Proposal and Performance Evaluation of Novel Architectures for the Provision of Optimal Connectivity and Services in Next Generation Mobile Network Environments

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Abstract. Current trends in mobile telecommunications suggest the use of WLANs or WMANs as supplementary access technologies to the existing cellular infrastructure. Overlay network architectures are expected to improve both service provision and resource utilization under the condition that sophisticated architectural options are followed. In this thesis, two different ways to combine wireless and cellular networks are presented. The first one is a new tight-coupled WLAN/UMTS architecture that offers flexible connection management and seamless handover. The proposed solution is described analytically on both protocol and signal basis. Moreover, its performance is measured with the help of a theoretical and a simulation model built for this purpose. The second architecture concerns the interworking of wireless and cellular networks with the aid of the IEEE 802.21 protocol. The potential of this protocol to support seamless handover is examined based on the description of a signaling exchange in a WiMAX to GPRS handover case.

Keywords: interworking, wireless networks, cellular networks, tight coupling, seamless handover.

1 Dissertation Summary

1.1 Introduction

During the past few years there has been a race among cellular operators to upgrade their infrastructure toward Third Generation (3G) systems (mainly, the Universal Mobile Telecommunication System — UMTS). At the same time, a recent phenomenon is the rising popularity of Wireless Local Area Networks (WLANs), especially with the wide use of 802.11-based networks. WLANs offer low deployment cost and high communication rates (up to several hundreds of Mb/s) in the unlicensed frequency bands of 2.4 GHz and 5 GHz. Based on proper planning to

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handle interference problems, these systems are considered to be perfect candidates, especially for wireless hot-spots, where users can enjoy increased bandwidth in limited geographical areas. The high penetration and data rates of WLANs prompted operators and manufacturers to investigate the possibility of combining them, as well as WMANs, with 3G systems in order to provide better quality and a wider range of services to their users. These new heterogeneous infrastructures are often referred to as beyond third generation (B3G) or fourth generation (4G) systems.

Design and implementation of these systems present many technical challenges, such as unified authentication, authorization and accounting (AAA), global security provision, common quality-of-service (QoS) support, integrated location management, and inter-system handover support (known as "vertical handover") [1]. Despite the efforts in interworking standardization [2–3], work is still required toward more efficient connection establishment and handover management schemes.

The main aim of this thesis is to propose solutions to the problems of i) connection establishment and handover in WLAN/UMTS networks and ii) handover between Worldwide Interoperability for Microwave Access (WiMAX) and General Packet Radio Service (GPRS) networks using the IEEE 802.21 technology [4].

1.2 Related Work

Interworking between access networks has always been an appealing issue to the networking community. A crucial issue that scientists often deal with is the design of efficient vertical handover mechanisms. These play an important role concerning the provision of seamless service continuity when moving from one access technology to another. A critical part of vertical handover is the monitoring and processing of the appropriate information in order to choose the best possible access network.

The plethora of the proposed integrated UMTS/WLAN architectures can be categorized into three major types of interconnection [5]: *loose*, *tight* and *very tight coupling*. In loose coupling, the point of integration is after the interface of Gateway GPRS Support Node (GGSN) with the Internet Protocol (IP) network, whereas in tight and very tight coupling, the interconnection is made at the core network level and the access network level of UMTS respectively. Loose coupling solutions offer simple and cost-effective implementation prospects, at the expense of larger handover execution time. On the other hand, tight and very tight coupling are considered more complex but also more efficient in providing seamless connectivity.

3rd Generation Partnership Project (3GPP) initiative is among the major standardization efforts. In [3], six different scenarios are defined for interworking between UMTS and WLAN. These scenarios describe different levels of interworking from a user's perspective varying from only common billing and customer care (scenario 1) to the provision of 3GPP Circuit-Switched (CS) services from WLANs (scenario 6). Currently, only the first three scenarios have been specified defining different loose coupling architectures.

