Modeling of Common Radio Resource Management Scenarios

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ABSTRACT

In this paper we first present a systematic view on common radio resource management (CRRM) problems. Then we classify different CRRM levels and propose a categorization framework for CRRM algorithms based on their relationship to load sharing strategies. The proposed model framework based on this systematic view enables a cost-benefit analysis of different CRRM algorithms and architectures. Different centralized or decentralized scenarios can be clearly defined based on five standard components (the radio access system, the environment, the user equipment, the CRRM information manager and the CRRM decider). The costs of CRRM operations are taken into account via chargeable messages. The clarity of the model enables an efficient investigation of CRRM algorithms based on optimization theory, game theory, physical models and other methods. We also describe the implementation concept of the model framework.

1. INTRODUCTION

At present wireless networks based on different radio access technologies (RAT) have been deployed to fulfill the demand for wireless communications. Satellite based wireless global area networks (WGAN) provide their services almost worldwide. Also wireless wide area networks or metropolitan area networks (WWAN, WMAN) like GSM, UMTS, CDMA-2000, WiMAX or broadcast systems like DVB-H provide large areas with seamless wireless connections for transmission of mobile data and multimedia services with high quality of service (QoS) demands. Recently wireless local area networks (WLAN) like Wi-Fi became important for wireless hot-spots and ad-hoc networks. Wireless personal area networks (WPAN) like Bluetooth are available in almost all mobile devices. This large variety of different co-existing RATs continues to persist in future mobile networks as one RAT is not able to meet the diverse requirements of mobile users. Besides, mobile providers need time to deploy next generation mobile networks and to transfer their customer base to use the new system. Mobile devices are often able to make use of different RATs; technologies like software-defined radio (SDR) will further improve this in the future [10].

Since wireless networks based on different RATs may co-exist at the same location the problem of an optimal common management of the network resources emerges. Different terms like common, joint, multi standard radio resource management (CRRM, JRRM, MxRRM) or always best connected networks are used to denote this topic [9,11-15]. The main aim is to increase the users' perceived QoS and to decrease installation, operation and maintenance costs of the wireless networks. This is achieved via an intelligent assignment of mobile devices to different radio technologies considering the specific advantages of each system. Published results of several working groups show that a capacity gain of the combined wireless systems compared to disjunct systems can be exploited [1-9]. These papers mostly focus on the possible algorithms and capacity gains and neglect the expenses needed to achieve this gain. The Question whether the algorithms work best in a centralized or decentralized CRRM environment is also not investigated. Our proposed model enables a cost-benefit analysis of different CRRM algorithms and architectures. Different system architectures can be readily defined based on standard components. We derived these standard components based on a systematic view of CRRM therefore our model covers many different possible applications of CRRM algorithms.

This paper is organized as follows. In section 2 we give a schematic view of CRRM. Section 3 gives an account of the derived framework and section 4 describes the simulator based on the developed model. Section 5 concludes the paper.

2. A SYSTEMATIC VIEW OF CRRM

The common logical structure of all different radio access technologies can be described as following: A user equipment (UE) is in wireless contact with a radio access system (RAS) which on its side is in contact with the core network (CN). A radio access network (RAN) can consist of several RAS. Each RAS has an autonomous local radio resource management (RRM) entity residing either close to the wireless transceiver or partly in the CN. The RAS can be a satellite in case of a WGAN, a cell layer in case of a cellular WWAN system like UMTS, or even a single cell in case of a WLAN system or other UE in case of ad-hoc networks. The Quality of Service (QoS) capabilities of the RAS have a major impact on the offered QoS of the whole network. This is due to the generally unreliable wireless connection, which is improved by diverse backward and forward error correction techniques. Each RAS uses different layer 1 and 2 protocols (ISO/OSI model) with unique QoS-features depending on the used RAT. The core network's main task is authentication, authorization, accounting (AAA), gateway support to other networks and QoS-brokerage. It can be assumed that the core network is capable to support the QoS-features of the connected RAS by design.

