Cooperation of 4G Radio Networks with Legacy Systems

Matthias Lott, Vaia Sdralia, Mylene Pischella, Delphine Lugara, Albena Mihovska, Seshaiah Ponnekanti, Elias Tragos, Emilio Mino

Abstract—**The flexibility for wireless access providers and end users to exploit the best suitable Radio Access Technology (RAT) for a particular situation is very important for combining the strength of different RATs in the best possible way. Moreover operators look for efficient resource usage of their different RATs and more cost effective ways to deploy networks. This contribution describes proposed cooperation mechanisms to be supported by a cooperation architecture, with the objective of the efficient coexistence of the newly developed air-interface in the IST project WINNER and legacy RAN air-interfaces.**

Index Terms— **Admission control, heterogeneous systems, mobility management, quality of service, vertical handover**

I. Introduction

FUTURE wireless services will be provided by many types of wireless systems using different radio access technologies (RATs) [1]. Within the WINNER project a new air-interface for a range of application scenarios will be developed [2]. To allow the seamless introduction of a new air-interface it is important to support the inter-working with existing wireless systems. This comprises the coordination of individual radio resources management (RRM) activities, associated to each radio access network (RAN).

Current RRM solutions consider only a single RAT owned by a single operator (single domain). Future wireless networks will be composed of multiple RATs and domains. Therefore, new RRM schemes are necessary for their cooperation [3]. When multiple technologies are introduced, different link layers will interact with each other and there should be a layer to act as the bridge between technologies. The IP layer could be used as such a bridge. In WINNER, Layered RRM with its multi-technology/multi-domain concepts is considered as a possible candidate for ensuring that the WINNER RAN will successfully cooperate with the legacy technologies [4]. A promising approach is to use a cooperative RRM entity (distributed or centralized) and a convergence layer, which can also be referred to as a part of the generic link layer (GLL), to harmonize different RANs.

To achieve seamless inter-working of the new WINNER RAN with the legacy systems, an appropriate architecture for cooperation is introduced and a number of cooperation mechanisms have been developed and are proposed in this paper. These are essential for an operator to use efficiently the resources in the different networks and comprise mobility management, admission control and QoS management.

An inter-system handover between WINNER and a legacy RAN is expected to take place either due to loss of coverage of the current system or in case of overlapping coverage due to user/operator preferences or traffic congestion. One solution to handle such a handover could be to extend the inter-system handover based on the common RRM (CRRM) framework defined in the 3GPP [5]. Another approach could be location-based handover where terminals make use of foreign measurements and location information, as defined in Section IV.A.3). An admission control algorithm is proposed in Section IV.B that bases the decision to accept or reject a new call on different criteria such as network load, QoS parameters, and type of call. Finally, in Section IV.C a possible QoS management scheme is introduced that could be based on the Cooperative RRM (CoopRRM) approach. The scheme foresees that a short-term and a mid-term functionality could collaborate to handle requests from the user plane.

This paper is organized as follows. In section II the requirements for the efficient cooperation of the new WINNER RAN with legacy RANs are presented. In section III we elaborate on an approach for the cooperation architecture while in section IV the cooperation mechanisms under study are analyzed. Finally, our conclusions are summarized in section V.

II. Requirements for Cooperation

A. Mobility Management

The focus of the mobility management work within WINNER is on the link and network layer mobility as they will be challenging tasks in the near future, when operators will want to offer seamless handover between their different networks and aim at optimal utilization of their resources while maintaining the services and QoS. In particular, algorithms for network and cell selection and handover between different operational modes of the WINNER RAN (intra-system-inter-mode HO) and between the legacy and the WINNER RANs (inter-system HO, commonly also referred to as vertical HO, VHO) have to be developed. Thereby, the following main assumptions and requirements have to be

