Guest Editorial Mobility and Resource Management in Next Generation Wireless Systems

SECOND GENERATION (2G) wireless systems such as Global System for Mobile communications (GSM), Personal Digital Cellular (PDC), North American Time Division Multiple Access (NA-TDMA), and Code Division Multiple Access (CDMAone) have brought mobile telephony to an impressive worldwide market. The deployment of next generation (NG) wireless systems, including 2.5G General Packet Radio Service (GPRS), and 3G technologies wideband CDMA (W-CDMA), cdma2000, and the Universal Mobile Telecommunications System (UMTS), will help increase both the number of mobile users and the variety of mobile services.

The third generation systems will operate at data rates of 144 kb/s for vehicular, 384 kb/s for pedestrian, and 2 Mb/s for indoor environment. Moreover, the 3G systems will support radio environments that range from high capacity pico cells, to urban terrestrial micro and macro cells, as well as Wireless Local Area networks (WLANs) and satellite networks. These requirements have been specified within the framework of International Mobile Telecommunications (IMT)-2000 by the International Telecommunications Union (ITU). Since 1999 there have been vigorous industry efforts in harmonizing the standards. One industry group, the 3rd Generation Wireless Partnership Project (3GPP), is developing the 3G standards for GSM-based and Wide-band CDMA (WCDMA) air interface. Also another partnership, the 3rd Generation Partnership Project 2 (3GPP2), is developing 3G standards for cdma2000-based systems, while the Universal Wireless Communications Consortium (UWCC) looks after the evolution of NA-TDMA technology.

With commercial development of 3G systems proceeding, the research community turns its attention to the fourth generation. While 4G technology is not as well defined as 3G, there is an emerging consensus that it will rely on Internet protocols and offer bit rates that are an order of magnitude higher than those of 3G systems. Goals for the fourth generation include support for interactive multimedia services like teleconferencing, global mobility, service portability, and the same telephone quality as the current wireline networks. Moreover, the terminal battery capacity/weight ratio should increase by one order of magnitude compared with terminals used for 3G systems. In addition, tight security features will protect the services from all types of security threats such as identity masquerade, unauthorized access, Trojan horse, and denial of service attacks.

The technical community faces rigorous challenges in realizing the full potential of emerging 2.5G and 3G technologies and achieving 4G goals. Many of these challenges are in the category of mobility and resource management, the subject of this special issue. Evidence of intense interest in these issues can be found in the 140 papers we received in response to the Call for Papers. Although many of them were of high quality, we had room for only 23 papers that best fit the theme. Unfortunately many fine papers could not be included in this issue. However, we anticipate seeing them in other publications.

The first seven papers deal with resource management techniques that will make it possible for NG wireless systems to satisfy the enormous demand for multimedia services.

Haas and McLaughlin introduce a new dynamic channel assignment scheme called TS-opposing technique for a TD-CDMA/TDD air-interface used in the UMTS. The new scheme enables neighboring cells to adopt different rates of asymmetry without a significant capacity loss. In each TS, the required transmitting power for a mobile terminal (MT) or base station (BS) is derived based on the interference experienced by the MT or BS from other MTs and BSs in the neighboring cells. The interference is reduced by changing the direction of transmission whenever outage would occur in a TS. The authors further demonstrate that the existence of asynchronous TS overlaps in a TD-CDMA/TDD system does not result in system degradation. This implies that the channel asymmetry between neighboring cells in a TD-CDMA/TDD system does not cause capacity reduction as a consequence of the same entity interference, i.e, MT to MT and BS to BS interference.

Calin and Areny investigate the impact of major critical parameters such as user mobility, activity factors, radio link quality, and the effect of radio resource allocation policies as well as the network topology effect on the performance of TD-CDMA systems. The authors carry out extensive analysis taking into account accurate modeling of user behavior, interference scenarios, and power budget limitations at both MTs and the infrastructure. The authors investigate the performance of a power management algorithm, dynamic channel allocation scheme, and management of active calls.

Berggren *et al.*, consider the downlink channel of a DS-CDMA data network. The authors present results regarding the control of interference for the downlink DS-CDMA cell by means of new dynamic scheduling and power control schemes. They show that one-by-one scheduling can be used to improve the energy efficiency when nonreal time users require only a minimum average data rate over a specified time interval. Moreover, the new scheduling scheme achieves the minimum time span for transmitting data to all users. The authors propose a new dynamic power control algorithm and show that the new scheme converges faster than the one used for continuous

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transmission. The proposed joint power control and intracell scheduling scheme results either in less energy consumption for the same amount of data transmitted compared with the continuous transmission scheme, or in an increased data transmission rate (or increased number of accepted users) for the same transmitting powers.

