# A Performance Management architecture for QoS enabled heterogeneous networks

Nikos Koutsouris, Krzysztof Loziak, Marek Sikora, Nuno Sénica and Efstathios Sykas

***Abstract*—In a composite radio environment, different radio technologies can be co-operating components of a combined heterogeneous infrastructure, managed by an advanced service and network management system. This paper presents an architecture that aims to maximize the derived benefits, by managing efficiently the performance of the underlying networks.**

***Index Terms*—Network Performance Management, QoS, heterogeneous networks, local optimisation**

## I. Introduction

THE continuous and rapid development of telecommunications during the last years, has inevitably led to the adoption and wide spreading of numerous diversified radio technologies, network topologies and terminals. The main characteristic of every modern telecommunication environment is heterogeneity, since inside there operate devices running different software, having different capabilities and communicating through different protocols. Heterogeneity of course has brought some problems and complications, but it can be extremely beneficial in conjunction with an advanced service and network management system like i.e. the one presented in [1] or Daidalos, which is described in this paper. The major aims of such systems are the exploitation of the special advantages of each underlying network protocols or technologies and the smooth and optimised operation of the infrastructure. This way, the ultimate goal of every communication system can be achieved, namely the provision of sophisticated services at the appropriate quality levels.

Daidalos platform is a framework developed to support seamless, pervasive access to content and services via heterogeneous networks according to user preferences. An important concept in Daidalos is the performance management of the composite radio environment (CRE). This paper presents the architecture on which this concept is based and details its modules along with their functionalities and interactions. The rest of the paper evolves as follows: Section II describes the network topology of the CRE. Section III presents the logical components involved in the performance management, while section IV provides more information on the communication aspects. Section V outlines a sample operation scenario and finally section VI concludes with some important remarks.

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## II. Network Architecture

The composite radio environment in Daidalos project can be comprised of various network technologies like IEEE 802.11, UMTS, DVB-T/H/S etc. and multiple administrative domains that can include one or more of these technologies. Each domain can be divided into the core network and one or more Access Networks. The resources in each access network are managed by the QoS Brokers (QoSB) the functionality of which is outlined in the next section. Each QoSB is responsible for a part of the network and cooperates with other QoSBs if necessary?. Other network entities considered in Daidalos' network architecture are the Access Routers (ARs) and the Points of Attachment (PoAs). An AR has in general several PoAs attached to it, which can operate in only one radio technology. Figure 1 depicts one administrative domain with three different network technologies.

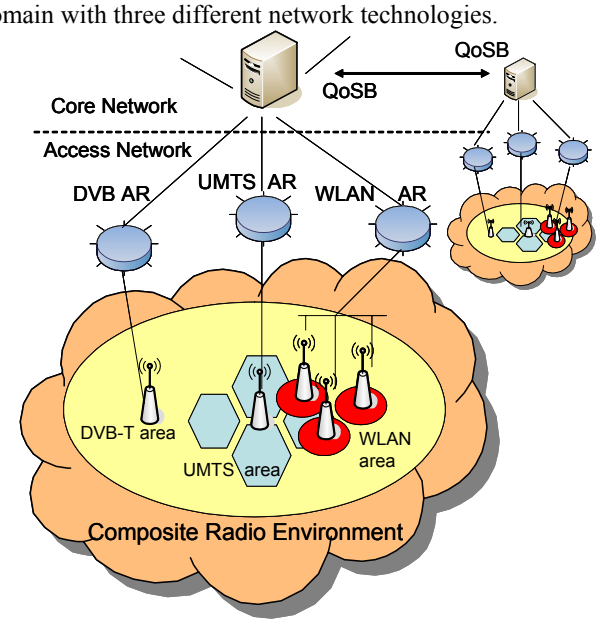


Fig. 1. An example of network architecture of one administrative domain

In order to ensure the QoS level offered to each running application, additional modules have been developed and incorporated in the aforementioned network architecture. More specifically, Performance Manager (PM) is located in the QoS Broker, Performance Attendant (PA) with Local Balancer Module (LBM) in the AR and Local Balancer Supplier Module (LBMS) in the PoA, as it is shown in figure 2. In the next section, these modules are described in detail.

