INTERACTIVE RECONFIGURATION OF RESOURCE MANAGEMENT FUNCTIONS AND NETWORK ENGINEERING

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ABSTRACT

In this paper, Joint Radio Resource Management (JRRM) functions in a heterogeneous environment are studied, where the sub-networks are Universal Mobile Telecommunication System (UMTS) and High Performance Radio Local Area Network (HIPERLAN/2). System performance for both non-cooperative and cooperative sub-networks in different scenarios has been compared and better Quality of Service (QoS) for the cooperative sub-networks was achieved. Two levels of JRRM approaches are distinguished: Joint Session Admission Control (JOSAC) and Joint Scheduling Algorithm (JOSCH). The values of gain of JOSCH compared to JOSAC in different network coupling scenarios for typical service types are obtained. It is assumed in adaptive radio multihoming supported network, high data rate traffic can be split between the cooperating sub-networks.

Reconfiguration can be taken place in network elements, the performance of deploying different levels of JRRM are compared. It is concluded that, according to Busy Hour (BH) based traffic estimation, network element, e.g., base station, antenna pattern, RAT selection, overlapping and coupling structure can be reconfigured, so that optimal system performance can be obtained.

1. INTRODUCTION

The end-to-end reconfiguration targets at reconfiguring mobile terminal and network elements to reach the optimal network performance. It is expected the reconfigurable system emerges, where the mobile terminal can be reconfigured to support multiple air interfaces, but also a reconfigurable network infrastructure consisting of existing radio access networks, being operated and inter-working. Depending on the available radio resources, reconfigurable devices can simultaneously or alternatively have different connections through heterogeneous RATs. In this case, tightly coupled networks are of great interests since they offer the chance for jointly designing and implementing Radio Resource Management (RRM) functions crossing MAC, DLC, RLC/RRC up to service layers. The target of those jointly managing approaches is on one hand to increase operable spectrum capacity and end user QoS and on the other hand to ease management over heterogeneous networks even belonging to different operators. Therefore, SDR technology is not restricted as conventional terminal reconfiguration oriented implementation task, but an end-to-end framework which targeting at efficient terminal reconfiguration, cost effective network deployment and optimized system management targets at optimized end user QoS. This paper is placed itself in the field of joint radio resource management (JRRM) under the working area of system connection management in terms of *Adaptive Radio Multi-Homing (ARMH)* [1]. It introduces improvement of JRRM by placing more RRM functions toward coupling point which supports the proposed ARMH concept for reconfigurable terminals with key issues like traffic prioritization, traffic splitting, sub-stream labeling, synchronization in radio link and buffer management.

It is expected that coupled networks with different radio access technologies (RATs) will support jointly designing and implementing Joint Radio Resource Management (JRRM) functions in order to enhance the operational spectrum efficiency and end user QoS. Based on feasibility given by network reconfiguration, functional architecture and traffic synchronization techniques under the concept of multi-homing, the performance comparison of different JRRM schemes w.r.t. network deployment and constellation is provided in this paper.

This paper is organized as follows: section 2 gives the introduction of different level of JRRM approaches; in section 3, network-engineering issues are tackled. Due to the importance of interworking between JRRM and network engineering, the importance of network coupling architecture is emphasized. In order to show the performance related with JRRM and network architecture, system level simulation is launched with reasonable traffic model and environment model.

2. JOINT RADIO RESOURCE MANAGEMETN

The deployment of radio Resource Management (RRM) over existing RATs can be modeled as three basic levels:

- Non-cooperative RRM: The management functions are designed independently in sub-networks, e.g., terminal being able to access to UMTS is not enabled to access to H/2.

- Joint session admission control (JOSAC): With the available reconfigurability of mobile terminals, terminals can be admitted alternatively through either RATs.
- Joint session scheduling control (JOSCH): Incoming traffic can be split and simultaneously admitted through sub RATs; therefore, the joint scheduling and synchronization are involved.

