Everest's Results on RRM/CRRM: An Overview

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***Abstract.-* This paper presents the general framework considered for the development of radio resource management (RRM) strategies in the EVEREST IST-project. A brief description of some of the research topics covered in the field of RRM and Common RRM in heterogeneous networks including 3G, 2G and WLAN systems are given. Throughput increases up to 40% have been observed thanks to CRRM.**

I. RRM IN A BEYOND 3G FRAMEWORK

The mobile communications sector will continue to be one of the most dynamic technological drivers within comparative industries. This is mainly to be attributed to our inherent needs for independence and flexibility; something an invisible wireless link all too well realises. The 'connected everywhere, anytime, anyhow' philosophy, however, will have to be corroborated with sophisticated business models, available technologies, network roll-out alternatives, etc. The pace of potential network development clearly superseded the one of network deployment. It is thus generally acknowledged today that beyond 3G encompasses network heterogeneity. A plethora of different network topologies will have to co-exist or be inter-connected. Example topologies are cellular circuit-switched networks, e.g. GSM, cellular packet-switched networks, e.g. GPRS or UMTS, and wireless local area networks, e.g. IEEE 802.11X. These network topologies ought to be inter-connected in an optimum manner with the ultimate objective to provide the end-user with the requested services and corresponding QoS (Quality of Service) requirements.

The provision of heterogeneous network topologies is conceptually a very attractive notion; however, it is certainly a challenge both to standardisation of interfaces and network design. Here, coupling between the networks of possibly different characteristics can be provided, leading to open, loose, tight and very tight coupling approaches. The stronger the coupling the better resources are being utilized leading to an optimum of performance. However, this comes along with an increased effort in the definition and implementation of required interfaces. Then, a suitable trade-off arises for specific systems where available radio resources of coupled networks will have to be managed jointly, up to the degree allowed by the coupling mechanism. Targeted is an optimum solution in terms of throughput, cost per packet, development and deployment cost, etc.

The QoS concept can be understood in many different forms and levels. Although inherently subjective, the realization of QoS in a communication network needs to be associated with quantitative parameters that characterize a satisfactory user's perceived service. QoS figures may range from parameters at a global network level to parameters on a per connection basis. QoS provisioning in mobile systems is particularly complex given the large number of effects that tend to degrade the communication links. Fading in propagation conditions, interference, channel distortion, etc. are only some examples. Although the ultimate objective of an end-to-end QoS will be retained, the focus here is on QoS in the radio segment.

Focusing on the radio segment, the operator's investment in radio network infrastructure is proportional to the number of base stations deployed, which, in turns, depends on the number of users to be supported, the service area, user's average transmission rate and the desired QoS level. The cost term associated to QoS provisioning plays a key role. The most basic way to guarantee QoS is by means of network and radio resource allocation overprovisioning. However, the challenge is to be able to provide the desired QoS level with the minimum possible resources, then minimising the operator's investment while meeting service requirements. Further, B3G wireless networks need to support a variety of well-defined as well as future emerging services. Therefore, the QoS framework for B3G air interface must be flexible and should also be practical, i.e. it should have low complexity of implementation and low volume of control signaling.

3G and Beyond systems will offer an optimization of the capacity over the air interface by means of designing efficient algorithms for Radio Resource and QoS Management. These functionalities are very important in the framework of 3G systems because the system relies on them to guarantee a certain target QoS, to maintain the planned coverage area and to offer a high capacity, as reflected in Figure 1, which somehow are contradictory to each other (e.g. capacity may be increased at the expense of a coverage reduction; capacity may be increased at the expense of a QoS reduction, etc.).

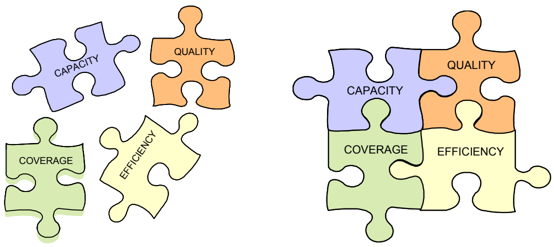

Figure 1 . RRM objectives subjects to tradee-offs

The research work carried out in IST-project EVEREST from January 2004 to December 2005 has been based on some considerations, for example:

The RRM strategies of legacy networks (i.e. GERAN) are of rather low dimensionality, i.e. only a few parameters are needed to tune their optimality. Joining these networks into a heterogeneous network, leverages the RRM strategies into optimisation problems with many more degrees of freedom.

