plane transport and QoS management functionality. The end-to-end service is provided by translation and mapping with UMTS external services. 3GPP defines QoS parameters such as Maximum bitrate, Deliver order, Maximum SDU size and so on.

2.2. QoS Parameters Mapping

QoS Parameters Mapping is the process that carries out the translation between representations of QoS at different system levels. In the context of

heterogeneous wireless networks, it is possible to establish the following levels at which the QoS parameters mapping are used:

- From QoS perceived by the user to QoS parameters from the wireless network,
- from wireless network QoS parameters to IP core QoS parameters,
- between different wireless networks or technologies,
- in 3G cellular networks according to the QoS standard proposed by 3GPP, and
- between different layers of a specific network.

Different wireless networks have different QoS provision mechanisms and different QoS parameters. To guarantee QoS in a scenario of seamless roaming over integrated networks, intelligent software agents may be located at different networks elements in order to negotiate and exchange parameters for QoS related functions (i.e. traffic prioritization, intelligent scheduling, QoS parameter mapping, etc) [2].

2.3. Radio Resource Management

Users are going to be requesting different services with different QoS parameters and values. In this context, Radio Resource Management (RRM) strategies or functions will be fundamental in providing the QoS required, which means focusing on handover management and call admission control RRM issues.

Handover Management refers, in general, to support for terminal mobility wherever the mobile node changes its point of attachment to the network. Each handover means network resources have to route the call to the next base station. If handover does not occur quickly, the QoS may degrade to below an acceptable level and the connection will be dropped.

Call Admission Control (CAC) is a provisioning strategy used to limit the number of call connections into the networks in order to reduce the network congestion and provide the desired QoS to already established connections. The function of CAC is to make the decision of whether to accept or reject a new connection request (call) with certain traffic characteristics and associated QoS parameters.

2.4. Wireless Technologies

Besides third generation cellular networks, diverse frameworks or schemes have been proposed for achieving QoS for the various wireless network technologies. Below we discuss only five of these technologies, in each of which our work can be applied.

Bluetooth technology is gradually developing into a full wireless networking solution. In [3], van der Zee and Heijenk investigate how Bluetooth can support applications that require Quality of Service. They divide QoS guarantees into four categories: Quantitative, Statistical, Qualitative and Relative, from a fuller to a more limited guarantee respectively. Each category defines QoS parameters according to its features. Different QoS parameters can be identified, such as bandwidth, delay, delay variation, reliability, and ordering.

Digital Enhanced Cordless Telecommunications (DECT) is a digital wireless technology for cordless telephones, wireless offices and even wireless telephone lines to the home. DECT uses time division multiple access (TDMA) to transmit radio signals to phones and it was designed especially for smaller areas with a large number of users, such as in cities and corporate complexes. Service (QoS) parameters may be negotiated during call setup and renegotiated during active sessions, but QoS DECT parameters have not been defined satisfactorily.

Wireless LAN (WLAN) standards are WLAN 802.11 and Hiperlan 2. The IEEE 802.11 standard specifies the physical layer and the datalink layer. Hiperlan 2 is a short-range variant intended as a complementary access mechanism for UMTS systems as well as for private use as a WLAN type system. Delay, Jitter, Packet loss and handoff latency are the typical WLAN QoS parameters considered.

Global System for Mobile Communication (GSM) is a digital mobile telephone system that uses a variation of time division multiple access (TDMA) and is the most widely used of the three digital wireless telephone technologies (TDMA, GSM, and CDMA). GSM is one of the evolving group of wireless mobile telecommunication technologies, prior to 3rd generation cellular networks, which includes **High-Speed Circuit-Switched Data (HSCSD)**, **General Packet Radio System (GPRS)**, and **Enhanced Data GSM Environment (EDGE)**.

Satellite Networks. The European Telecommunication Standards Institute (ETSI) describes the satellite component in the mobile communication system of 3rd generation (UMTS). Nevertheless, an explicit specification for it is still lacking and just a few initial considerations are given, such as the possible scenarios and the visualization of the satellite component as an access network, e.g. UMTS Satellite Radio Access Network (US-RAN).

