Abstract:
This report identifies mechanisms and techniques for the efficient cooperation among heterogeneous radio access networks (RANs), with focus on the cooperation between the WINNER RAN and legacy RANs (GSM/GPRS/UMTS and IEEE 802.11, 802.16, and DVB). The report has two main parts. The first part is an initial description of cooperation architectures and coupling schemes, later to be analyzed for obtaining the best candidate for WINNER wireless network. The second part presents the measurements and triggers needed for the cooperation mechanisms and gives a description of cooperation mechanisms that should be supported by the WINNER RRM architecture.
Executive Summary

This report presents different possible network architectures and mechanisms for the cooperation of WINNER RAN (Radio Access Network) with other new RANs and legacy RANs. Conversely to the currently deployed RANs, WINNER RAN should incorporate flexible, multi RAN supporting different RATs (Radio Access Technologies). Cooperation between RANs can be done, in a centralized way, by a network element that will manage the individual RRM entities. Alternatively, the cooperation element could be distributed between the different RANs. Another option is to distribute RRM between layers, and to use a convergence layer (GLL or IP2W) to harmonize the communications and protocols of the different RANs’ lowers layers towards upper layers. The idea is to coordinate the individual RRM activities, associated to each RAN. The degree of coupling of wireless networks determines the type of integrated network services that can be offered (e.g. inter-RAT handover, Accounting, Authorization, Authentication). A promising approach is to use a convergence layer to harmonize different RANs and a Cooperative RRM entity (distributed or centralized).

The different types of triggers and measurements have been described since they are the basic inputs of cooperation RRM algorithms, in particular of inter RAT handovers. The first general guideline for the definition of the WINNER radio interface implies that the WINNER RAN should facilitate the handover with the legacy RANs. Specifically the WINNER system should be consistent with the already defined inter-RAT handover procedures in UMTS, and the design of the WINNER RAT should take into account specific requirements to enable measurements on UMTS. The next steps will define requirements for cooperation with other legacy RANs and more details will be given. An alternative to measurements on each RAT by the terminal is also proposed in this document and is based on location information. For this purpose location techniques are described in the deliverable.