In [6], however, a tight coupling architecture is defined aiming at seamless service continuity between GPRS and WLAN. A new network component, named Generic Access Network Controller (GANC), enables mobile terminals to connect through WLAN access networks to the cellular core network. This is achieved by emulating Base Station Controller (BSC) functionality inside the WLAN access network. In this way, mobile terminals can be either associated with GPRS or WLAN according to various terminal modes or network policies. The main parameter taken under consideration to select the most suitable access network is the received signal strength. Similarly, an interworking entity that hides the particularities of WLAN and allows it to connect directly to the UMTS core network is proposed in [7]. A large part of the existing infrastructure is reused in a way that ensures at least service continuity. Despite that, when the signal is lost in one network, all the connections of the terminal are handed over to the other network as in [6].

Although some loose coupling solutions have been proposed for handover of individual connections (such as the one described in [8]), only few tight coupling architectures deal with this problem. One of them is [9], where terminals are able to have connections over UMTS and/or WLAN at the same time. However, no detailed architecture for efficiently handing over the connections is given. Another similar approach considers a primary network (i.e., the UMTS) that is always available and an alternative network (i.e., the WLAN) that is used to route traffic through it when possible [10]. Although this scheme alleviates traffic load in the traditional UMTS core network by introducing new core network components, it does not specify the exact messaging procedures, necessary for connection establishment and handover.

In terms of efficient radio resource management, [11] proposes a scheme for managing terminals in heterogeneous networks following a policy-based perspective. The network manages to distribute the terminals properly, according to parameters such as user preferences, network policy, network availability, and cost, but treats all connections as one group during handover.

Concerning the interworking of WiMAX and GPRS using the IEEE 802.21 protocol, only few solutions have been proposed. In [12] the handover process can be enhanced by incorporating mechanisms for service continuity, mobility policies, power saving and adaptation support at application layer. Addressed issues include the minimization of communication interruption during handover, the effect of user's preferences, cost and security on handover decision, the use of smart techniques in order to activate interfaces only when needed, etc. In order to achieve these, a mobility manager is proposed that results in less handover delay for both IEEE 802-to-IEEE 802 and IEEE 802-to-non-IEEE 802 handover cases. The claimed improvement reaches even 75% compared to the handover delay without this mechanism. Seamless behavior is also provided by the mechanism proposed in [13]. However, in this solution the key element for achieving low handover latency is a mechanism for fast re-authentication referred to as Media-independent Pre-Authentication. This mechanism works for any IEEE 802 and non IEEE 802 network, while its philosophy is to pre-authenticate, pre-configure the new link and establish a bi-directional tunnel over the old link with the target network at layer-3.

1.3 Proposed Architectures - Contribution

Based on the previous work, a new mechanism has been proposed that is able to route connections independently from each other in a tight-coupled WLAM/UMTS network [14-15]. This is done over both access technologies and at the same time. Its novelty lies in that, in contrast to similar tight coupling solutions [9-10], a description of the extended architecture is given that includes sophisticated entities for radio resource management. Furthermore, the signalling exchange during connection establishment and handover is described in detail. In addition, a theoretical model and a simulation model have been built in order to evaluate the concept of flexible connection management. The improvement in system performance against other tight-coupled WLAN/UMTS architectures is showed regarding new call and handover blocking probabilities as well as resource utilization. Moreover, the effects of the proposed architecture on signalling and power consumption in the mobile terminal are described for completeness. Simulation results obtained from the respective model show that blocking probabilities are reduced at the cost of more signalling in the network and more energy consumption at the mobile terminal.

Another architecture concerned the proposal of interworking between WiMAX and GPRS networks with the aid of the IEEE 802.21 protocol [16]. In this architecture, the ability of the IEEE 802.21 standard to support seamless mobility has been demonstrated with a WiMAX to GPRS handover case study. This example along with a brief discussion has demonstrated that IEEE 802.21 covers many seamless mobility principles and therefore seamless mobility is largely supported. However, the standard should be extended in order to further facilitate seamless handover provision.