3. QoS in Heterogeneous Wireless Networks

In compiling a state-of-the-art of solutions for guaranteeing QoS in heterogeneous networks, including wireless and wired networks, we found there were a large number of studies. Most of these works propose partial solutions to the problem, however, they have been considered because provide important elements in the development of a comprehensive QoS framework.

In [4] a broadband radio access system is described, with the goal of integrating 2G, 3G and broadband WLAN systems through a common IP based network platform. In this way, they try to solve the problems of providing seamless service for broadband users in the high bandwidth hot spots that are provided to 3G systems by Wireless LAN. In [5], there is a wide-ranging review of how to extend and improve UMTS in more fundamental ways. The main network concepts considered here are unified mobility management and QoS support in an “all-IP” infrastructure.

In [6] the main theme is the development and introduction of QoS mechanisms for the Internet. A first step that should be performed when setting up QoS is to extend the backbone routers in the Internet using *differentiated services* developed within the IETF. To manage all these QoS mechanisms, new management functions should be developed and the existing management protocols, which have been aimed primarily at fault management, should be enhanced to allow end users to select specific QoS classes and modify the associated parameters.

In [7], three possible architectures for accessing heterogeneous wireless networks are presented: a multimode device, a common access protocol, and an overlay network. On the other hand, in [8], different QoS schemes are presented that are designed to allow QoS support among multiple heterogeneous wireless networks in an overlay or hierarchical wireless architecture. The article also, introduces fault-tolerant architectures, likely time and location dependencies, to provide continued QoS support in case of failures.

Multimedia Integrated network by Radio Access Innovation (MIRAI), [9], provides a set of signalling functions: radio-access-network discovery and selection, heterogeneous paging, and vertical handoff. In [10], a tree-plane QoS framework, based on QoS signaling architecture and policy framework to provide seamless support for future applications is proposed. In [11], a generic COPS-SLS protocol for dynamic service level negotiation is presented. This protocol is integrated into an overall QoS management architecture that defines a flexible

building block for providing the end-to-end service level over a heterogeneous environment.

4. Multiagent Systems

Mobile IP has evidenced that can be used in wireless networks with a good performance. To date, Mobile IP is the main option for implementing QoS in different wireless networks. The basic component of the Mobile IP is the agent concept, using Home Agent and Foreign Agent. Other telecommunication works have also taken advantage of agent technology, for instance in [12] [13] [14] [15]. A multi-agent system (MAS) is a loosely coupled network of problem-solver entities that work together to find answers to problems that are beyond the individual capabilities or knowledge of each entity [16].

Communication Protocols enable agents to exchange and understand messages. **Interaction Protocols** have been devised for systems of agents; when agents have conflicting goals or are self-interested, the objective of the protocols is to maximize the payoffs (utilities) of the agents; when agents have similar goals or common problems the objective of the protocols is to maintain globally coherent performance without violating autonomy (i.e. without global control).

The Foundation for Intelligent Physical Agents (FIPA) [17] provides specifications (such as protocols and ontologies) for the construction of complex agent-based systems with a high degree of interoperability among autonomous systems. One of the FIPA Interaction Protocols that could be used as negotiation mechanism in our proposal is the **Contract Net Interaction Protocol**, where one agent (the initiator) takes the role of a manager that wants to have some task performed by one or more other agents (the participants) and further wants to optimize a function that characterizes the task. For a given task, any number of the participants may respond with a proposal; the rest must refuse. The proposals are binding on the participant, so that once the initiator accepts the proposal, the participant acquires a commitment to perform the task. Once the participant has completed the task, it sends a completion message to the initiator in the form of an inform-done or a more explanatory version, an inform-result.

5. A QoS Framework in Heterogeneous Wireless Networks using a MultiAgent System

In heterogeneous wireless networks, guaranteeing QoS is a complex problem. Some transactions may

be time-sensitive, while others may not tolerate any packet loss; management of call routing and location is difficult; and the new location may not support the minimum QoS needed, even with adaptive applications. We have to identify the list of QoS parameters for each network involved in our framework, and then establish the different algorithms to carry out the QoS parameters mapping in order to maintain the QoS required.

