Radio Resource Management in Heterogeneous Networks – A Survey

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Abstract— Today's multimedia application has many requirements in terms of quality of service and users always want to be best connected anywhere, anytime, and anyhow. To satisfy these demands, many access technologies have become available: WLAN, WMAN, and Cellular networks. For service provider, it is difficult to select the best network for requesting services and to control the quality level of ongoing connections due to coexistence of these technologies in the same region. Thus, resource management is needed to prevent overloaded or underutilized networks as well as to best satisfy users is necessary. This survey paper addresses the problem of Radio resource management, existing resource management techniques and their limitations.

Key words: Heterogeneous Network, Radio Resource Management (RRM), Radio Resource Allocation, Quality of Service (QoS), Mobile Terminal (MT)

I. INTRODUCTION

Currently, the wireless communication network is more effective with overlapped coverage from different networks in heterogeneous environment [1][2]. These wireless access networks include cellular networks, Wireless Metropolitan Area Networks (WMANs), Wireless Local Area Networks (WLANs), and so on. Such networks have complimentary service capabilities in terms of bandwidth, coverage area, and cost. Hence, in this heterogeneous wireless access medium, the integration of these different networks will lead to better service quality to mobile users and enhanced performance for the networks [2] like coverage area and data rate.

A very important component of the heterogeneous network architecture is radio resource management mechanisms for bandwidth allocation and call admission control. These mechanisms are essential in order to satisfy the required bandwidth by Mobile Terminals (MTs) via different available wireless networks and to make efficient utilization of the available resources from these networks.

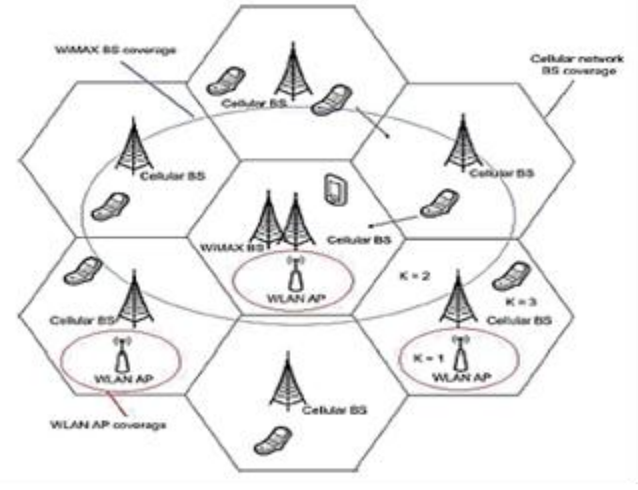

Fig. 1: Heterogeneous network

In literature, there are many works have studied the radio resource allocation problem in a heterogeneous wireless access medium. Mainly two types of radio resource allocation mechanisms can be distinguished, first type, referred to as single-network resource allocation and utilizes a single radio interface of an MT. Hence, each call obtains its required bandwidth from a single access network at any time instant. The second type, referred to as multi-homing resource allocation, utilizes multiple radio interfaces of an MT are used simultaneously to satisfy the user's requirement. Here, the MT obtains its required bandwidth from all wireless access networks available at its location.

The multi-homing resource allocation mechanism is further classified into centralized and distributed technique. In the centralized, control is aggregated into one central point which is usually situated in the core network. Where as in distributed or decentralized architecture, opposite of centralized architecture, where control is allocated into several places either on the network or eventually on the user terminal.

The remainder of this paper is organized as follows. Section II presents the architecture of radio resource management of a heterogeneous wireless network. Section III presents formulation of radio resource management problem in heterogeneous network. Section IV presents different solutions to radio resource management problem and finally, conclusions are drawn in Section V.

