Effective Cross Layer Radio Access Design Assisted by the Location Manager for Systems Beyond 3G

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ABSTRACT

Future-generation communication systems need to cope on a global scale with new forms of personal communications as well as man-machine interaction. This demand will be also helped by delivering IP-based, real-time, person-to-person multimedia communications, integrating real-time person-to-person with non real-time person-to-machine, providing the ability for different services and applications to interact, and allowing the end user to easily set up multiple services in a single session. This contribution proposes a concept for the architectural realization of future adaptive, scalable and user-centered wireless communication networks. Specifically, we focus on the demand for co-operative radio resource management of the underlying networks. Towards this end, we propose some details of a flat type IP architecture that enables a rapid deployment of micro-and pico type of reconfigurable base stations and incorporates the open radio access network (RAN) within the all-IP paradigm. Within that architecture, wireless nodes or access points have to be interconnected using a long-haul backbone network with fixed nodes. Further, the proposed architecture exploits the idea of cross-layer design concepts to facilitate intelligent radio resource management (RRM) and radio-aware scheduling. The RRM frame work proposed here absorbs the smart scheduler design and link adaptation strategies to yield a cross layer radio access design methodology and, furthermore, the assistance of the location based server is incorporated into the framework.

I. INTRODUCTION

Current wireless trends include increased demand for high bit rates in IP-based, real-time, person-to-person as well as machine-to-machine multimedia communications. To meet this requirement, an information transport platform must provide high-speed, large volume, good quality, global coverage and flexibility to roam. Hence, high degree of adaptivity and high performance are the key parameters. Reconfigurable networks imply the design of new communication mechanisms at different layers (following the taxonomy of the OSI model).

The reconfiguration actions have impact on various levels of mobile systems architecture and introduce high complexity that has to be handled by some reconfigurability management intelligence (distributed or not). Micro- and pico- cell-based networks, together with intelligent node-B distribution are expected to play a significant role because they have the potential to extend cost-effectively the coverage and improve on spectral efficiency, thus reducing the cost of future-generation services. Overall radio resource management and its interplay with middleware will play a crucial role in ensuring that scarce radio and network resources are utilized sufficiently.

This paper provides some of the building blocks of the concept of a rapidly customizable RAN and the underlying intelligent layered RRM techniques. By realizing dynamic radio link adaptations, exchange of knowledge is ensured between functionalities in different layers, while each network node is aware of the relevant PHY-layer parameters associated with the corresponding nodes. Some perspectives on assimilation of the inter-node RRM framework with the advanced physical layer adaptation are presented. This has been illustrated through connecting the link adaptation to a coupled packet scheduling.

The paper is organized as follows. Section 2 defines, the concept of virtual wireless node Bs followed by the proposed co-operative RRM framework. In Section 3, based upon the rationale of the co-operative resource management framework, the concept of coupled scheduling and link adaptation is outlined. Section 4 concludes the paper.

II. VIRTUAL WIRELESS NODE BS

The proposed architecture, as shown in Figure 1, is based on the all-IP distributed server paradigm [1–6]. The wireless node-Bs utilise the underlying IP based neighbour discovery and auto-configuration mechanisms to join and sustain group communications.

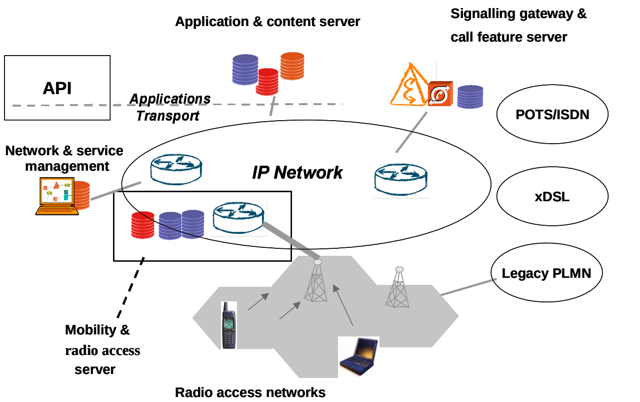

Figure 1 Network Context of the All-IP network and wireless Node-Bs

Figure 2 presents the concept of virtual wireless node-Bs. The concept has been presented in details in [1]. Two different types of node-Bs are distinguished, namely core node-Bs and leaf node-Bs. For the purpose of resource control, the core node-Bs are logically associated to the core network and the leaf node-Bs are governed within the RAN. The leaf node-Bs are connected via wireless links to the core node-Bs. Mobile terminals can connect both to the core and leaf node-Bs.