Finally, the most relevant Radio Resource Management (RRM) cooperation mechanisms for WINNER have been presented. These can be summarized as follows: Mobility management (handover and location based RRM), Admission control, Scheduling/load control) and QoS based management.
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<tr>
<td>AP</td>
<td>Access Point</td>
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<td>AR</td>
<td>Access Router</td>
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<tr>
<td>ARMH</td>
<td>Adaptive Radio Multi-Homing</td>
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<td>ASM</td>
<td>Advanced Spectrum Management</td>
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<tr>
<td>BCCH</td>
<td>Broadcast Control Channel</td>
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<td>BLER</td>
<td>Block Error Ratio</td>
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<td>Basic Service Set</td>
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<td>C/I</td>
<td>Carrier to Interference</td>
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<td>CC</td>
<td>Central Controller</td>
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<td>CCA</td>
<td>Clear Channel Assessment</td>
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<td>CCPCH</td>
<td>Common Control Physical Channel</td>
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<tr>
<td>CDF</td>
<td>Cumulative Distribution Function</td>
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<td>CM</td>
<td>Compressed Mode</td>
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<tr>
<td>CPICH</td>
<td>Common Pilot Channel</td>
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<tr>
<td>CSMA/CA</td>
<td>Carrier Sense Multiple Access with Collision Avoidance</td>
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<tr>
<td>CTP</td>
<td>Context Transfer Protocol</td>
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<td>DCM</td>
<td>Database Correlation Method</td>
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<tr>
<td>DFS</td>
<td>Dynamic Frequency Selection</td>
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<td>DiL</td>
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<td>DL</td>
<td>Downlink</td>
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<td>DOTD</td>
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<td>E2E</td>
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<td>FCS</td>
<td>Frame Check Sequence</td>
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<td>FDD</td>
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<td>GGSN</td>
<td>Gateway GPRS Support Node</td>
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<tr>
<td>GLONASS</td>
<td>Global Navigation Satellite System</td>
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<td>GPRS</td>
<td>General Packet Radio Service</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>GSM</td>
<td>Global System for Mobile Communication</td>
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<tr>
<td>GUID</td>
<td>Globally Unique ID</td>
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<td>HHO</td>
<td>Horizontal Handover</td>
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<td>HIPERLAN</td>
<td>High PERformance Local Area Network</td>
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<td>HIS</td>
<td>Hybrid Information System</td>
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<td>HMM</td>
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<td>HTTP</td>
<td>Hypertext Transfer Protocol</td>
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<td>IAPP</td>
<td>Inter-Access Point Protocol</td>
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<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<td>IETF</td>
<td>Internet Engineering Task Force</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<td>LAN</td>
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<td>MBMS</td>
<td>Multimedia Broadcast and Multicast Service</td>
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<td>MH</td>
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<td>MME</td>
<td>Measurement Management Entity</td>
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<td>MMS</td>
<td>Multimedia Message Service</td>
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<td>MT</td>
<td>Mobile Terminal</td>
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<td>New Access Router</td>
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<td>NCHO</td>
<td>Network Controlled Handover</td>
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<tr>
<td>NIHO</td>
<td>Network Initiated Handover</td>
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<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
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<tr>
<td>OTDOA</td>
<td>Observed Time Difference of Arrival</td>
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<td>OVSF</td>
<td>Orthogonal Variable Spreading Factor</td>
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<td>PAR</td>
<td>Previous Access Router</td>
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<tr>
<td>PDF</td>
<td>Probability Density Function</td>
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<td>PDU</td>
<td>Protocol Data Unit</td>
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<td>PILC</td>
<td>Performance Implications of Link Characteristics</td>
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<td>PSAP</td>
<td>Public Safety Answering Point</td>
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<td>QAM</td>
<td>Quadrature Amplitude Modulation</td>
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<td>Quality of Service</td>
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<td>QPSK</td>
<td>Quaternary Phase Shift Keying</td>
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<td>RAT</td>
<td>Radio Access Technology</td>
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<td>RPI</td>
<td>Received Power Indicator</td>
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<td>Received Signal Code Power</td>
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<td>RSSI</td>
<td>Received Signal Strength Indicator</td>
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<td>RTD</td>
<td>Real Time Differences, Round Trip Delay</td>
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<td>RTS/CTS</td>
<td>Request-to-Send / Clear-to-Send</td>
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<td>RXLEV</td>
<td>Received Level</td>
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<td>RXQUAL</td>
<td>Received Quality</td>
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<td>SeaMoby</td>
<td>Seamless Mobility</td>
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<td>SGSN</td>
<td>Serving GPRS Support Node</td>
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<td>SIG</td>
<td>Special Interest Group</td>
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<td>SME</td>
<td>Station Management Entity</td>
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<td>SMS</td>
<td>Short Message Service</td>
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<td>STA</td>
<td>Station</td>
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<td>Time Division Duplex</td>
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<td>TDMA</td>
<td>Time Division Multiple Access</td>
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<tr>
<td>TDOA</td>
<td>Time Difference Of Arrival</td>
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<td>TFC</td>
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<td>ToA</td>
<td>Time of Arrival</td>
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<tr>
<td>TPC</td>
<td>Transmit Power Control</td>
</tr>
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<td>TRIGTRAN</td>
<td>Triggers for Transport</td>
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<tr>
<td>UE</td>
<td>User Equipment (UMTS notation for Mobile Terminal)</td>
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<tr>
<td>UL</td>
<td>Uplink</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunication System</td>
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<tr>
<td>UTRA</td>
<td>Universal Terrestrial Radio Access</td>
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<tr>
<td>UTRAN</td>
<td>UMTS Terrestrial Radio Access Network</td>
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<td>VHO</td>
<td>Vertical Handover</td>
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<tr>
<td>W-CDMA</td>
<td>Wideband Code Division Multiple Access</td>
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<td>WG</td>
<td>Working Group</td>
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<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
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<td>WWRF</td>
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1. Introduction