II. ARCHITECTURE OF RADIO RESOURCE MANAGEMENT

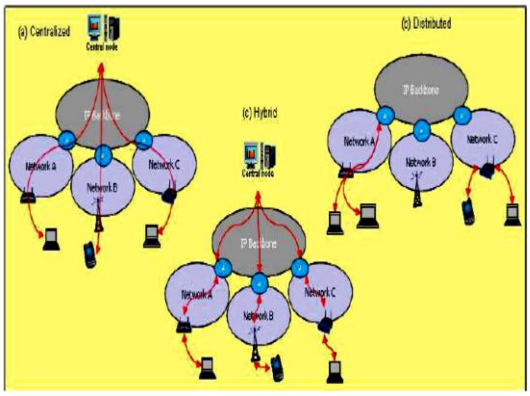

Fig. 2: Different types of RRM architectures

The architectures for resource management found in most of the papers can be categorized into three types described below [10]. The first one is centralized architecture illustrated in Figure 2a. In this architecture, control is aggregated into one central point which is usually situated in the core network. The opposite of centralized architecture is distributed or decentralized architecture illustrated in Figure 2b. Control in this architecture is allocated into several places either on the network or eventually on the user terminal. In general, the control is placed at access router if network provider wants to manage the access network.

Figure 2c illustrates the last one called hybrid architecture; this type of architecture combines centralized and distributed architectures described above. It composed of central node that manage global resource and distributed nodes to manage resource locally.

The existing resource allocation mechanisms that support MTs with multi-homing capabilities in a heterogeneous wireless access medium require a central resource manager to perform the resource allocation and admission control [11].

A central resource manager is needed in these cases as the allocated bandwidth from each network BS/AP to a given connection should sum up to the bandwidth required by the connection. As a result, a global view of the BS/AP resource availability of every network is required in order to perform coordination among the allocations from different networks to satisfy the total required bandwidth for the connection. This global view is provided by the central resource manager.

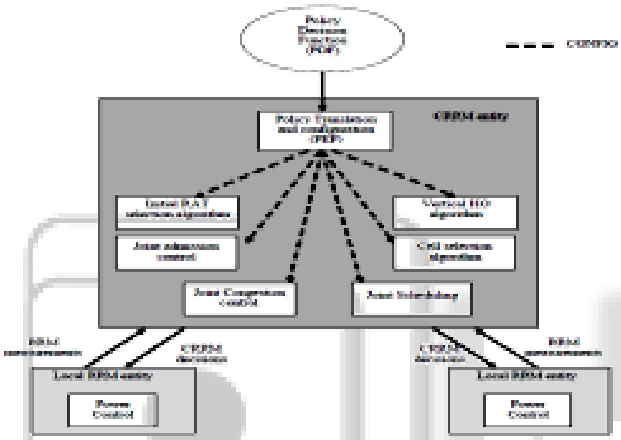

Fig. 3: Central resource manager (CRRM) architecture

In [3] Decentralized Resource Allocation algorithm is proposed to support MTs with multi-homing capabilities in heterogeneous wireless access medium. Using this algorithm, each network BS/AP solves its own utility maximization problem to allocate its resources to multi-homing MTs. The MTs coordinate the allocation from different networks in order to satisfy its total required bandwidth.

III. FORMULATION OF RADIO RESOURCE ALLOCATION PROBLEM

The problem of radio resource management in a heterogeneous wireless access medium is studied in [1] - [5]. The existing solutions can be classified in two categories, namely single network and multi-homing resource allocation mechanisms. This classification is based on whether a single radio interface or multiple radio interfaces of an MT are used simultaneously for the same application.

The single-network resource allocation mechanisms are studied in [6] and [7]. The single-network resource allocation mechanisms suffer from a limitation that an incoming call is blocked if no network in its service area can individually satisfy the required bandwidth of the call. Hence, these mechanisms do not fully utilize the available resources from different networks.

The multi-homing resource allocation mechanisms are studied in [8] and [9]. The mechanisms of [8] and [9] support multi-homing MTs, each call obtains its required bandwidth for a specific application from all wireless access networks available at its location. This has the following advantages: 1) The available resources from different wireless access networks can be aggregated to support applications with high required bandwidth. 2) The multi-homing concept can reduce the call blocking rate and improve the overall system capacity.

