Chapter 13
Centralized and Distributed CRRM in Heterogeneous Wireless Networks

Abdallah AL Sabbagh, Robin Braun, and Mehran Abolhasan

Abstract. The evolution of wireless networks has led to the deployment of different Radio Access Technologies (RATs) such as GSM/EDGE Radio Access Network (GERAN), UMTS Terrestrial Radio Access Network (UTRAN) and Long Term Evolution (LTE). Next Generation Wireless Networks (NGWNs) are predicted to interconnect various Third Generation Partnership Project (3GPP) Access Networks with Wireless Local Area Network (WLAN) and Mobile Worldwide Interoperability for Microwave Access (WiMAX). A major challenge is how to allocate users to the most suitable RAT for them. An intelligent solution will lead to efficient radio resource utilization, maximization of network operator's revenue and increasing in the users' satisfactions. Common Radio Resource Management (CRRM) was proposed to manage radio resource utilization in heterogeneous wireless networks. This paper discusses the need of CRRM for NGWN. Then, the paper presents a comparison between implementing or not the CRRM in heterogeneous wireless networks. After that, the interaction between RRM and CRRM entities is discussed. Then, different approaches for the distribution of RRM and CRRM entities among the Core Network (CN), RATs and User Terminals (UTs) will be presented. Finally, a comparison between distributed and centralized algorithms is presented.

13.1 Introduction

The integration of different Radio Access Technologies (RATs) led the Next Generation Wireless Network (NGWN) to be a heterogeneous wireless network and to be an Internet Protocol (IP) based networks. This will allow the interconnection between the Third Generation Partnership Project (3GPP) Access Networks such

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as GSM/EDGE Radio Access Network (GERAN), UMTS Terrestrial Radio Access Network (UTRAN) and Long Term Evolution (LTE), IP networks (Internet) and the non 3GPP wireless access networks such as Wireless Local Area Network (WLAN) and Mobile Worldwide Interoperability for Microwave Access (WiMAX) [11, 17, 22].

The motivation in NGWN comes out from the fact that no single RAT could support widespread coverage and provide continuous high QoS levels over multiple hotspot areas, e.g. office, cafe, public smart areas, etc. [15]. In this case, multiple access networks that come from different technologies are spread in the same geographical space. The Third Generation Partnership Project (3GPP) has proposed different interconnected heterogeneous wireless network architectures such as Beyond 3G (B3G), Long Term Evolution (LTE) and LTE Advanced. B3G interconnects GERAN, UTRAN and WLAN through a common platform. LTE interconnects with all 3GPP wireless access networks such as GERAN and UTRAN and all non 3GPP wireless access networks such as WLAN and Mobile Worldwide Interoperability for Microwave Access (WiMAX). One of the key challenges need to be addressed in heterogeneous wireless network is how to allocate users to the most suitable RAT for them. An optimized solution will lead to efficient radio resource utilization Radio resource utilization and at the same time, it will increase the users' satisfactions. Common Radio Resource Management (CRRM) was proposed to manage radio resource utilization in heterogeneous wireless networks and to guarantee required Quality of Service (QoS) for users [4, 18].

A number of CRRM algorithms have been proposed in the literature for heterogeneous wireless networks. References [7, 5] present these algorithms. These algorithms can be categorized into centralized such as load balancing algorithm and policy based algorithm or distributed algorithms such as service based algorithm. Each one has its benefits and limitations. A comparison between some of these algorithms is presented in [8].

Centralized RAT selection algorithms have the benefit of considering more criteria during the making decision process. However, centralized algorithms do not guarantee required QoS for all admitted calls. In addition, they reduce network capacity as a result of the introduced signaling overheads or delay resulted by the communication between the network entities.