The fact that the leaf node-Bs are connected via a wireless link with core node-Bs gives the architecture a greater flexibility. Depending on the offered traffic, a leaf node-B can be connected to the core network with enough bandwidth, using the wireless link of the core node-Bs. When the traffic in the leaf node-B increases it is connected to more core node-Bs and, when the offered traffic decreases the connections are torn down again. The concept of virtual wireless node-Bs is shown in Figure 2.

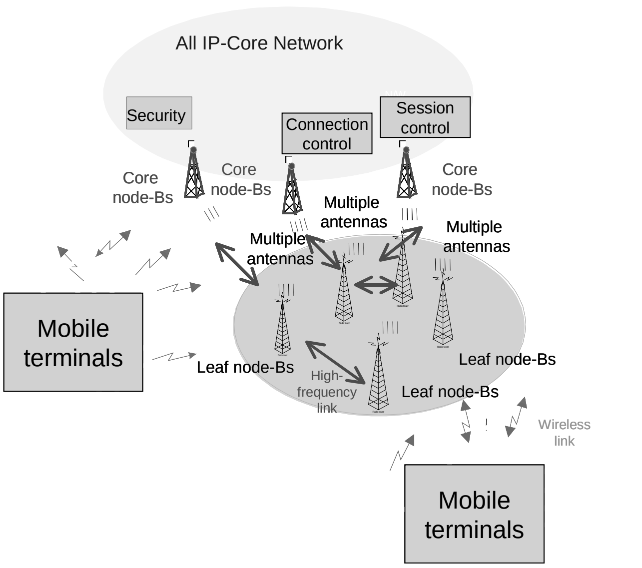

Figure 2 Concept of Virtual Wireless Node-Bs.

The core node-Bs are connected to the core network via fiber and communication between the leaf node-Bs and the core node-Bs is based on wireless transmission possibly utilizing high-frequency bands. The frequency of operation maybe decided upon available standardization scenarios. The optimization of the packet transfer amongst the wireless node-Bs is cast as a link optimization in partial ad-hoc networks. To achieve a capacity enhanced architecture, catering for the hot-spot traffic demands, the deployed node-Bs communicate with each other through directional antennas (MIMO structures). The configuration is based on traffic dynamics and allows for management of micro/pico cell hot-spot situations. Thus, in the near term, it helps to avoid the bottleneck caused by backhaul loading. In the long term, an enhanced architecture may be designed to provide plug-and-play Node-Bs. The layered distribution of the architectural components requires co-operative resource management as shown Figure 3 where a client server resource management architecture is devised to support the virtual wireless Node-Bs. Furthermore, the architecture will seek support from a location based server to make intelligent decision making process. The RRM functionality is synthesised into slow and fast RRM. The slow RRM is considered an outer loop resource optimisation and, on the other hand, fast RRM is considered as inward resource adaptation.