Consider a geographical region with a set, N, of available wireless access networks using different technologies, $N = \{1, 2, . . .,N\}$. Each network, $n \in N$, is operated by a unique service provider. Network $n \in N$ has a set, S_n, of BSs/APs in the geographical region, $S_n = \{1, 2, . . ., S_n\}$. The BSs/APs of each network have different coverage areas from those of other networks. With overlapped coverages from different networks in some areas, the geographical region can be described by a set, K, of service areas, $K = \{1, 2, . . .,K\}$. A unique subset of BSs/APs from all the networks cover each service area, $k \in K$, as shown in Figure 1. The set of networks available at service area k is given by N_k, and the set of BSs/APs from network n covering service area k is given by S_{nk}. The downlink transmission capacity of each network, $n \in N$, BS/AP, $s \in S_n$, is C_{ns} Mbps.

Consider a downlink scenario, where an MT, m, can get its required bandwidth, B_m, on the downlink from all wireless access networks available at its location using its multi-homing capability. The set of MTs available in the geographical region is denoted by M. The set of MTs which lie in the coverage area of the s^{th} BS/AP of the nth network is denoted by M_{ns}. The allocated bandwidth in the downlink from network n to an MT m through BS/AP s is denoted by b_{nms}, where $n \in N$, $m \in M_{ns}$ and $s \in S_n$. Let $B = [b_{nms}]$ be a matrix of allocated bandwidth from network n through BS/AP s to MT $m \in M$.

As multi-homing resource allocation is employed to support applications with a high required transmission rate, we consider video service applications such as on-demand streaming. A video call of MT m is considered to be a variable bit rate (VBR) service that is allocated a bandwidth B_m in the range $[B_m^{\ min}, B_m^{\ max}]$, where $B_m^{\ min}$ guarantees a minimum quality-of-service (QoS) requirement for the video call. The more allocated bandwidth to a video call, the higher the perceived video quality experienced on the MT. However, there is a maximum bandwidth $B_m^{\ max}$ that can be allocated to a video call, which is enforced to incorporate the MTs technical limitations. With sufficient resources in the service area, a VBR call is allocated its maximum required bandwidth $B_m^{\ max}$. However, when all BSs/APs in the service area reach their capacity limitation, the allocated bandwidth for the VBR video call is reduced towards the minimum required bandwidth $B_m^{\ min}$ in order to accommodate more calls.

The resource allocation problem for MTs with multi-homing capabilities in a heterogeneous wireless access medium is expressed by the following optimization problem,

$$\begin{aligned} \max_{B} \quad & \sum_{n=1}^{N}\sum_{s=1}^{S_n}\sum_{m\in\mathcal{M}_{ns}} \ln(1+\eta b_{nms}) \\ s.t. \quad & \sum_{m\in\mathcal{M}_{ns}} b_{nms} \le C_{ns}, \qquad \forall n\in\mathcal{N}, s\in\mathcal{S}_n \\ & B_m^{\min} \le \sum_{n=1}^{N}\sum_{s=1}^{S_n} b_{nms} \le B_m^{\max}, \qquad \forall m\in\mathcal{M} \end{aligned}$$

Where η is used for scalability of b_{nms} and [B_m^{min} ,B_m^{max}] is defined for service l of MT m among the L available service classes. We refer to above optimization problem as optimal resource allocation problem (ORAP). The resource allocation objective of the ORAP is to find the optimal allocation b_{nms}, $\forall n \in N$, $m \in M_{ns}$ and $s \in S_n$, that maximizes the total utility in the region. The first constraint in above expression satisfies the BS/AP capacity limitation, while the second constraint satisfies the call required bandwidth of MT m from all wireless access networks available at its location. The heterogenity in the network settings of optimization problem appears in two aspects. The first aspect is the heterogenity in networks capacities, which is introduced by the term C_{ns}. The second aspect is the heterogenity in coverage areas, which is introduced through the term M_{ns}. The transmission technologies for different networks are handled through the MT's different radio interfaces.

There are many algorithms are proposed for optimal solution for radio resource allocation problem when different networks are operated by different service providers. We will study each in next section.

IV. SOLUTIONS TO RADIO RESOURCE ALLOCATION PROBLEM

A. Centralized Optimal Resource Allocation (CORA):

A centralized implementation of the CORA algorithm is illustrated in Figure 4.

