Implementable Wireless Access for B3G Networks — Part IV: Resource Management Issues

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ABSTRACT

In this article the fourth in a series of four offers as a compilation of material which has been presented in detail elsewhere (see references within the article). In this article the focus is on resource management based methods for B3G mobile communications systems. As well as feeding into the industry's in-house research program, significant extensions of this work are now in hand, within Mobile VCE's own core activity, aiming towards securing major improvements in delivery efficiency in future wireless systems through cross-layer operation.

INTRODUCTION

The first three parts of this series of four articles focused on MIMO channel models and architectures, how these impact the performance analysis and design of space-time trellis coding strategies, and on the performance and complexity reduction of various beyond third generation (B3G) code-division multiple access (CDMA)-based transceiver structures in a multi-user environment.

In this final part of the article the accomplished increase in link and system capacity requires proper management of resources. To this end, CDMA-centric high-performance cross-layer optimized radio resource metric estimation algorithms are presented as well as algorithms related to self-organizing B3G networks.

RESOURCE METRIC ESTIMATION

INTRODUCTION

The next generation of mobile systems will be required to support mixed traffic types (Internet data, FTP, video, voice, etc.), each with different quality of service (QoS) requirements. Providing such diverse QoS in the face of rapidly changing link and traffic scenarios requires a new approach to radio resource management (RRM)

in the form of the resource metric estimator (RME) [1]. Current RRM functionality in second-generation (2G) and 3G systems utilize wireless physical resources directly without intermediate layers. Research work incorporating an RRM that takes into account the conditions of the physical layer resources suggests the need to focus on its potential impact in the intermediate layer (i.e., radio RME), which can be aware of the cross-layer capabilities and states. Based on the knowledge of the desired loads and channel and radio resources, the RRM in cooperation with the RME can manage both up and down the protocol stack. Thus, it can decide and control the parameters and functions required to optimize the desired features such as QoS, throughput, power utilization, and overall system capacity.

Resource metric estimation is a crucial part of the radio resource allocation (RRA) algorithm that performs call admission control (CAC), resource scheduling, and power/rate scheduling. With its in-built capacity models, the RME:

- Uses the radio channel characteristics and session quality requirements for optimal power and rate allocation
- Uses the current channel load, characteristics, and quality requirements to control the resource scheduler
- Assists the CAC in accepting or rejecting new sessions

Figure 1 is an illustration as to how an RME could interact with the other RRA algorithms in the base station (BS).

Also of interest is the air interface likely to be adopted in fourth-generation (4G) systems. From the RRM point of view, a multicarrier-based CDMA system is a good air interface candidate since it has the flexibility of a common pool of available resource units (RUs) such as frequency unit and code slot unit. In this section we describe the use of RME in both a conventional CDMA system and a generic multicode multicarrier CDMA (MC2-CDMA) system.

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■ Figure 1. RME's interaction with RRA algorithms at the BS.

EFFICIENT INTERWORKING BETWEEN LAYERS VIA A RESOURCE METRIC MAPPING FUNCTION

The role of the RME is to efficiently deliver the measured link quality information to the CAC and other RRA algorithms. This aim is similar to that of the interface between link and system level simulations. A solution for efficient interworking between the physical layer and higher layers — the resource metric mapping function (RMMF) — is proposed [2]. The RMMF deals with this issue by monitoring the mean of the signal-to-interference ratio (SIR) bursts and also the availability of the code pool by estimating the standard deviation of SIR bursts. The RMMF is defined and demonstrated by means of an average raw bit error rate (BER) mapping function as a function of the mean and standard deviation of SIR bursts, as shown in Fig. 2, which was obtained via Monte Carlo simulation of a time-division duplex (TDD)-CDMA system as defined within the Universal Mobile Telecommunications System (UMTS).

By using the RMMF, the link quality in terms of average raw BER observed by a user can be determined very accurately. Furthermore, in higher layers this mapping function can be used as a resource lookup table, having actual radio mobile channel and interference characteristics, and as a monitor of resource availability.

RRA WITH PREDICTIVE LOAD-BASED RME

In an aggregated traffic stream the estimation of available resources can be either optimistic or conservative due to inaccurate link quality information and the coarse estimation of over-

■ Figure 2. RMMF as a function of the mean and standard deviation of burst SIR.

flow traffic, resulting in under-exploitation of the RUs. If we know the resource availability (i.e., the required total average resource plus the excessive resource that cannot be utilized due to stringent call admission criteria), this information allows the acceptable resource metric region (RMR) to be established on a call, packet, or time slot basis, thus enabling the RRA algorithm to maximize resource utilization.