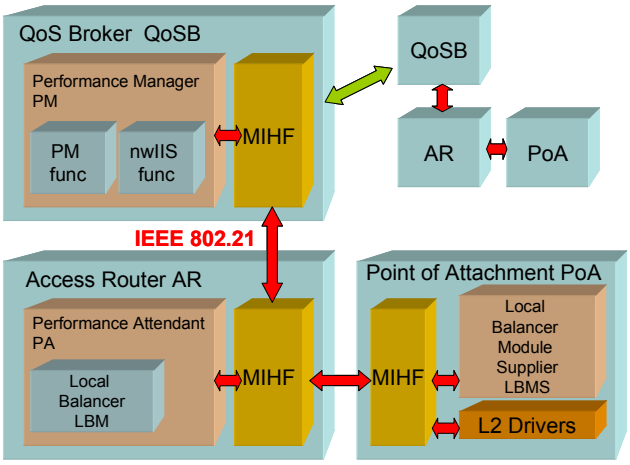


Fig. 2. Performance Management Logical components

The performance of wireless networks depends heavily on the clients' ability to identify Point of Attachment offering the best service. The current PoA affiliation mechanism implemented in most wireless client devices is based on signal strength estimations of surrounding PoAs. Since users tend to localize themselves in particular parts of the access network coverage area, they raise user congestion at certain popular spaces (called "hot-spots"). In most cases no load balancing is provided, however various vendors have incorporated load-balancing features in their terminals and PoA firmwareas well. PoAs supporting this feature maintain measurements of the load in their respective cells and broadcast messages containing this load to the user within their proximity. Processing such kind of information by load balancing mechanisms enabled users to determine the least loaded PoA. But such simple, distributed algorithms lead to a suboptimal and heuristic solution. On the contrary, semi-centralized approach gives additional benefits coming from better knowledge of the network parameters and the potential of network forced handover of a mobile terminal (MT).

## III. Communication and Interaction

### A. IEEE 802.21 protocol

Before continuing we have to mention one important characteristic of the discussed architecture, which is the fact that the communication within the Performance Management concept is based on the new IEEE protocol for media independent handovers, namely IEEE 802.21 that will soon become a standard. The IEEE 802.21 specification [7] is intended to provide a generic interface between the link layer users in the mobility-management protocol stack and existing media-specific link layers, such as those specified by 3GPP, 3GPP2 and the IEEE 802 family of standards and therefore defines media access mechanisms that enable the possibility of performing handovers across heterogeneous systems. The key concept of 802.21 standard is an abstraction layer called MIH Function, which provides services to the upper layers through a single technology-independent interface (the MIH Service Access Point, MIH_SAP) and obtains services from the lower layers through a variety of technology-dependent interfaces (media-specific, MIH_LINK_SAPs). Local and Global Optimisation components, namely LBM, LBMS, PA and PM act as MIH Users and communicate using MIH messages. The following link events and link commands are exchanged between lower layers (driver layers) and the MIH_LINK_SAP and then conveyed to the MIHF@PoA:

1) Link_Configure_Thresholds – to set up overloading thresholds at the PoA.
2) Link_Up, Link_Down – notification of PoA's L2 connectivity related events.
3) Link_Parameters_Report – link parameters have crossed preconfigured thresholds.

Consequently MIH events and commands exchanged between MIH_SAP, MIH Users (LBM, LBMS, PA, PM) and MIHF layers, as well, are:

1) MIH_Capabilities_Report – report of PoA capabilities sent during the PoA bootstrapping procedure.
2) MIH_Configure.Req/Resp – to set up PoA parameters.
3) MIH_Handover_Commit.Req/Resp – to perform a handover to a selected target – network and PoA.
4) MIH_Handover_Complete.Req/Resp – notification from a new serving MIHF@PoA to the previous one to indicate the handover completion and to notify that any pending packets can be then forwarded to the new PoA.
5) MIH_Event_Register.Req/Confirm – registering for events reporting at the PoA or MT.
6) MIH_Link_Up/Down – notification of L2 connectivity related events.
7) MIH_Get_Status.Req/Resp – request to get information related to an MT/PoA (like i.e. current load). This message doesn't convey static data in this case and this is a deviation from the standard.