CRRM is accomplished by specialized entities which are in contact with local RRMs. Thus it is an enhancement of the existing networks. An overview of the three different possible levels of CRRM is given in figure 1. Level A represents the CRRM between different RASs of one RAT (Radio Access Technology) operated by a single provider; e.g. this could be the CRRM of a micro and a macro cell layer. The CRRM of different RAT belonging to one provider is subsumed under level B. This could be e.g. the common management of the resources of a GSM/GPRS, UMTS and a DVB-H network. The last level C stands for the CRRM of resources of different providers. Every CRRM level has unique requirements. Especially level C needs a minimization of required information about the current state of the networks because of security and business concerns.

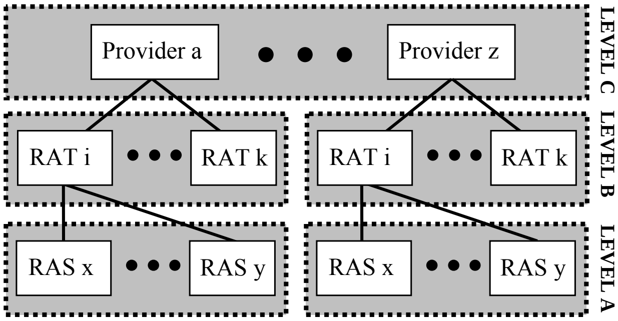

Figure 1: Three levels of CRRM

The CRRM entities may reside on the side of the network or within the UE. The latter is the case if the UE itself decides whether it connects to a particular RAS depending on the properties of the RAS and the needed service. This is often the case for the initial choice of the RAT for connection establishment. All in all the CRRM can be seen as a control mechanism with a closed-loop control as shown in figure 2. The first step of the control loop is to measure the state of the network, the state of the UE and the QoS offered for existing services. There exist different measuring points on the network side (e.g. base station, radio network controller, mobile switching center) or on the side of the UE which depend on the measured parameters. Some information can only be obtained by measuring at the side of the UE, like signal quality at the position of the UE. Other information, like load of the cell, can only be obtained by measuring at the side of the network. Some information can be obtained on both sides, like the position of the UE, e.g. by using a GPS receiver in the UE or by evaluating the properties of the received signal and the cell ID at the RAS. Since there are different measuring points it is necessary to distribute the collected information to the CRRM entities. Information to be distributed to the CRRM entities are for example the availability of different RAS at the position of the UE, the technical capabilities of the UE and the state of the services and RAS. The implementation of this distribution architecture has to account for the balance between the amount, actuality and costs of measuring as well as administration of the information. The storage and distribution management of information can have either a distributed, a hierarchical or a central architecture.

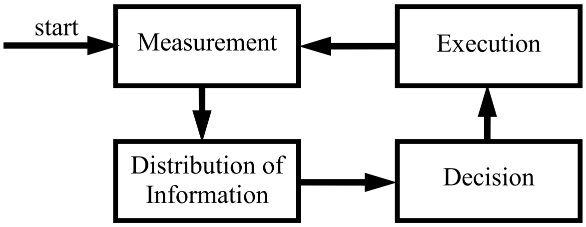

Figure 2: CRRM control loop

After distributing the information it has to be processed in CRRM decision entities. The architecture of these decision entities may be distributed, hierarchical or central. Examples for distributed or central architectures for CRRM are given in 3GPP 25.891 [15]. The organization of the decision management is not necessarily similar to the organization of the information management. Thus it is possible to have a central information management and a distributed decision management. This will become obvious after comparing CRRM with the classification-model for load sharing algorithms in [16]. CRRM must be able to handle situations such as the following one: A set of services residing on different UEs is not satisfied with the offered QoS. At the position of these UEs a set of RASs exists with different properties. Not all UEs are able to connect to all of the RASs due to technological and administrative limitations. The CRRM decision entities try to find the optimal solution under the given constraints. The solution has to account for the dynamics of the system (e.g. low blocking, low dropping, and only few ping pong handovers) and for offering sufficient QoS to all active services and for minimizing costs as well. Many different factors can play a role in this decision.