5.1. QoS Framework

The goal of the QoS framework in heterogeneous wireless networks is to achieve a seamless handover with a highly efficient allocation of radio resources and a low call-blocking rate. A seamless handover implies reliable mapping of QoS parameters between dissimilar networks and between the wireless network and the IP wired backbone. This mapping must consider the initial requirements of the user and the possible large differences (frequency, bandwidth bounds, etc.) between the wireless networks. In addition, the framework must provide a balance between the Heterogeneous Wireless Network and its cost. But such features involve high complexity, high costs, high signaling load, and high response times.

An alternative is to distribute the framework functionality. The framework must be flexible enough so that any wireless network, no matter what its particular structure is, can monitor its own performance or change strategies in order to continue meeting its objectives efficiently. This can be achieved by means of negotiating or re-negotiating coordinated mechanisms, with cells of the current network as well as with cells of a different network.

In our proposal, we assume a hierarchical system with the following features:

- A hierarchical system. Each layer consists of networks whose cells are covered by a cell of a network placed in an upper layer, with the highest layer consisting of the network with the largest coverage
- An IP backbone. Each network is connected by means of a gateway to the IP backbone in order to provide services such as web, ftp, real-time applications, etc.
- General mobile device. A mobile device with different interfaces capable of communicating with any network belonging to the system, according to the location, class of service and required QoS parameters.
- Common interface. The multi-tier system has a common communication interface by using middleware, which is independent of the network characteristics.

- QoS parameters. For each of the cell types, it is possible to select a set of supported QoS parameters.
- Handover. Three handover categories are possible for maintaining connectivity: Horizontal, between cells with equal hierarchy level; Vertical, between different hierarchy levels; and Internal, where the user changes service profile within the same cell.
- Registration. Registration takes place only within the first attempt to communicate, via any network.
- Mapping. Each network provides a mapping from fixed Internet QoS parameters to QoS parameters used in core network and wireless interface.

The mapping of QoS parameters can be explicit (throughput, latency, jitter, reliability) or implicit (dependent on service class). Mapping functions are provided for transforming a QoS description from the user perspective to QoS parameters and negotiation at the application and network level.

We propose a Multiagent system, where each Access Point (AP) in each technology or network has a group of agents. The framework can make use of agent abilities, for instance, in the following ways:

- Perceiving of the environment, including requests for resources allocation from new calls, handover requests, borrowing resource requests and orders for blocking resources.
- Communication; handling message exchange for the resources management and in the negotiation processes.
- Reactivity/Pro-activity; carrying out tasks such as allocating, releasing, locating, locking and re-allocating resources; managing normal and supervised handovers and finishing unsuccessful requests properly.

5.2. The Multiagent System (MAS)

We envisage several agents with different roles cooperating or competing in order to achieve the greatest benefit, continuously negotiating limited resources and carrying out conversions (of parameters) in a constantly changing heterogeneous marketplace. A vast number of possible scenarios, agents and their respective instances would exist. For these reasons, coordination techniques and good task assignment are indispensable for solving distributed problems like this.

The MAS works over a marketplace whose negotiations are ruled by different mechanism classes (e.g. Contract Net). In the marketplace, there are Local and Global Information Centers specialized in

particular topics. Initially, these Information Centers can be conceptualized like a Knowledge Base which is distributed over the whole Heterogeneous Wireless Network. This Knowledge Base is divided into three specialized areas:

- Registry, which contains the knowledge base where the system keeps the information about the user, such as user profile, the current location, etc.
- Trade, which contains information about negotiation mechanisms, general rules and policies. This information is considered when the agents carry out the transactions.
- Resources, where the mapping agents play an underlying role, the agents get and manipulate the different resources and carry out the necessary conversions of the QoS parameters of their own network.