2 Results and Discussion

2.1 A tight-coupled WLAN/UMTS Architecture

System Architecture. The proposed architecture considers a UMTS system interconnected with various WLAN hot-spots dispersed in the area of UMTS coverage. All active terminals have a signalling connection with the UMTS established at all times. Their multimode capability enables them to connect to both networks simultaneously, when WLAN coverage is also available, and handover their connections from one network to another. Moreover, new functionality is introduced in order to take proper handover decisions and differentiate between disparate connection requirements. The reference UMTS/WLAN architecture is depicted in Fig. 1.

As shown in Fig. 1, UMTS and WLAN networks are interconnected in a tight coupling way. This is feasible through an RNC Emulator (ERNC) that manages the WLAN network resources similar to a UMTS RNC. More specifically, ERNC collects information concerning the resources of the attached APs (traffic load, serving terminals, signal strength of the terminals, etc.) and is responsible for the establishment of radio paths with the User Equipment (UE).

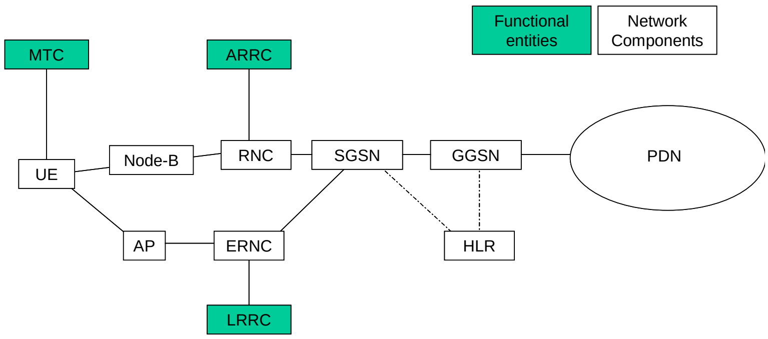

Fig. 1. UMTS/WLAN reference architecture

In order to provide sophisticated usage of the radio resources and advanced handover decision capabilities, three new functional entities are introduced: the Mobile Terminal Controller (MTC), the Advanced Radio Resource Controller (ARRC) and the Light Radio Resource Controller (LRRC). ARRC is focused on the radio resource management of the supervising network elements. ARRC is an extended version of RRC. It manages the resources of the underlying UEs and Node-Bs, while it communicates with LRRC to acquire load traffic information. LRRC is limited to gathering and reporting this information to ARRC and does no further sophisticated action. Therefore, it is referred to as "light" RRC. Finally, MTC is integrated into the RRC of the UE and is responsible for radio link monitoring and processing of terminal parameters. The important property of these new functional entities is that they are incorporated in existing network components and protocols and do not burden the network infrastructure. This is a logical choice if minimal alterations in existing UMTS functionality is the main target. The exact placement of these entities in the UMTS and WLAN protocol stacks will be described in the next subsection.

Concerning the interaction between the new functional entities for advanced handover decision, the main aim is to minimize signaling exchange. Therefore, some fast changing parameters are used close to the point of generation (e.g., the UE for radio signal measurements), while others are requested when needed (e.g., WLAN traffic load report towards RNC).

The system assumes two major points for radio resource management decisions: i) the MTC (in the UE) and ii) the ARRC (in the RNC). Each time the UE wants to establish a new connection, the locally kept parameters are processed in order to choose the target network. More specifically, the user, the terminal and the service profiles are filtered along with the network availability measurements and the result is compiled in an ordered list. In this way, the UE prioritizes the candidate access networks and sends this provisional decision to RNC for further processing. Upon receipt, the RNC may re-order the list, based on the traffic load of the candidate access networks and the operator's policy. The first network in the list is the target network and is reported to the UE as the final decision. In this way, the network has full control of the radio resources, but the user preferences are taken into account as well. Also, some processing load is transferred to the UEs, unburdening the RNC. This is considered a significant improvement, since the amount of information exchange required in heterogeneous networks, where users will have the freedom to dynamically choose between different access technologies or even operators, will not favor for centralized processing.