According to JOSCH algorithm, certain traffic can be split into sub-streams, a base layer and one or more enhancement layers, e.g., the scalable video traffic and the HTTP traffic with distinction between the main object and inline object. Due to the wide coverage of UMTS and high bandwidth of H/2, it is advantageous to schedule the video traffic in such a way that the base layer goes through UMTS and the enhancement part goes through H/2 sub-network.

2.1. Dimensioning of Gain Analysis

The functions of joint radio resource management is not only the joint power control design, the handover algorithm and admission control. If the erroneous dimension is not considered, extreme conditions can be reached, where the system capacities reach the upper bound; however, it does not guarantee the higher bound of capacity gain. It implies that in erroneous cases, e.g. two systems are unbalanced loaded; the gain could be different to the capacity-increasing tendency. There are two basic layers of Joint RRM being of great interest, namely the joint call/session admission control (JOSAC) layer and joint radio resource scheduling (JOSCH) layer. On the other hand, gain from JRRM also depends on switching technique, i.e., circuit switched and packet switched.

2.2. Gain in Error Free Circuit Switched System

For networks with different capacity, the gain of circuit switched traffic can be obtained through simple Erlang B formula. Erlang B formula is designed for conventional telephone systems. By upgrading the available number of servers and processing rate, gain of JOSAC and JOSCH can be evaluated.

For two independently operated systems, if we assume the incoming traffic is based on Poisson distribution with arrival rate λ and one basic channel has the capability to process the incoming call with rate μ, the call blocking probability becomes:

$$p_i = \frac{(\lambda/\mu)^{m_i} / m_i!}{\sum_{k=0}^{m_i} (\lambda/\mu)^k / k!} \qquad (1)$$

With i the index of sub-system. In this example, $i \in \{1,2\}$. The blocking probability is calculated as the average of them. In the JOSAC case, the call blocking probability is from the total available number of servers, e.g., $\sum_i m_i$. Thanks to the traffic splitting, the JOSCH allows number of servers increases by 3 dB. Since the ratio of incoming rate and processing rate does not change, performance gain is obtained by increment of available servers.

2.3. Gain in Erroneous Environment

For a system allowing multiple simultaneous accesses with certain interference from multiple connections (MAI), the channel capacity individually will be degraded as far as the number of users increases. If there are *n* active transmitters at a time when certain stage in the queuing model can be found, the system decoder has a total information resolving power of:

$$nW \ln(1 + \frac{P}{(n-1)P + N_o W}) \qquad (2)$$

With the assumption of (2), a degradation of service time models resulted from the effect of party effects can be obtained. In any Markov chain mentioned, a generic model could be employed which allows recursive calculation of system blocking rate, i.e., an aspect of system GoS. Suppose in stage *k* of a M/M/N system, a *processing unit* is shown as the following figure:

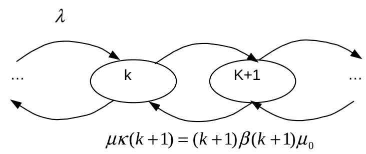

Figure 1, *K*-th Stage Processing Unit of M/M/N Model

With μ_0 the processing rate in the first stage, where only one user participating in the model, *β(k)* the degradation factor of stage *k* compared to stage 1. The reason to introduce the multiplicity factor is to ease the recursive calculation introduced in later section.

Name the signal to noise radio in single user case is $\xi = \frac{P}{N_o W}$, the stage based degradation factor can be derived:

$$\beta(k+1) = \frac{W \ln(1 + \frac{1}{k + \xi^{-1}})}{W \ln(1+\xi)} = \log_{1+\xi}^{1+\frac{1}{k+\xi^{-1}}} \qquad (3)$$

Degradation factor for single system within stage *k+1* should be upgraded according to processing rate of base station. The lower processing rate in reality can be reached by either retransmission due to packet loss/error or link adaptation. The interference-limited effect to conventional call blocking system will be shown based on the changed features of $\beta(\cdot)$ function.

