A Radio Resource Management Architecture for a "Beyond-3G Network"

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Abstract

Radio Resource Management (RRM) has a number of roles to perform in order to manage the resources at the air interface. These roles typically include scheduling, resource allocation and monitoring. The goal is to make the most efficient use of the resources available, since these are often quite scarce in comparison to the resources available in the fixed network. The following paper describes a Radio Resource Management architecture for use in future networks where multiple access technologies are deployed. The network studied is that of an IP-based "Beyond-3G" network which can also support ad hoc node behaviour, and is the work of the IST MIND project. This paper presents the work to date within the MIND project on RRM and demonstrates how an access technology independent framework for RRM can be produced. The special considerations that are introduced by an ad-hoc environment are also discussed and the interactions between RRM and other MIND concepts are outlined.

1. Introduction

In this paper we look at how an architecture and framework for Radio Resource Management (RRM) can be formed for future mobile systems. This work looks beyond that of current 3G network developments to future networks that exhibit ad-hoc behaviour both within the core of the network and at the fringe where ad-hoc extensions may be formed. Typically the network will be built upon a number of access technologies, for example combinations of different WLAN technologies and other access technologies (e.g. UMTS) providing a heterogeneous environment in which RRM is required.

Radio Resource Management has a number of roles to perform in order to manage the resources at the air interface. These roles typically include scheduling, resource allocation and monitoring. The goal is to make the most efficient use of the resources available, since these are often quite scarce in comparison to the resources available in the fixed network. However, there is quite often a trade-off between efficient scheduling of resources and resource allocation/QoS issues. This juggling act can make RRM quite complex.

RRM has been studied quite extensively over the years with the aim of providing maximum resource efficiency for particular air interface technologies, therefore, the architectures developed are optimised for a network operating using a single link layer technology. Existing research into efficient RRM algorithms has already been carried out for different link layer technologies such as [25], but [25] particularly considers high level design and does not consider in detail the RRM function interaction between layers (i.e. between network layer and link layer). Whereas [10] considers the interaction of RRM functions between layers but only for UMTS system. However the results of this research have been leveraged by the MIND project.

In contrast to previous work, MIND hopes to provide a unique investigation of RRM by examining RRM in heterogeneous environments where RRM must be co-ordinated across a number of access technologies co-existing within the same network. Inter-RRM signalling is also required to transfer information between RRM entities upon which resource allocation and admission control decisions can be based. The following paper concentrates on these concepts and concludes with a look at how the presented framework extends to a network that exhibits some ad-hoc behaviour.

This paper begins by explaining how this work fits in with the IST MIND project and describes the scenario in which RRM functions are considered. Two case studies of WLAN technologies (IEEE 802.11a and HIPERLAN/2) are then presented and their approach to RRM studied.

A RRM architecture is then presented, and its applicability to the previously studied access technologies is demonstrated to highlight the technology independence of the architecture. The signalling between the distributed RRM functions within the architecture is crucial to the efficiency of the RRM process and this is discussed in detail including the identification of the information that should be transferred and possible protocol options for carrying this information.

A key part of future networks will be their ability to cope with ad-hoc behaviour and this is discussed within section 6 of the paper, where a detailed analysis of how RRM can be deployed in the ad-hoc scenarios is provided. Finally, the interactions between RRM functionality and the other functions within the MIND network, e.g. Mobility, Handover, and QoS, are discussed.

2. Our Motivation (The MIND Project)

The following section introduces the MIND network and the environment within which RRM is being investigated. The motivation for the approach taken within MIND is also discussed.

2.1 An Introduction to MIND

The MIND [21] project is looking at a network evolution beyond UMTS, and continues the work begun during the BRAIN [22] project, both of which were conducted as part of the IST 5th framework [23] program. Both projects consider providing services to mobile users in an IP-based access network, and are concerned with the concept of a "native-IP" network that has a unified QoS and mobility management framework. A holistic approach to providing such a service was taken, so issues from the applications layer through to the radio interface were investigated.

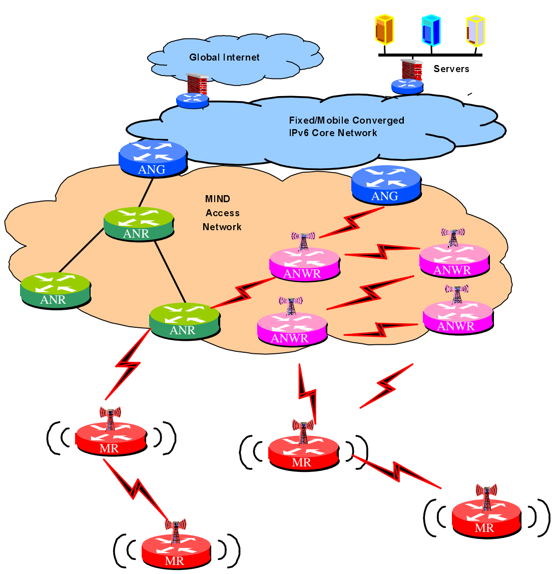

Figure 1. The MIND Network.