On the other hand, distributed algorithms have the benefit of considering users' preferences. A number of different distributed algorithms are proposed in [3, 9, 16]. These algorithms allow User Terminal (UT) to select the most efficient RAT that maximizes its satisfaction which is based on its preference such as best QoS or cheapest cost. However, distributed algorithms do not take into account the network benefits and policies. This may lead to inefficient radio resource utilization and it may create network bottlenecks. Radio resource utilization

The remainder of the paper is organized as follows. Sect. 13.2 discusses the need of CRRM in heterogeneous wireless networks. In Sect. 13.3, a comparison between implementing or not the CRRM in heterogeneous wireless networks is studied. The interaction between RRM and CRRM entities is presented in Sect. 13.4. In Sect. 13.5, different approaches for the distribution of RRM and CRRM entities among the Core Network (CN), RATs and UTs are studied. Distributed and centralized algorithms are compared in Sect. 13.6. Finally, this paper is concluded in Sect. 13.7.

13.2 Need for CRRM

In a homogeneous wireless network, each RAT has a local RRM entity that is responsible for admission control, congestion control, power control, packet scheduling, initial RAT selection algorithm, horizontal handover (HO) and vertical HO (VHO). It is implemented efficiently for the RAT that it is developed for. However, it is not suitable for a heterogeneous wireless network. Implementing RRM entity separately for each RAT will not have the ability to achieve efficient radio resource utilization and provide QoS for each call in a heterogeneousRadio resource utilization wireless network. Therefore, there is a need for CRRM to manage radio resource utilization and to guarantee the required QoS for users [12].

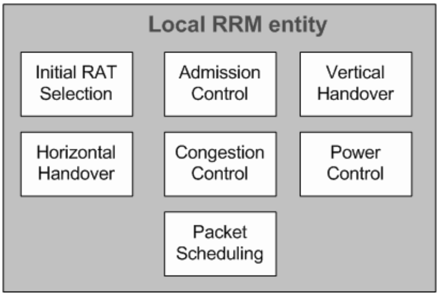

Fig. 13.1. Local RRM entity

CRRM is essential to guarantee the required QoS across different RATs, improve network reliability and stability, consider users' preferences and increase their satisfactions, allow network operators to gain maximum revenue, reduce blocking and dropping probability, and efficient utilization of radio resources. These factors are described in the following subsections.

13.2.1 Efficient Utilization of Radio Resources

There is an increasing demand for efficient utilization of radio resources in heterogeneous wireless networks. CRRM will distribute users load among the different available RATs. This will increase the efficiency of radio resources utilization.

Making the best use of radio resources is one of the most important objectives of CRRM which will enable the provision of QoS for users in heterogeneous wireless networks.

13.2.2 Reduce Blocking and Dropping Probability

Implementing CRRM will improve the utilization of radio resources in heterogeneous wireless networks and will provide requested new or VHO calls an opportunity to be allocated to another RAT if the selected RAT is unable to serve these calls. This will reduce both blocking and dropping probability.

13.2.3 Improve Network Reliability and Stability

An efficient utilization of radio resources will maximize the load capacity of each RAT in heterogeneous wireless networks. CRRM was proposed to manage radio resources and to support an equivalent distribution of network load between available RATs. This will lead to an improvement of the network reliability and stability.

13.2.4 Allow Network Operators' to Gain Maximum Revenue

Radio resources are always expensive in wireless systems. Therefore, an efficient utilization of radio resources will allows more users to be connected simultaneously. In addition, CRRM will allow users to have the ability to use multiple types of services such as voice call, web browsing, and video call, etc. As a result, CRRM has the potential to increase the network operator's revenue. Reference [24] proposed a CRRM algorithm which maximizes the network operator's revenue and compares it against non CRRM algorithm. Results show that the proposed CRRM algorithm has increased the network operator's revenue.

13.2.5 Guarantee Required QoS across Different RATs

Guaranteeing the required QoS for all users and their different types of request is one of the challenging tasks in a heterogeneous wireless network. When there is limitation in the availability of radio resources, congestion happens. CRRM will allocate user calls to the suitable RATs in heterogeneous wireless networks to achieve the required QoS. This will lead to a reduction in blocking and dropping probability, and improvement in the level of QoS.