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M. Lott is with Siemens AG, Communications, Munich, Germany (e-mail: matthias.lott@siemens.com). V. Sdralia is with Samsung Electronics Research Institute, UK (e-mail: vaia.sdralia@samsung.com). M. Pischella is with France Telecom R&D, France (e-mail: mylene.pischella@rd.francetelecom.com). D. Lugara is with France Telecom R&D, France (e-mail: delphine.lugara@francetelecom.com). A. Mihovska is with Aalborg University, Denmark (e-mail: albena@kom.auc.dk). S. Ponnekanti is with Aalborg University, Denmark (e-mail: SESHAIAHPO@aol.com). E. Tragos is with National Technical University of Athens, Greece (e-mail: etragos@telecom.ece.ntua.gr). E. Mino is with Telefonica R&D, Spain (e-mail: emino@tid.es).

taken into account:

The WINNER system should be consistent with the already defined inter-RAT handover procedures, e.g., those defined in UMTS or for WLAN, and the design of the WINNER RAT should support the retrieval of measurement reports from legacy systems like UMTS and WLAN, e.g., by means of signaling of available systems and their operation frequency. At the same time mobile terminals should be capable to quickly change the AP and attach to a new AP of the same or a different RAT with a minimum packet loss and delay. For that purpose, any “triggers” available should be utilized in order that actions can be taken in advance of the actual handover (planned handover). This includes the context transfer but also any forwarding of buffered packets (tunneling) from the old to the new access router. However, the planned handover should be able to fall back gracefully to an unplanned one (in case it fails). A common goal for all the aforementioned algorithms and protocols is to minimize the signaling between the systems.

B. *Admission Control*

Admission control schemes are the decision making part of networks with the objective of providing to users services with guaranteed quality in order to reduce the network congestion and call dropping probabilities and achieve as much as possible resource utilization. The call requests are divided into new (calls that don’t have already established a connection with any network) and handover (calls that are ongoing –have a vital connection to a network). Every call is assigned a priority according to its requirements and normally, calls with low delay tolerance and handover calls are assigned a higher priority. The assumptions and requirements include load balancing and sharing of transmit resources between the different RATs in an efficient manner. As per the current state-of-the-art, the typical parameters that could be used for triggering the admission control process are the available bandwidth, latency, and reliability (limited HO failure). Closely related to the AC is the selection process of the best suited RAT, respectively RAN in case there exist several options, which is part of the mobility management. For example, the power consumption might be one criteria that influences the decision for the application/user to choose the reachable RAN with the least power consumption. However, after a selection of an available network the admission control decides whether a respective connection can be established. For that purpose, the network entity in conjunction with the terminal may also consider detailed metrics including estimated connection duration time and estimated connection set up time. Bandwidth arbitration is anticipated to be integral component of this process. This requires continual performance monitoring at RAT/RAN layers to collect bandwidth usage at various base stations/access points and periodically announce this information. Finally, the cost of using a particular RAN as a primary bearer is a function of several parameters including bandwidth, power consumption and the cost of the network itself.

C. *QoS Management*

When several radio technologies may at the time attend the user services demand a decision is necessary to select the most suitable RAT on a per user basis. Factors like network accessibility and radio resources availability will influence that decision, possibly the operator preferences as well. To ensure end-to-end QoS in a WINNER scenario covering WINNER and legacy RANs, effective resource control and arbitration mechanisms for the RAT prioritization, and selection and to determine a RAT contention are needed. Towards this objective, the following two components are required in the current co-operation regime in WINNER.

- Layered scheduling coupling the radio interfacing variations to the CoopRRM entity. An intelligent scheduler, resident at Node Bs/ Access Points, has been considered in other work packages in WINNER. In addition to that, a multi-RAN scheduler implementation may be required at the CoopRRM entity to maintain the queues for the inter-RAN packet flows.

- Intersystem QoS management controller functionality enhancing the existing cooperative entity to ensure cooperation between RANs and to guarantee users access to whatever throughput they might require. The controller aggregates various crucial parameters including the capacity usage profile at each RAN, user mobility pattern from each RAN, interference dynamics at each RAN and the user preferences/capabilities from each RAN.