A major challenge for the future-generation mobile communications is that the networks architecture will have to be very flexible and open, capable of supporting various types of networks, terminals, and applications. The fundamental goal is to make the heterogeneous networks transparent to users. Another goal is to design a system architecture that is independent of the wireless access technology. Such considerations lead to a set of requirements that are specifically relevant to heterogeneous networks. The major elements can be summarized as follows:

- Multiservice user terminal (multi-module/SDR-based) for accessing different RANs
- Wireless system discovery
- Wireless system selection
- Unified location update and paging
- Cross-system handover
- Simple, efficient, scalable, low-cost
- Energy-efficient
- Secure
- QoS support
- Personal mobility/universal ID

Current Radio Resources Management (RRM) solutions consider only the case of a single wireless technology (single RAT) owned by a single operator (single domain). Future heterogeneous wireless networks, however, such as the one proposed by the WINNER project, will be composed of multiple RATs and domains. Therefore new RRM schemes are necessary for these new RANs and for the cooperation of new RANs and legacy RANs.

The WINNER solution covers from the short range to the wide-range area scenarios, given the joint functionality of current cellular systems and WLANs in an integrated ubiquitous wireless system, but with very enhanced features. The WINNER system will be composed of a new RAN and RAT with multiple modes, to be adaptable to the different scenarios.

This deliverable presents the state of the art on cooperation architectures and mechanisms applicable for the WINNER RAN and identifies the guidelines for their enhancement or the adoption of new suitable mechanisms according to the specifics of the WINNER RAN. The deliverable is organized as follows.

Section 2 gives the definitions of cooperation architectures, and other relevant terms, as a common understanding for the work carried out in WP4. The reader should note that almost all of these architectures are not standardised. They have been used, but not defined, in some research projects, and therefore their definition is sometimes controversial.

Section 3 outlines the evolution of current RANs, as per 3GPP and other for specifications.

Section 4 identifies advanced architectures of cooperation schemes for the usage of the available resources in the most efficient way. In that context, the coupling of heterogeneous wireless networks is presented, with reference to the UMTS to WLAN coupling, and the characteristics of loose and tight coupling are given. Then Combined RRM, a centralized architecture with tight coupling approach, and the two related architectures Common RRM, defined by 3GPP, and Joint RRM (JRRM), defined in various research projects are presented. Their description is followed by the description of Concurrent RRM a decentralised architecture, where a local RRM entity is used in each RAN, and collaborates with other RRM entities in a distributed manner. The last architecture introduced here, is the Layered/Cross Layered RRM, which is especially relevant for Multi Technologies-Multi Domain scenarios, where different link layers (L2) will interact with each other. In such a case a layer should be present that will act as a bridge between the different technologies. A possibility is to use the IP layer (L3) through an IP2W interface.

Section 5 presents the measurements, triggers and mechanisms what will support the cooperation of legacy systems with the new defined systems, as well as with systems using the new air-interface.

Section 6 describes the cooperation mechanisms in the scope of WP4 including mobility management and especially inter-system handover, location based RRM, and location based handover, admission control, scheduling/load control and QoS based management.

Section 7 summarizes the undertaken work and highlights the main points.
2. Definitions

**Handover** is the process in which the radio access network changes the radio transmitters or radio mode or radio system used to provide bearer services, while maintaining a defined bearer service QoS and minimum added system load.

**Inter-system handover** is a switching from a serving cell of a different RAT type to another radio technology, e.g. UMTS FDD to GSM/WLAN or vice versa.

**Horizontal handover** is an intra-system handover between two different radio cells within the same system on the same layer or between cells belonging to different layers in a system with overlay structure (e.g. handover between macro-cell and micro-cell/pico-cell in GSM).

**Vertical handover** is an inter-system handover between two different radio systems on different layers of the overlay structure (e.g. UMTS FDD to WLAN). A downward vertical handover is a handover to a cell of smaller size. An upward vertical handover is a handover to a cell of larger size.

**Radio Resource Management (RRM)** refers to network controlled mechanisms and architectures that support intelligent admission of calls, sessions, distribution of traffic, QoS, power and the variances of them, thereby aiming at an optimized usage of radio resource and maximized system capacity.