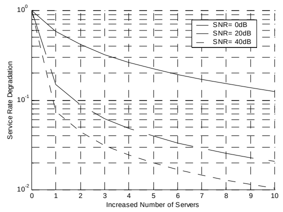

Figure 2, Service Rate Degradation w.r.t. Servers and SNR

Lemma 1: System holding services with high SNR requirement or system having low orthogonality characteristics is soft blocking sensitive system.

Higher SNR requirement for single user requires higher transmission power for the reference radio link, as will effect other on going connections more effectively. From the stage based degradation factor viewpoint, the degradation factor will decrease dramatically, as Figure 2, shows. In a system with sufficient number of servers, the system capacity will be highly reduced, see the following investigation. For system with poor orthogonality characteristics, the same effect can be founds, since the noise rise dramatically with the rise of number of radio links. Lemma 1 is the preparation to show Theorem 1.

As the conventional approach to derive the blocking rate for M/M/N system, blocking rate in non-cooperative system (A_N) is down as the following:

$$p_k = \begin{cases} p_0(\frac{\lambda}{\mu})^k \frac{1}{k!}\frac{1}{\prod_{j=0}^{k}\beta(j)} & k \le M \\ 0 & else \end{cases} \quad (4)$$

With totally M available servers. The system blocking probability is:

$$p_B(\rho, m) = \frac{(\rho)^m \frac{1}{m!}\frac{1}{\prod_{j=0}^{m}\beta(j)}}{\sum_{k=0}^{m}(\rho)^k \frac{1}{k!}\frac{1}{\prod_{j=0}^{k}\beta(j)}} \quad (5)$$

The previous equation is based on the assumption $\beta(0)=1$, although $\beta(0)$ naturally does not exist. Thanks to the introduction of multipliable factor, recursive calculation of blocking rate when m increases can be employed:

$$p(\rho, m) = \frac{\frac{\rho}{m\beta(m)}p(\rho, m-1)}{1+\frac{\rho}{m\beta(m)}p(\rho, m-1)} \quad (6)$$

The blocking probability with respect to different signal to noise ratio is shown in Figure 4. It can be seen in low ξ case, the blocking probability is similar to non-erroneous situation. As the single user SNR increases, processing rate will decline faster than the gain given by more available servers. Ideally speaking, the optimal admission control should work in a way to minimize the given transmission power for signal user and number of servers.

Base on our previous work [1], the water filling principle should be applied to the resource-sharing systems. Therefore, JOSAC mechanism (A_C) should be modelled as set-partitioning Markov model. A set is composed of two concatenated stage, where the processing rate is the same thanks to the load sharing mechanism, as the following figure specifies.

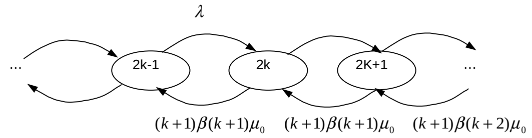

Figure 3, JOSAC Model for Erroneous Situation

The conventional m_1+m_2 model will be upgraded by assigning two immediate concatenated stages, i.e., '*2k*' and '*2k+1*', the same processing rate, the degradation factor is therefore upgraded as the following:

$$\beta(k) = \log_{1+i}^{1+\frac{1}{i+\xi^{-1}}}, \text{ with } i = \lfloor k/2 \rfloor \quad (7)$$

The same principle can be applied in JOSCH case (A_S), the period of degradation upgrade is number of cooperated system times number of equally split sub traffic streams. In most typical cases, the period equals to 4. The comparison of blocking probability is shown in Figure 4. Since there is no intersection points among those thee meshes, through upper one to lower one, JRRM algorithms A_N, A_C and A_S can be distinguished.