The MIND project has extended the work in the BRAIN project to include multi-homed and multi-interfaced devices, self-organising mesh networks and ad-hoc extensions (the ad-hoc fringe). This requires additional thought on how to provide QoS mechanism and mobility management. The MIND project also extends the work by considering multicast routing in the network and how a RRM framework for such a complex network can be developed (the latter of which is the focus of this paper).

The MIND network shown in Figure 1 is based on a "native-IP" approach. By this it is meant that not only is IP used for the transportation of packets in the network but that the QoS, routing and mobility mechanisms will all be IP-based throughout the whole network from the gateway router to the first base station. Indeed the first base-station itself is considered to now be an IP router.

The MIND access network contains the following nodes:

- Access Network Gateway (ANG) that provides the interface between the access network and external networks,
- Access Network Router (ANR), which is a standard IP router, with both fixed network and wireless interfaces
- Access Network Wireless Router (ANWR), which is an ANR with no fixed network interfaces, and as such can be deployed in an ad hoc fashion within the Access Network by the network operator.
- Mobile Router (MR) extends the coverage of the access network in an ad hoc fashion. These are different to ANWRs since these are not owned by the access network operator, and are potentially much more mobile, for example, it could be a user laptop offering forwarding services to mobile nodes outside the range of the access network.

Mobile nodes can connect to the access network via ANRs with wireless interfaces, ANWRs, or MRs. [24] gives a more detailed description of the MIND network and how the mobility and QoS architectures are integrated.

There is a consensus that "beyond-3G" networks will have to consider the integration of different air interface types of widely different characteristics in order to be able to support a wide range of scenarios. It is desirable that this integration is optimised and to achieve this commonality of network components between the different physical and link interfaces must be maximised. This means that the integration is pushed to the edge of the network. With the native IP approach being considered this therefore means that the IP to link layer interface is critical. Within BRAIN, the concept of the 'IP-to-Wireless' (IP_2W) interface was developed, which supports an access technology specific convergence layer but allows the co-ordination of the IP-layer management with link-layer functions. In order to support RRM in the MIND network, extensions to this interface will be required as is discussed in more detail in later sections.

By extending the IP2W to include RRM functions/interactions, generic link layer independent RRM functions can be placed at L3 where the resources available at different interfaces on a multi-homed terminal can be controlled in a co-ordinated manner. This is the first step towards having the ability to adjust and allow for access technology switching depending on the demands on the network and alternate radio resources. This provides a more efficient use of the radio resources available within the network.

2.2 Why is MIND considering RRM

Although a number of RRM architectures can be found in a wide range of sources, none exactly match the requirements of the BRAIN and MIND projects. The scenarios considered within these projects require cross technology resource management and, within the MIND ad hoc fringe, do not easily provide support for centralised management paradigms.

2.3 The Need for a Multi-layered Approach

The MIND network can be formed not only of multiple technologies but also multiple domains. This obviously indicates that four occurrences can occur when we come to interaction:

- Single Technology – Single Domain
- Single Technology – Multi Domain
- Multi Technology – Single Domain
- Multi Technology – Multi Domain

Current RRM solutions consider the first case, and indeed this approach provides the most efficiency since RRM is managed solely at the link layer (L2). With a single technology but multiple domains it is still possible to have a L2 solution, however in the "native-IP" environment this could cause conflicts with the network layer (L3) interactions that will be taking place. Therefore communication with L3 entities becomes important.

When multiple technologies are introduced, different link layers (L2) have to interact with each other. In the following scenarios we have an area of commonality, that of the IP Layer (L3), so it is natural to use this layer as the bridge between the technologies through the IP_2W interface. At L3, a decision can then be made on the best resource management across the multiple technologies. Similarly in the Multiple Domain – Multiple Technology case, L3 decisions are needed not only in order to manage cross -technology RRM but also to remove inter-domain management conflicts at L3.

Figure 2 shows the framework for the multi-layered approach, where we see entities at both L2 and L3 relating to RRM. It also clearly demonstrates where the IP2W provides the generic interface between L3 and L2. The multi-layered approach has a manager function that manages interactions between A-T Specific RRM entities, such as co-ordinating handover.

