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Institute of Communication Networks and Computer Engineering
University of Stuttgart
Pfaffenwaldring 47, D-70569 Stuttgart, Germany
Phone: ++49-711-685-68026, Fax: ++49-711-685-67983
email: mail@ikr.uni-stuttgart.de, http://www.ikr.uni-stuttgart.de

Realization aspects of Multi-Radio Management based on IEEE 802.21

Christian M. Mueller[1], Harald Eckhardt[2], and Rolf Sigle[2]

[1] Universität Stuttgart
Institute of Communication Networks and Computer Engineering
Pfaffenwaldring 47, 70569 Stuttgart, Germany
christian.mueller@ikr.uni-stuttgart.de
[2] Alcatel-Lucent Bell Labs
Lorenzstr. 10, 70435 Stuttgart, Germany
{harald.eckhardt,rolf.sigle}@alcatel-lucent.de

Abstract. In this article, we present a multi-radio management (MRM) architecture for intelligent access selection and load balancing over multiple radio access technologies. We discuss possible implementations of this MRM architecture and analyze to what extent the IEEE 802.21 'Media Independent Handover' framework can be applied here. Starting from the fundamental building blocks of the multi-radio management architecture, we find several issues with respect to the integration with and the interworking between today's 3GPP and non-3GPP networks. Because support of 802.21 can largely differ from one access technology to another, we propose ways to compensate for these differences and finally present an adapted MRM architecture.

1 Introduction

In a heterogeneous mobile communication network, if more than one radio access technology is available at a given location, an intelligent access selection algorithm is needed to select the currently best-suited access technology for a particular service. In a user-centric approach, this algorithm is located in the terminal and the access selection is under user control. In a network-centric approach, the algorithm is located in some control and management device in the operator's network. This has the advantage that cell load information and network status can be taken into account and thus allows for a more efficient utilization of the available resources. Due to an integration with existing radio resource and mobility management procedures, a network-centric approach enables seamless handovers and allows to maintain a high service quality even in a largely heterogeneous environment.

One of the key issues to a multi-radio management is the inherent cross-layer interaction and interworking problem between largely different radio access technologies (RATs). Multi-radio management components need to know about the currently available access technologies and have to issue commands to lower layers. This is not trivial, given that systems today do not always provide this information and it is usually not propagated through the protocol stack. In addition, lower layer interfaces are access system-specific, which leads to complex implementations due to the intrinsic heterogeneity of the problem. Over the last years, several research projects have addressed the question how a generic cross-layer interface shall look like, which services it has to provide and how it can best be implemented [1,2]. Standardization bodies have adopted these ideas and now standards emerge that have the potential to largely facilitate the realization of the multi radio management ideas. One of these standards is the recently published IEEE standard 802.21 *Media Independent Handover (MIH)* [3].

The idea of a network-centric multi-radio management with 802.21 has already been addressed by a couple of authors. In [4], the authors suggest to locate an 802.21-enabled multi radio device in the access network of different RATs and focus on vertical handovers and measurement reporting. The authors of [5] assume a single 802.21-enabled resource and mobility manager in the core network and evaluate handover sequence, load balancing algorithms and the resulting additional signaling load on the air interface. Eastwood et. al [6] concentrate on 802.21-based mobility between WLAN and WiMAX networks and provide detailed handover sequences on 802.21 service primitive level.

Although these authors describe how 802.21 can generally be used for multi-radio management, only few attention is given to an integration of an 802.21-enabled solution with existing 3GPP and non-3GPP networks. To fill this gap, we thoroughly investigate a 802.21-based realization of a representative multi-radio management framework, denoted as *MRM*. For each of the building blocks of MRM, we evaluate how 802.21 can be used and how it integrates with different radio access technologies. For GSM, UMTS, WiFi and WiMAX networks, we discuss how the relevant 802.21 service primitives are mapped on RAT-specific functions and which further mechanisms are defined to support MIH services. Finding that support of 802.21 primitives is not the same for all RATs, we propose an adapted implementation of the MRM architecture, which is based on 802.21 where applicable, but also includes other mechanisms where necessary.