13.2.6 Consider Users' Preferences and Increase Their Satisfactions

Different types of users have different preferences. Some may require best Quality of Service (QoS) and others may require cheapest cost of service or a RAT which offers a longer battery life time for their devices which will allow users to be connected for longer time when they are running out of battery or may require a RAT that has higher coverage area (because they are in high mobility) which will reduce the unnecessary VHO. CRRM can be used to achieve the users objectives based on their preferences, and therefore will lead to increasing the users' satisfactions.

13.3 Heterogeneous Wireless Networks with and without CRRM Algorithm

CRRM was proposed to manage radio resource utilizationRadio resource utilization in heterogeneous wireless networks and to improve RATs performances. RAT selection algorithms are part of the CRRM algorithms. Simply, their role is to verify if an incoming call will be suitable to fit into a heterogeneous wireless network, and to decide which of the available RATs is most suitable to fit the need of the incoming call and admit it. The flowchart of RAT selection process in a heterogeneous wireless network is presented in Fig. 13.2. It is composed into two main directions: with implementing CRRM algorithm and without implementing CRRM algorithm. In the first direction, when a new or VHO call arrives, firstly RATs will be sorted according to the RAT selection algorithm. Then, the RAT with highest satisfaction will be selected to serve the call. Therefore, radio resources will be allocated for the requested call. If the selected RAT is unable to serve the call, the RAT with second highest satisfaction will be selected. If none of the available RAT is able to serve the requested call, the call will be rejected. In the second direction, when a new or VHO call arrives, the RAT will be selected according to the selection algorithm results. If the selected RAT is unable to serve the requested call, the call will be rejected.

As shown in Fig. 13.2, it is clear that CRRM algorithms minimize the blocking and dropping probability. References [23, 1, 21, 13] present the CRRM environment. They compare the performance of the heterogeneous wireless networks against non CRRM algorithm. In [23, 1], results show that the use of CRRM algorithm outperforms the non CRRM algorithm in term of blocking probability. Fig. 13.3 shows the result of reference [23]. In [21], results show that admission control algorithms for CRRM schemes can reach 60-80% traffic gains when compared to the non CRRM scheme. Reference [13] shows that implementing the CRRM in