Protocol Stacks. The location of the new functional entities and the necessary modifications in the system protocol stacks are presented in Fig. 2 and 3 for the control and the data plane respectively.

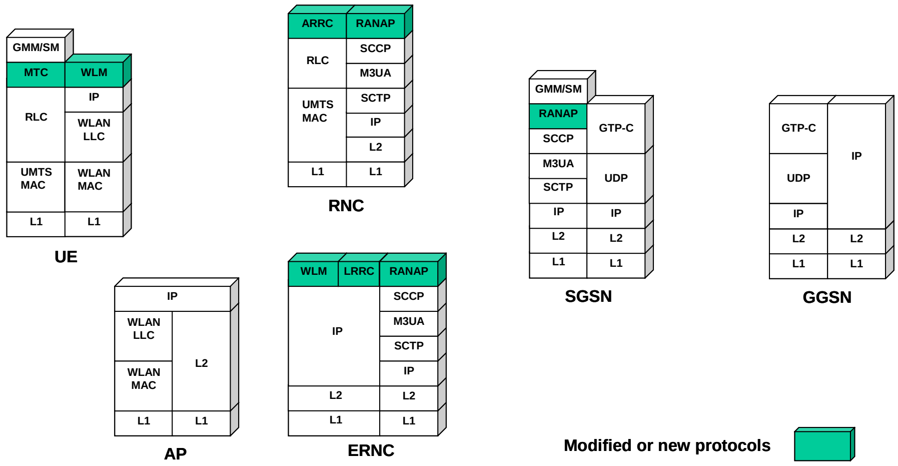

Fig. 2. Protocol stacks in the system (control plane)

In the control plane, RRC in the MT and the RNC are enhanced with MTC and ARRC functionality respectively. In the WLAN part, LRRC is placed besides a new protocol entity named WLAN Management protocol (WLM) that is responsible for establishing the radio connections over WLAN with its counterpart in the UE. RANAP message semantics have been slightly changed to uniquely indicate handover per connection and allow independent handling of resources.

Routing of downlink packets for each connection is feasible due to network layer routing in the UE and the SGSN, which is based on the NSAPI/IMSI pair. Moreover, since each connection is associated with one PDP Context, one NSAPI and one RAB ID in a one-to-one relationship, the allocation of resources for each connection in both access networks can be made in terms of different RABs.

The routing of uplink packets can be based on the same identification pair as in the downlink direction. However, the selection of the proper radio interface takes place in the Network Access Selection Layer (NASL). NASL is configured appropriately in order to route IP packets over the correct interface even after network attachment point changes.

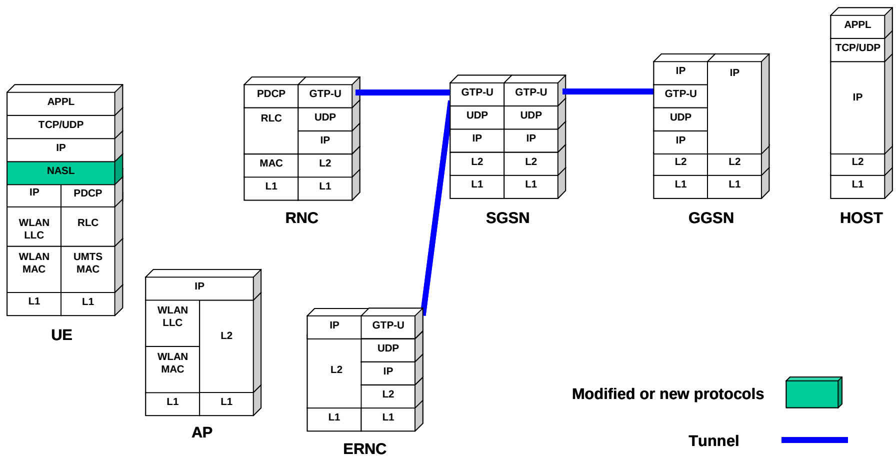

Fig. 3. Protocol stacks in the system (data plane)