**Combined RRM**
Cooperative RRM between heterogeneous systems, whereby the resources are allocated centrally for all involved RATs by a single entity. Joint RRM and Common RRM are included in this category.

**Joint Radio Resource Management (JRRM)**
JRRM is the process that enables the management (allocation, de-allocation of radio resources like time slots, codes, or frequency carriers) within a single or between different radio access systems for the fixed spectrum bands allocated to each of these. Joint RRM, is a mechanism and an architecture to support the heterogeneous terminal in a Beyond 3G. JRRM implies the use of some new RRM mechanisms; joint admission control, joint scheduling strategies, allocation, de-allocation of radio resources like time-slot, codes, frequency carriers, etc.). It was proposed by the IST projects TRUST and SCOUT and is similar to CRRM, but complements it with additional features and algorithms and further radio systems, like HIPERLAN/2.

**Common RRM**
This is the architecture proposed by 3GPP to make UMTS and GSM/GPRS networks cooperate. It includes a CRRM entity, which is responsible for coordinating the individual RRM entities of each radio access technology.

**Concurrent RRM**
Cooperative RRM between heterogeneous systems, whereby the resources are allocated within each RAT by a local entity in a distributed manner.

**Layered RRM**
Cooperative RRM between heterogeneous systems whereby the resource allocation is jointly done by different layers, e.g. L2 and L3.

**Radio Access Network (RAN)**
The RAN is the network that provide the connection between mobile terminals and the core network. The clear functional split between RAN and core network might disappear in future mobile and wireless radio systems. In the case of UMTS the RAN is called UTRAN and is composed of Node Bs and RNCs.

**Radio Access Technology (RAT)**
The Radio Access Technology is the air interface that is used to allow the link between the end user equipment and the Access Point or Base Station of the RAN. Usually the RAT is associated to an RAN. The UMTS Radio Access Technology is CDMA.

**Radio Access Modes (modes)**
The different ways of a given RAN/RAT to cover different scenarios. UMTS has two basic modes UTRA-FDD and UTRA-TDD, each one using specific CDMA adaptations W-CDMA and TD-CDMA respectively.
Cooperation Mechanisms
Mechanisms that support the cooperation of legacy RATs with the new defined 4G RAT and cooperation of 4G RATs with other 4G RATs. Cooperation mechanisms intend to support an efficient inter-working between future wireless systems to exploit the scarce resource spectrum in an optimal way and satisfying the user requirements at the same time. Examples are joint or concurrent RRM, vertical handover, joint or distributed scheduling, etc.

3. Evolution of RANs

3.1 Developments related to RANs in 3GPP and MWIF

In current 3G systems, several innovative concepts have been introduced for a radio access technology suitable to be adopted as 3G interface. Some of these are relevant to the WINNER objectives, include the concept of dedicated shared channels, and the concept of common channels. Furthermore, the support of cell broadcast functionality and further evolution of RAN to support Multimedia Broadcast / Multicast Service (MBMS) for the broadcast and multicast bearers could be seen as setting a backdrop for the future systems. In this section, developments in the RAN architecture are briefly captured from the 3GPP specifications.

Following the preliminary trends in the 3GPP architecture evolution [1], it is noted that the RAN is moving towards an open distributed topology. Figure 1 shows an example functional split of the present (Radio Network Controller (RNC) functionality into different functional entities and the classification of the resulting entities in the control or user plane according to their scope.

![Figure 1.- Decomposition of traditional RNC functions](image)

Based on this a set of two evolutionary paths for the UTRAN architecture were proposed in the 3GPP.

The first architecture is presented in Figure 2. The RNC functions are decomposed and mapped onto two new types of network entities that complement today’s RNCs:
- Radio Control Servers (RCS) and
- User Plane Servers (UPS).