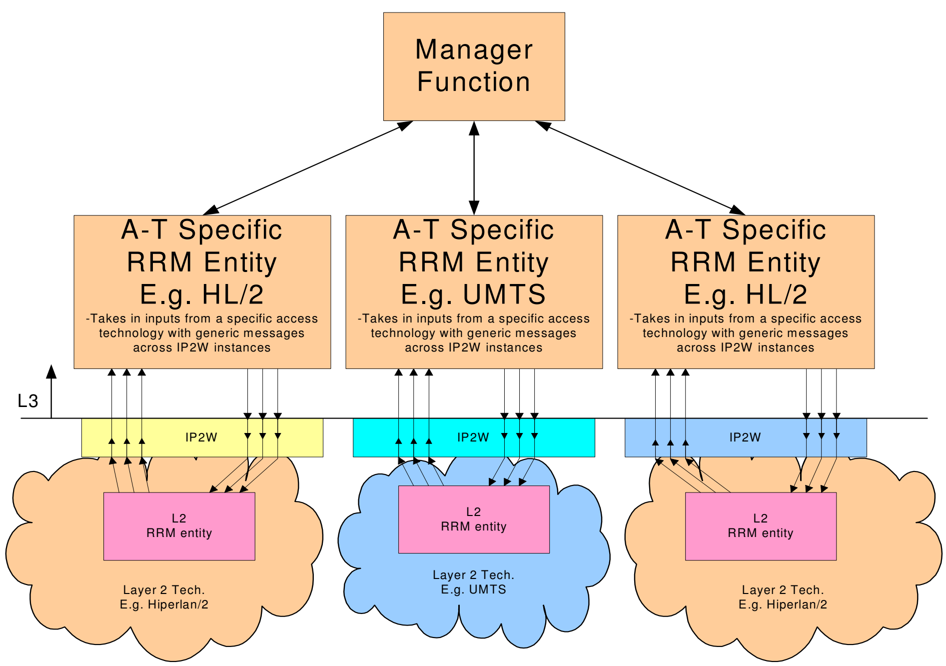

Figure 2: The Multi-layered approach

3. Case Studies of RRM in WLAN Architectures

The following sections introduce two wireless LAN (WLAN) technologies as case studies for the RRM architecture discussions.

3.1 HIPERLAN/2

The following sections provide an introduction to the HIPERLAN/2 architecture, highlighting the RRM aspects of the system.

3.1.1 HIPERLAN/2 System Architecture

An Access Point (AP) consists of one Access Point Controller (APC) and one or several Access Point Transceiver (APT). The interface between APC and APTs is not specified within the HIPERLAN/2 standard. The distinction between APC and APT is only relevant for radio handover. Figure 3 shows the HIPERLAN/2 system architecture. The radio coverage by one APT is called "cell", and one APC with its APTs can be called "bunch" or "system".

In another basic architecture the HIPERLAN/2 system consists of a single APT, and the AP is usually referred to as the Central Controller (CC). The radio coverage of the CC is called "subnet". If the capacity of a single subnet is insufficient, or the area is too large to be covered by a single subnet, multiple subnets, which operate on the different frequency, can be deployed. Each subnet is controlled by its CC, and works independently of the other subnets.

The Mobile Terminal (MT) communicates with the AP over an air interface as defined by the HIPERLAN/2 standard. HIPERLAN/2 supports two basic modes of operation between MTs and AP/CC:

- *Centralised mode.* In this mode an AP is connected to a core network. All traffic has to pass through the AP, regardless of whether the data exchange is between the MT and a terminal elsewhere in the core network, or between MTs belonging to the same AP.
- *Direct mode.* In this mode, the medium access control is still managed in a centralised way by the CC, but the user data traffic is exchanged directly between terminals without going through the CC.

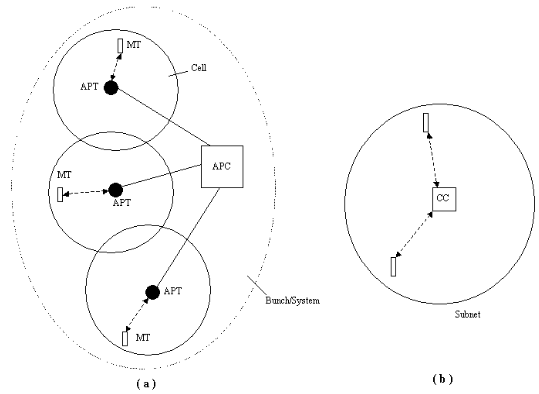

Figure 3: Basic HIPERLAN/2 System
(a) Many cells
(b) One cell or single subnet

3.1.2 Medium Access Control (MAC)

The MAC mechanism is based on dynamic TDMA/TDD scheme with a centralized control concept. A MAC frame has a constant length of 2ms. Data and control information is mapped onto transport channels. The transport channels are the basic elements used to construct PDU trains that are delivered to, and received from, the physical layer. Each MAC frame consists of transport channels including a BCH (Broadcast CHannel) and at least one RCH (Random CHannel). If user data is to be transmitted, a DL (Down Link) phase and/or an UL (Up Link) phase is provided. If direct mode is used and data has to be transmitted, a DiL (Direct Link) phase between the DL and UL phase is used. More details about the HIPERLAN/2 standard can be found in [4,5,6].

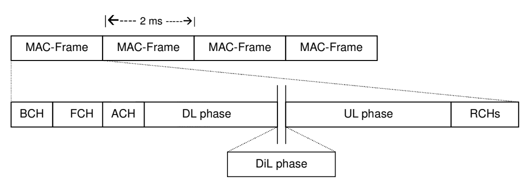

Figure 4: Basic MAC Frame Structure (DiL phase optional) [6]

3.1.3 The HIPERLAN/2 RRM Overview

The AP, or CC in centralized mode, dynamically assigns the radio resources for both the uplink and the downlink phase to the individual MTs. In the direct mode the radio resources of the direct link between two MTs are assigned by the AP/CC. The MT requests resources from the AP/CC and report their state via Resource Request (RR) messages. The allocation of resources assigned by the AP/CC is reported to the MT via Resource Grant (RG) messages. RRs and RGs are defined on a per-connection basis and one MT can utilise more than one connection. The assignment of resources to the individual MTs and their connections are not static but may change dynamically from one MAC-frame to another. The radio resources controlled by the AP/CC include transmit power, frequency, channel allocation.