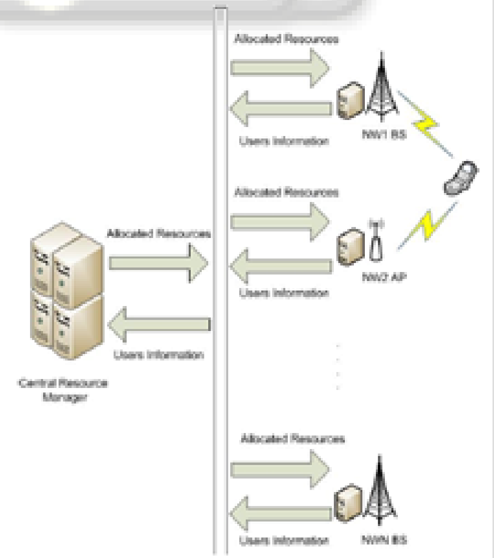

Fig. 4: Implementation of the CORA algorithm.

In this implementation, each MT reports to all BSs/APs available at its location its service type, service class, and home network using its multiple radio interfaces. This information is made available to the central resource manager via different BSs/APs. As a result, the central resource manager has the information of the service area, MT minimum and maximum required bandwidth, and MT priority parameter. Given the transmission capacities of all the BSs/APs, the central resource manager determine network assignment and bandwidth allocations for new incoming MTs with single network and multi-homing services, updates bandwidth allocations and initiates vertical handovers for existing MTs if necessary.

B. Decentralized Optimal Resource Allocation (DORA):

The DORA is an iterative algorithm. It performs an optimal bandwidth allocation to a static set M of calls at the BSs/APs of all networks based on the update of three parameters, namely link access price of network n BS/AP s and coordination parameters of MT, over a number of iterations, until an optimal solution is reached. Each network BS/AP starts with an initial feasible value for its link access price. Similarly, each MT starts with an initial feasible value for its coordination parameters. The MTs broadcast their coordination parameters to all BSs/APs available at their locations. The BSs/Aps perform their bandwidth allocation to the MTs based on their link access price values and the coordination parameters from the MTs. Each BS/AP updates its link access price value based on its capacity limitation and the total traffic load carried in its coverage area. Also, each MT updates its coordination parameters based on the allocated bandwidth from different BSs/APs and its required bandwidth. The MTs broadcast their updated coordination parameters to the BSs/APs and the process continues until the algorithm converges to the optimal.

The algorithm is originally proposed for a static system model, without arrivals of new calls or departures of existing ones. The study in [3] identifies the role of each entity in the heterogeneous wireless access medium in a decentralized architecture.

C. Decentralized Resource Allocation In A Dynamic Environment:

In a dynamic system, the call traffic load at each BS/AP fluctuates over time with call arrivals to and departures from its coverage area. This results in a fluctuating (time-varying) optimal value for the link access price and bandwidth allocation matrix with every call arrival or departure. Hence, bandwidth reallocations to the existing calls are triggered. In order to reach the optimal bandwidth allocation in such a decentralized architecture, information exchanges between MTs and BSs/APs for coordination parameter updates are required for the I iterations. This should take place with every call arrival to or departure from any service area. Hence, applying the DORA in a dynamic system incurs high signaling overhead. In addition, it is possible that an arrival or departure event occurs during the DORA I iterations, thus it may not converge to an optimal solution. As a result, the DORA is not practical to implement in a dynamic scenario.

In next section, we discuss how to address the aforementioned implementation challenges and propose a sub-optimal decentralized algorithm for efficient resource allocation in a dynamic system.

D. Constant Price Resource Allocation (CPRA):

In order to perform an efficient decentralized radio resource allocation in a dynamic network environment, one strategy is to avoid solving the Optimal Resource Allocation Problem (ORAP) for every call arrival to or departure from any service area. Meanwhile, our main objective is to satisfy the required resource allocation per call for a certain call blocking probability. These objectives are achieved by employing fixed link access price values for resource allocation at different networks BSs/APs independent of call arrivals and departures. With time-invariant BS/AP link access price values, the corresponding resource allocation is referred to as constant price resource allocation (CPRA).