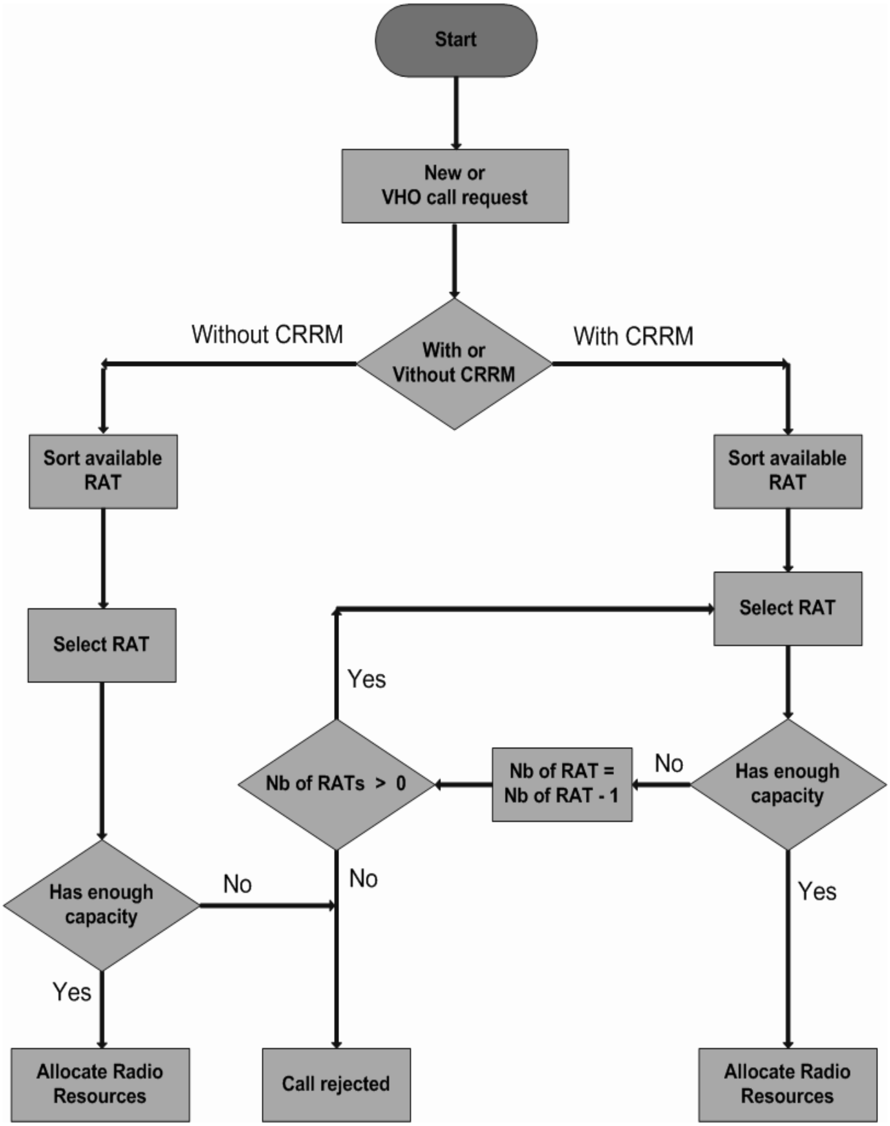

Fig. 13.2. RAT selection process with and without CRRM algorithm

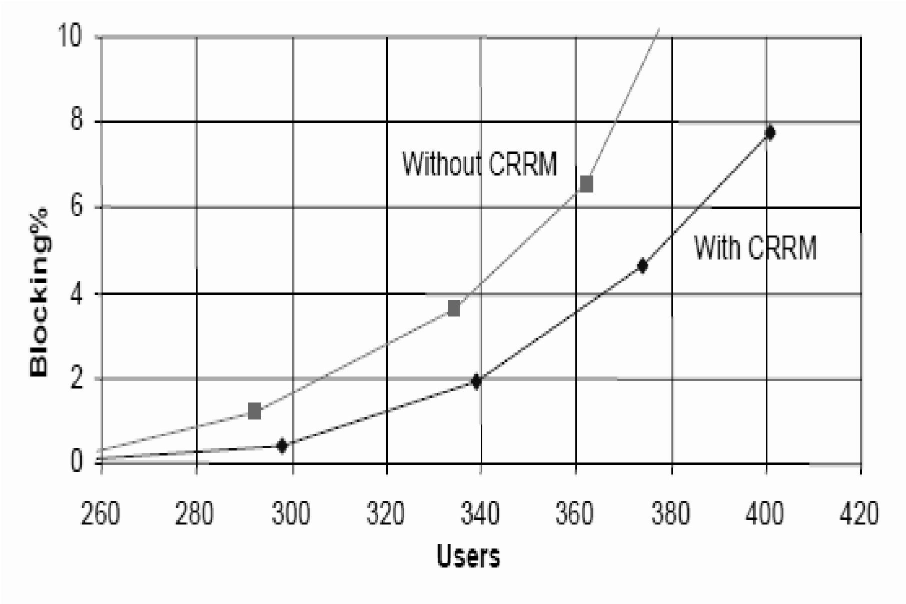

Fig. 13.3. Blocking probability with and without CRRM algorithm. Result presented from Ref. [23].

heterogeneous wireless networks can increase the throughput, performance, accessibility, survivability and modularity.

13.4 RRM and CRRM Interactions

CRRM was proposed to support the RRM decision related to the use of radio resources. Therefore, each RRM entity can take into account the availability of radio resources in other RRM entities of different RATs [2]. Therefore, CRRM entity will have information on the state of the RRM entities that are related to different RATs and it will be responsible for them.