3.2 IEEE 802.11

The following section provides an overview of the 802.11 WLAN technology, highlighting the RRM aspects of the technology.

3.2.1 Architecture and Services of IEEE 802.11 Networks [15,17]

The basic element of the 802.11 networks is the *Basic Service Set* (BSS), which consists of a set of 802.11 stations (STA) controlled by a single *Coordination Function* (CF). These co-ordination functions are described in more detail in the following sections.

An Independent BSS (IBSS) is the most basic IEEE 802.11 network configuration, and acts as an ad-hoc network. A BSS may be also part of a larger network, the Extended Service Set (ESS). The ESS consists of multiple BSS interconnected by the Distribution System (DS). Typically, the DS is a wired backbone LAN. The ESS appears as a single BSS to the IEEE 802.2 LLC layer.

A station connected to the DS is called an Access Point (AP). A Portal is the logical point where a non IEEE 802.11 LAN is connected to the DS. A station cannot associate with more than one AP at the same time, and selects the appropriate AP out of several possible candidates using information from the APs beacons.

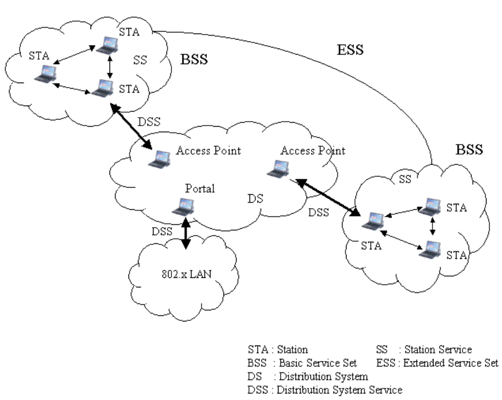

Figure 5 : IEEE 802.11 Architecture

The services are divided into two categories: the Station Services (SS) and the Distribution System Services (DSS). The SS services are: Authentication, Re-authentication, Privacy and MSDU delivery. The DSS services are: Association, Disassociation, Distribution, Integration and Re-association. In an IBSS, only the Station Services are available. The Distribution System Services are used to distribute messages in the Distribution System and to support mobility. Two types of mobility are supported by 802.11. These are *No-transition* (Stations are stationary or move within a BSS) and BSS-transition (Stations move from one BSS to another BSS within the same ESS).

3.2.2 IEEE 802.11 MAC [15,16,17]

The IEEE 802.11 MAC mechanism uses a distributed access scheme, which is based on a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. This MAC protocol provides two types of service: asynchronous and contention-free. The asynchronous service is provided by the Distributed Coordination Function (DCF), which implements the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) access method. The contention-free service is provided by the Point Coordination Function (PCF), which implements a polling access method. The PCF is implemented on top of the DCF.

Each frame consists of the following basic components:

- A *MAC header*, that comprises frame control, duration, address, and sequence control information;
- A *variable length frame body*, that contains information specific to the frame type;
- A *frame check sequence (FCS),* which contains an IEEE 32 bit CRC.

The format of the MAC frame or the MAC protocol data unit (MPDU) comprises of a set of fields that occur in a fixed order in all frames and is shown in Figure 6.

Octet : 2	2	6	6	6	2	6	0-2312	4
Frame Control	Duration/ ID	Address1	Address2	Address3	Sequence Control	Addres 4	Frame Body	FCS

MAC Header

Figure 6: General MAC Frame Format [17]

The different kinds of individual frame types of the MAC frame are the Control Frame, Data Frame and Management Frame. The Control frames are Request To Send, Clear To Send, and ACK. The Management Frames include the Beacon and Association Request frames.

3.2.3 The IEEE 802.11 RRM Overview

IEEE 802.11 RRM is distributed, so all stations control their own radio resources. The stations can communicate with each other without control via an AP, which is not possible with the HIPERLAN/2 basic specification. The drawback is that the performance is limited, in particular in a radio environment where not all stations are able to detect transmission of all the others [8]. This can lead to interference between stations, and, in some circumstances, unfair treatment of traffic flows.

IEEE 802.11a uses link adaptation algorithms for choosing the PHY modes. Once selected, the IEEE 802.11 system keeps operating the same carrier and does not apply dynamic power control unlike the HIPERLAN/2 system [20]. The power control of the IEEE 802.11 only manages two power modes, active mode, where the station is fully powered and can receive frames at any time, and power save mode where the station is unable to transmit of receive, and consumes very low power.

4. The RRM Architecture

In this section, we propose the RRM architecture for ad-hoc networks. This RRM architecture, Figure 7, is inspired by the work described in [9]. The following listing specifies some main characteristics of the RRM architecture proposal:

- support self organisation functionality (*Establishment and re-establishment automatically and lack of a priori network planning)*. Nevertheless, the RRM parameter can be modified on the request by the user,
- retain functionality such as power control, admission control, etc.,
- provide QoS support based on IP-QoS (user requirement perspective),
- maintain flexibility/cooperation (different algorithms in RRM or between functions in RRM entities should be able to interwork tightly).
- RRM algorithms in network / upper layer should are not be heavily dependent on air interface technology.