A second architecture was also considered in the Release 6 discussions, as shown in Figure 3, for the enhancement of the current Node B to a new node called Node-B+. 
Here, the functions of a monolithic RNC have been distributed down to Node Bs (NodeB+). There is, therefore, no longer an Iub interface in this evolved architecture. Instead, there is a Radio Network Gateway (RNG) acting as an interworking unit to RANs and CNs of the earlier releases. The RNG hides the bigger number of NodeB+s to conventional CN over Iu and conventional RNC over Iur. Furthermore, the RNG acts as a mobility anchor, hiding the SRNS relocations between NodeB+s to the CN. There is an Iur interface between NodeB+s and Iu interface between NodeB+s and RNGs. There is a ‘many-to-many’ relationship between NodeB+s and RNGs. There is also an Iur interface between NodeB+ and RNG for the interworking with RAN from earlier releases in case of a drift situation. The Iu and Iur interfaces in the evolved architecture (red color) have some enhancements themselves compared to existing interfaces.

A long-term OPEN RAN architecture has been discussed by the MWIF [2], as part of the activities within mobile systems outlining new and innovative mapping functions for both 3GPP UTRAN and 3GPP2 CDMA2000 Radio Access Network (RAN) architectures. The MWIF has defined the MWIF OpenRAN Reference Architecture. This architecture interacts with MWIF’s Core Network Reference Architecture via the Access Gateway as shown in Figure 4.
3.2 Relevant Issues related to near-term architecture in 3GPP

Figure 5 gives an overview of the UTRAN radio interface protocol architecture. It handles different types of traffic that can be transported in two modes: circuit-switched mode for real-time services and packet-switched mode for higher data rate services.

The UTRAN protocol stack is consisted of protocols ranging from Layer 1 up to Layer 3. Layer 1 is the PHY layer protocol, Layer 2 is the data link layer and comprises the medium access protocol (MAC), the radio link control (RLC) protocol, the broadcast/multicast control (BMC) protocol and the packet data convergence protocol (PDCP).

Layer 3 contains the Radio Resource Control (RRC) protocol. Its main task is to manage the network level signaling within the RAN, meaning that functions involve the handling of information to be broadcast, mobility issues and managing the procedures related to the establishment, reconfiguration and
release of the radio access bearers. The radio resources needed for the radio bearers are also managed by the RRC. These functions are performed in collaboration with other network layer entities, namely, the packet scheduler (PS), the admission control (AC) and the load control (LC) entities located in the RNC and forming the RRM module. The RRC is also in charge of ensuring that the requested QoS requirements per radio bearer are met. All the related to the radio connection measurements that are accomplished in the underlaying layers are reported to the RRC [3]. All the protocols can be found in the UE side (see Figure 6). Their peer protocol entities are usually located in the RNC. The node B contains only the physical layer and serves as a relay between the UE and the RNC.

Figure 6.- User plane protocol stack in the case of establishment of dedicated channels between the UE and the network.

3.2.1 RRM and RAN design considerations in a Beyond 3G scenario

Evolution towards a next-generation system means that cellular, (broadband) fixed wireless access (BFWA), WLAN, and other wireless access systems can be cooperating components in a composite radio environment. Currently deployed RANs support only one single radio access technology, although sometimes they share a common supporting infrastructure (i.e., the same antenna in GSM and UMTS).

In other cases, like GPRS and WLANs, they are fully isolated, and communication between them is performed via an external, fixed, data network. It is expected [4] that this will be one of the main differences between current/legacy RANs and the new ones. A new RAN should incorporate flexible, multi RAN supporting radio access technology. This cooperation is expected to enhance the functionality, performance, flexibility and radio coverage.

Cooperation between different RANs is currently being investigated with respect to vertical handover, AAA, and common radio resource management. Existing RANs can at this moment be modified or updated for cooperation only at high level layers of the mobile network, which translates into routing at the RNC or an equivalent network element.

For successful coexistence of different RANs, it is proposed [4] that cooperation mechanisms are developed at the radio segment level of the new RANs, rather than at high-level network layers. They can be implemented at network elements of the rank of node Bs and below. It should be possible to activate cooperation mechanisms from the radio access level to optimise radio performance. Additionally, other elements should also be able to activate them to ensure the fulfilment, for example, of end-to-end requirements for QoS. It is important to find commonalities between the different coexisting RANs so that some generic RRM criteria can be established.