5.3. Functional Specification of the Agents

MAS tasks are carried out in various steps and by different agents in two well identified phases: first, to find out the best region to attempt moving the call to (and to team up with in a joint plan), and, secondly, to carry out the handover requests in a coordinated manner. The global functions of the MAS are:

- Call Admission Control, to accept or to reject the incoming call
- Registration of the call with the security policies
- Negotiation
- Resource allocation
- QoS parameters Mapping with the IP backbone if necessary
- Continuous monitoring of a better network (proactive activity)
- In the case of low level signal or interference, to make the decision as to whether the ongoing call goes to another cell of the same network, or if it is necessary to pass it to a cell in a lower or higher layer in the architecture (reactive activity)
- Achievement of function estimation so that the best cell is chosen in cases where several feasible cells exist.
- Adaptation to other upper protocols in the network during the handover
- QoS parameters mapping with the new network
- Execution of the handover

At each network AP, several QoS management entities are placed. The agent concept is used to perform QoS negotiation, adaptation and mapping between the communication levels. Resource managers request, control and reserve local resources to guarantee the requested QoS.

The MAS being a distributed system, is divided into different classes of agents according to the responsibilities in every AP. The Knowledge Base layers provide them the necessary information to carry out the specific function. The classes of agents proposed and their roles are described below (See also Figure 1).

Ongoing Call Agent (OCA). For each ongoing call, an instance of OCA is created when the call request is accepted in the network. This agent is responsible for maintaining the user profile and the QoS requirements of the session and, carrying out the requests to the Radio Resource Manager Agent (RRMA). The OCA is the representative of the ongoing call in both the negotiation and the registry process.

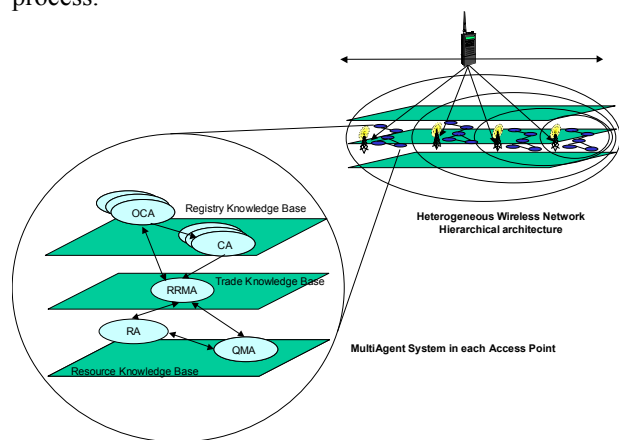


Figure 1: Global MAS Architecture in the Heterogeneous Wireless Network

Control Agent (CA). The CA is the gatekeeper for each ongoing call. It is responsible for monitoring the Signal to Noise Ratio (SNR) or the presence of a cell (AP) in another network with better disposition (lower cost). The CA also keeps track of the mobile device location.

Radio Resource Manager Agent (RRMA). RRMA is the agent responsible for distributing the resources, carrying out the negotiations with the RRMA of other cells. It is responsible for resource allocation and admission control to support traffic distribution. Other responsibilities are the status of the AP, the available resources and the execution of vertical or horizontal handover.

QoS Mapping Agent (QMA). The QMA is responsible for controlling and signaling in the convergence point between the two interworking networks. It is also responsible for mapping QoS parameters between wireless networks and wired network (e.g. the IP backbone).

Routing Agent (RA). The RA is responsible for obtaining information on the availability of network resources in the wired network.

5.4. Negotiation Global Algorithm

The interactions among agents in a Heterogeneous Wireless Network environment could be classified according to the layers involved during the negotiation process into two levels. The First Level (Interaction Protocol), when the negotiation is between agents of the same layer, and the Second Level (Interaction Protocol), when the negotiation is between an agent in one layer and agents in the layer above or below it in the Heterogeneous Wireless Network. See Figure 2.

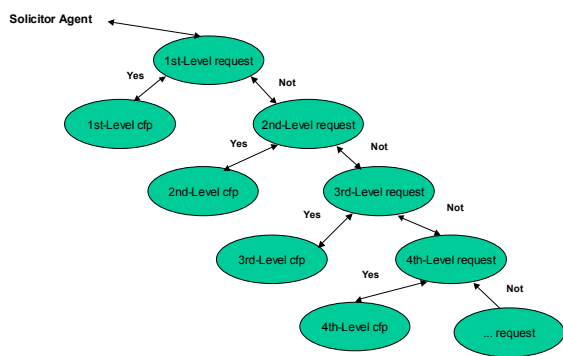


Figure 2: Negotiation Model Layers

The negotiation model is based on different Interaction Protocols (i.e. the FIPA Request and Contract Net Interaction Protocols). The CA into the AP can detect two possible causes for soliciting the resources of another AP belonging to the same or another network:

- The CA detects an progressive increment in the SNR
- The CA detects the presence of other AP offering the same QoS at a lower cost to the user.