### B. Other messages and primitives

Local Optimisation scenario discussed below, requires an additional message type to be introduced due to handover triggering purpose. The message strictly relates on the underlying technology and is driver dependent. In general it is called L2_Handover_Trigger and consists of the physical address of a trigger recipient (MT) and selected target parameters including the L2 address of a target PoA and a radio channel the PoA operates on. Upon the reception of the L2_Handover_Trigger the MT follows the included information and performs the L2 handover procedure.

## IV. Performance Management Concept

Performance Management procedures in Daidalos are structured in two levels: local and global. In any case the goal

is to find a new distribution of the traffic load among the PoAs of the managed area and so the output is always a set of Network Initiated Handover (NIHO) commands to the terminals. The difference is that local optimisation is based on technology specific input parameters and affects PoAs under a single AR, while global optimisation uses only abstract input information and can be applied for the PoAs of several ARs, belonging to various radio access technologies (RATs). So the Local Optimisation procedure covers the scenario of intra-AR Mobile Terminal handovers due to performance reasons, while the Global Optimisation handles congestion situations by inter-AR handovers as well. The existence of local optimisation functionality in the AR is optional and in Daidalos it will be supported only for WLAN PoAs. The synchronization between local and global procedures is accomplished through the Performance Attendant, which is the module that triggers them, as it is presented below.

### *A. QoS Broker*

Quality of Service Broker performs admission control and takes care about network resources by controlling access routers according to the type and requirements of services that the terminals are using. Whenever a terminal starts a service, the allocated resources at both Layer 2 (PoAs) and Layer 3 (ARs) are managed by the QoSB. The running services and their characteristics are stored in QoSB's internal database acting as a part of the input for the performance management subsystem.

As an admission control entity and local domain manager for quality of service, QoSB upon handover request checks the running services of that terminal and the available services on the target PoA and informs the terminal about its decision. If there are available resources on the target PoA, they are immediately allocated in order to be available when the terminal connects there. This kind of operation can also be performed on a single service instead of the set of services a terminal is running.

### *B. Performance Manager*

Performance Manager module is the one that includes the main intelligence of the global network optimisation process. It is physically located in the QoS Broker, since it can manage an area of many ARs of various radio access technologies. It comprises two main functionalities. The first is PM optimisation functionality, which is technology independent and can be applied to every network technology.

The optimisation algorithm tries to split the traffic demand among the PoAs under control in such a way that there are no overloaded PoAs in the service area and at the same time network policies and user profile restrictions are satisfied. The algorithm is triggered when the traffic load at one or more PoAs surpasses a preconfigured threshold. It uses an objective function in order to find the optimal solution [2]. In general the input needed for this task is:

1) The list of the heavily loaded PoAs and some relative data per PoA like e.g. current load, available capacity, mean delay etc.
2) The list of the mobile terminals served by the aforementioned PoAs and again some relative data per terminal i.e. list of visible PoAs, capabilities, profiles of the logged users, list of flows etc.
3) The list of the cooperating (visible) PoAs per MT that are in fact the candidate PoAs for accepting the traffic. Again some relative data is required i.e. current load, available capacity, mean delay, cost etc. It has to be noted here that cost has a pre-specified value and it is used to differentiate the preference for a specific network technology comparing to another and it doesn't refer necessarily to monetary units.

The output of the algorithm is a list of flows that have to be handed over to a different PoA, which can belong to the same or another AR, but always within the same administrative domain. There is also a possibility, if there is no other solution, that some flows are transferred to a lower QoS level.

The second functionality of the Performance Manager is an intelligent algorithm which is used to select the best interface for each flow of a single MT. This is called network intelligent interface selection (nwIIS) function and aims to help terminals that face communication problems, like high bit error rate or signal degradation. Part of the input will have to do with the user's preferences, while the output will be in the same notion as PM's output.