The remainder of this article is structured as follows: Section 2 gives details of the network-centric the multi-radio management (MRM) architecture. Section 3 then provides a short introduction to 802.21 and its services. In section 4, we discuss the use of 802.21 services for the main MRM building blocks and analyze to what extent these services are supported by the different underlying radio access technologies. Based on the results from this analysis, in section 5, we describe a modified implementation of MRM. Finally, section 6 concludes our work.

2 Multi-Radio Management (MRM)

The multi-radio management solution considered here provides resource and mobility management over different 3GPP and non-3GPP radio access networks and enables intelligent network-centric access selection and efficient load balancing. It follows the same principle of abstraction as presented in [7] and consists of a technology-specific part and a part containing generalized functions that are the same for all RATs. In the following, we briefly describe the building blocks of MRM. For a more detailed description of MRM, we refer to [8, 9]. Please note that these building blocks are common to all network-centric multi-radio management solutions and our further analysis is thus not limited to the MRM architecture.

2.1 Building Blocks and Requirements

Access Selection This block includes the algorithms used to select one access network for a given service out of a number of available networks, e. g. based on policies or other multi-criteria decision making techniques. (The algorithms will not be further considered here, for details see [8, 9].)

Measurement Reporting This includes configuration and reporting of intra- and inter-RAT link measurements. The network-side component needs to be able to detect when the currently serving system becomes insufficient for an ongoing application. In addition, it has to initiate scan commands for candidate neighbor systems, especially in preparation of an inter-RAT handover.

Handover Execution This includes the handover negotiation phase and the execution of inter-system handovers, i. e. the change from one access technology to another.

Besides these main functional blocks, there are further issues that are non-trivial to resolve when it comes to an implementation in a heterogeneous environment. A brief description of these issues is given in the following:

Neighbor Information Provisioning To avoid power-consuming scanning for available RATs, information about neighbor systems has to be provided by the network. To support idle mode terminals in their initial access selection, broadcast or multicast channels are required that are accessible without being registered to the network.

Message Transport The multi-radio management entities need to exchange signaling messages for measurement configuration and handover execution. The signaling transport channels available in the various RATs differ from each other and the MRM components need to adapt accordingly.

Discovery and Registration A mobile terminal needs to detect whether a system provides multi-radio management functionality and if so, requires a means to access the network-side management entity.

System Interfaces A multi-radio management entity needs access to lower layer primitives to interact with an existing resource management. These primitives are system-specific or might even not exist at all, because, at the time a system was designed, it has not been foreseen that they need to be accessed by an external application.

2.2 Functional Architecture of MRM

The MRM architecture consists of three different functional entities as illustrated in Fig. 1. The MRM-TE is located in the user terminal and provides

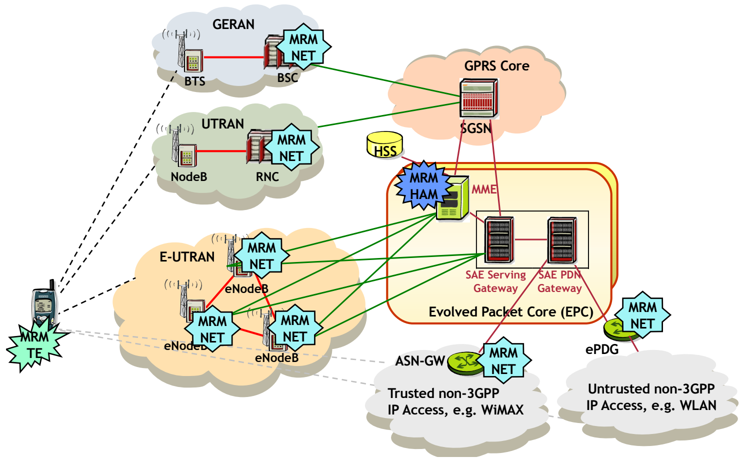


Fig. 1. MRM network architecture

inter-system measurement functions and an initial access selection algorithm that is used as long as the terminal has not yet established a connection with the access network. The MRM-NET is located in the access network and is associated with all active users within its service area. It communicates with MRM-TE and is implemented on top of the already existing radio resource and mobility management functions of the respective RAT. Its responsibility is to monitor and configure radio and link measurements on user terminals and to trigger inter-system handovers. Therefore, it needs to be involved in existing RRM procedures (e. g. bearer setup, link quality measurements, inter-system handover procedures). Finally, the *heterogeneous access management* element (MRM-HAM) takes access selection decisions based on various input parameters such as link performance, resource usage and availability measurements. The MRM-HAM can either be located as a single MRM server in the core network, or it can be distributed over the respective access network devices together with the MRM-NET.