Using FIPA Interaction Protocols and the agent classes defined for our QoS framework, the two following scenarios can be described :

a) The Ongoing Call Agent (OCA), in the current AP, sends the alarm signal to the Radio Resource Manager Agent (RRMA). The RRMA sends a request message to other RRMAs in the neighboring APs in the same network, asking if they are receiving a good signal from the terminal used by the user. If the answer is positive, the RRMA sends a cfp message, which contains the QoS parameters, to each one of the APs that could feasibly carry out the handover. If several of the reachable APs have the necessary QoS requirements, the RRMA of the

current AP has to estimate the greatest benefit according to a function that depends on different variables (distance, congestion, etc.) and probabilities. This function also depends on the number of users, mobility patterns, the amount of available resources, the QoS parameters, the call duration (exponential function); and the handover attempts (Poisson function). If the current RRMA does not have a positive answer or none of the reachable APs can provide the QoS required, the request message is sent to the APs in the next layer of the Heterogeneous Wireless Network and so on. See Figure 3.

b) The negotiation occurs between just two agents. The first one offers its services, and the current AP estimates whether or not the transaction will bring a greater benefit.

While each AP is carrying out the negotiation process between different cells, or different networks, the rest of the agent classes are interacting to provide the necessary information.

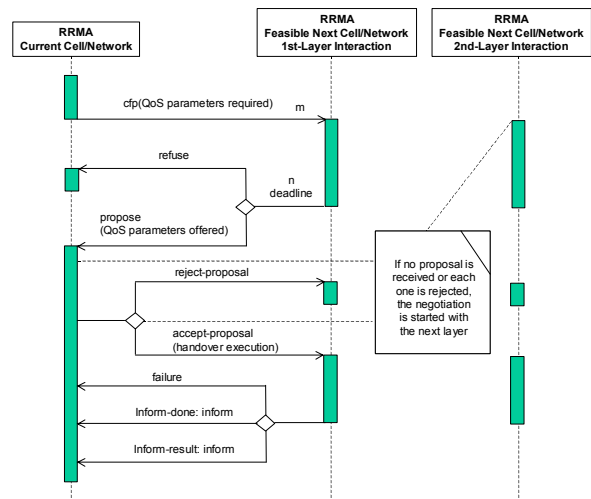


Figure 3: Negotiation Interaction Protocol

5.5. Simulation Model

The goal of the simulation model is to develop a realistic simulation in order to evaluate our QoS framework performance. We are interested in measures of performance such as scalability and predictability for call blocking, handoff delay, fractional QoS achieved, and resource utilization. Independent Poisson processes with equal mean generation rate for new calls and handoff attempts are assumed. The call duration time has been assumed to be exponentially distributed. Some of the simulation parameters are mobility patterns, number of networks that can be accessed by a user, amount of

resources available, number of handoffs in a call and QoS requirements

The system is written in Java, organized into a set of components; and the main agent behaviors are written as abstract classes. Currently, we are improving the system and results will be shown during the conference.

6. Conclusions and future work

In this paper, we presented a proposal for the design of a distributed QoS framework for heterogeneous wireless networks. The proposed MAS comprises several agent classes, each one with different roles involving Call Admission Control (CAC); vertical, horizontal and internal handovers management; mapping of QoS parameters between networks and resource coordination.

The main advantage of this framework is a improved performance of the wireless communication because the best network is selected according to the QoS parameters. Initially, the negotiation protocol between agents is based on FIPA Contract Net, but, as we obtain more results from simulations, there will be some necessary changes in the interaction protocol and ontologies to be made in the future. Improving the mathematical formulation for determining the function for selecting the best network to carry out handover is another crucial point that needs to be addressed.

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