In the case of UMTS, a huge amount of human and material resources has been devoted to date that led to a vast plethora of 3GPP specifications, first manufacturer products and operator roll-outs. In the coming years when more and more radio engineers are becoming familiar with 3G and beyond technologies, it ought to be mandatory to increase and harmonise the general knowledge on WCDMA RRM strategies. Clearly, optimised RRM algorithms are the only key to successfully handle highly loaded networks, which are being envisaged to dominate the wireless arena in five years from now.

WLANs are also expected to play an important role in the provision of high data rate services. Here, wireless indoor coverage could be better provided by WLAN as high power resources would otherwise have to be spent in UMTS. Again, a new dimension in the RRM problem is introduced, the influence of which needs to be assessed.

For each aforementioned and emerging technology, the development of common RRM (CRRM) algorithms within the radio access network (RAN) is vital for a proper functioning of a heterogeneous network topology. Developed, assessed and compared have to be CRRM algorithms for tight and very tight coupling.

Thus, EVEREST project has focus on devising and assessed a set of specific strategies and algorithms leading to an optimised utilisation of scarcely available radio resources for the support of mixed services within heterogeneous networks. In this line, EVEREST has progressed towards the provision of tangible contributions for a heterogeneous realisation of 2G/2.5/3G and 3.5G networks (e.g. HSDPA). The proposed solutions suit a range of deployment scenarios, technological functionalities, network topologies and services mixes.

This project is clearly driven by operators, who ensure identifying the scenarios of interest to be considered at different time scales and for different network roll-out phases. From the operator side, it is well understood that suitable approaches for RRM fall well beyond a mere network deployment. They thus constitute an innovative research field with clear indications on how to manage radio resources in heterogeneous networks accommodating traditional and novel services. In this respect, the operator-oriented approach adopted in EVEREST has ensured that the analysed scenarios will be market-relevant and user-centric. Furthermore, it is worth noting that the open nature of the algorithms developed within the project and its availability to the entire wireless community is expected to contribute to a better transition from the different evolutionary scenarios considered. Outputs from EVEREST constitute a valuable reference for operators, manufacturers and academia, facilitating further progress in this field for many years to come.

In this context, this paper describes some of the progress achieved in EVEREST in RRM and CRRM strategies development. The management of radio resources can be seen as a problem with multiple dimensions. Every RAT is based on specific multiple access mechanism exploiting in turns different orthogonal dimensions, such as frequency, time and code. Then, RRM mechanisms are needed for every considered RAT: GERAN, UTRAN and WLAN in the case of EVEREST, as shown in Figure 2. CRRM is based on the picture of a pool of radio resources, belonging to different RATs but commonly managed, as shown in Figure 3. Then, the additional dimensions introduced by the multiplicity of RATs available provide further flexibility in the way radio resources can be managed and, consequently, overall improvements may follow.

In terms of RAN deployment, different spatial availabilities are found for the different RATs, with GERAN tending to be the most widespread RAT, UTRAN with more confined coverage and WLAN with reduced coverage areas. The CRRM vision allows considering different amount of radio resources spatially available.

With the above considerations, the rationale behind the work plan developed within EVEREST is based on initial emphasis on RRM for different RATs, since these are the pillars for the efficient development of common strategies. At this stage, the different RATs have received different levels of elaboration, with, comparatively, more focus placed on UTRAN because of the larger number of dimensions involved (i.e. frequency, time, code and also power). With some RRM issues already explored, CRRM mechanisms have already been targeted and strengthened in the second year of the project run.

The rest of this paper is structured as follows. Section 2 is devoted to RRM mechanisms and considerations for UMTS. Section 3 covers RRM for GERAN, while Section 4 is devoted to WLAN. Then, Section 5 presents the overall vision of the CRRM problem as well as some evaluations. Finally, Section 6 summarises the conclusions.