4. Architecture of cooperation schemes

Future wireless systems are supposed to provide high-bit-rate services in IP-based, real-time, person-to-person as well as machine-to-machine multimedia communications. These systems will include a number of coexisting subnetworks with different RATs. The interworking between radio subnetworks and especially the tight cooperation between them is very interesting in operating RATs for system capacity
optimization. The reconfiguration technology provides adaptation of the radio interface to varying RATs, provision of possible applications and services, update of software and enabling full exploitation of flexible resources and services of heterogeneous networks. Reconfigurable terminals, with embedded radio link layer functionalities according to network architecture, will be able to enable cooperation between multiple Radio Access Technologies (RATs).

RRM has been extensively studied over the years, with the aim of providing maximum resource efficiency for particular air interface technologies, therefore the architectures developed are optimized for a network that is operating using a single layer technology. In future heterogeneous wireless networks, RRM must be coordinated across a number of access technologies co-existing within the same network. Inter-RRM signalling is also required in order to transfer the information between RRM entities upon which resource allocation and admission control decisions can be based.

In this chapter the previous work that took place in the architecture of cooperation schemes, as well as a first vision about the WINNER RRM architecture of cooperation are presented. First, the integration case between the UMTS and WLAN systems and the different cases of interworking between those two networks are presented. Then, the three most studied schemes are presented here; the Combined RRM, which includes the Common RRM and the Joint RRM schemes, the Concurrent RRM and the Layered RRM. In Combined RRM the resources are allocated centrally for all involved RATs by a single entity; in Concurrent RRM the resources are allocated within each RAT by a local entity in a distributed manner; in Layered RRM the resource allocation is jointly done by different layers i.e the link layer and the network layer. After that, the WINNER RRM architecture of cooperation is presented. WINNER will introduce a new Radio Access Technology and Radio Access Network with multiple modes in order to cover different deployment scenarios for the cooperation between the WINNER RAN and the legacy RANs.

4.1 State-of-the Art

This section presents an overview of previous works performed in standardization groups and in various IST projects on architecture for cooperation schemes between heterogeneous RANs. These works essentially focused on cooperation between UMTS and WLAN or between UMTS and GSM/ GPRS networks since these systems are already (or currently) deployed, quite independently so far. Efficient interworking between UMTS and 2G networks is essential for operators to ensure continuity of service, benefit at most from previous GSM investments and enhance networks capacity. Moreover, cellular operators want to benefit from the rapidly evolved WLAN technology and offer high-speed data services to their subscribers with one subscription, one bill, one set of services and so on. WLAN networks could also improve their security mechanisms through interworking with cellular networks. For these reasons, there is currently a strong need for interworking mechanisms between cellular data networks and WLANs. We present in the following the different activities that have been initiated to stimulate this further.

4.1.1 Generic coupling between UMTS and WLAN

Interworking between WLAN and UMTS networks has been driven primarily by ETSI / BRAN [9] and is going on within the 3GPP [5]. The feasibility of UMTS and WLAN interworking was drafted in the recommendation 3GPP TR 22.934 [6], where not only different levels of interworking but also different environments were defined. Broadly it has been classified under two methods, i.e. Loose Coupling and Tight Coupling. From a macro point of view the main difference is how and where the WLAN is coupled to the UMTS network. The choice is mainly a trade-off between the required degree of modifications to standards, the seamless degree of interworking and amount common infrastructure.

Figure 7 presents the degree of coupling depending on the WLAN attachment point with the UMTS network [7]. The different coupling scenarios have also been investigated in the scope of the IST projects SCOUT [8] and MIND [18].
4.1.1.1 No Coupling
In this scenario (called Open Coupling in Figure 7) there is no real integration effort between access technologies:
- The current session in use will always have to be terminated as it enters to a new RAT.
- Seamless handover will never be possible.
- WLAN and UMTS networks are considered as two independent systems
- Separate authentication procedures are used (i.e. SIM based authentication for UMTS and simple user name and password for WLAN)

4.1.1.2 Loose Coupling
In this scenario, presented in Figure 8, there is a common customer database and an authentication procedure.
- The operator will still be able to utilize the same subscriber database for existing 3G clients and new RATs (WLANs) clients.
- Loose coupling don’t allow vertical handover.
- It allows centralized billing and maintenance for different technologies.
- Loose coupling is defined as utilization of a generic RAT (e.g. WLAN in Figure 8) as an access network complementary to current 3G access networks [9].
- It avoids the use of the SGSN, GGSN nodes (don’t use Iu interface).
- The new link AAA-HLR requires standardization.
- As at present this is regarded by many the most attractive solution as tradeoff of network complexity and performance.