Connection Establishment and Handover Procedures. In this section, the establishment of an outgoing connection through WLAN and the handover from UMTS to WLAN procedures are presented in more detail. Handover from WLAN to UMTS follows a similar procedure. The first procedure is presented in Fig. 4. After the UE powers on, it establishes a signalling connection with the UMTS that remains active until power-off. The UE listens to radio signals from other APs or Node-Bs periodically. When a new connection has to be established, the UE issues an Activate PDP Context Request message to the SGSN. This message contains several parameters such as QoS information, the requested NSAPI identifying the connection and a PDP address field (if a dynamic PDP address is assigned by the network, this field will be filled by the APN Server). Upon receipt, SGSN checks if the user has a valid subscription and chooses the proper GGSN for the UE. By sending a Create PDP Context Request message, SGSN asks from the GGSN to allocate an IP address for the UE and establish a tunnel between SGSN and GGSN. When SGSN receives a Create PDP Context Response, it orders the serving RNC to allocate resources (RAB Assignment Request). RNC, in turn, asks from the UE to report its measurements. This triggers a process that prioritises the accessible APs or Node-Bs according to signal strength, user, terminal and service profiles and creates an ordered list that is transmitted to the RNC. This list is checked to comply with the available network resources and operator’s policy, and may be re-ordered by the RNC. If the WLAN network is on top of the list, an ARRC message indicates to the UE that it should associate with the WLAN. With this message the UE is informed to configure the NASL to route outgoing packets over the WLAN interface as soon as the new path is established.

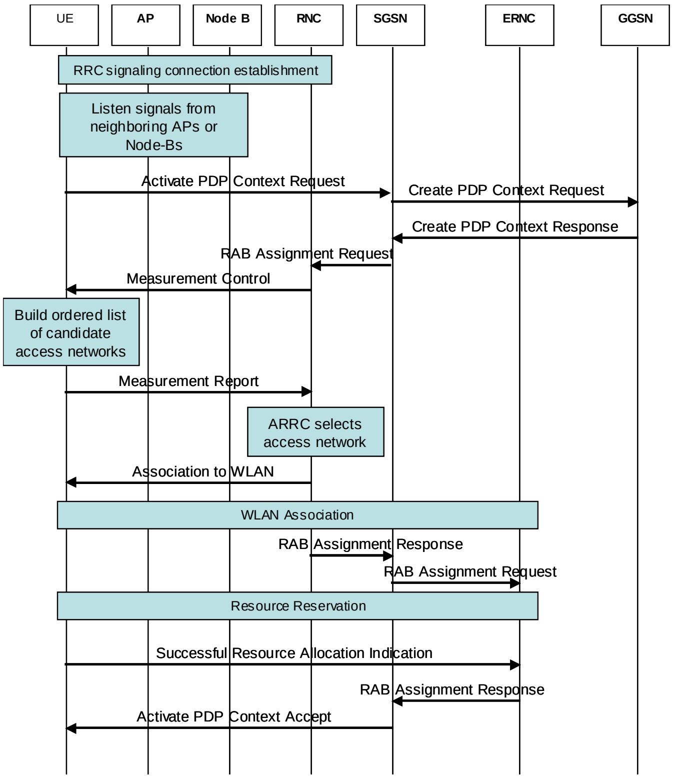

Fig. 4. Establishment of an outgoing connection through WLAN

In the mean time, the RNC answers to the SGSN that it cannot serve the current connection and SGSN issues a new RAB Assignment Request towards the ERNC. After the end of the reservation procedure, a Successful Resource Allocation Indication message informs the ERNC that resources have been reserved over WLAN. ERNC sends a RAB Assignment Response to SGSN to report the successful outcome, while SGSN sends an Activate PDP Context Accept message to the UE. With this message, the establishment procedure is completed and communication may commence.