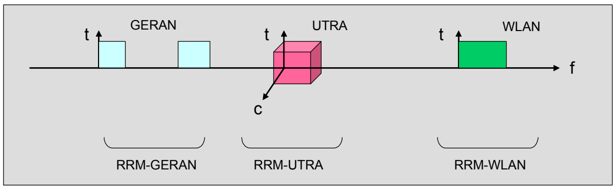

Figure 2 . RRM at single RAT level managing orthogonal multiple access dimensions

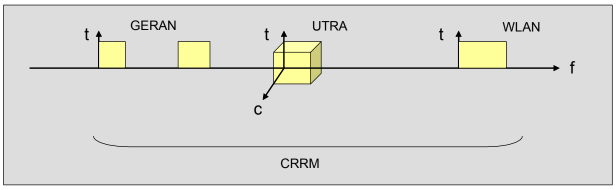

Figure 3 . CRRM managing a pool of orthogonal multiple access dimensions

II. UMTS

An innovative mathematical framework capturing the air interface coupling among the different cells in the scenario has been developed, in the form of a compact formulation for both uplink and downlink. The presented analytical model has been exploited by obtaining the derivative of the reference cell uplink load (alternatively the transmitted power in downlink) with respect to any neighboring cell. These derivatives allow to identify the most critical cells and users influencing a reference cell, then the definition of smart RRM algorithms (e.g. admission control, congestion control, packet scheduling) may follow. In particular, a congestion control algorithm has been presented and evaluated, showing the benefits of it compared to reference algorithms. Further, multicell admission control as well as principles for multiple carrier management and allocation have been developed using the introduced formulation.

An analytical framework has been developed to study the integrated voice/data network, in which the recursive process is used to model the interactions between CDMA cells through inter-cell interference caused by the data congestion function at link level. This framework offers an insight view into the integrated CS/PS cellular systems with and without power control error.

The importance of indoor traffic in WCDMA has been stressed. In this framework, an analytical model to assess the impact of indoor traffic on cell capacity depending on different scenario parameters such as the cell radius, the in-building penetration losses and the target quality requirements has been developed. Then, based on some cost/benefit operator's analysis (i,e. higher cost of new cells deployment versus benefit of major spectrum efficiency with micro and picocellular structures), the model can be used to decide the capacity degradation that makes tecno-economically interesting the deployment of additional micro and picocells.

Additionally, a simple analytical model comparing the power increase in uplink and downlink due to indoor traffic was derived. From this, it was concluded that the power increase will be higher in the uplink direction and the higher the load in the system the higher the difference with respect to the downlink will be. Consequently, a lower degradation caused by indoor traffic is expected in the downlink when compared to the uplink. Particularly, when half of the users are indoor, the reduction in the uplink is 88% while in the downlink it is only 15%.

Following with the analysis of practical situations in WCDMA with potential implications on the overall radio access network performance, the case of static traffic has received attention as long as some high bit rate data services can be envisaged to be associated with still conditions. Then, a downlink Admission Control strategy based on user's path loss measurements reports has been proposed and compared with a reference algorithm based on the average power transmitted by the base station. The throughput gain is very significant especially in those scenarios with large cell radius and high bit rates, where throughput gains over 35% can be achieved.

The impact of using repeaters within UTRAN has been analysed, taking into account an outdoor environment. In order to estimate the capacity gain, a hot-spot scenario has been considered. The achieved simulation results suggest using repeaters only in UTRAN macro cells used to offer the service in area with high density of users.

Additionally, we have simulated an UMTS operator using two frequencies in an indoor traffic hot spot within an urban area. Different strategies to distribute the load of the different services between the two carriers have been analysed. The different methods affect on blocking ratio, dropping ratio and bit rate.

The reported study on HCS aims to assess the performance in a multi-layer deployment versus a single-layer layout, in terms of capacity. In the study two situations have been considered: macro- and micro- cellular layers with the same radio frequency (layer discrimination is only power-based) and macro- and micro- cellular layers with different radio frequencies (layer discrimination by means of radio frequency). For the analysed scenario, in the first case an increasing of capacity of about 86% has been estimated, comparing the values of capacity of both the situations (without and with the microcellular layer). Using two layers with different frequencies (second case), the improvement is about 133%. According to the achieved results, HCS can be considered as a valid solution for network operators for trying to solve some congestion problems due to areas where there is a great amount of traffic (hot spots).

Further studies on HCS and multiple carrier deployments in UMTS have been covered. This includes, on one hand, the application of the analytical framework based on derivatives developed in EVEREST for a suitable frequency allocation in a HCS scenario. On the other hand, the explotation of suitable low interference opportunities for non real time traffic transmission in a HCS with microcells embedded in macrocells has also been studied.