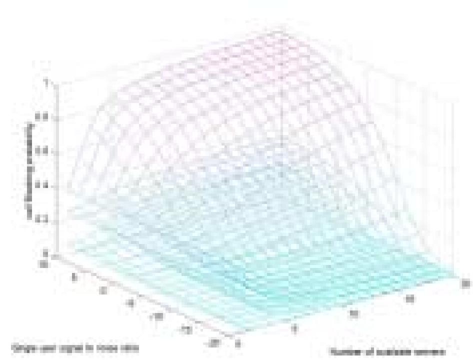

Figure 4, Call Blocking Probability from Different Viewing Angels (with respect to ξ and m)

In JOSCH approach case, the degradation factor can be upgraded as:

$$\beta(k)=\begin{cases}\log_{1+i}^{1+\frac{1}{i+(\xi/2)^{-1}}}, & \text{with } i=2j+1,\ j=0,1,2... \\ 1, & \text{else.}\end{cases} \quad (8)$$

The above analysis proves an important theorem for JRRM deployment. This theory shows the gain by deploying to be discussed ARMH approach.

Theorem 1: More gain can be obtained by applying detailed JRRM (JOSCH) into Soft blocking sensitive systems. System capacity gain drops with increment of available servers in subsystems.

3. NETWORK ENGINNEERING

3.1. Sub-System Introduction

Two typical systems are considered in the performance analysis: the H/2 system and UMTS cellular system. H/2 works on 5G band with 20MHz subband, where OFDM/TDD/TDMA alike air interface is deployed. The MAC usage restricts the user throughput, which results from the right link mode selection, reserved resource for the BCH, FCH, ACH and RCH for controlling information. Due to the defined MAC protocol, the more users being allocate simultaneously in the MAC, the longer fields in FCH need to be reserved for indicating user resource allocation [2]. H/2 provides a flexible platform for a variety of business and home multimedia application that can support a set of bit rates up to 54 Mbits/s with effective user throughput as 46 Mbits/s. In a typical business application scenario, a mobile terminal gets services over a fixed corporate/public network infrastructure. In the home scenario, a low-cost and flexible networking is supported to interconnect wireless digital consumer devices [3].

The essential air interface used by UMTS/FDD is based on WCDMA technique, which is expected that this new wireless system will support multimedia services with high quality of services (QoS) provision, e.g., high quality images and video, and access to information and services with enhanced data rates and new flexible communications capabilities. The chip rate goes up to 3.84Mcps by different spreading factor, where, higher spreading factor results in lower user data rate and higher processing gain (spreading gain) [4]. Based on the assigned spreading codes, users are separated in the code domain, where each is assigned a code out of a family of codes (OVSF) supposed to be completely orthogonal, enabling therefore exact elimination of interfering signals of other users with proper processing at the receiver side [5]. Due the capacity drop resulted from non-orthogonality, it is summed in this paper only one OVSF tree available in both forward link and reverse link. The limitation on the maximum number of users is not adequately justified by the available codes taken out from OVSF tree (hard blocking), it has been proven the required transmission power in both uplink and downlink generates interference to other users due to transmission at the same, non-perfect interference cancellation as well as non-exact code orthogonality. The near-far problem results in cell breathing effect; e.g., in higher loaded CDMA system, remote users cannot get access. Therefore, limit from system soft capacity (soft blocking condition), or number of user that could be accommodated simultaneously gives an important constrain of WCDMA system.

3.2. Coupling Architecture

The interworking between different radio access technologies is an important topic, especially in the standardization bodies. Different approaches can be taken, depending on the level of integration/interworking between sub-radio system. 3GPP in [5] studies the feasibility of interworking between 3GPP systems and Wireless Local Area Networks (WLANs). In this document six different scenarios of 3GPP-WLAN interworking ranging from common billing to the provision of services seamlessly between the WLAN and the 3GPP system are given. Based on the guideline, the following system coupling structure can carry out the service requirement respectively. Since the key topic of this paper is not to define right system architecture, therefore, only simple comparisons among interested types are discussed, which supports the JRRM mechanisms.

The network coupling structure is interested not only by standardization bodies but also operators, since co-operability, billing model and potential system efficiency enhancement will be very much related with this topic. The following figure shows a reference model in the PS domain to briefly explain the difference between different coupling scenarios which will support different cases discussed in 3GPP. Similar hierarchy model for circuit switched (CS) domain consisting of G-MSC and MSC can be extrapolated.