One approach to this concept is where the measurement of SIR and traffic is followed by a Kalman-based prediction utilizing the measure-

■ **Figure 3.** DCL and aggregate residual data rate for a WCDMA and multi-code MC-CDMA system.

ments, or observations, on the mean and variance of SIR, traffic, and interference measurements. This provides measured or predicted resource parameters for the resource scheduler to search their current position on the surface of the RMMF and deliver the actual status of resource usage [3].

RME WITH DEGREE OF CONFIDENCE LEVELS IN W-CDMA AND MULTICODE MC-CDMA

As mentioned in the previous section, in conventional systems, due to stringent call admission criteria some underutilized resource can exist in a wireless system. An estimate of this free resource and the level of confidence in its availability will clearly aid in its utilization. Thus, we have proposed a predictive RMR-based RME with a degree of confidence level (DCL) of capacity and user status that can deliver the available capacity of resource margin considering the systematic error [3, 4]. The DCL is defined as the capacity status by comparing the optimal capacity limit and the pessimistic capacity limit to estimated current user status with the amount of the predicted variation of the available number of users from the Kalman predictor. By using this DCL parameter, the current and predicted capacity statuses of users are delivered to the RRA algorithm to accept or reject a new coming call. Figure 3 shows the admissible and residual aggregate data rate (ADR, i.e., total data rate) with/without DCL in terms of frame index for a wide-band CDMA (WCDMA) system and an MC²-CDMA system (similar simulation parameters were assumed). It is demonstrated that the DCL of MC²-CDMA is relatively higher than that of WCDMA, which means that for the MC²-CDMA system, the fidelity of information of the capacity status is more reliable than for WCDMA since long-term fading is assumed in

our study. The performance is clearly dependent on the quality of the predicted behavior, and Fig. 3 illustrates the performance of several methods, discussed in detail in [2–4].

SELF-ORGANIZING RADIO NETWORKS

INTRODUCTION

Despite the offering of new services and advanced technologies of UMTS, the network planning approach is an old one, resulting in inefficiencies in spectrum usage, cost of infrastructure, capacity, and cost. This is mainly due to two reasons. First, wireless radio networks are fully dynamic in nature as the system status depends on not only geographical variations but also interference variations. Coverage and capacity have to be considered jointly, and more work has to be done in the network optimization stage rather than in the network planning stage. Second, the schemes for RRA such as admission/congestion control, power control, and handover mechanisms in UMTS are based on fixed and predetermined parameters, and operate in an isolated manner without support from each other.

Therefore, it appears that there is an urgent need for research in autonomous, intelligent, adaptive, and flexible yet robust control mechanisms for UMTS. Provision of such an intelligent mechanism could potentially change the conventional and old communication infrastructure planning and design procedures and pave the way toward a more effective approach to providing UMTS. These are the driving forces behind the importance of research on self-planning/planning radio networks.

A self-organizing network should intelligently respond to the dynamics of the system quickly and transparently to users to achieve better coverage, capacity, and QoS, and hence ultimately yielding high radio spectrum efficiencies. To achieve this goal, it needs to take into account the dynamics of the system (traffic, service demand, mobility, channel fading conditions) and use them in the RRM process (CAC, handover/soft handover [HO/SO], power control [PC], spreading factors, etc.) continually and automatically.

STRUCTURE OF SELF-ORGANIZING RADIO NETWORKS

The main functions of achieving defined self-organizing features can be addressed as follows.

Tracking system dynamics — automatic cell coverage estimation: Cell coverage in a CDMA-based mobile system is highly irregular and time varying, heavily depending on traffic and propagation variations. Therefore, cell coverage estimation in such a system is fairly difficult. However, in future mobile communications systems, RRA should be fully adaptive to system dynamics such as propagation and traffic variations, where instant cell coverage potentially provides a new dimension to RRA strategies.

Integrated RRA strategy: From a user's point of view, an intelligent and integrated resource allocation scheme should be applied. This

scheme is intelligent in that the main functions, such as handover and admission control, are adaptive to system variations. Also, the main functions work in an integrated way where they are jointly considered to support each other, hence achieving flexible trade-off between link quality and resource utilization. Moreover, an integrated RRA scheme should exhibit robustness, which, through adaptation to system dynamics and monitoring qualities in both links, will inherently change each user's behavior, thereby achieving a stable system performance regardless of the system situation.