The handover from UMTS to WLAN is illustrated in Fig. 5. The UE monitors periodically for conditions that may initiate a handover (e.g., signal deterioration, user preferences). When such a condition arises for a specific connection, a measurement report is sent to the RNC. This message contains an ordered list of candidate access networks according to radio signal measurements, user, terminal and service profiles.

When the RNC receives this report, it may re-order the reported network list based on the available network resources and the operator's policy. If the target network on top of the list is the same with the one that serves the specific connection, then the request is simply rejected. Here, the WLAN is assumed to be on top of the list and the serving network for the specific connection is UMTS. Therefore, a relocation preparation phase begins and RNC issues a Relocation Required message towards the SGSN. SGSN orders ERNC to allocate resources (Relocation Request and Relocation Request Ack) and then issues a Relocation Command to the RNC. The RNC informs the UE that it should associate with the WLAN and that resources should be reserved (Inter RAT Handover From UTRAN). In addition, UE is informed to configure the NASL to send all outgoing packets for this connection over WLAN, when the new path is established. When WLAN association and resource reservation procedures end, the UE informs the ERNC that the resources have been reserved successfully (Inter RAT Handover From UTRAN Indication) and ERNC reports the detection of the relocated connection to SGSN (Relocation Detect), which triggers the data flow over WLAN. Finally, the completion of handover procedure is reported to SGSN (Relocation Complete) and a pair of Iu Release messages is exchanged between RNC and SGSN in order to release old radio bearer for this connection.

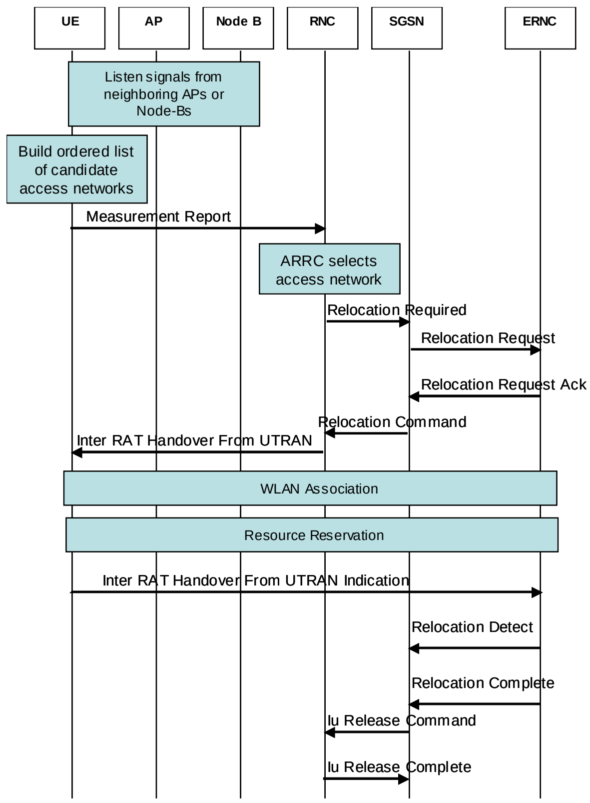

Fig. 5. Connection handover from UMTS to WLAN

Simulation Model and Results. To evaluate the performance of the proposed architecture, a reference system following the same architectural principles with the one described in [6] (also known as “Unlicensed Mobile Access-UMA”) was considered. According to [6], the UE can be either in WLAN or GPRS mode, and handover involves the relocation of all connections over the same network. To make the comparison more interesting, a load balancing mechanism was also considered in both the UMA and the proposed architecture.

More specifically, the simulation model evaluated three different architectures: i) simple UMA, ii) load-balanced UMA and iii) the proposed system. In the case of simple UMA, the UEs initially connect to WLAN (WLAN preferred mode is assumed) and handover to the alternative network is based on user preferences only (no network decision involved). In the load-balanced UMA, UEs are allocated to the network with the less traffic load. Finally, in the proposed system, the same decision policy with load-balanced UMA is followed, but per connection and not per UE. The target of the simulations was to evaluate the performance in terms of handover blocking probability and connection blocking probability.