III. COOPERATION ARCHITECTURE

Existing architectures are optimized for a network using a single layer technology, even though they sometimes share some common supporting network infrastructure such as GGSN, SGSN, VLR and HLR in GSM/GPRS and UMTS. In other cases, like GSM/GPRS/UMTS and WLAN, they are fully isolated and communication between them is performed via an external network. In future heterogeneous wireless networks, the RRM must be coordinated across a number of access technologies co-existing within the same network. Inter-RRM signaling is also required in order to transfer the information between RRM entities upon which resource allocation and admission control decisions can be based.

From a high level perspective the WINNER cooperation architecture should support the inter-working with the current wireless systems to exploit the installed base of wireless systems and to allow the gradual introduction of WINNER networks.

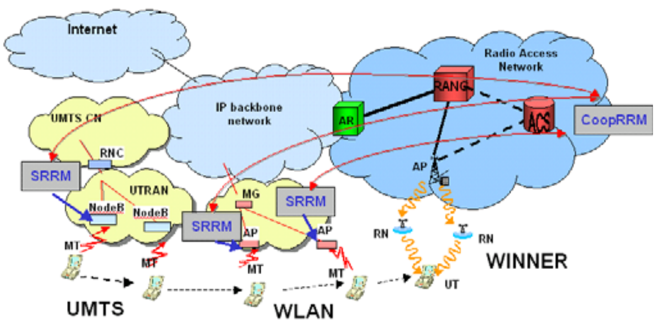

Figure 1: Architecture for cooperative RRM

In Figure 1 the architecture for the RAN cooperation is represented, following a partially centralized approach. The different RATs have their individual specific RRM logical entity (SRRM) that are working in a distributed manner, and that are coordinated by the CoopRRM entity, which is located in the new WINNER network. In the CoopRRM and SRRM entities the inter-RAN cooperation algorithms (cooperation mechanisms) will run: mobility management, admission control, QoS based management. The CoopRRM will have interfaces with other CoopRRM of the same or different operators.

The logical functionality of the CoopRRM and SRRM will be divided in a common part (RRM-g) and a specific part (RRM-s) for each RAN, with the common part containing the functionalities common to all RANs, and will provide a common interface towards upper layer functions/protocols. The specific part will be devoted to deal with specific details of each RAN.

The CoopRRM will be associated to, or reside, in the Access Control Server (ACS) that is the physical node that controls the access to the radio interface resources. It terminates generic control plane protocols. The SRRM will be in charge to obtain an efficient cooperation between RANs. This cooperation might be realized at the network layer. The SRRM will be associated to, or reside, in the RNC, BTS and IWU (interworking unit) of UMTS, GSM and IEEE802.11 networks, respectively.

At L3 a decision can be made on the best resource management across the multiple technologies. In particular, in a multi technology-multi domain case, L3 decisions are needed not only in order to manage cross-technology RRM, but also to remove inter-domain management conflicts at L3.

IV. COOPERATION MECHANISMS

For the efficient inter-working of the new WINNER RAN with the legacy systems, specifically UMTS and WLAN based on IEEE 802.11, the following cooperation mechanisms are involved: mobility management, admission and load control, and QoS management. Though they are separately described in the following subsections they closely work together and make partly use of the same information available in the CoopRRM, respectively SRRM entity. The tight coupling can be explained by the following example: A user traverses through the heterogeneous wireless 4G system.

To maintain the required QoS with the least cost and in a most efficient way, the 4G system checks continuously the link conditions and wireless networks being available. The QoS management is basically responsible for this task and is supported by the mobility management. As far as a change of the point of attachment (handover) is decided, e.g. because of the degradation of link conditions or the availability of a better suited network, the admission control has to decide whether the change can be performed. In parallel, the load and congestion control regulates the traffic flows of the active connections to guarantee the QoS.

One very important topic in existing and future systems is security and accounting. However, it is assumed that security and accounting mechanisms do not have a strong impact on and are not so tightly coupled with the mechanisms described in this section, and, consequently, are not taken into account here. They can be considered as an additional cooperation mechanisms that will be part of future 4G systems.