When there is an admission for a new call or a necessary VHO call, CRRM and RRM entities will make a decision regarding admitting the call or rejecting it depending on the degree of interaction between them. Different possibilities of coupling between CRRM and the RRM entity of each RAT may coexist in a heterogeneous wireless network. These types have been proposed in [18, 2]. They can be categorized into:

13.4.1 Loose Coupling

Loose coupling approach is presented in Fig. 13.4. It is a minimum interaction between the CRRM and the local RRM entities. In this approach, CRRM entity is involved only in the decision for the initial RAT selection and VHO. CRRM entity receives the measurements from each local RRM entity that include the cell load for each RAT. Therefore, CRRM can take into account the availability of radio resources for each RAT. It selects the appropriate RAT for the requested new or VHO call. After the RAT has been allocated, the local RRM entity treats the requested call with admission control, packet scheduling, power control, congestion control and necessary horizontal HO.

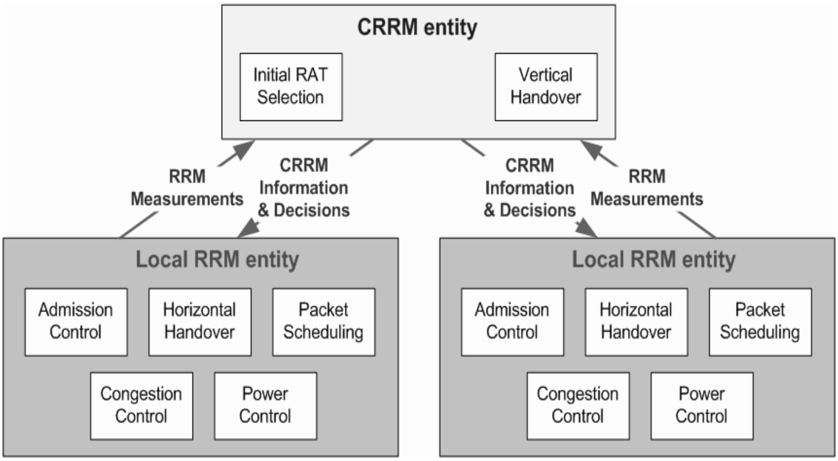

Fig. 13.4. Loose coupling

13.4.2 Tight Coupling

A higher interaction between the CRRM and the local RRM entities is shown in Fig. 13.5. In this approach, CRRM entity is involved in the decision for the initial RAT selection, admission control, horizontal and vertical HO and congestion control. In the tight coupling approach, CRRM entity did not stop by selecting the appropriate RAT for the requested new or VHO call but it becomes involved in deciding the specific cell for the selected RAT.

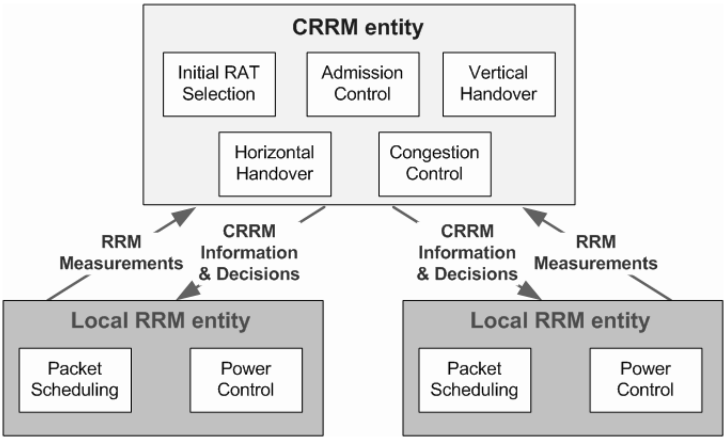

Fig. 13.5. Tight coupling

13.4.3 Very Tight Coupling

A very strong interaction between the CRRM and the local RRM entities is presented in Fig. 13.6. In the very tight coupling approach, CRRM entity is involved in the most decisions for local RRM entities. It selects the appropriate RAT and cell for requested call and it is also engaged in the packet scheduling policy for the call.