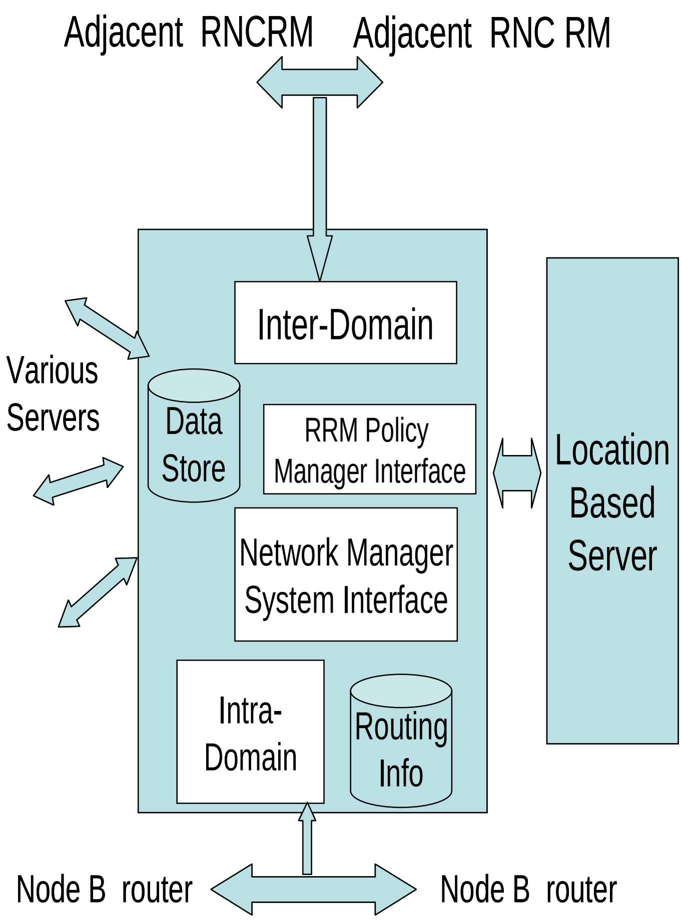

Figure 3 Co-operative Resource Management coupled with Location Server

The RRM functionalities may be incorporated into the RRM Policy Manager Interface as shown in the Figure 3. The RRM decision making is performed in an all-encompassing manner to check the traffic status at the neighbouring nodes. Our previous research has identified, two key components for the framework namely, scheduler, link adaptation. Here we extend our framework to exploit the existence of a location based server. The interworking between the routing blocks, network management system and location based server is crucial to the RRM framework proposed here. An example implementation of the interworking between smart scheduler and other aforementioned entities supporting the partial ad hoc connectivity is shown in Figure 4. Details of the handshaking procedure with the location based server will be reported in the future publications.

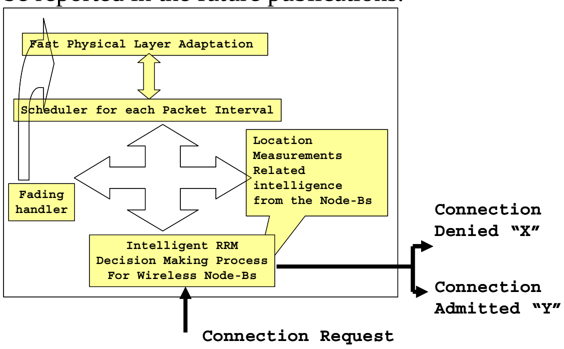

Figure 4 Admission Decision Making for hot-spot packet floiw

The underlying principles of the scheduler [2] are stated as follows.

- Provision of short-term fairness among flows which perceive a clean channel;
- Provision of delay bounds for packets at every node in the network;
- Short-term throughput bounds for flows with clean channels and long-term throughput bounds for flows with bounded channel error;
- Optimized schedulable region for flows with different decoupled delay/bandwidth requirements;
- Support for delay sensitive and error sensitive data flows;
- Graceful service degradation for flows that have received excess service.

In order to realise a lean RRM framework, a reduced complexity scheduler can also be designed to support the mechanisms for service differentiation that are to be offered in mixed service environment. The preferred mechanism depends on the desired service: guaranteed service levels, fairness criteria etc. In such architecture, we propose to use a mix of Priority queuing and Weighted Fair Queuing. Weighted fair queuing is used for reserved data streams, e.g. real-time traffic or voice circuits and the priority queuing is used for the users with a relative service level (different service classes), with the best-effort users as the users with the lowest priority. Instead of the priority queuing, threshold dropping can also be used. In that case the behaviour of the scheduler is a different in the sense that with low system load there is no service differentiation between the queues, but at higher traffic levels the users with lower priority levels are pushed out. In the case of priority queuing, the data of the higher priority user always has priority over the other users. This mainly influences the delay performance of the service classes in the system. The choice between the two mechanisms is therefore mainly dependant on the desired delay performance, in case of strict delay requirements Priority Queuing has to be used, in other cases Threshold Dropping can be used which gives a more fairly distributed delay performance. Figure 5 depicts the proposed scheduling structure. The choice for Priority queuing here is motivated by the presence of delay sensitive data in the system, signalling information being an example of this. If the signalling information is treated as relative traffic of the highest priority, it will always capture a slot in the WFQ and thus effectively it will serve as a random access channel.

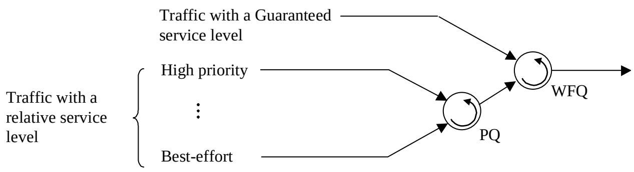

Figure 5 Simplified Coupled Scheduler

The link adaptation (LA) scheme proposed here is based on the 3GPP High Speed Packet Data Access (HSDPA) [3]. The objective of LA is to choose best possible transmission format based on the channel conditions to support very high-speed data applications. LA running at each wireless Node-B provides the "local" intelligence for partial ad hoc co-operative RRM proposed in this paper.