Properties of the RAS:

- offered QoS (data rate, delay, jitter, bit error rate, security, packet- or circuit switched connection, support of priorities and QoS-guarantees)
- point to point, multicast or broadcast medium
- load in the cells, size of cells, signal properties (strength at the UE, frequency, coding)
- costs (energy consumption, monetary costs of equipment usage)
- affiliation to different providers
- technological and administrative access pre-conditions (e.g. RAT support, roaming contracts)

Properties of the UE:

- QoS demands of the active services of the UE
- resource consumption
- type of customer (premium or best effort)
- supported RAT
- mobility parameters (e.g. velocity, position)

After evaluation of the available information several actions are possible to meet the defined goals of the CRRM. One of the most important options is to handover the UE to another RAS (intersystem handover, vertical handover). Other options are to adapt the offered QoS according to each service's QoS profile or to change the RRM-properties of the RAS (e.g. allocate additional frequency bands). The CRRM decision entities need suitable protocols and communication connections to initiate the execution of their commands. In our model framework in section 3 we generally assume such protocols and connections are already available. After the execution of the decisions new measurements are performed to assess the new system state. This closes the control loop.

Since CRRM has a very close relation to load sharing algorithms, the theoretical framework of [16] can be applied to categorize CRRM algorithms. The categories cover

- system model
- transfer model
- information distribution model
- coordination model
- time horizon
- stability control
- adaptivity

The system model describes the target topology in which the CRRM algorithm is executed. The transfer model describes how services can be transferred between different RAS and whether they are preemptive or not. The information distribution model describes the architecture of the information exchange. It defines whether CRRM entities have partial or full knowledge of other entities' states and whether CRRM entities collect information system wide or locally. The coordination model describes the type of CRRM architecture (distributed or centralized) and whether CRRM entities act corporative, competitive or autonomous. It also describes whether an asynchronous or a synchronous decision process of the different CRRM entities will be applied. The stability mechanism describes how costs and ping pong handovers are accounted for. Additionally the time horizon defines the time span necessary for decision and execution. This time span may cover milliseconds or even days or weeks. CRRM algorithms can also be distinguished with respect to their adaptivity. Fixed strategies or adaptive strategies depending on the system state are possible, e.g. low and high traffic load strategies.

3. MODEL FRAMEWORK

The proposed model framework is based on the systematization presented in section two. With this framework we can easily model different CRRM scenarios. The aim of the model is to represent the fundamental structure of wireless systems of different RATs. Additionally the model is also able to associate costs with CRRM operations. This enables us to assess CRRM algorithms in different scenarios not only by their ability to achieve good QoS for services but also by their expenses. The model components are environment (ENV), user equipment (UE), radio access system (RAS), CRRM information manager (CRRM-IM) and CRRM decider (CRRM-D). These components exchange messages over free and chargeable connections. The layout of these connections is based on real world communication paths depending on the scenario. A message from a network side CRRM-IM needs to use a RAS connection to reach the UE component. Each transport of a message over chargeable connections causes costs and time delays. All CRRM relevant information and commands are sent by this kind of connections. On the other side free connections are used to transport system inherent information not related to CRRM activities. CRRM components are only able to use chargeable connections. The layout of these connections is different for distributed, hierarchical or centralized scenarios. Figure 3 shows a scheme of all possible component connections.

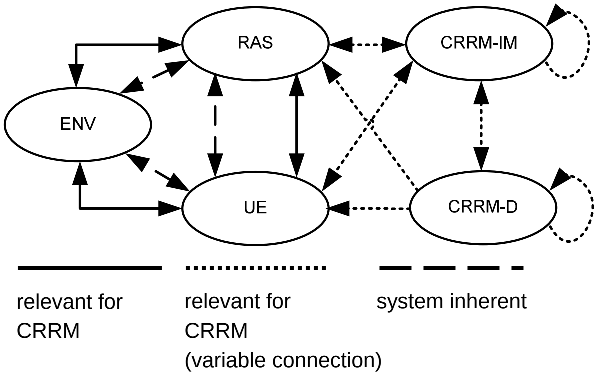

Figure 3: Model entities and their connectivity

The component environment (ENV) models the dynamic behavior of the system regarding the mobility of the UE. It provides information about the position or velocity of the UE and the local signal quality of different RASs. The component radio access system (RAS) processes the service demands of the UE. Input parameters are mobility, service demands and technological capabilities of the UE as well as local signal reception quality and CRRM commands. Analytical models of the different RATs provide values for offered QoS and traffic load in the RASs. Additionally implemented are RRM-algorithms to establish call admission control. Necessary functions of the CN like AAA control or RRM control are also included in the RAS component. The component user equipment (UE) models the technological capabilities (e.g. supported RAT) and the dynamics of service demands of different UE classes. This component sets up the mobility parameter of the UE as well. Connections to RASs are restricted to RASs with supported RAT. Input parameters are offered QoS, measurement reports on available RASs and CRRM commands.