### *C. Performance Attendant*

Performance Attendant module is located at the Access Router and is responsible for three main actions: The first is to collect the required parameters related to PoAs and MTs using the appropriate IEEE 802.21 primitives. Another responsibility is to provide them to PM in case of a global optimisation process or to LBM in case of a local optimisation process and to trigger the corresponding functionality. Finally, PA also triggers LBM in case a signal degradation notification is received for a single terminal. If local optimisation is not supported in this AR or it fails, the nwIIS function of PM is triggered.

Performance Attendant needs to be topology aware in order to handle correctly the congestion events received by the MIH Function at the AR (MIHF@AR). Thus, it uses MIH_Get_Information request/response messages to retrieve the necessary topology information required, from the Media Independent Information Service (MIIS) described in the IEEE 802.21 standard [7].

### *D. Local Balancer Module*

The Local Balancer Module collocated with Performance Attendant is the main part of a Local Optimisation concept. Its goal is to create the most up-to-date intra-AR domain network image and, moreover, to run an optimisation algorithm in case of a PoA overloading notification. As a result, the optimisation algorithm generates a new topology of MT associations across Points of Attachment connected to a single Access Router.

A wide variety of load balancing algorithms exist in the

literature. Most of them present a simple heuristic approach, focusing only on admission control or even selection of optimal point of attachment. Most of the algorithms work in a distributed manner, relying on measurements taken by the MT. The MT is trying to estimate load of the neighbouring PoAs by measuring timing parameters (beacon delay) of the PCF cycle [3]. However, most of the simple distributed load balancing algorithms are limited only to optimal selection of the point of attachment which is not sufficient in case of a mobile subscriber and thus may lead to suboptimal network performance. There are also centralized load balancing algorithms based entirely on RSSI measurements [4]. More elaborated algorithms should make use of technology dependent information e.g. algorithms designed to operate in multi-rate environment. Better results can be achieved by cooperation with traffic scheduling algorithms running on PoA. Centralized algorithms offer wider possibilities by introducing a concept of network initiated handover of an MT as an additional tool of load balancing. The lack of a forced handover mechanism may disqualify the distributed approach, since extensive measuring is then required, which is a time consuming process that eliminates the possibility of seamless handover for real-time applications. An example of a centralized heuristic load balancing algorithm using both admission control and forced handover is presented in [5].

Optimal load distribution can also be determined analytically. In [6] authors give a theoretical background for using optimisation methods in solving the problem of load balancing in wireless networks. The algorithm proposed is an adaptation of a well-known transport problem to achieve min-max fair network load. Authors derived a load definition enabling the algorithm to operate in multi-rate networks. The algorithm used in LBM module is based on the approach proposed in [6] with additional constraints applied in order to reduce frequent handovers between neighbouring cells.

The LBM module operates on an event driven manner which leads to reduction of AR resource utilization comparing to periodical operation. Triggers for the LBM module may come from both PoA and network side (MIHF@AR).

The optimisation process is applied only when preconfigured network load thresholds are exceeded and reported by a PoA; otherwise, all the triggers are ignored.

For the proper operation of the LBM algorithm some additional information concerning the MT and PoA is required. The Layer 2 (L2) QoS related information for a specific PoA includes knowledge about its load level, average transmission rate per single MT, nominal transmission rates in use and available free PoA's resources. On the other hand, the MIHF@AR registers for measurement reports at the MTs to obtain each MT's neighborhood details, especially signal strength of all available PoAs, so as to be able to select between possible handover targets. By receiving all this information, LBM creates a local domain network image and updates it with events which are reported from PoAs' side.

If the minimum load constraint is met, the algorithm may be triggered by the following events:

1) association of the new mobile terminal
2) overloading of the PoA
3) new flow admitted by QoS Broker
4) de-association of the MT

In case of flow re-distribution demand, the optimisation process results with a series of handover triggers sent via the corresponding LBMS to the PoA L2 drivers and then directly to the MTs. It should be noted that LBM algorithm is technology dependent, as well as the implementation of the handover trigger at the PoA driver layer.