Figure 2 shows the interaction between MRM-TE and MRM-NET at the example of an inter-RAT measurement request: the terminal is being served by a UMTS network and MRM-NET requests scans for a potentially available WiFi hot spot near its current location (step 1). The measurement request is transmitted over a dedicated signaling radio bearer (2), interpreted by the terminal-side MRM component and a measurement command is issued to the local device driver (3). The measurements are taken (4) and the response is then sent back to MRM-NET(5). Different colors in Fig. 2 indicate which elements are generic, which are part of the underlying RAT and which are needed as an adaptation layer in between to map generic MRM commands to system-specific service primitives.

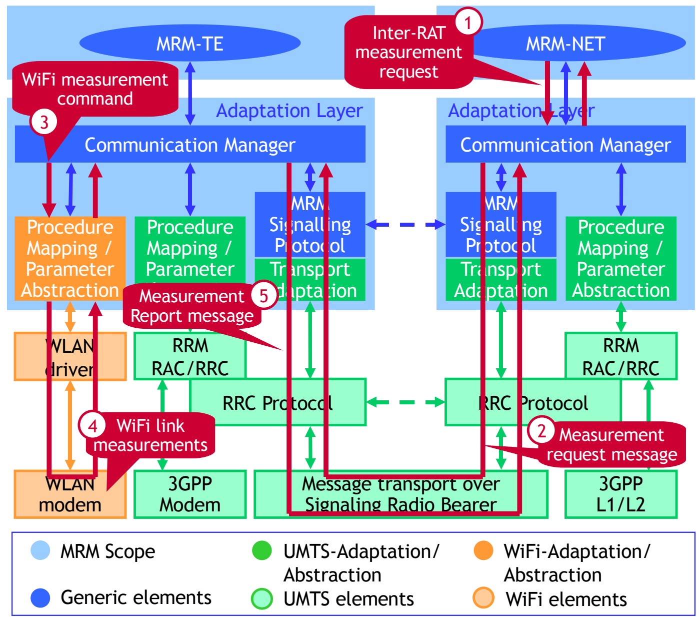
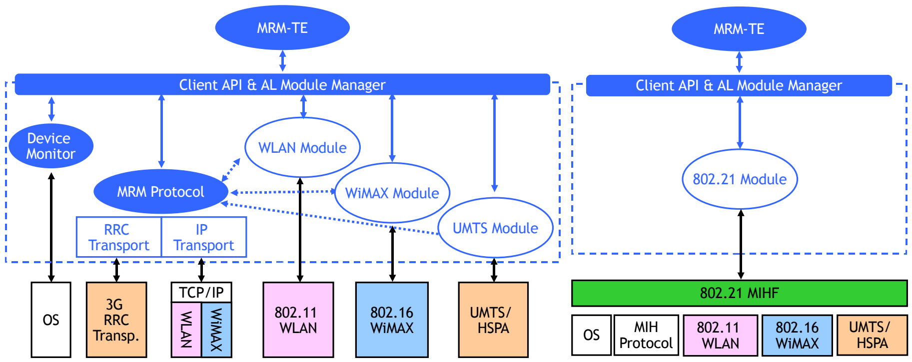