Figures 6(a) and (b) provides an illustration of the throughput performance and distribution of the multiple channel state (MCS) levels at a particular SNR in a high-speed mobile scenario. This analysis highlights the advantage of Adaptive Thresholds leading to selection of low MCS levels even though instantaneous SIR may tempt the designer to select high MCS levels. This conservative approach to the MCS selection results in throughput improvement whilst reducing number of retransmissions. In this case study, the decoding performance was the dictating factor to select relatively low MCS levels. Similarly, other crucial parameters including number of retransmissions, SIR, MIMO/spatial processing related parameters may be extracted from the LA and used by the local RRM entity resident in the node. This will be revisited in the reduced complexity scheduler section where a threshold is used in a mixed service environment.

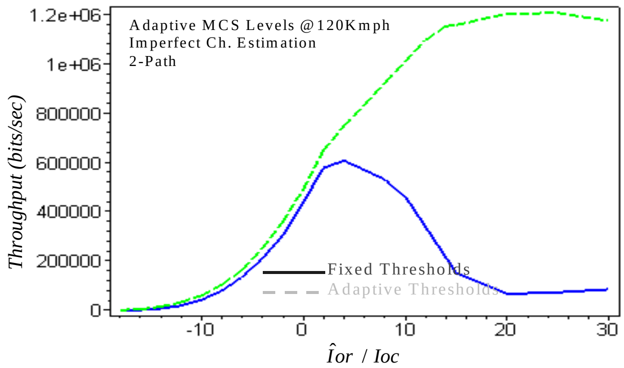

Figure 6a Throughput Performance with Fixed and Adaptive Thresholds in HSDPA Link Adaptation

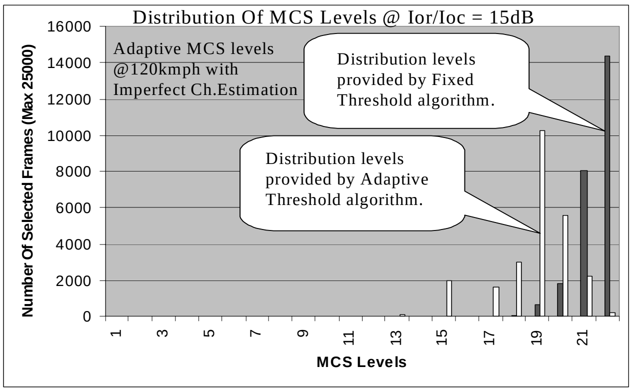

Figure 6b Case study to show the effect of adaptive link adaptation

In the following section, we describe the mechanisms to couple the scheduler to the link adaptation to support high speed data transfer between wireless nodes

III Coupling of the Scheduler and Link Adaptation

The radio-aware scheduling in conjunction with adaptation techniques is the key "enabler" for the co-operative RRM technology in partial ad hoc networks. The framework for the co-operative RRM is shown in the Figure 7. Here, two adaptation loops are foreseen to support the wireless Node-Bs RRM. The LA provides an inner loop adaptation between the User Equipment (UE) and the Node-B. The coupled adaptation, on the other hand, utilises the feedback from LA entities to intelligently queue the packets in dynamic manner. The parameter set may include some of the following metrics.

- Average cell throughput
- Average packet call throughput
- The packet service session frame error rate (FER)
- The residual FER
- The averaged packet delay for the sector
- System outage

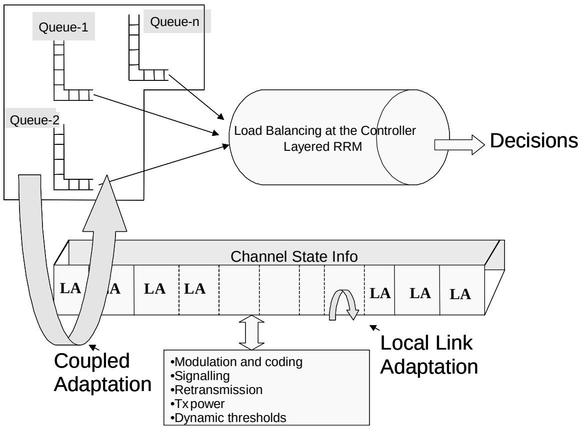

Figure 7 Illustration of the co-operative radio-aware adaptation

The coupled scheduler could also be supplied with indirect information extracted from the ongoing LA history including the parameter set, as mentioned in section 2, could be utilised. Two cases of scheduler regimes that could be coupled with LA are shown in Figure 8 where threshold dropping [4] and priority scheduling are shown side by side respectively. In the former case of threshold dropping, two data streams are considered namely preferred (λ_1) and non-preferred (λ_2). If the queue length (L) exceeds a predetermined "threshold", packets from non-preferred flow are dropped. Here, the intelligence from the LA can be used to adjust the threshold according to the channel behaviour. In case of priority scheduling, two queues are used, one for the preferred data flow and one for the non- preferred data flow. The queue length of the preferred buffer is K and non-preferred buffer is L. Buffer management of the these two queues can also be coupled to the LA.