Song and Mandayam deal with a joint singal-to-interference (SIR) and rate control problem in an RLP-based forward link CDMA data network. The objective is to find the optimal SIR and transmission rate that maximizes a utility function under some constraints. The overall goal is to solve an optimization problem. The authors solve this problem by separating the jobs of base stations and MTs. This separation makes the problem tractable by a distributed (by each mobile) approach. The basic idea is that each MT minimizes its own SIR requirement under a delay constraint, and the base station maximizes the utility function based on the SIR requirements, which are minimized by each MT. The main contribution is that the optimal algorithm is shown to have a hierarchical structure that makes it implementable in a distributed manner at the MT and BS.

Saraydar *et al.* address the problem of distributed power control in a multicell wireless data network. This problem is formulated as a noncooperative game, where users choose BS and the power level and try to maximize their utility. Two criteria for BS assignment are considered, namely received signal strength (i.e., pick the closest BS) and received SIR ratio. It is demonstrated that both assignment schemes result in an inefficient operating point (a Nash equilibrium) for the system and that the introduction of pricing of transmission power results in improved performance. Since the game leads to an inefficient equilibrium point, a pricing mechanism is introduced to improve the efficiency. The authors further propose a centralized scheme to enforce each MT to achieve same SIR for a more equitable distribution.

Sallent *et al.* study the radio resource management (RRM) issues with the objective how to guarantee a given QoS in 3G systems. The authors investigate the impacts of a packet scheduler on the system performance first. Further, they propose a new packet-oriented scheduling strategy for soft QoS guarantees. They investigate the combined packet scheduling and spreading factor adaptation in W-CDMA. Furthermore, they propose a model for soft QoS requirements for Web traffic.

Eriksson studies the dynamic resource management in the downlink channel with 10–20 Mbps of the wireless asymmetric Internet access by combining the cellular and terrestrial digital broadcasting system. The author evaluates the dynamic single frequency networks by exploiting the macro diversity capability of the OFDM modulation scheme. Eriksson achieves a spectrum efficiency of 0.45 bit/s/Hz/site with omnidirectional antennas under certain conditions which is an improvement of 170% compared to a fixed channel allocation solution with static handover.

The unpredictable variations in bandwidth and resource availability in wireless environment create new challenges within mobility management, in particular, the support for the notion of global roaming in the 3G and 4G wireless sytems with QoS requirements must be addressed. The next three papers are devoted to address these problems.

Aljadhai and Znati address the problem of predictive bandwidth allocation for an MT that expects QoS support in wireless systems. The proposed scheme incorporates the call admission control with the mobility profiles of the mobile users. The mobility profiles include the estimation of the user's trajectory and arrival/departure times in each cell along the user's path. These cells constitute the most likely cluster. Based on the timing information, the systems then examine, reserve, and release bandwidth for a user, depending on a predefined time window and service types such as integral and fractional guaranteed services. Different call admission algorithms are proposed for new and handoff calls, respectively. The performance is evaluated by comparing with the known shadow cluster concept.

Zhang *et al.* address resource prediction and reservation in wireless multimedia networks. In particular, radio resources require real-time estimators on traffic demands in near future. The authors discuss the limitations of the current estimation methods and propose two new approaches for predicting resource requirements of handoff calls in a multimedia environment. The authors introduce several solutions in (an autoregressive model of) regression theory to build up easily applicable prediction models in handover traffic estimation in wireless IP networks with bursty data traffic. These solutions help to decide on the amount of bandwidth needed for prioritized connections considering QoS guarantees. The authors then develop a simulation study to show that the new methods perform well for non-Poisson and nonstationary handoff call distributions. They also show by simulation that the new methods produce comparable results in the case of Poisson handoff call arrivals.

Wong and Leung present a scheme for determining an optimal location update boundary on a per user basis taking into account the mobility pattern of the user and the underlying network topology. The problem of determining an optimal registration boundary is formulated as a Markovian decision system and is solved using a value iteration algorithm. In the proposed scheme whenever a mobile updates its location, a new location update boundary is computed by the base station and downloaded to the mobile. The authors provide some results on sensitivity of the proposed scheme with respect to the error in estimation of call arrival rate and cell crossing rate. It is concluded from the simulation results that it may be better to overestimate the values of call arrival and cell crossing rates in order to reduce the margin between the cost computed using an approximate value of call arrival rate and cell crossing rate and the actual cost.