Fig. 2. Inter-RAT measurement procedure for terminals served by UMTS

3 IEEE 802.21 Media Independent Handover

IEEE 802.21 'Media Independent Handover (MIH)' aims at the support of handovers among heterogeneous fixed and mobile networks. 802.21 defines an Information Service (IS) to retrieve and provide mostly static information about current and neighbor networks. The Event Service (ES) provides a standardized set of layer 2 triggers and includes primitives for measurement reporting. The Command Service (CS) defines means to control physical and link layer states and coordinate handover execution. These services are provided by the so-called MIH Function (MIHF) and can be accessed by an MIH User over the MIH Service Access Point, or MIH_SAP. The MIHF does not interpret lower layer triggers or measurements and does not comprise algorithms for access selection or mobility management. This is left to the MIH user. Hence, it merely constitutes an abstraction of RAT-specific lower layer functions, with the MIH_SAP being the uniform interface to access lower layer functions in a media-independent way. 802.21 also includes means to exchange messages among MIHFs and to issue commands to remote MIH-enabled devices by the so-called MIH Protocol, either by using dedicated management frames on layer 2, or by using an IP-based transport protocol.

The IEEE 802.21 has been officially published at beginning of 2009. The analysis here is based on an earlier stable draft version [3]. The draft standard 802.11u 'Enhancements for Interworking with External Networks' [10] defines 802.21-specific extensions for WiFi networks. The recently published amend-



(a) Variant with direct access to RAT primitives (b) Variant based on 802.21

Fig. 3. Block diagram of MRM entity on the mobile terminal

ments 802.11k 'Radio Resource Measurements' [11] and 802.16g 'Management Plane Procedures and Services' [12] contain further MIH-related functionality for WiFi and WiMAX.

4 Analysis of MRM based on 802.21

MRM services can be implemented with a RAT-specific adaptation layer for every supported RAT technology. A block diagram of the resulting structure of the MRM-TE is depicted in Fig. 3a. For each RAT (only three different RATs are depicted for simplicity reasons), a dedicated module is required to adapt to the particularities of this RAT. To exchange MRM signaling messages between MRM-TE an MRM-NET, different transport channels have to be used, depending on the current context. To determine the number and type of the available interfaces, an interface to the operating system is required.

It is obvious that such a realization is complex and cumbersome to implement. From the guiding principles of abstraction and generalization [7], the preferable solution would consist of generic MRM components on top of a standardized interface that provides an abstraction from the underlying technology. A standardized management interface then allows to decouple the implementation efforts for the modules above and below this interface and thus facilitates the interworking between and the combination of services from different providers. As an emerging standard, IEEE 802.21 is a strong candidate to provide this interface. A possible realization of the MRM-TE based on 802.21 is depicted in Fig. 3b. In the following, for each of the building blocks identified in section 2.1, we analyze whether the required MRM functionality can be provided using 802.21 primitives. We do this under the specific constraints imposed by current GSM/EDGE and UMTS/HSPA access network architectures, as well as the non-3GPP RATs 802.11 and 802.16. For our analysis, we take 802.21-specific extensions from [10–12] into account.

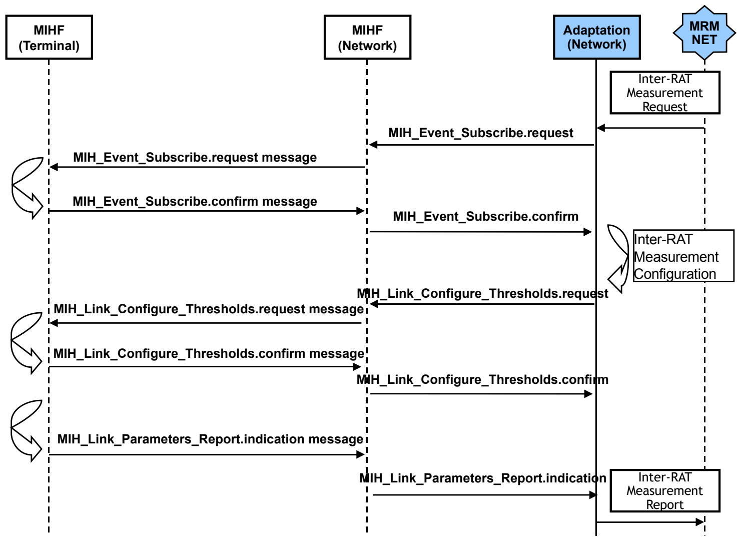


Fig. 4. Measurement reporting signaling diagram

4.1 Access Selection

As it has been mentioned in section 3, 802.21 does not include an access selection algorithm. This is consistent with the MRM architecture described in section 2.2, which sees the access selection as a generic element located above the interface towards the media.