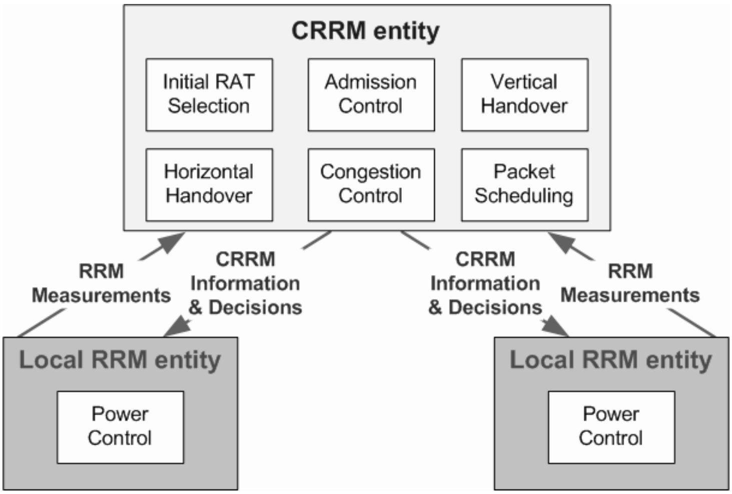

Fig. 13.6. Very tight coupling

13.4.4 Discussion

Different possibilities of coupling between CRRM and the local RRM entities can coexist. A small interaction between the CRRM and the local RRM entities is not able to guarantee required QoS for users and achieve efficient radio resource utilization. StrongRadio resource utilization interaction between the CRRM and the local RRM entities will lead to more efficient radio resource utilization; however, it may lead to a higher quantity of signal overhead.

13.5 Distributing RRM and CRRM Entities among CN, RAT and UTs

CRRM was proposed to support the interconnection between different RATs in heterogeneous wireless networks. The distribution of CRRM functions can be categorize into three approaches: centralized CRRM (CRRM server), integrated CRRM or distributed CRRM (terminal

13.5.1 Centralized CRRM

The centralized CRRM approach has been proposed in [18, 1]. In this approach, CRRM server is added to the core network, and the RRM entity is located in the BSCs in GERAN, RNCs in UTRAN and APCs in WLAN. In this approach, CRRM server is used to support the decisions of RRM entities in BSCs, RNCs and APCs when a new or VHO call is requested. RRM entities report information regarding their RATs to the CRRM entity. The centralized CRRM approach improves network scalability. However, it increases the cost of the network as new element was added and it reduces the system capacity as a result of additional delay coming by delayed selection of RAT and HO decision and by having a signal delay introduced by the communication between the CRRM server and the RRM entities. Fig. 13.7 shows the CRRM server approach.

13.5.2 Integrated CRRM

References [18, 1] propose an integrated CRRM approach, it is shown in Fig. 13.8. In this approach, the CRRM entity and the RRM entities are presented between the BSCs in GERAN, RNCs in UTRAN and APCs in WLAN. CRRM entity may exist in all BSCs, all RNCs and all APCs or in only one subset for each RAT. CRRM functions act immediately between RATs instead of working through the core network.

This approach is already implemented in some heterogeneous wireless networks such as Beyond 3G (B3G) network where IuR, IuR-G & IuR-W interfaces already contain the required components for supporting the CRRM entity. The main advantages of this approach are to limit the infrastructure changes of the network and use the existed functions that can achieve the required system performance. In addition, this approach will achieve the required functions for interconnection in the heterogeneous wireless networks without increasing the delay for initial and VHO RAT selection procedures. Furthermore, minimizing the delay in VHO will have a positive impact on power control and thus maximizing the system capacity. However, this approach may lead to scalability problems when the number of interconnections between RRM entities grows as a result of increasing the number of RRM entities.