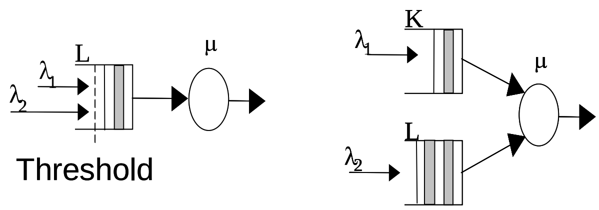

Figure 8 Scheduling schemes at intermediate nodes

In the future work, integrated evaluation of the capacity enhancement by using the proposed co-operative RRM strategies is crucial for dynamic selection of 'intelligent node-Bs' (i.e., core and leaf node-Bs), which are characterized as slowly varying ad-hoc networking nodes. Additionally, it is also relevant for the evaluation of the adaptivity techniques between the UE and the node-Bs, which allows for the provision of end-to-end high capacity spectrally efficient communications. In particular, it exploits the capability to relocate, replace, and remotely communicate without degrading the QoS.

The intelligent layered RRM that may be required here is broken down into two stages, namely:

- Inter-node 'over-the-air' RRM between the wireless node-Bs. This can be based on advanced physical layer and multi-antenna solutions and includes link adaptation and distributed packet scheduling.
- UE-node-B RRM between the UE and the node-Bs, including link adaptation of downlink and uplink packet scheduling for bursty packet traffic. The key gap area here is integrating the application dynamics at the UE side into link adaptation giving the basis for an all-layer optimization

For the "simultaneous" optimization of the radio interface utilization between the node-B links and the node-B/UE links, carefully thought coupled RRM functions are needed. A detailed cross layer model that couples the mapping of QoS requirements at the IP and the radio layer between the wireless node-Bs as well as the mapping between the node-B and the user is required for this framework. Further more, this should consider the differences among the different services, not only in terms of QoS requirements but also in terms of the nature of the offered traffic, bit rates, and so forth. The coupled RRM functions include coupled admission control—accept or reject a new connection depending on the load it adds to existing connections; coupled congestion control, and coupled optimization mechanisms for the management of transmission parameters.

The resource controller in the layered RRM framework has been designed to manage the status of the QoS of the core network, to coordinate with other network functional entities that track the QoS requests and usage for the purpose of core network resource management, to interface with the reconfiguration controller and to interface with the channel predictor and layered RRM. An example synthesis of the layered RRM functionality was illustrated [1].

It may be noted that in the architecture proposed here, the functionality of the Node-B will increase significantly. However, developments in the MWIF forum [5] are encouraging to pursue this further, although some 3GPP discussions are ongoing and are, clearly, in a preliminary stage. This may mean that evolved Node-B architectures will be considered for systems beyond 3G. Furthermore, IST-MIND [6] and several other international research projects including WWRF are also discussing related issues.

IV. CONCLUSIONS

This paper proposed a concept that incorporated wireless node-Bs into the all-IP architecture to cater the needs of bursty multimedia bearers in systems beyond 3G. The overriding concern of this architecture is to enable the design and creation of a rapid service-provisioning path over congested hotspots using short-range pico/micro cell solutions. The main advantages of the architecture can be summarized as follows.

- The architecture embraces the all-IP and open-RAN concepts to retain the backward compatibility.
- Introducing the "slow" ad-hoc connectivity reduces the backhaul costs, which are normally significant.
- Dynamic network adaptation to alleviate the congestion in the network.
- Coupling with the location based server to carry out effective resource controlling mechanism

The methodology adopted here is not only complementary to the ongoing international efforts on mobile ad-hoc networks but also exploits the advances in this area. However, the chief distinction here is to introduce the co-operative resource management to support the flat architecture described in this paper. The building blocks of the resource management were described. Particular emphasis is laid on the model that couples the link adaptation and location measurements at the radio layer to a twin scheduler. Furthermore, scheduling is considered to be one of the important enabling technologies in the flat architecture and accordingly a predictive scheduler could be integrated into the link adaptation scheme. It is also underlined that the modeling of the cross layer design and the middleware aspects are critical to rapid reconfiguration of the dynamically varying QoS demands required for future radio access systems.

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