4.2 Measurement Reporting

With the primitives defined for ES and CS, 802.21 provides a flexible mechanism to configure and report measurements of the currently serving and potential neighbor RATs. As an example, Fig. 4 depicts an inter-RAT measurement sequence analog to Fig. 2, now carried out using service primitives of 802.21. It is assumed that the MRM-NET has already discovered which other RATs are available on the mobile terminal, e. g. by using the *Get_Link_Parameters* primitive. The MRM-NET subscribes for measurement reports using the *Event_Subscribe* primitive. The *Link_Configure_Thresholds* command configures the measurements and results are reported in a *Link_Parameters_Report*. In contrast to Fig. 2, there is no MRM adaptation layer on the terminal-side, because the measurement request is handled completely by the MIHF.

The measurement values provided by 802.21 contain several media-independent parameters, e. g. link speed and packet error rate, as well as RAT-specific values, such as the received signal strength indicator RSSI for 802.11. The interpretation of these values is left to the MIH User, respectively the MRM adaptation layer of the access network MRM entity.

Although the MIH_SAP defines the primitives required for measurement configuration and reporting, they are not equally well supported by the underlying media: For WiFi, the MIH_SAP primitives are mapped to primitives of the sublayer management entity (MLME), as specified in [11]. For WiMAX, corresponding measurement primitives are defined for the Control SAP (C-SAP) and the Management SAP (M-SAP) in [12]. For GSM and UMTS, according to [3], MIH measurement primitives are mapped on GSM and UMTS session management primitives RABMSM and SNSM. However, these primitives do not provide access to channel measurements, but only allow to set or retrieve the QoS parameters that are currently configured for a given radio bearer [13]. For 3GPP networks, it is thus not yet possible to determine the current channel quality or to gather information about the current throughput.

4.3 Inter-RAT Handovers

Although 802.21 defines a set of handover primitives, it does not include a mobility or location management protocol. Using the MIH handover primitives a mobile terminal can request a handover from a network MIHF entity or the network MIHF can request handover initiation from the mobile terminal. Further primitives are available to query an MIHF in a target system for available resources and to notify an MIHF when a handover has been completed. In [14], detailed handover sequences between 3GPP and non-3GPP access networks are already defined. The task of MRM-NET is thus only to trigger these procedures, which can be done using the *MIH_Net_HO_Candidate_Query* and *MIH_Net_HO_Commit* primitives.

4.4 Neighbor Information Provisioning

Information about potentially available neighbor networks and their characteristics reduces unnecessary scanning procedures of the mobile terminal. The scanning primitive defined by 802.21 does not provide a way to communicate scanning parameters such as target frequency, scrambling codes or similar. This information thus has to be made available to the terminals using the MIH Information Service.

For WiFi, the *Generic Advertisement Service* [10] allows mobile terminals to access an MIH Information Service database in the network even before an association with the access point has been created. It further allows to send an MIH response as a broadcast to all terminals in the cell.

For WiMAX, with [12] a similar mechanism is in place, by which terminals can send so-called *MIH Initial Service Requests* over the Primary Management Channel before they have completed the network entry procedure. As for WiFi, a query response can be sent as unicast or as broadcast.

For GSM or UMTS, although there are ongoing discussions on a Access Network Discovery and Selection Function (ANDSF), which might be based on the 802.21 IS [15], no such functionality has been defined yet. Neighbor information would have to be sent together with other cell list advertisements in system information objects that are sent over the existing broadcast channels.

4.5 Message Transport

For 802.21 services, communication between MIHF entities can be done either on layer 2, or using an IP-based transport protocol. For WiFi, dedicated management frames are defined for L2 transport. For WiMAX, new primitives have been defined to transport MIH messages over the Primary Management Channel. In configurations such as in Fig. 1, where a WiFi or WiMAX access network is connected to a 3GPP core network over intermediate gateways, L2 communication is not possible and an IP-based transport solution is required.