As shown in Fig. 6, the proposed architecture manages to decrease the handover blocking probability even when a load balancing mechanism is assumed in UMA. More specifically, the handover blocking probability in the proposed architecture is actually 100 times better than in the simple UMA in the medium load scenario and 5 times in the heavy load scenario. In light load conditions, the proposed system has zero handover blocking probability. Compared to load-balanced UMA, the handover blocking probability is reduced from 1.6% to 0.1% in the medium load scenario and from 8.9% to 5.8% in the heavy load scenario. This improvement is mainly attributed to the flexibility the handover management per connection offers.

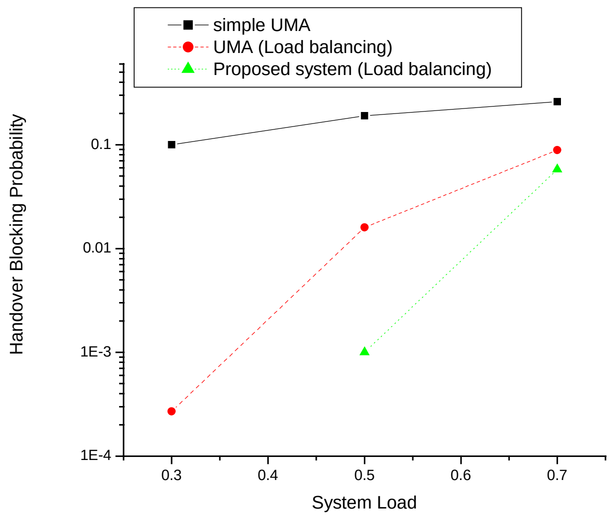

Fig. 6. Handover blocking probability

Similar results were produced for the connection blocking probability as well (Fig. 7). In simple UMA, the ratio of the new sessions that get blocked is 10%, 14% and 18%

for the three load scenarios respectively. With load-balanced UMA, these values are considerably reduced and reach 0.52%, 1% and 4% for the same scenarios. However, in the proposed architecture these values are further decreased to 0.5%, 0.6% and 2% respectively.

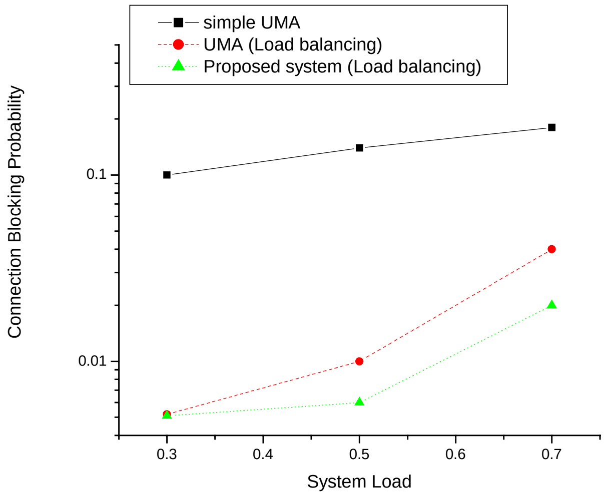

Fig. 7. Connection blocking probability

3 Conclusions

Emerging WLAN/WMAN technology and existing cellular network infrastructure comprise a unique challenge for providing advanced services to the end users. Seamless service continuity can be achieved if flexible architectures exist. In this thesis, two heterogeneous architectures have been proposed. The UMTS/WLAN integrated architecture provides seamless service continuity by introducing sophisticated entities that allow per connection handover and flexible connection establishment. Performance results have shown that this can improve the network availability, and reduce both handover and connection blocking rates. The other architecture evaluates the advantages and disadvantages of the new emerging IEEE 802.21 standard concerning the provision of seamless mobility. Moreover, the ability of the standard to support seamless mobility has been demonstrated with a WiMAX to GPRS handover case study and future directions for improvement have been given.

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