The CRRM components are defined according to the separation of information management (CRRM-IM) and decision management (CRRM-D). The CRRM algorithms are implemented in these components. The CRRM-IM component starts and stops measurements of system parameters, as well as collects and stores the results. The CRRM-D component processes these collected information and initiates the adaptation of the system to meet the service demand requirements. Figure 4 shows how different CRRM levels may be realized with the proposed model framework. The indices i, j, k indicate that several instances of these components are possible. The components RAT, Provider and Roaming are only used for structuring the resulting architecture.

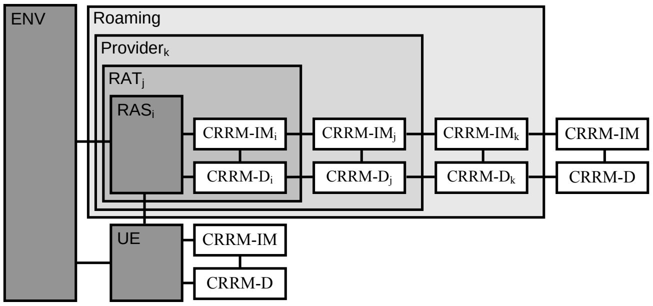

Figure 4: Modeling of different CRRM levels

Omitting different CRRM components creates distributed, hierarchical or centralized CRRM architectures. For example level B CRRM (see figure 1) with a distributed decision and centralized information management can be realized as shown in figure 5. The figure shows a CRRM of GSM and UMTS micro/macro cell layer. The CRRM-IM component collects information of all RASs (micro/macro-layer) and UEs (via RAS) and provides them to the CRRM decision components. The CRRM-D components are able to relay their commands to other CRRM-D components.

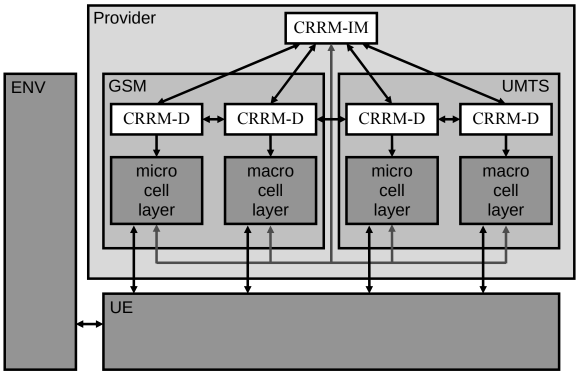

Figure 5: Example for level B CRRM

4. CRRM SIMULATOR

The model framework described above is implemented by using the discrete event simulation system OMNeT++. CRRM scenarios are specified by defining layouts for the model components introduced in section 3 (Figure 3) and by setting up the component parameters. The simulator includes analytical RAT models to represent different mobile communication technologies, e.g. models for GSM/GPRS and UMTS. The dynamics of the system is characterized by a random waypoint mobility model [17] and ON/OFF service models [18] for real time and non real time services. The model components communicate via free and chargeable messages using the defined free and chargeable connection paths. The logic of the components ENV, UE, RAS, CRRM-D and CRRM-IM is implemented under the following considerations:

Component ENV:

For each network type (WPAN, WLAN, WWAN, WGAN) layers with different spatial grid resolutions are defined. The WPAN layer has a very fine resolution whereas the WGAN layer has a very coarse one. Due to this partitioning the simulation process gains efficiency. The mobility of the UE is implemented at the grid element level. The UE travels from grid element to grid element and the camping time is calculated from its mobility parameters and the element's dimensions. The grid resolution is chosen related to the RAT of the UE's connection. Each grid element carries information on the receivable RAS. If a UE connected to a receivable RAS enters or leaves a grid element a cost free message is sent to the RAS. The analytical model of the RAS is updated with each message.