### *E. Local Balancer Module Supplier*

The Local Balancer Module Supplier is a module which takes part in the Local Optimisation process (Fig. 2). The main role of LBMS is to interconnect the LBM module with L2 technology dependent drivers residing at the PoAs. The communication between LBMS and LBM is organized in conformity with IEEE 802.21 MIHF interface definition [7]. When LBMS starts for the first time, it supplies the LBM module with PoA operational parameters such as Network ID, technology ID, PoA L2 and L3 addresses, radio channel the PoA operates on and nominal transmission rates. During the bootstrapping procedure the LBM can also set up specific thresholds at the PoA::LBMS which are to be monitored during the normal operation. The main activity of the LBMS module is to trigger LBM to run the Local Optimisation algorithm upon the PoA's overloading detection. As a result of the LBM's algorithm, the LBMS module receives a collection of handover triggers pointing associated Mobile Terminals to perform a handover procedure to a specific target. The handover triggers are then transformed into L2 specific messages consisting of L2 address of MT and target PoA, as well as radio channel identifier, and are sent via L2 driver to the MT. In case of WLAN based technology, supplying the MT with a radio channel of target PoA can radically reduce the scanning latency during the re-association procedure, while the additional implementation of IEEE 802.11r Fast BSS Transition mechanisms can introduce a smooth handover capability within the access network.

## V. SAMPLE OPERATION

### *A. Local Optimisation*

In Figure 3 a detailed message flow in case of L2 handover due to Local Optimisation and flow re-distribution is depicted. For simplicity reasons, the diagram presents messages exchanged between only one PoA and the AR. Actually, this communication is replicated for each PoA connected to the AR within a local domain. Four basic steps are shown at the message sequence chart: registration of a newly connected PoA to the access network (step 1); process of PoA thresholds configuration (step 2); forming of an intra-AR network image (step 3) and the most important – handover execution (step 4) after running local optimisation algorithm.