For mobility management, especially for location registration, location tracking and handoffs, the databases play a key role. The next two papers are focused on problems related to databases.

In wireless systems, the visiting location region (VLR) is used to temporarily store profile information of mobile users who are currently visiting the coverage area of VLR. Due to unpredictability of mobiles' roaming characteristics, a VLR with many visiting users may be overflown, leading to service inaccessibility for those users who roam there without memory space available in the VLR. Hung *et al.* address this database overflow problem. For this problem there exist typically two solutions in the literature: one is to store a pointer at a VLR to indicate the user is an overflow user (pointer can reduce the

space), the other one is to develop a replacement scheme, i.e., replace a record so that the reclaimed space is used to store the new roaming user's information. The authors propose a new replacement scheme called the most idle replacement policy. The idea is whenever the overflow occurs upon a new mobile registration arrival, the record corresponding to the longest period in which no call activities occur will be replaced by the new registration arrival. The authors develop an analytical model for performance evaluation and show that the new scheme performs better than the random replacement scheme, and under certain conditions it even performs better than the known inactive replacement policy.

Gil *et al.* present a new database restoration scheme by introducing mobility learning and prediction into the restoration process, which helps systems to locate users after a failure of mobility databases. The movement of users is tracked by a neuro-fuzzy inference system (NFIS). In case of failures, an inference process of the NFIS is initiated, and the user's future location is predicted which helps to locate lost users after a failure. The authors show that the new scheme reduces the cost to restore the location records of lost users after a failure compared to the known check-pointing scheme.

The next three papers address the problems of routing, rerouting, and multicasting issues in wireless systems.

Lin and Gerla introduce an admission control scheme which guarantees bandwidth for real time applications in multihop mobile networks. The overall functionality of the approach includes calculating the end-to-end bandwidth; slot assignment/scheduling (once the appropriate routes between source and destination that satisfy bandwidth constraints are determined); determining multiple routes (not necessarily including the shortest-path) that satisfy bandwidth constraints; and dealing with any reconfiguration resulting from connection breakage due to mobility, etc. The authors present simulation results that reflect upon the performance of the approach. Mobiles are assumed to move randomly with certain speed in a uniform area. Three routes of varying bandwidth requirements (QoS1, QoS2, and QoS3) are discovered. Several simulations provide the impact of system parameters such as mobility on throughput, average incomplete ratio, average delay, and maximum connections for each of the three discovered routes. A comparison of the length of routes discovered using the proposed flooding method with the shortest-path routes is also conducted.

Mirhakkak *et al.* propose an extension to the resource reservation setup protocol (RSVP) in an effort to study the feasibility of achieving dynamic QoS at the routing level. In particular, the authors introduce a new protocol called dynamic RSVP (dRSVP) to demonstrate and evaluate the dynamic QoS concept. The protocol and a new application-programming interface (API) for this dynamic QoS are described. Further the authors provide qualitative and quantitative assessments of the dynamic RSVP protocol.

Chen *et al.* introduce an algorithm for dynamic reconfiguration of multicast delivery trees, as necessitated by the movement of MTs in a wireless cellular system. The new approach has significant scaling advantages over core-based trees (CBT), especially, for very high multicast workloads.

An essential traffic type in the 3G and 4G wireless systems will be multimedia in particular, video and audio traffic which are the focus of the next two papers.

Fitzek and Reisslein focus on the transmission of prerecorded multimedia streams over wireless links. The proposed protocol makes use of rate adaptation capabilities of CDMA channels; it uses the join-the-shortest-queue principle and the channel probing to detect channel conditions. The strength of the proposed scheme is its flexibility (it supports variable and constant rate streams, e.g., MPEG, H.263). Moreover, it can be adapted to live streaming of multimedia traffic, given that a certain prefetch delay is provided. Thus, it is a practical and useful scheme for multimedia applications that have a play-out buffer. In addition, several well-explained simulation experiments clearly show the benefits of the protocol.

Leung *et al.* investigate how the error performance for MPEG-4 advanced audio coder (AAC) music can be improved by link adaptation and power control with a goal of achieving a target error performance in an EGPRS cellular network. In particular, the authors show by using simulation models that the combined link adaptation and power control scheme achieves a target error rate, referred to as the error-based scheme, which enhances the performance of the EGPRS block and the AAC frame level. The authors further introduce the throughput-based scheme which provides the maximum network throughput. Finally, they examine the capacity gain by the error based scheme for a given AAC frame error rate.