Principally the RRM architecture proposal contains a measurement entity, Resource Manager (RM) entity, Admission Control (AC) entity, queue and scheduler entity and output conditioner entity**.**

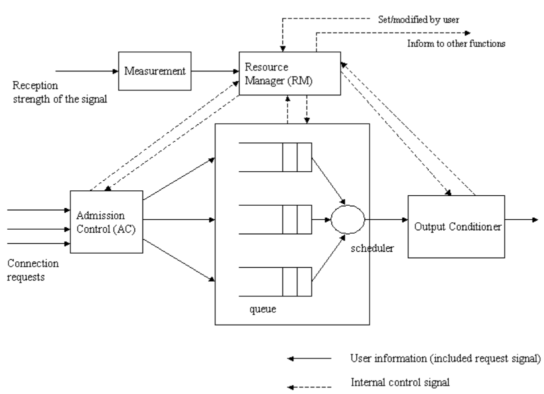

Figure 7: RRM Architecture

The measurement entity measures the reception strength of the signal. The RM entity controls and manages all other functions in the RRM architecture as well as acting as a "gateway" to upper layer functions and to other functions outside of the RRM function such as routing or handover. An output conditioner is also present in the architecture, which conditions the data flow to meet the current radio link. This function is dependent on the air interface technology. In the HIPERLAN/2 system it contains dynamic power control and link adaptation algorithms.

The queue and scheduler entity manages the fair and efficient distribution of the capacity among the different QoS of the connections. The Admission Control (AC) entity contains the AC algorithm for admitting / rejecting new connections, a channel allocation model that is dependent on the air interface technology, and a classifier model that depends on the network layer service model.

4.1 Layering of RRM Function Entities

The location of RRM functions can be distributed between the link layer and the network layer. The analysis of which functions should reside at which layer should consider the information requirements and functions that are available at other layers. The division of the RRM architecture on each layer is based on the "target object" or "environment" that must be proceeded by the RRM function. For example, the output conditioner entity (in HIPERLAN/2, this contains power control and link adaptation) is located in the link layer (L2). The "target object"/"environment" of this entity is the air interface or L2.

However, in some cases, the RRM entity function seems relevant in both layers (L2 and L3), for example, the RM entity and scheduler. In these cases, the function is divided across both layers with different aspects of the function resident in different places coinciding with the different "target object" or "environment". For functions that are split in this fashion, there must be close co-operation between layers to ensure efficient RRM control.

One approach is to use one function as a "gateway" between layers, for example the RM function. This approach still needs further research, but implies that this RRM architecture uses the central controlling approach in each layer allowing close co-operation without tight integration. We believe that this approach can achieve good overall system performance.

4.2 The Layered RRM Architecture

The following section describes the generic layered RRM architecture, with the justification of the division of RRM functions between L2 and L3. Where appropriate, the case studies from the previous sections are used to confirm this decision, and to demonstrate how the location of the function is suitable for more than one technology. The architecture is illustrated in Figure 8

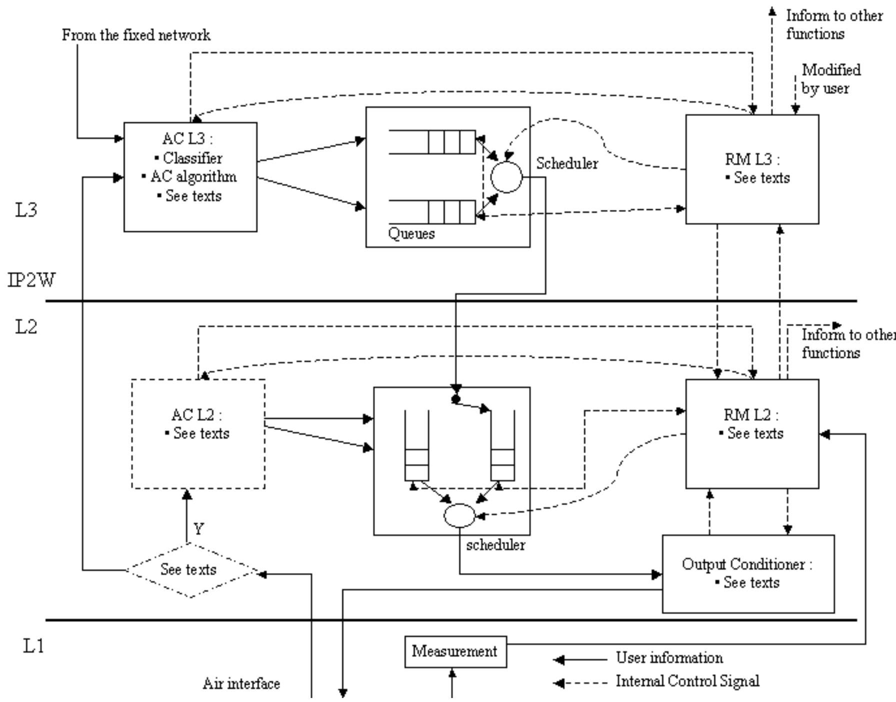

Figure 8: The Layered RRM Architecture

The functions and their location within the architecture are described and explained in the following sections.

Measurement Entity

For HIPERLAN/2 and IEEE 802.11 technologies, it is obvious that this entity is located in the physical layer (L1) only. The measurement entity measures the reception strength of the signal and is dependent on the air interface technology.