A. Mobility Management

Traffic balancing strategies are essential for an operator to use efficiently the resources in the different networks. Inter-system (or vertical) handovers are key mechanisms to implement traffic balancing strategies. In legacy systems, these algorithms are mainly based on coverage criteria. In B3G systems, in particular in the WINNER system, the cooperation at RRM level between different RANs will be an integrated feature, while the RRM algorithms will be able to use more metrics and information as inputs (triggers), since information will be exchanged between networks and new metrics are becoming available, allowing sophisticated traffic balancing strategies. Example of such metrics are load and service based criteria, location, velocity, user's environment (indoor, outdoor, etc.), terminal capabilities and handover statistics.

1) Inter-system Handover with WINNER

The inter-system handover between WINNER and a legacy RANs e.g. UMTS is expected to take place either due to loss of coverage of the current system or in case of overlapping coverage due to user/operator preferences or traffic congestion. A number of triggers are expected to be used for the initiation of an inter-system handover. However, the importance of those triggers will not be the same. The highest priority has triggers that necessitate a handover and, therefore, if a handover does not take place the call will be dropped. Example triggers for this group are the signal strength, interference level, BER/PER, and carrier-to-interference ratio (C/I). Triggers on the current RAT/Cell and on the target RAT/cell that can cause a handover but do not necessitate it belong to the first group. Examples are the current cell load, the user preferences (price, operator), reachable QoS, the user's class of service (bronze users on GSM/ gold users on UMTS for instance), the operator's policy concerning service (voice on GSM for instance), service availability, QoS violation, and the terminal location.

Although a handover might be initiated it might not be completed. Reasons for such a handover rejection might be that the target RAT belongs to a non acceptable operator, the load in the target RAT already might be too high, or the QoS will be violated. Reasons for rejecting handover at the MT (assuming the AP doesn't have the information) might comprise limited MT capabilities and QoS violation, too.

2) CRRM based VHO

In this section, we present a solution how to extend the inter-system handover based on the CRRM framework defined in the 3GPP, which allows the exchange of load information between UMTS and GSM networks, to any kind of inter-system handover, in particular handovers between WINNER and legacy systems. In general, static and dynamic information exchange on the different systems involved in handover is necessary.

Figure 2 illustrates the principle of inter-system handover and its relation with admission control algorithm. The inter-system handover algorithm is a cooperative RRM algorithm implemented in the RAN and consists of two phases: first the decision to trigger the handover and prepare it, and then the selection of the most suitable target network to execute the handover to. Both criteria can be based on various inputs (triggers) such as measurements coming from terminals (signal strength, interference) or heterogeneous networks (load), or services attributes and QoS requirements.

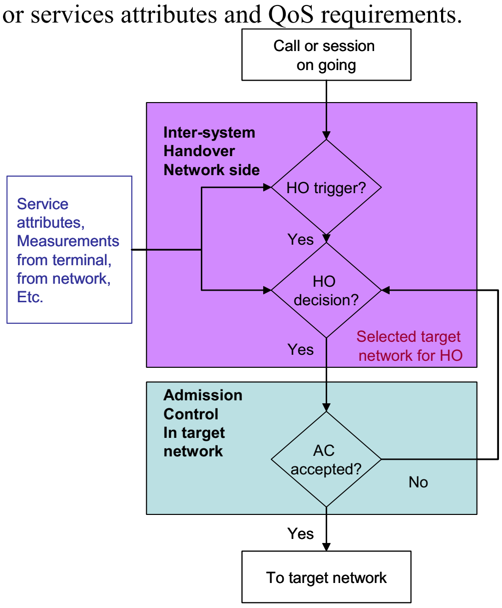

Figure 2 - Inter-system handover diagram

Once the target network for handover has been selected by the handover algorithm, the admission control on that target network will check if the call or session can actually be accepted. If not, another system must be chosen, but the handover algorithm should be defined so as to minimize the rejection of calls / sessions by admission control.

3) Location-based VHO

An indispensable precondition to achieve integration of different networks is the possibility to allow for execution of handover between these systems. However, the new association of the terminal can only be initiated if respective information about the status of the destination network is available. One way is to autonomously perform measurements in the destination network to collect respective data by the terminal itself. Another way for gathering information about a target cell is to adopt foreign party based measurements. The idea is that a nearby located MT of the other system makes a status report and transfers this report by a gateway to the currently employed network. Hence, an overview of the conditions of possible destination systems is provided without the need for leaving the current system.