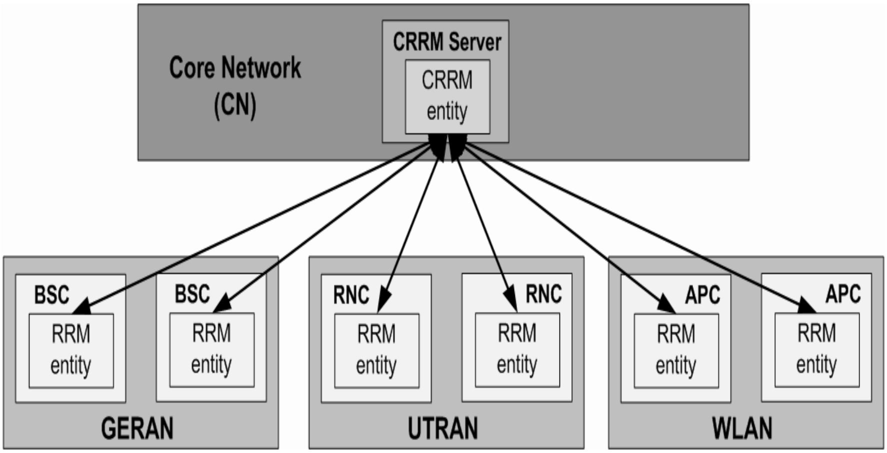

Fig. 13.7. CRRM server approach

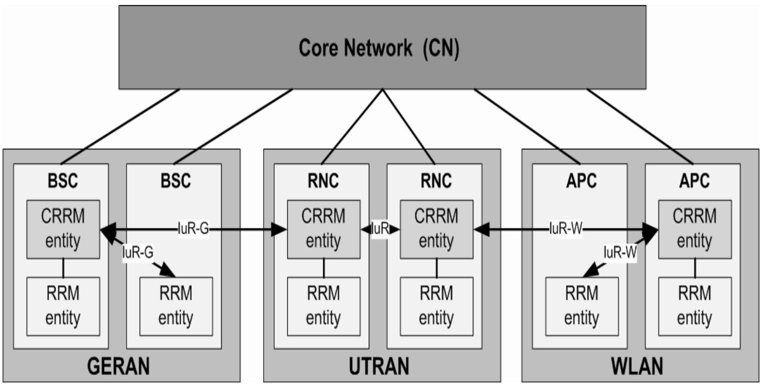

Fig. 13.8. Integrated CRRM approach

13.5.3 Distributed CRRM

Reference [14] proposes a terminal controlled CRRM approach. In this approach, CRRM functions are distributed in the UTs where the CRRM entity can make the decision regarding the suitable RAT that a new or VHO call can be allocated. The main advantages of this approach are providing users with the best possible connection and achieving higher QoS for UTs. However, distributed CRRM approach may lead to inefficient radio resource utilization. Fig. 13.9Radio resource utilization shows the terminal controlled approach.

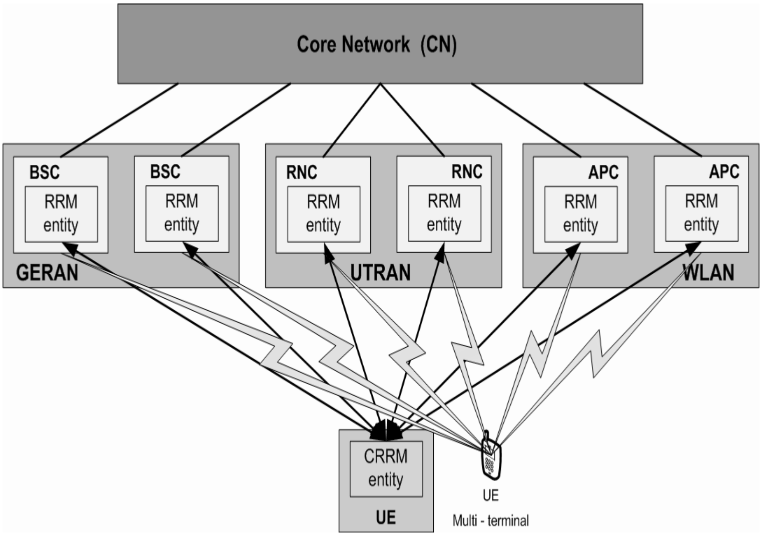

Fig. 13.9. Terminal controlled approach

13.5.4 Discussion

A heterogeneous wireless network can combine these approaches together. Centralized approach could be used for some RRM functions such as overall load sharing. Integrated approach could be used for other RRM functions such as VHO. Terminal controlled approach could be used for other RRM functions such as initial RAT selection. Centralized approach performs better for slow mobility and network functions control; however, integrated and terminal controlled approaches outperform in the case of dynamic resource control.