UTRA-FDD has also been investigated under non-homogenous conditions. This has included the performance assessment in the presence of traffic hot spots, characterizing the effects under different conditions. Further, solutions to cope with overload situations derived from dynamic hot spots have been proposed and evaluated, showing the benefits and gains of the developed solutions.

As part of DiffServ aware RRM study, color-aware link adapation are studied. This overall DiffServ aware RRM study intends to offer a consistence in the resource management between core network DiffService domain and radio access networks, which has been proposed in EVEREST end-to-end architecure.

HSDPA link performance has also been studied in two theoretical scenarios: hotspot in urban environment and hotspot along main road in suburban environment. Further, given that the scheduling method used to decide which user is allocated to the channels is of great importance, simulations have been performed to test three methods that are very common in HSDPA literature. In particular, the three analised schedulers are Round Robin (RR), Max CQI and Proportional Fair (PF). It is expected to propose and evaluate additional scheduling alternatives for HSDPA within EVEREST activities. Furthermore, a range of enhancements have been proposed and assessed, this including the explotation of a DiffServ-aware priority queuing mechanism, a Biased Adaptive Modulation/Coding to Provide VoIP QoS over HSDPA and code multiplexing aspects in HSDPA.

Several RRM issues about services and users prioritization have been studied. Basically, the considered scenario is inspired in a business area of one the main cities of Spain; high office buildings, residential blocks and a principal avenue characterize it. The effect of giving priority to some services opposite others has been studied. It has been found that it works properly when the nodeBs are almost saturated in traffic transmission power, the number of connected users requesting the prioritized services grow up. The effect of giving priority to business users opposited to consumer ones has been studied. It has been found that it works properly when the nodeBs are almost saturated in traffic transmission power, the number of connected business users dramatically grow up.

Last but not least, RAN sharing strategies for UMTS have been discussed, accompanied by some relevant simulation results.

III. GERAN

The evolutionary path from GSM towards UMTS encompasses the exploitation of the General Packet Radio Service (GPRS). In this framework, an overview of the state of the art in QoS management functions enhancing initial best-effort data services have been included, covering both admission control and packet schedluing. As a result of the overview work, the focus of the resource management problem has been placed in admission control rather than in packet scheduling, given the much larger number of available references in the later compared to the former.

An admission control algorithm based on available resources, i.e. the available number of available PDCH, and the multiplexing capabilities of the system has been presented. Results showing the role of the admission threshold on the delay experienced by the packets have been presented by means of system level simulations.

Service architecture and characterization on video streaming service over GPRS has been presented. Some QoS requirements for video streaming have been identified, as well as the most relevant radio related parameters. Furthermore, the emphasis has been placed in presenting simulations with streaming application, aiming to fix the value of some parameters, which are not imposed by GPRS specifications, in order to optimize the network and the streaming client performances.

IV. WLAN

A novel Admission Control policy for IEEE 802.11 family of standards has been introduced. The policy can be applied in order to make the wireless LANs able to support also real-time data services (i.e. conversational and streaming classes). For these services, a minimum amount of offered throughput must be guaranteed as well as a specified maximum level of mean delay for packet transmition. For these reasons, a specific amount of radio resources should be reserved for real-time services and, consequently, only a maximum number of users should be supported by the wireless LAN system.

A proposal based in acting at IP level instead of MAC level has been analised, based on the Hierarchical Tocken Bucket algorithm. Applying this concept, a plain and sustained throughput with low standard deviation to stations or even to differentiated services can be achieved.

Finally, a set of more long term evaluations for QoS enhancements on 802.11e have been carried out. In particular, the enhanced distributed channel access (EDCA) has been assessed. Simulations have been made to evaluate 802.11e in terms of jitter, MAC delay, throughput and packet loss. Additionally, one of the crucial concepts introduced by 802.11e draft, Transmission Opportunity (defined as an interval of time when a particular 802.11e station has the right to initiate transmissions onto the wireless medium), has been considered in some of the evaluation results.