However, once the coupling architecture is fixed, it gives great interest only to compare the signaling below coupling point, which is defined as the entity in the network architecture model interfacing sub-RATs. Signaling above coupling point (core network) might be necessary to support the JRRM algorithms; it doesn't give too much difference between JRRM according to available capacity. From the network coupling viewpoint, four basic different subnetwork coupling approaches can be classified, namely:

- Very tight coupling (coupling point is RNC, which requires high-end RNC or fast interworking between WLAN AP and RNC.)
- Tight coupling (coupling point is SGSN, which generates relatively slower interaction between sub-networks)

- Loose Coupling (Coupling point beyond GGSN, MG or VAP, no Iu interface involvement [6])
- Open Coupling (No interworking between subsystems, but only billing system shared between them [7][8])

3.3. Network Reconfiguration

Network reconfiguration consists of the function redefinition of network elements, parameters setting for network entities, e.g., power value, antenna pattern selection, coupling structure and even location of RF sets when the transceiver is programmable.

The delivery of seamless mobile multimedia services, enabled by the inter-operability of wireless heterogeneous radio access networks, poses new requirements and addresses new challenges concerning radio network planning. Inevitably, the concise definition, development and integration of new methods and mechanisms for network planning and network deployment in an E2R context is vital. Operators should co-ordinate the operation of their heterogeneous wireless access systems. The cooperation between operators is materialized through the agreement of absorbing traffic from other networks with certain coupling structure, in order to assist them in the handling of new service area conditions (e.g., hot-spot situations, traffic demand alterations, etc.), or service management requests. Based on different coupling structures with respect to the cooperating RATs, system performance are changing. This paper gives the first step trial for the interworking between gain of JRRM and network coupling structure showing the feasibility of deploying network with respect to JRRM implementation.

4. SIMULATION AND ANALYSIS

4.1. Traffic Modeling

Besides to the HTTP traffic model (see [9]) employed in this research activity, scalable video traffic is modeled, which consists of mainly two important parts, one is the variable data rate due to the scalable video ability of H.263 and MPEG-4 standards and the second is the constant bit rate traffic. The video coding has the ability of splitting the traffic into sub-streams in order to fulfill the maximizing of the spectrum efficiency.

In order to have the same throughput rate of information, we consider the incoming traffic with rate R_0. The split traffic types are base layer with rate R_B and enhancement layer R_E. We assume that R_0 has bell like distribution. The base and the enhancement layer has a tight relationship with

$$R_B + R_E \approx R_0 \qquad (9)$$

In case that a bell-liked video traffic being split, a constant bit rate is generated which is modeled as R_B with a const value. The enhancement layer is left as R_E, which is modeled as the difference between the original and base layer.

The current MPEG-4 has an average rate of *390kbits/s*. Using this data we can assume that there exists 10 times less data rate compared to the conventional video traffic. The parameters assumed are $a=0.8781$ and $b=0.1108$. The assumption is taken that there are 2.5×10^4 pixels per frame and there are 30 frames that are transmitted during one second. The average value of the Gaussian variable is 0.572 [10].

4.2. Effect on Overlapping Scenarios

Due to different propagation characteristic in operational carrier and maximum transmission power specified for base station, UMTS offers relative bigger coverage compared to Hiperlan/2 (H/2). Based on the pre-defined overlapping factor $\phi = A_H / A_U$, with A_H and A_U being the covering area belonging to H/2 and UMTS respectively. Different overlapping scenarios of H/2 network and UMTS are investigated, namely the center overlapping, remote overlapping and random overlapping. (e.g., center overlapping is the term for the case when H/2 network in the center of UMTS cell). Selected results of user QoS according to those network deployments are given in order to generate the network reconfiguration policy.

To compare different scenarios, effective throughput, weighted throughput and number of satisfied users are compared. In Table 1, results for different scenarios and different numbers of users are shown. Results comparing different overlapping

for remote and central overlapping in more details are shown.