In the following this position-based, location-aided VHO is explained in more details. Each active MT reports about the current link condition, see (1) in Figure 3. Together with the measurement report, the location of the reporting MT is stored in a Data Base (DB) (2). A MT that intends to perform a VHO sends a request to its BS/AP, see (3). The AP/BS in turn acquires the corresponding measurement report from the DB, depending on the current location of the MT, (4), and signals the HO decision (respectively related information that allow the MT to take the decision) to the MT (5). The MT can then perform the VHO, which is marked by step (6) in Figure 3.

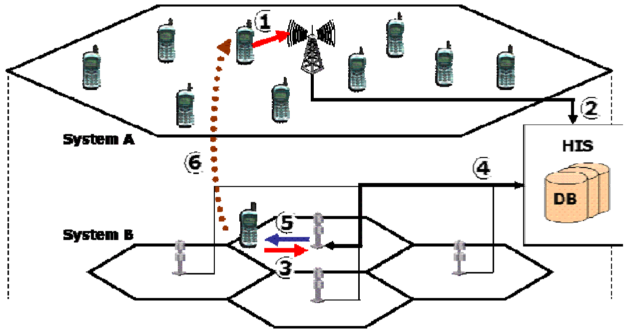

Figure 3: Exchange of HO reports between systems

In this basic approach, which is referred to as Hybrid Information System (HIS), measurements that are inherently available for each system are made available to heterogeneous systems as well to support the inter-working between heterogeneous systems.

B. Admission Control

The admission control algorithm makes decisions based on certain criteria: 1) The load of the network must remain underneath a specific threshold, which can be different for different priority calls and networks. 2) QoS parameters such as mean throughput, bandwidth demands, priority of the new request must also be taken into account for the decision (i.e. a call that needs high bitrate cannot be admitted if there isn't enough bitrate available in the network). Thereby, this step is closely coupled with the QoS management. 3) The interference of the new call to other already admitted calls (and vice versa) is calculated and if the link quality falls under a threshold the call is rejected. 4) Handover calls are assigned to higher priority than new calls.

The AC algorithm is triggered whenever there is a new call request for a specific RAN and first checks the characteristics / requirements of the call, respectively its priority. Then, for the target network the algorithm checks if there are sufficient resources in order to admit the call. If not, it checks if another network can serve the call. In our case, the AC algorithm checks if a call request that cannot be admitted in a legacy RAN (or WINNER) is possible to be admitted in WINNER (or an appropriate legacy RAN). The selection procedure for potential candidate networks is the one used within the mobility management to decide on the best suited target network. Consequently, the AC and mobility management closely works together, respectively makes use of the same information. If no other network is available for that call and the call has high priority, then it is checked if some low-priority ongoing calls can be served by another network that is suitable for them or else if a QoS degradation of some low-priority ongoing calls will gain enough resources to admit the call. This decision is consequently made in close relation with the QoS management. If the call has low priority, then it is rejected. If the call is a handover call (which is a high-priority call) and in neither way can be admitted, then it enters the handover queue, until the needed resources become available or the call leaves the cell (i.e the user moves to another cell) or it is terminated due to timeout.

C. QoS Management

A possible QoS management scheme can be based on the CRRM approach of 3GPP and will implement in the CoopRRM entity (see, Figure 1) the multi-RAN scheduler and the QoS management controller described in Section II.C. The QoS controller in conjunction with the CoopRRM signaling aggregates the profiles of the various RANs according to capacity, performance, mobility, and interference. User profiles are also aggregated here. The main function of this entity is to build up and maintain an active set of candidate RANs. Based on the user request and the relevant user profile, the QoS controller instructs the multi-RAN scheduler (2) to forward the packets within the cooperative RAN cluster to one or a set of candidate RANs depending on the bearer/service attributes. Figure 4 show the positioning of the two entities (i.e., multi-RAN scheduler and QoS controller) within the cooperative entity. The red (bold) dotted lines indicate the interfaces to the scheduler (1) at the AP/relay that communicates information about the WINNER RAN, and the legacy RANs. The position of the inter-system handover management entity manages handover related to WINNER inter-mode switching and between RANs.