V. CRRM

With respect to Common Radio Resource Management (CRRM), a first contribution of the project has been the outline of a functional model for having a common management of the pool of radio resources in heterogeneous scenarios. In the presented model, the CRRM refers to the set of functions that are devoted to ensure a proper coordination between the different radio access networks to achieve the most efficient use of the available radio resources. Different approaches to the CRRM and RRM interaction have been presented, outlining the potential levels of coordination in the radio resource management decisions in the identified functionalities. Finally, the requirements in terms of interworking capabilities and considerations about the physical CRRM implementation have been detailed. According to this framework, and taking into account the scope and time-frame of the EVEREST project, the CRRM studies reported here assume the functionality split in which the CRRM takes charge of the RAT selection procedures, including both initial RAT selection and vertical handover, while the RAT-specific RRM algorithms, like admission control, congestion control or packet scheduling are executed locally at the RRM entities.

Furthermore, a general policy-based framework for the specification of CRRM algorithms has been defined and different policies have been proposed. Simulation results for several RAT Selection algorithms, either based on service considerations, radio network conditions or load-balancing principles have been included. Relevant results have been obtained during the analysis of how the load sharing between RATs impacts on the GoS of the heterogeneous (UTRAN and GERAN) network and how a joint admission control based on service priorization affects to the final number of attended users per service.

With respect to vertical handover, the interworking between horizontal and vertical handovers has been studied, with two considered approaches, namely the tight approach T-VHO, in which the vertical handover algorithm is executed at every time that a horizontal handover algorithm should be carried out, so that both possibilities are considered prior to taking a decision, and the loose approach L-VHO, in which the vertical handover algorithm is executed only when a horizontal handover fails or when a call dropping is about to occur due to bad propagation conditions. It has been shown that the traffic distribution among the considered RATs can be quite different with the two approaches. In that sense, the tight approach allows a better fulfilment of the initial RAT selection policy, due to having more chances to execute a vertical handover than in the loose case. On the other hand, a higher number of vertical handover procedures are also required with the tight approach, which increases the signalling overhead.

Load balancing (LB) is a possible guiding principle for resource allocation in which the RAT selection policy will distribute the load among all resources as evenly as possible. Taking this into account, the performance of load balancing principles in the RAT selection procedure has been covered and compared against a service-based policy. The introduction of VHO capabilities allows higher flexibility in the allocation of multi-service users in a multi-access scenario. Results indicate that no remarkable improvement is noted on the total aggregate throughput when using the LB policy as opposed to the service-based policy. Moreover, with LB, interactive users undergo higher average packet delays which impact the user's perceived QoS. However, we have seen that load balancing procedures may improve the call dropping probability due to a more flexible allocation of users onto both RATs, which is also a key performance indicator to consider.

The concept of network-controlled cell- breathing (NCCB) for CRRM in heterogeneous TDMA/CDMA has been proposed. The envisaged algorithm achieves a reduction in the interference level of the CDMA system by controlling the effective CDMA cell radius through initial RAT selection and vertical handover policies. The strategy has been evaluated by means of system level simulations in a scenario with UTRAN and GERAN as two examples of access networks using the CDMA and FDMA/TDMA technologies. The NCCB strategy has been compared against a classical load balancing strategy that tries to keep the same load level in both RATs. Results reveal that a significant improvement in terms of capacity for both uplink and downlink is achieved with the proposed strategy. It has been also shown that, by a proper setting of the maximum path loss PLth, load balancing principles can also be achieved in NCCB, thus obtaining the benefits in terms of flexibility of load balancing while at the same time exhibiting a higher capacity than a pure load balancing.

The impact of multi-mode terminals with an initial RAT selection policy has also been assessed. Results indicate degradation in terms of throughput introduced by the limited operation of single-mode terminals. By considering a reservation scheme in GERAN for interactive users, we can improve the average packet delay for such users. While for a high multi-mode terminal availability results indicated that the reservation scheme was not necessary, for lower multi-mode terminal availabilities this scheme improved both aggregated throughput and packet delay figures.

The impact of CRRM strategies on TCP throughput has also been studied in a scenario including 3G with HSDPA, 2G and WLAN systems. Four different CRRM algorithms have been evaluated and compared against the manual RAT selection algorithm. Without HSDPA, throughput increases up to 40% have been observed thanks to CRRM. When introducing HSDPA capabilities, the improvement in 3G throughput leads to increases of up to 60%.

VI. CONCLUSIONS

This paper has described the general framework considered for the development of EVEREST IST-project. Furthermore, some of the research topics that have received attention in RRM and CRRM strategies have been identified and briefly described. All these issues are further detailed in [1], [2] and [3].

VII. ACKNOWLEDGEMENTS

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