In each table the gain of JOSCH over JOSAC could be found. This gain has been defined as follows:

$$G_E = \left[R(A_S) / R(A_C) \right] - 1 \qquad (10)$$

$$G_W = \left[R_W(A_S) / R_W(A_C) \right] - 1 \qquad (11)$$

Where G_E is the gain for effective throughput, $R(A_S)$ the average of effective throughput in JOSCH case and $R(A_C)$ the average of effective throughput for JOSAC scenario.

G_W is the gain for weighted throughput and is defined by ratio of the average weighted throughput for JOSCH ($R_W(A_S)$) to this value for JOSAC ($R_W(A_C)$) minus one. The weight factor from user QoS perspective is modeled as $o_v = 10$. Besides that, let D_U and D_H denote original user density in UMTS and WLAN subsystems respectively, overlapping factor ϕ varies in the range (0, 1). It should be pointed out that not all users in the simulation are necessary to be active, which is resulted from admission control functions. Performance of affordable system capacity for HTTP traffic is shown in Table 2.

Table 1, Throughput Gain for JOSCH in Compare to JOSAC

Video Traffic	ϕ	D_U	D_H	G_E	G_W
Remote Overlapping	10%	150	3	0.1489	1.2108
	20 %	150	3	0.0779	0.6923
	50 %	150	3	0.0139	0.1450
	99 %	150	3	0.0005	0.0002
Central Overlapping	20 %	15	3	0.1790	0.2823
	20 %	150	3	-0.0380	-0.0403
	50 %	150	3	0.0052	0.0036
Random Overlapping	20 %	150	3	0.0188	0.2359

Table 2, Results for HTTP Traffic with Remote Overlapping and User Density with [DU, DH]=[150, 3]

ϕ	$\rho_{T,N}$ [Erlang]	$\rho_{T,C}$ [Erlang]	$\rho_{T,S}$ [Erlang]
10 %	34.1765	45.6667	87.6078
20 %	39.7647	55.1569	99.0784
30 %	50.0196	72.3725	121.3137
40 %	57.1176	92.9020	144.6078
50 %	77.0000	125.2157	170.6471
60 %	89.1961	141.1961	185.2353
70 %	104.6471	175.8235	219.4118
80 %	129.6078	215.1765	241.4314
90 %	146.0196	233.6275	250.0588
100 %	152.4510	235.4902	245.9020

Table 2 shows the results for HTTP traffic intensity with remote overlapping constellation pattern, whereas, the maximum allowed traffic intensity in three basic scenarios are shown as $\rho_{T,N}$, $\rho_{T,C}$, $\rho_{T,S}$. Compared to video, HTTP has a smaller error probability margin, which results in higher required SIR and thus a higher Blocking rate.

As the overlapping factor increases, the less relative gain from JOSCH is obtained. In other words: as the derived theorem, the complete overlapping between two unbalanced systems, the higher system with higher capacity absorbs traffic to optimize system capacity. On the other hand, due to the soft-blocking characteristic of UMTS FDD, by replacing WLAN access point in the remote area of UMTS base station, significant system capacity gain can be obtained by employing JOSCH approach.

5. CONCLUSIONS

From system level simulations, following principals of deploying JRRM can be derived:

- Remote overlapping of WLAN as complimentary radio networks to UMTS enhances coverage under the constrain of the same computational power and number of access points/base stations.
- Less overlapping factor and more remote overlapping between sub-networks result in more benefit of deploying JOSCH, e.g. pure throughput will increase by more than 50% in 10% overlapping case; in case the main object/sub-stream has 10 times significance against the rest of traffic, the effective throughput will be increased by more than 100%.
- In center overlapping scenario and lower user density scenario, JRRM function need not to be configured to JOSCH level, i.e., JOSAC level based JRRM offers even better throughput performance than JOSCH.
- JOSCH requires service scalability, which requires on one hand more functionality defined for coupling point need to be considered by network reconfiguration, and significant trunking gain compared to JOSAC.

Based on the measurement of user call application and service profile, optimal solutions of network deployment, terminal reconfiguration and needed implemented JRRM approaches can be derived.

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