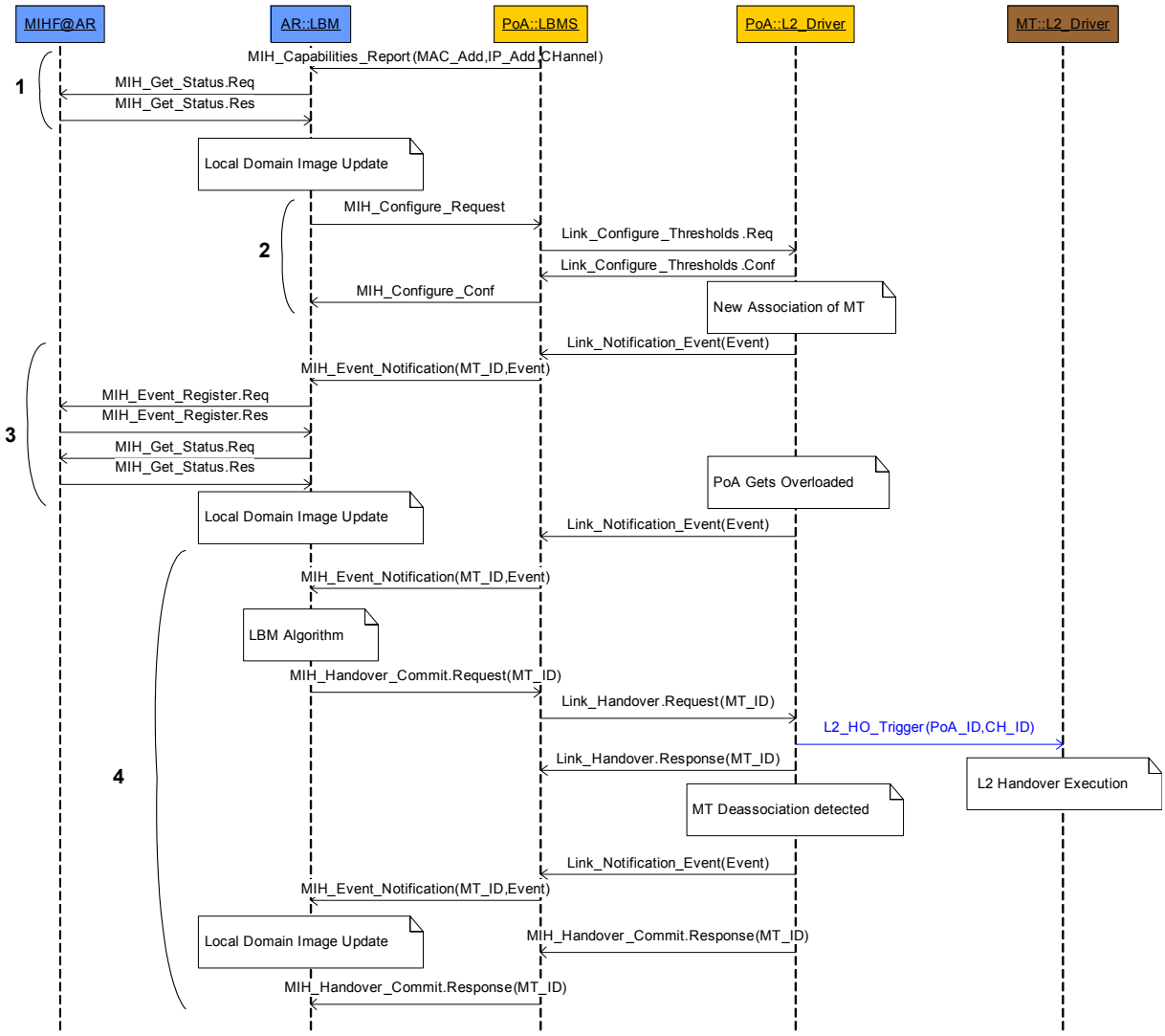


Fig. 3. MSC of a Local Optimisation scenario

### B. *Global Optimisation*

In the case of Global optimisation, the first three steps are the same, but PoA overloading event in step 4 triggers the PM algorithm and the list of handovers to be performed is sent to the QoSB, which is responsible for approving them, making the necessary reservations and then initiating the corresponding handover procedures.

## VI. Conclusion

This paper presents an integrated architecture, which is based on the innovative IEEE 802.21 standard and manages efficiently a composite radio environment by applying local and global optimisation procedures. Its necessity is addressed and modules and functionalities are described in detail. The next steps are the testing and the evaluation of the platform, so as to obtain actual data that will prove the benefits for network operators and users that derive from the use of this platform.

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## References

[1] P.Demestichas, N.Koutsouris, et al "Management of Networks and Services in a Composite Radio Context ", IEEE Wireless Communications, Vol. 10, No 4, Aug 2003

[2] P.Demestichas, V.Stavroulaki, L.Papadopoulou, A.Vasilakos, M.Theologou, "Service configuration and distribution in composite radio environments", *IEEE Transactions on Systems, Man and Cybernetics* Journal, vol. 33, No. 4, pp. 69-81, Nov. 2003

[3] S. Vasudevany et al, "Facilitating Access Point Selection in IEEE 802.11Wireless Networks,";in Proc of 6th ACM SIGCOMM on Internet measurement, pp. 257 – 262, 2006

[4] Shiann-Tsong Sheu and Chih-Chiang Wu, "Dynamic Load Balance Algorithm (DLBA) for IEEE 802.11 Wireless LAN," in Tamkang Journal of Science and Engineering, VOL 2, pp 45-52, 1999

[5] Anand Balachandran et al "Hot-Spot Congestion Relief in Public-area Wireless Networks," in Proc. of Fourth IEEE Workshop on Mobile Computing Systems and Applications, p. 70, June 2002

[6] Yigal Bejerano et al, "Fairness and Load Balancing in Wireless LANs Using Association Control," in Proc. Of International Conference on Mobile Computing and Networking, pp. 315 – 329, Philadelphia, 2004

[7] IEEE 802.21 Draft IEEE Standard for Local and Metropolitan Area Networks: Media Independent Handover Services; September 2006