Component UE:

This component implements the algorithms for a set of different UE-classes. For each UE-class it is specified which RATs it supports and which services are used. The QoS demands (data rate, delay, bit error rate) for each service are defined via a utility profile:

$$P_i = \begin{cases} 0 & \text{if } V_i < V_{i,\min} \\ \dfrac{V_i}{V_{i,\max}} & \text{if } V_{i,\min} \le V_i < V_{i,\max} \\ 1 & \text{if } V_i \ge V_{i,\max} \end{cases} \tag{1}$$

where P_i is a QoS parameter profile, V_i is its momentary offered value and $V_{i,\min}$, $V_{i,\max}$ are its corresponding minimal and maximal needed value. If $\prod P_i = 0$ the connection is not feasible for the service of the UE. New services are started according to a Poisson arrival process and stopped after their service demands are fulfilled or an error occurred (e.g. no coverage). Each type of service has its specific ON/OFF model. Resources are only assigned to the service during the ON-phase. The ON phase of a circuit switched real time speech service equals the duration of the connection. The ON/OFF phase distribution of a packet switched WWW-browsing service can be implemented according to the behavioral model of Choi and Limb in [19]. According to this model the ON phase represents the time needed for fetching all objects belonging to one web request. The OFF phase represents the reading time of the user.

Component RAS:

Each RAS can consist of several cells which represent one micro or macro cell layer. The grid elements defined in the ENV component are assigned to each cell distinguishing the cases good, intermediate and no signal reception. A perfect power control is assumed. During measurements equivalent signal quality values are reported. Different analytical RAT models provide values for the traffic load in the cells and the offered data rate, delay and bit error rate.

The load index ρ_k with ($0 \le \rho_k \le 1$) for each cell k is calculated according to the proposed model in [4]. Each connected service i causes a load quantified by a parameter α_i which together sum up to the overall cell load ρ_k.

$$\rho_k = \sum_{\forall i} \alpha_i \tag{2}$$

The load caused by each service is e.g. based on the amount of used traffic channel time slots for GSM/GPRS or of the noise-/power rise for UMTS in the up and downlink, respectively. Call admission control is based on the load index.

Data rate and bit error rate are based on the received signal quality and the standards defined for the RAT.

The calculation of the delay of IP-packets during ON phases is based on a GI/G/1 model (solved with the Krämer/ Langenbach-Belz formula for the mean waiting time [20]). The arrival process is characterized by the mean arrival rate of the IP packets and the coefficient of variation of the interarrival times. The service process is defined by the mean service time of IP packets and its coefficient of variation which are derived from a sub model sketched below. In case of a shared channel the superposition of different services' arrival processes is evaluated by means of the QNA approach [21]. Long range dependencies and self-similar properties of IP traffic are neglected, since these properties can not be represented under the given model constraints due to their computational complexity. The model for the service process of IP packets is based on the work in [22]. This model calculates the mean service time of IP packets and its coefficient of variation according to the size of RLC blocks (radio link control layer block), their amount per IP packet and their retransmission properties. The retransmission properties depend on RLC parameters and the block error rate of the connection which are defined by the received signal quality and the RAT.

The RAS model is updated at the occurrence of one of following events:

- UE establishes or ends a connection to a cell of the RAS component.
- UE enters or leaves a grid element of the ENV component assigned to the RAS.
- Services of the UE connected to the RAS start or end their ON phases.

Component CRRM-D and CRRM-IM:

The CRRM components implement different CRRM algorithms. The CRRM-IM component can start, stop and collect measurements in the UE and RAS components. The CRRM-D component processes the collected information and generates commands to influence the behavior of RAS or UE components, e.g. performing intersystem handovers or service demand adaptations. All activities of the CRRM components are associated with chargeable messages.

5. CONCLUSION

In section 2 we presented a systematic view on CRRM. We classified three CRRM levels and proposed a categorization framework for CRRM algorithms which are based on the relationship to load sharing algorithms. We also described the four steps of the CRRM control loop. The resulting framework enables a cost-benefit analysis for different CRRM algorithms and architectures. Different centralized as well as decentralized scenarios can readily be defined basing on five standard components (radio access system, environment, user equipment, CRRM information manager and CRRM decider). The concept of our implemented simulator is presented. Future work will focus on the further evaluation of the simulator and the suitability assessment of different CRRM algorithms for diverse CRRM scenarios.

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Biographies

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