For GSM or UMTS networks, the usage of an IP-based transport is hardly applicable, given that no IP connectivity exists between mobile terminals and radio controllers. IP packets carrying MIH messages would have to be sent to the core network and then be routed back to the currently serving radio controller. This is inefficient and currently not foreseen in the 3GPP architecture. Because no transport mechanism for MIH messages on lower layers is defined, exchange of 802.21 messages among MIHF entities located in a 3GPP radio access network and on the terminal is currently not possible. To resolve this issue, we propose to use the UMTS RR Direct Transfer, respectively the GSM Application Information Transfer mechanism to transparently deliver MIH messages between the mobile terminal and an MRM-NET entity located on a radio controller [16, 17].

4.6 Discovery and Registration

A mobile terminal needs to deduce if an access network supports 802.21 respectively MRM functions or not. It further has to determine the address of the network-side multi-radio management entity.

For WiFi and WiMAX, an MIH capability flag has been defined that is part of the beacon frame, respectively the WiMAX Downlink Channel Descriptor. The address of the network-side MIH or MRM entity can be provided in configuration options during the network entry procedure, or by using a DHCP or DNS based address discovery procedure defined for MIH by the IETF Mipshop working group [18].

For GSM and UMTS, there is no MIH capability flag defined so far. A DNS-based discovery is possible if IP-based communication is available. Alternatively, new System Information elements could be specified for this purpose.

5 MRM Realization with partial use of 802.21

Summarizing the analysis, it can be observed that current WiFi and WiMAX networks (including the respective amendments) provide sufficient support for 802.21 functions. However, in 3GPP access networks, support for 802.21 services is still very limited. A certain lack of functionality or mismatch of services primitives can be observed with respect to measurement reporting and the support of discovery and registration. A provisioning of information about neighbor networks based on the 802.21 Information Service can not be integrated in 3GPP

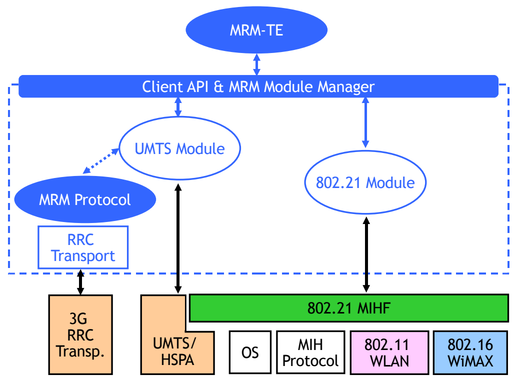


Fig. 5. partial use of 802.21

RATs as easily as it is the case for WiFi or WiMAX. The most severe problem arises with respect to the exchange of signaling messages between MIHFs on the terminal side and in the access network, where currently no appropriate transport solution exists.

We therefore conclude that a RAT-agnostic MRM realization on top of 802.21 as shown in Fig. 3b is not yet possible. Assuming that an MRM-NET within a 3GPP access network will not be based on 802.21 for these reasons, we propose a modified implementation of the MRM architecture which distinguishes whether the mobile terminal is currently being served by a 3GPP or a non-3GPP network. Table 1 provides an overview how the different MRM tasks are carried out in these two cases. The resulting structure of the MRM-TE is shown in Fig. 5. While the terminal is being served by a 3GPP network, MRM-NET monitors the current link quality by directly accessing 3GPP measurement primitives, i. e. without using an intermediate 802.21. The same is true for the initiation of handovers. For link availability and link quality measurements of non-3GPP RATs, a 3GPP MRM-NET issues measurement commands to MRM-TE as shown in the right hand side of Fig. 2, using an RR Direct Transfer mechanism. However, on the MRM-TE side, the measurement command is now passed to the local MIHF instead of directly accessing the non-3GPP driver. While the terminal is being served by a non-3GPP network, all procedures are mapped to services provided by 802.21. The advantage of this implementation alternative is that MRM can still make use of 802.21, despite its limited support by 3GPP RATs.