Output Conditioner Entity

The Output Conditioner Entity in both HIPERLAN/2 and 802.11a contains the power control and link adaptation functions.

In HIPERLAN/2, the main aim of link adaptation is to select a suitable PHY-Mode (modulation and coding scheme), depending on the current interference situation, fading, and noise. Thus, the selection of an appropriate PHY-Mode by AP/CC is based on the status (PER/CIR) of received packets which is used to predict the future channel conditions and according to the Quality of Service demands of the connections [3,4].

In 802.11a, link adaptation also selects a suitable PHY-Mode depending on the current interference situation, fading, and noise. The PHY modes of 802.11a have the most number of similarities with PHY modes of the HIPERLAN/2 system, as can be seen in [16,18,19].

HIPERLAN/2 dynamic power control enables the transmitting station to always set its transmit power level appropriately. The power control algorithm can be applied separately for UL phase, DL phase and DiL phase of each connection and each MT. The MT is included in the UL and the DiL power control process [4,5].

IEEE 802.11 power management decides which power modes should be used. The power management mechanisms of the infrastructure BSS are different than the power management of the independent BSS [15,17]. The IEEE 802.11a system keeps operating power of the carrier (keeps operating the same carrier) once it has selected it and does not apply dynamic power control like in the HIPERLAN/2 system [20].

The differences between these entities as regard the link adaptation and power management functions clearly indicates that these aspects of RRM have to be optimised to a particular link layer technology, and should remain at L2.

Queue and Scheduler Entity

The network layer scheduler ensures that all flows receive the desired service [11]. The task of the queue and the scheduler in L3 is closely related to the service model in the L3. For example in the pure DiffServ router, the queue and the scheduler could have the shaper/ the dropper function. The shapers delay some or all of the packets in a traffic stream in order to bring the stream into compliance with a traffic profile. A shaper usually has a finite-size buffer. The shaper may discard packets if there is not sufficient buffer/queue space.

The scheduler and its queue in L3 should be aware of the link layer conditions and receive the information about the current state of the L2 scheduler from the RM entity such as the condition of L2 buffers/queues. The L3 queues and scheduler send their current state to the L3 RM entity.

The task of the link layer scheduler is to ensure that the wireless link functions are optimally deployed and should not contradict with the fairness of the service provided.

In HIPERLAN/2, the MAC scheduler [5] takes responsibility for: allocation of resources for transmission of user and control data in the UL, DL and DiL phases, such as inserting a guard time between UL PDU trains, frame composition, etc. The link layer scheduler is applied on a MAC frame-by-MAC frame whereas the network layer scheduler is applied on a packet-by-packet basis. In the L2 scheduler there is a selector to put the packet (to become an appropriate MAC frame) according to the result of establishment of the L2 QoS parameter. The L2 queues and scheduler send their current state to the L2 RM entity. The L2 scheduler receives information from the L2 RM such as the current PHY Mode allocation, PER (CIR), load of the system as well as error correction/checking mechanisms. That information is useful for deciding when the channels can be used.

In IEEE 802.11, the functions of the MAC queue and scheduler manage a fixed order of the frames, manage the buffered retransmission frame, etc. Owing to the IEEE 802.11 supports very limited QoS compared QoS support of the HIPERLAN/2 system, then the queue and scheduler mechanisms of the IEEE 802.11 should simpler than one mechanism of HIPERLAN/2. Also they can not perform most services of the L3 (e.g. Integrated Service).

As can be seen, queuing and scheduling has a L2 and L3 aspect, and should therefore be present at both levels of the architecture. However, close co-ordination of these functions is required, and is managed by the RM entities at L2 and L3. The RM functions perform a mapping of QoS parameters defined on the IP layer (e.g. DiffServ and IntServ parameters) to the "local" QoS parameter of the link layer such as delay, targeted error rate, throughput. Mapping of QoS parameters should be performed in the L2 RM. This mapping is based on the kind of service that must be supported by the link layer, and based on the characteristic of the air interface system.

Admission Control (AC) Entity

The objective of the Admission Control algorithm is to admit or reject new connection calls/handover calls based on: the current system state (e.g. interference, current capacity demand, load); the traffic (e.g. throughput, the number of users, rate); and QoS requirements of the service that has to be supported. Newly admitted sessions/connections should not disrupt existing connections.

In HIPERLAN/2, the AC algorithm can be applied both at UL and DL phase as well as DiL phase. The AC algorithm is always done when setting up or modifying an UL or DL or DiL connection for signalling (control) or data, and executed during handover. The admission control entity in L2 contains AC algorithms that are related to radio handover, Dynamic Frequency Selection (DFS) algorithm and Time Division Multiple Access (TDMA) channel allocation algorithm. The AC L2 algorithm that related to radio handover is based on a frame-by-frame basis, not packet basis. In the case of radio handover, where a MT moves from one cell to another, which is served by the same APC, the network layer is not involved. Thus, the radio handoff connections are accepted or rejected only by the AC algorithm in L2.