Therefore, in a self-organizing radio network, estimated cell coverage information is applied to the RRA strategy. Moreover, the radio resource is allocated in an integrated way in that first, the uplink and downlink are considered together to balance their link qualities, and second, different resource allocation schemes such as CAC and SHO work in an integrated manner to support each other. Furthermore, the link qualities or overall system performance are fed back to the resource allocation strategy to enhance its robustness.

AUTOMATIC CELL COVERAGE ESTIMATION

An automatic coverage algorithm should be transparent to users, and change with the up-to-date system propagation and traffic dynamics. In the proposed estimation algorithm the cell area is divided into regular bins, and all the users located in a bin are considered in the center of the bin. Periodically, all active users measure and report back to the Node-B their locations and received E_b/I_0 . The Node-B contains a data matrix, recording the E_b/I_0 samples from each bin. Based on enough such samples, the network decides the coverage of each bin, according to the location probability required. The coverage information of all the bins together forms a coverage map of the desired cell. Furthermore, a cell boundary map can be derived from the coverage map if required.

In order to implement this algorithm in a practical system, a two-stage mechanism is proposed. We divide the estimation process into two different stages: training and updating. The training stage is the initial stage, which is long-term, to collect enough measurements from each bin for the algorithm to converge. Once the algorithm reaches its convergence, the first coverage map of the cell of interest is obtained. After that, the process turns to the regular stage, or the updating stage, where the new incoming measurement set will replace the most out-of-date measurement set. Based on the updated matrix, a new coverage map is produced. By applying this mechanism, a new coverage map can be achieved after a measurement interval time of, say, 500 ms.

INTEGRATED RESOURCE ALLOCATION STRATEGY

The proposed integrated resource allocation strategy consists of an adaptive SHO algorithm and an adaptive CAC scheme working together to optimize the resource allocation and to balance the link qualities. In this strategy the link quality indicators are defined that are able to reflect both current and previous link situations.

■ Figure 4. Satisfied user rate, GoS, call blocking rate, and call dropping rate vs call arrival rate.

They are then incorporated with SHO and CAC to construct adaptive thresholds. The dynamic thresholds are designed in such a way that they will improve one link without impairing another. Moreover, adaptive SHO and CAC will work in an integrated and balanced manner to achieve target link outage probabilities in both links as much as possible.

Furthermore, the estimated cell coverage information is applied to SHO thresholds in a distributed way. If a piece of user equipment's (UE's) location is covered by the serving cell and not covered by the target cell, both of its *adding* and *dropping* thresholds will increase. If the UE's location is not covered by the serving cell while covered by the target cell, both thresholds will reduce 1 dB. The thresholds will not change otherwise.

PERFORMANCE IMPROVEMENTS

It can be observed from Fig. 4 that the proposed self-organizing radio network noticeably improves service qualities. Compared to a fixed-parameters-based UMTS terrestrial radio access (UTRA) network, it achieves lower call blocking rate as well as lower call dropping rate, jointly resulting in a better grade of service (GoS), particularly in heavily loaded scenarios. As a consequence, it further shows that the satisfied user rate (R_s) in the proposed network is improved compared to the UTRA network. A satisfied user is defined as a user who is not blocked or dropped, and whose link quality is above the target for more than 95 percent of the communication.

The results in Fig. 5 demonstrate the averaged transmission powers in decibels for Node-B and UE that are normalized by their maximum transmission powers, respectively. It shows that

■ **Figure 5.** Normalized Node-B and UE transmission power vs. call arrival rate.

compared to a UTRA network, the self-organizing network demands less power consumption from the Node-B's perspective. Furthermore, the power consumption required from a UE is similar to that in a UTRA network, and under heavy cell load it uses slightly less power. It has to be noted that these power assumptions are achieved in a system where the supported users are more than in a UTRA network, due to the lower call blocking rate.

CONCLUDING REMARKS

This article, the fourth of four, has presented the technical activities within Mobile VCE's Wireless Access research area. Since the research was defined and driven by the leading companies in mobile communications, the research naturally focused on the provision of wireless access in future networks.

Low-inertia radio resource metric estimation algorithms were shown to cope with the higher system capacity accomplished by the aforementioned single- and multi-user transceiver designs. The high performance of such algorithms has been attributed to an optimized cross-layer design. In addition, self-planning and dynamically reconfigurable CDMA networks have been considered, where it is recognized that algorithms enabling dynamic optimization of network performance with varying traffic and propagation conditions will be important for future wireless networks.

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