The CPRA has two phases, namely setup phase and operation phase. The setup phase is executed only once at the initial operation time of the networks, while the operation phase is executed every time a new MT joins the networks.

1) The Setup Phase:

This phase is to determine the fixed BS/AP link access price values based on steady-state statistics of call traffic and user mobility in order to achieve satisfactory performance in terms of allocated resources per call and call blocking probability in the operation phase.

2) The Operation Phase:

In this phase, the bandwidth allocation process is performed for each user joining the networks.

(1) An incoming MT uses its multiple radio interfaces to listen to the link access price values of the BSs/APs available at its location.
(2) The MT then uses the link access price values to solve for the bandwidth share from each BS/AP such that the total amount of resources allocated from all the BSs/APs satisfies its required bandwidth.
(3) MT asks for the bandwidth share from BS/AP of network, which performs the allocation if it has sufficient resources. The MT call is blocked if the total allocated resources do not satisfy its required bandwidth.

As the BS/AP link access price values are independent of call arrivals to and departures from different service areas, no resource reallocations to existing calls are required. Furthermore, the I iterations required to reach the desired resource allocations from all the BSs/APs to satisfy the total required bandwidth is solved locally at each MT without information exchange between the MT and the BSs/APs for every iteration as in DORA. Hence, the CPRA approach requires almost no signaling overhead in order to reach the required bandwidth from each BS/AP. The convergence of the CPRA algorithm follows the convergence of the DORA algorithm. However, the CPRA algorithm provides a suboptimal solution to the ORAP of as the link access price value is not updated with every call arrival and departure.

E. Prediction Based Resource Allocation (PBRA):

The CPRA performs the resource allocation based on Target value of number of calls of service class l in service area k estimated based on link access price value calculated according to the steady-state (long-term) call traffic and user mobility statistics. In a dynamic environment, Target value of number of calls can deviate from actual number of calls for some time. However, the resource allocation in the operation phase does not adapt to short-term dynamics in the call traffic load. A call can be allocated only its minimum required bandwidth even if there exist sufficient resources in the BSs/APs at its current location that can be used to provide better service quality. In CPRA, these extra resources which are not utilized (at a low traffic load) are actually reserved for possible incoming calls, so that the target call blocking probability can be achieved. For a better service quality compromise between the existing calls (in terms of the amount of allocated resources to each call) and the potential incoming calls (in terms of the call blocking probability), resource allocation adaptive to a short-term call traffic load (via resource re-allocation to the calls in service) can help. To do so, in the following, we propose to update Target value of number of calls of service class l in service area k in the operation phase periodically with period τ, and hence update the corresponding BS/AP link access price values, based on the instantaneous number of calls at time t. We refer to the corresponding resource allocation as prediction based resource allocation (PBRA).

In the operation phase, the PBRA updates the target value by every period using the current number of calls in service. With this extra information, the PBRA can make a better prediction of the call traffic load in a short-term, and hence an improved resource allocation is expected over the CPRA. The PBRA algorithm provides an improved sub-optimal solution to the ORAP as compared to the CPRA algorithm. The convergence of the PBRA algorithm to this sub-optimal solution follows the convergence of the DORA algorithm.

Parameters	Resource allocation Method			
	CORA	DORA	CPRA	PBRA
Signalling overhead	High	High	Low	Low
Processing time(convergance time)	High	High	Low	Low
Vertical Handover	More	More	Less	Less
BW allocation dependance to call arrival/Departure rate	Yes	Yes	No	No
Failure rate	More	less	less	less
Optimal resource allocation	Yes	Yes	Sub-Optimal	Sub-Optimal

Comparison of different Resource allocation methods in dynamic system

V. Conclusion

This paper explains about the introduction of heterogeneous network. It also provide an overview of Radio Resource Allocation problem in Heterogeneous Network and many different solutions to radio resource allocation problem. It mainly concentrated on centralized and distributed mechanisms and considering their advantages and disadvantages under various conditions.

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