The AC algorithm of the IEEE 802.11 system is different than the AC algorithm of the HIPERLAN/2 system. The IEEE 802.11a system keeps operating frequency (keeps operating the same carrier) once it has selected it and does not apply dynamic frequency selection like in the HIPERLAN/2 system [20]. Also, the IEEE 802.11 standard does not include information about how handover should be handled. It is currently assumed that AC L2 entity is still needed, but further research may establish that there is a minimum amount of functionality in the L2 AC entity for 802.11 networks.

At L3, the AC algorithm needs generic information from L2 regarding allocated capacity, total available capacity, etc. The L2 AC entity reports its results to the L3 entity. The admission control mechanism may need the reliable user identification or user administrative permissions to make the request.

The other contents of the admission control entity in L3 are closely related to the service model in the L3. For example in the Border Router of the IntServ over DiffServ Networks [14] the AC L3 entity may contain policy control and admission control algorithm, a classifier and a marker. This information is not available at the link layer, indicating the need for AC functions to reside at both L2 and L3.

As can be seen, there are aspects of admission control that are specific to the link layer, and aspects that require information only available at L3. Therefore, this function resides at both the link and network layer.

Resource Manager (RM) Entity

The resource management entity generally controls access to the link layer and network resources for traffic flows. This function resides at both the link layer, where technology specific information is managed, and at the L3, where certain resource request information is only available.

Some functions of the RM L2 entity that have been identified include:

- controlling and monitoring the radio channel characteristics (e.g. evaluate CIR or PER),
- controlling the power control and link adaptation based on the current radio channel characteristic (e.g. CIR) and QoS requirements,
- controlling the queue and scheduler L2 based on the current system load in L2, AC algorithm in L3 (i.e. for HIPERLAN/2 the amount of traffic load accepted in UL and DL),
- controlling the current system load in the L2,
- assisting L2 AC algorithms in accepting or rejecting the radio handoff request, (i.e. amount of traffic load accepted in UL, DL and DiL),
- mapping the IP QoS parameter to the QoS parameter of the L2 (although 802.11a supports very limited QoS),
- informing current RRM state information at L2 to other functions, including L3 RM, such as current available capacity, current system load in L2, CIR (interference measurements).

Some functions of the L3 RM entity that have been identified include:

- receiving and processing of the information from the RM L2 entity,
- managing the L3 RRM signalling and reporting the current state of the RRM to other functions needing this information, such as L3 routing, network handover, etc,
- controlling the L3 queue and scheduler entity based on such as the current capacity of the L2,
- assisting the AC algorithm in accepting or rejecting new or network handoff connections,
- controlling the current system load in L3 while taking the current system load in the L2 into account.

5. Signalling

This following section describes the issues associated with signalling RRM information between distributed RRM functions within a network. RRM information will be exchanged at both the link and network layers, depending on the information being conveyed, and where in the network it needs to be communicated.

RRM Signalling in the Link layer

Signalling at the link layer is dependent on the radio interface technology that being used. Signalling at layer 2 mainly concerns the exchange of information about the neighbouring cells (see Figure 3) based on the same technology, for example load information between neighbouring cells in a HIPERLAN/2 network. However, as is discussed in the next section, this might not be enough for some scenarios, especially in an environment where with heterogeneous link layer technologies.

RRM Signalling in the Network Layer

Signalling for RRM is required at L3 for a number of reasons. Firstly, where base stations are using different link layer technologies, they may wish to exchange load information either with each other, or with a centralised resource management entity in order to aid decisions regarding when and where a mobile should handover. This information cannot be managed at L2 because of the inter-technology nature of the network.

Secondly, in ad hoc environments, the previous scenario becomes more complex as each ad-hoc node needs information about neighbouring cells, and potentially more remote cells in order to prevent interference as mobiles move around the network.

The signalling occurs between L3 RRM entities, and is controlled by the RM entity described within the architecture. The kind of the information that may need to be exchanged by the L3 Resource Manager protocol includes:

- Information from the L2 (link layer) including the current transmission power and the current received power, interference measurements and allocated capacity and the total available capacity of the radio interface. This would need to be provided in a generic format that can be understood by a generic L3 RRM entity.
- Information from the L3 (network layer) such as:
  * The result of the AC algorithm and the policy control algorithm that describes the decision of the new user request or network handover if admitted or rejected by this node/ AP/CC/router.
  * The current amount of resources available in the queues and scheduler at the network layer (of course with taken the amount of resources in the L2 into account). This information needs to signal to the source of the signal request.
  * The current system load in the L3, which can be used for severe congestion detection and notification. This information can also be used for handover decisions.

The information of the link layer is primarily relevant only between adjacent cells, but may need to propagate further to help RRM functions manage interference as terminals move round the network.

The signalling protocol used between the RM entities still needs further investigation. It may be possible to "piggybacked" RRM information into existing L3 signalling protocols in the network, but it is difficult to guarantee that these messages will be processed by all the nodes in the network where the RRM information is required. Alternatively, a dedicated protocol may be developed, with the desirable characteristics for distributing the RRM information to the relevant nodes in the network.

6 The Usage of the RRM in the Ad-hoc Networks

As previously described, the MIND network includes the concepts of both limited ad-hoc behaviour in the core and also ad-hoc behaviour in the edge. In the following section the usage of RRM architecture proposal in the ad hoc networks is highlighted, and issues that are unique to such an environment are outlined.