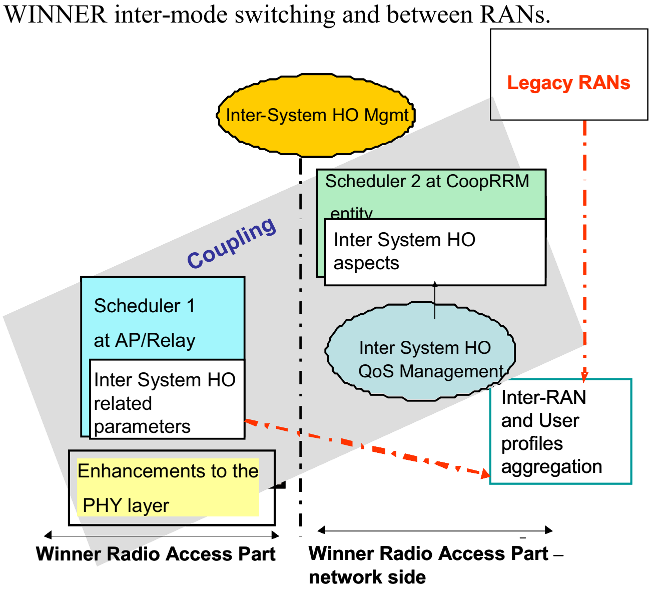

Figure 4 Implementation of a QoS provisioning scheme in a heterogeneous environment.

Thus, the the WINNER air-interface dynamics can be exported to the CoopRRM entity and be added to the RAN active list. In a possible scenario, a situation might occur that may require distribution of the traffic load to the RANs. Such a situation can be for example, degradation of delivered service quality or increase of the traffic load. A resource management functionality can then be triggered to try and obtain information about status of users and availability/status of networks. A distribution functionality can be triggered by the CoopRRM entity as a response to act upon requests from cooperating networks to handle the arisen situation. This will happen in the preparation phase before a decision for the selection of a RAN is taken. Such requests can contain capacity or cost-related information. Based on the networks status, a global functionality (the CoopRRM entity) can decide on the assignment of services or traffic to the corresponding network. During the acceptance phase, (when the final decision based also on information from the admission control entity) the proposed solution can be accepted by the cooperating RANs.

The objective of driving the user to the appropriate QoS level and best suitable network can be achieved by a short-term optimization process that assigns a user to a specific RAN. In that manner, real-time services can be obtained efficiently in terms of cost and QoS.

V. CONCLUSIONS

In this paper, the requirements for cooperation between 4G Radio Networks and legacy systems and respective cooperation mechanisms developed within the IST FP6 Project WINNER are presented. The WINNER RAN shall be integrated in a cooperation architecture enabling relevant RRM cooperation mechanisms that support seamless handover between different RANs and between WINNER's operational modes, and individual user's QoS by optimizing traffic distribution between RANs.

A respective cooperation architecture has been proposed in which the different RANs have their individual specific RRM entities, which are working in a distributed manner, and that are coordinated by the cooperative RRM (CoopRRM) that is located in the new WINNER system (or RAN). Moreover, different triggers for inter-system handovers with WINNER have been classified. They will serve as inputs for future cooperative mobility management algorithms, like the CoopRRM-based VHO, which makes use of information on several RANs gathered by the CoopRRM entity to take the handover decision, or the location-based VHO, that allows to obtaining information on the target RAN without performing costly measurements on it. Additionally, an admission control algorithm for the cooperation between WINNER and legacy RANs has been presented. The decision to accept or reject a new call is based on different criteria such as network load, QoS parameters, and type of call. Finally, a proposal for QoS provisioning in a WINNER scenario has been presented. It requires two new components, one implementing layered scheduling and the other, enhancing the existing CoopRRM entity, and where the profiles of the different RANs are aggregated. Based on this aggregation decisions are taken.

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