In NG wireless systems, mobile subscribers expect that QoS will be maintained throughout the duration of their service while traveling not only from cell to cell, but also from one system to another using different technology, i.e., intersystem roaming. Accordingly, mobility management, which consists of location registration and call delivery, will involve more than one system, thus increasing the signaling traffic. Additionally, the growth of new mobile services and the number of mobile users also lead to an increasing traffic load in the network. Therefore, it is desirable to devise a new protocol which is cost-efficient while supporting intersystem roaming. Wang and Akyildiz introduce a new signaling protocol for intersystem roaming where the signaling burden is alleviated, and the latency of call delivery as well as the call losses are reduced. Under this protocol, mobile users are allowed to register at the new network prior to their arrival. In order to capture the up-to-date location information of each user, a cache database boundary location register (BLR) is used which maintains a list of roaming users with their current locations. This scheme does not impose any changes on existing entities in current wireless networks. As a result it is easily deployable in the existing systems. The authors develop a detailed procedure for location registration and call delivery. Analytical results demonstrate that the new signaling protocol yields significant improvement in system performance compared to the existing protocols.

Scheduling is one of the important research topics, especially to decide which packets should be served first by distinguishing different multimedia types and taking into account their different QoS requirements. Liu *et al.* propose an opportunistic scheduling policy in a wireless system where each MT is assigned a time slot to transmit the subject to its time-fraction

assignment constraint. The authors propose mechanisms to achieve both long-term and short-term fairness. A stochastic model is introduced that captures a time-varying channel condition for each user. Specifically, the user satisfaction is modeled as a stochastic process which represents user utility. The scheduler then assigns a user to each time slot based on the user that has the best gain from transmitting in that time slot. Standard stochastic programming methods are utilized to generate numerical results.

In the 4G wireless systems the mobile IP gateways (MIGs) are used to enable the mobile users to access the IP backbone. For example, an MT in a wireless local area network (WLAN) will be able to communicate with an MT in personal communication service (PCS) wireless networks through the MIGs, in which the necessary link layer protocols provide the accessibility to the IP backbone. In addition, the protocols should be capable of handling high bit error rates resulted from wireless links and real-time multimedia traffic. The next two papers introduce new MAC protocols for LANs with multimedia traffic types and QoS requirements. In particular, these papers provide solutions for access to the Internet to support wireless Internet applications from WLAN domains.

Sheu and Sheu propose a MAC protocol (DBASE) for IEEE 802.11 compatible *ad hoc* LANs. The MAC protocol is designed to support both asynchronous data traffic and time-bounded (real-time) traffic. Asynchronous traffic is managed according to the conventional DCF CSMA/CA-based procedure of the IEEE802.11 standard. Time-bounded traffic is assigned resources according to a new distributed reservation procedure specifically proposed by the authors. The authors then develop an analytical model for the DBASE performance in terms of throughput and packet losses. An analytical model has been validated by extensive simulations.

Veres *et al.* propose a method to implement service differentiation in a random access-based wireless network. This is based on IEEE 802.11 DC, and differentiation is achieved by means of having different backoff parameters for different classes. Essentially, the high priority flows have smaller minimum and maximum backoff parameters than the low priority flow class. By these means, there is a tradeoff between shorter delay for the high priority class and total system throughput. Moreover, the authors propose a Virtual MAC/Virtual Source (VMAC/VS) algorithm to passively monitor the channel, so that statistics can be collected on-line. This algorithm can be used to estimate typical delays, packet loss, and collisions.

The 3G wireless systems have a hierarchical cell structure (i.e, pico, micro, macro, satellite cells are within the reference architecture) and the MTs can have global roaming seamlessly between these different hierarchical layers. The paper by Ahn *et al.* deals with practical design of macro–micro CDMA cellular overlays in the existing big urban areas. The authors develop a spatial traffic distribution model of current big urban areas where multiple hot spots exist. Further, they introduce a macro–micro cellular overlay with an enhanced cell deployment algorithm. Using extensive simulations the authors evaluate the performance by considering several important aspects about the design and operation of macro–micro cellular overlays.

Wu *et al.* describe iCAR, a new architecture that integrates cellular and *ad hoc* networks to balance traffic among cells, reduces the call blocking and dropping probabilities, and improves the overall throughput. The idea of the new architecture is to place a number of ad hoc relaying stations. The use of these relaying stations is intended for those areas in the cellular network that can became "hot spots" (congested areas). The architecture is investigated both analytically and by simulation in great detail, and it is compared with the conventional cellular architecture. The obtained results show the effectiveness of the use of *ad hoc* relaying stations to decrease the call blocking/dropping probabilities and to increase the overall throughput.

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