6 Conclusion

For the multi-radio management architecture MRM, we analyzed how its implementation can be facilitated by employing the services provided by IEEE 802.21. We evaluated how these services are supported by an underlying GSM, UMTS, WiFi or WiMAX network. It has been found that, although 802.21 defines a

Table 1. MRM realization with partial use of 802.21

	Terminal in non-3GPP	Terminal in 3GPP
Measurements (within 3GPP/non-3GPP)	802.21 Command and Event Service	Direct access to 3GPP primitives
Measurements (between 3GPP/non-3GPP)	802.21 Command and Event Service	Indirect measurements via 802.21 and RR Direct Transfer
Neighbor system information	802.21 IS and Generic Advertisement Service	ANDSF (using 802.21 IS) or System Information elements
Inter-System Handover execution	Triggered using 802.21 CS primitives	Direct access to 3GPP primitives
Discovery and registration	DHCP/DNS and MIH capability flag	Dedicated System Information elements
Message transport	IP-based transport of 802.21 messages	RR Direct Transfer

media-independent interface, it is still necessary to distinguish whether a terminal is being served by a 3GPP or non-3GPP access network. This is due to the different degree of support of 802.21 by the respective RATs, especially the absence of signaling transport channels for 802.21 messages in 3GPP access networks. This observation lead to a modified structure of the MRM components that has been presented and discussed here.

References

1. Bandholz, M., Gefflaut, A., Riihijarvi, J., Wellens, M., Mahonen, P.: Unified link-layer API enabling wireless-aware applications. In: IEEE PIMRC. (2006)
2. Farnham, T., Gefflaut, A., Ibing, A., Mähönen, P., D.Melpignano, Riihijärvi, J., Sooriyabandara, M.: Toward an open and unified link-layer api. In: Proceedings of the IST Mobile and Wireless Summit 2005, Dresden (Germany) (June 2005)
3. IEEE: IEEE 802.21: Local and metropolitan area networks: Media independent handover services. Draft Standard, v7.0 (July 2007)
4. Lampropoulos, G., Salkintzis, A., Passas, N.: Media-independent handover for seamless service provision in heterogeneous networks. IEEE Communications Magazine **46**(1) (2008)
5. Melia, T., de la Oliva, A., Vidal, A., Soto, I., Corujo, D., Aguiar, R.: Toward IP converged heterogeneous mobility: A network controlled approach. Computer Networks **51**(17) (2007)
6. Eastwood, L., Migaldi, S., Xie, Q., Gupta, V.: Mobility using IEEE 802.21 in a heterogeneous IEEE 802.16/802.11-based, IMT-advanced (4G) network. IEEE Wireless Communications **15**(2) (2008)
7. Sachs, J., Aguero, R., Daoud, K., Gebert, J., Koudouridis, G., Meago, F., Prytz, M., Rinta-aho, T., Tang, H.: Generic abstraction of access performance and resources for multi-radio access management. In: IST Mobile and Wireless Communications Summit. (2007)
8. Piao, G., David, K., Karla, I., Sigle, R.: Performance of distributed MXRRM. In: IEEE PIMRC. (2006)

9. Blau, I., Wunder, G., Karla, I., Sigle, R.: Cost based Heterogeneous Access Management in multi-service, multi-system scenarios. In: IEEE PIMRC. (2007)
10. IEEE: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment: Enhancements for Interworking with External Networks. Draft Standard 802.11u (2008)
11. IEEE: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 1: Radio Resource Measurement of Wireless LANs. IEEE standard 802.11k (2008)
12. IEEE: Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 3: Management Plane Procedures and Services. IEEE standard 802.16g (2008)
13. 3GPP: Mobile radio interface signalling layer 3; General Aspects. TS 24.007 (2005)
14. 3GPP: Architecture enhancements for non-3GPP accesses (Release 8). TS 23.402 (2008)
15. 3GPP: System Architecture Evolution (SAE); CT WG1 aspects. TR 24.801 (2008)
16. 3GPP: Radio Resource Control (RRC); Protocol specification. TS 25.331 (2008)
17. 3GPP: Mobile radio interface layer 3 specification; Radio Resource Control (RRC) protocol. TS 44.018 (2007)
18. IETF Mipshop: Mobility Services Framework Design (MSFD). draft-ietf-mipshop-mstp-solution-06, work in progress (2008)