6.1 HIPERLAN/2 Ad-hoc Networks

In the first scenario, Figure 9, there is a multi-hop network with a central controller based on HIPERLAN/2 system architecture. All mobile terminals and mobile routers are in the coverage area of the CC/AP. In the second scenario, Figure 10, there is still a multi-hop network, but control of resources is distributed, and some mobile routers are out of the coverage area of the CC/AP. All mobile terminals / routers associated to the same AP/CC, and appear to be connected to the same (IP) subnet on a common shared medium.

The mobile terminal only has measurement, power control and link adaptation algorithms for supporting RRM function. In the multi-hop scenario with central controlling, the signalling of connection management (i.e. DiL phase) of terminals is still controlled by the CC/AP. Thus, in this scenario the routers behave like the mobile terminals with DiL phase capability.

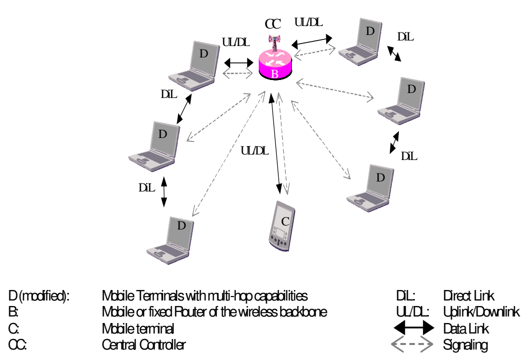

Figure 9: Multi-hop Scenario with Central Controlling [2]

In the distributed scenario, some mobile routers act as forwarders. Therefore they have two modes: as a forwarder and as a mobile terminal. As a forwarder with mechanisms in [13], the RRM architecture in mobile routers is similar to the RRM architecture (Figure 8) in the AP/CC.

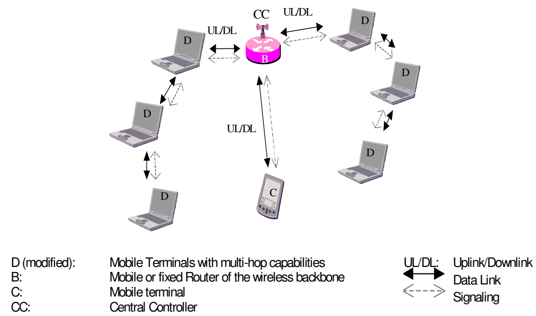

Figure 10: Multi-hop Scenario with Distributed Controlling [2]

The goal of the forwarder is to extend the radio communication range of an AP/CC. In HIPERLAN/2 networks, different kind of forwarding mechanisms can be applied such as frequency based, time based and frequency & time based. The forwarder or Forwarding Mobile Terminal (FMT) [13] generates HIPERLAN/2 MAC Sub-Frames (SF) to communicate with the Remote Mobile Terminal (RMT) associated with it. The RMT is a mobile terminal that can not communicate directly with the AP/CC on the one hop but need a forwarding link.

The structure of the SF is the same as that of the normal MAC frame, but the length of the structure is less than 2 ms. The structure still gives opportunity for the FMT to work as a mobile terminal at the same time. The FMT needs the scheduler and other RRM functions to handle the SF. Therefore, basically the RRM architecture in a FMT is similar to the one in the Figure 8. The difference is how to manage the SF with less 2 ms period and to co-ordinate with the AP/CC.

6.2 IEEE 802.11 Ad-hoc Networks

In IEEE 802.11, the RRM is distributed anyway and can be easily used in this scenario. However, there are still some unresolved issues associated with co-ordinating resources in the multi-hop environment where it is possible for two nodes that are trying to send data via a common intermediate node to interfere with each other, and this can lead to unfair treatment of user traffic.

7 Interactions with other MIND Functions

The RRM function within the MIND network has interactions with many other aspects of the overall solution. These include:

- Routing – information about available links and their quality can be used by routing protocols to build tables of available routes across the network. This is especially required in networks that are supporting QoS routing.
- QoS/Admission Control – RRM pays a major part in allocating resources to sessions, providing

feedback regarding on-going resource availability, and performing admission control.

- Multihoming – RRM needs to provide multihoming entities with information regarding what interfaces are active at the network node, and what resources are available.
- Handover – RRM functions may initiate handover, and may provide information regarding suitable handover targets.

In addition to these functions, the IP_2W interface also needs some extensions to handle the information exchanges required between the RRM entities residing at L2 and L3. The primitives defined for RRM communication between RRM entities at L2 and L3 will allow the exchange of measurement information, interface availability information, and current load and resource availability.

8 Conclusions

In this paper we have introduced the issues for RRM in networks "beyond-3G" that will be typically formed by the multiple access technologies. We have also provided and demonstrated a framework for a RRM architecture, which is both access technology independent and capable of coping with ad-hoc environments. Conceptually the RRM architecture proposal contains a measurement entity, resource manager entity, admission control entity, queue and scheduler entity and output conditioner.

We have gone on to show how the signalling between these RRM entities will work and the issues surrounding this.

We have finally considered how the RRM must interact with the other functions of the MIND network highlighting the issues that this raises the solutions identified and the open matters for future work.

The work we have presented here is part of work within the MIND project, more information on this work can be found in [21].

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