13.6 Distributed vs. Centralized CRRM Algorithms

With the increase in capacity, ability and power of mobile terminals, a distributed approach (terminal controlled) has been proposed in the literature to get benefits from mobile terminals ability where some of the management workload can be transferred from network to UTs.

A terminal controlled selection approach is presented in [3, 9]. The main idea of the terminal controlled approach is to minimize the management workload in the network equipment and distribute some of them to the UTs. UT keeps some information and measurement for its capacity, profile and preference. Therefore, UT can make decision on selection of the appropriate RAT by analysing the information and measurements. A fully terminal controlled RAT selection approach for heterogenous wireless networks is proposed in [16] without any change in the network infrastructure. This approach allows the UT to select the most efficient RAT that maximizes its satisfaction. By implementing distributed RAT selection algorithms, users will be able to choose the best RAT that achieves their preferences and satisfactions. Also, distributed algorithm reduces the signalling in the network. Therefore, the network capacity is increased. Moreover, there is no need for any change in the existed network infrastructure to implement this approach. However, distributed algorithm does not take into account the network benefits and policies. This may lead to inefficient radio resource utilization and it may cause an unbalanced network load.

On the other hand, a number of centralized RAT selection algorithms have been proposed in the literature for heterogeneous wireless networks. These algorithms improve the overall network stability. Centralized RAT selection algorithms have the benefit of considering more criteria in making decision. However, centralized algorithms do not guarantee the required QoS for the admitted calls. Moreover, they reduce the network capacity as a result of the introduced signal load or delay resulted by the communication between the network entities.

Distributed RAT selection algorithms do not consider networks preferences and policies. Centralized RAT selection algorithms do not guarantee the required QoS for the admitted calls and reduce the network capacity. A hybrid RAT selection algorithm (distributed with network assistance) seems to be a solution for this problem. In the hybrid approach, the network will provide the UTs some information that assists them in their decisions to select the most efficient RAT that maximizes their satisfaction and in the same time improve the efficient radio resource utilization. IEEE P1900 Standards Committee proposes an IEEE P1900.4 Protocol [10] that is able to provide the required support to the hybrid approach. This protocol is described in the next section.

A distributed RAT selection strategy at the UT by using IEEE P1900.4 protocol is proposed in reference [20]. It takes the NCCB RAT selection algorithm proposed in [19] for heterogeneous CDMA/TDMA scenario and implements it in a distributed approach using IEEE P1900.4 protocol. Results show that the distributed NCCB RAT selection algorithm using IEEE P1900.4 protocol performs better then the centralized load balancing RAT selection algorithm.

13.7 Conclusion and Future Works

CRRM is essential for heterogeneous wireless networks. An intelligent implementation strategy will improve the efficiently of radio resource utilization, increase users' satisfactionsRadio resource utilization and maximize network operator's revenue. In this paper, we discuss the need of CRRM in heterogeneous wireless networks. A comparison between implementing or not the CRRM in heterogeneous wireless networks is studied. Then, the interaction between RRM and CRRM entities is presented. After that, different approaches for the distribution of RRM and CRRM entities among the CN, RATs and UTs are studied. Finally, a comparison between centralized and distributed CRRM algorithms is presented. Centralized algorithms have the benefit of considering more criteria in making decision. However, they have a disadvantage in terms of reducing the network capacity. Distributed algorithms allow UTs to select the most efficient RAT that maximizes their satisfactions. They maximize the network capacity. However, distributed algorithms are inefficient because of the limitation of information at UT such as cell load, and network policies and preferences. A best solution could be by implementing a hybrid CRRM approach (terminal controlled with network assistance), where the network will assist the UTs in making RAT selection decision by providing information and policies related to the network. Future research works may include the following: provide an evaluation between different centralized and distributed CRRM algorithms in terms of blocking probability, dropping probability, throughput and users' satisfactions probability, propose an intelligent hybrid CRRM approach to support the RAT selection in heterogeneous wireless networks, simulate the proposed intelligent hybrid approach in different scenarios and do an analytical approach for the proposed intelligent hybrid approach using Markov Model.

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