Figure 7.- Degree of coupling in function of WLAN attachment point [7]

Figure 8.- Loose coupling inter-working architecture [10]
4.1.1.3 Tight Coupling

The key characteristic of the tight coupling scenario are the following:

- Possibility of seamless handover between UMTS and a WLAN. This is the key difference with Loose Coupling.
- It requires additional standardization.
- The additional RATs networks are connected to the rest of the UMTS network (the core network) in the same manner as other UMTS RATs (UTRAN, GERAN) via SGSN, using the Iu interfaces by means of Interworking Unit (IWU).
- The interconnection with GGSN as an extension to the packet-switched domain as alternative to the interconnection to the SGSN is not defined in [9]. Corresponding to the Iu interface the very similar new Iuhl2 interface is used to connect to H/2, see Figure 9.

![Tight-coupling interworking architecture](image)

Figure 9.- Tight-coupling interworking architecture [9]

4.1.1.4 Very tight coupling

The very tight coupling or integration scenario is similar to the previously described method regarding seamless handover. However in this case a WLAN can be viewed as a cell managed at the RNC level. This concept is not widespread because robust network planning is not applicable for WLANs yet; interference levels are not considered because in common scenarios geographical spreading of Access Points (AP) ensures lack of interference from neighboring cells. However it should be noted that this method would be the ideal case from the end user’s perspective.

4.1.2 Combined RRM

Various sub-networks with different air interfaces are co-existing, the inter-working between these sub-networks and others is of great importance, and especially the tight cooperation between them, for optimizing networks resources and services delivery and offering ubiquitous coverage.

Different RATs could be best suited for specific services or service quality. The user should seamlessly get the best-suited radio access at any time for every requested service. For the operator there will be the need for providing an optimal set of services without wasting valuable radio resources. Co-ordination among the different radio access technologies will be mandatory.

Combined RRM will refer to a cooperation approach where the resources are managed centrally for all the involved RATs by a single functional entity.

Two examples of combined RRM scheme have to be analysed thoroughly, to highlight requirements for the future cooperation mechanism to be defined in WINNER and to point out the advantages / drawbacks of such a scheme:

- Common Radio Resource Management (CRRM) defined within 3GPP to allow better inter-working between UMTS and GSM/GPRS networks.
Joint Radio Resource Management (JRRM) as defined in the IST project SCOUT for interworking between HIPERLAN2 and UMTS.

The need for supporting various applications and services in a combined broadband and cellular environment (heterogeneous environment) requires more intelligent and complex RRM techniques. An example of a combined RRM mechanism [11] to support the coexistence of various RANs, including the WINNER RAN is shown in Figure 10.

![Figure 10.- Example of combined RRM](image)

This mechanism is based on a hierarchical structure with elements, IMU (Interface Management Unit), RMU (Resource Management Unit) and the CMU (Common Management Unit). The centralized CMU is a core component providing global resource management to the RANs and further help to the RMU tasks. It collects information about connectivity and availability of each RAN and distributes the traffic accordingly.

4.1.2.1 Common RRM

CRRM (Common Radio Resource Management) is a solution developed within the 3GPP UTRAN and GERAN groups to make UMTS and GSM/GPRS networks cooperate. CRRM is a mechanism for intelligent distribution of traffic among these systems, offering the possibility to increase the overall network capacity and user perceived quality of service, thereby reducing network costs. In release 99, procedures for inter-system handover have been defined, but they could result in a failure due to high load in the target cell. The Release 5 work resulted in the introduction in GSM and UMTS of the possibility to exchange cell load information between RNC and BSC.

In 3GPP, the whole set of radio resources for an operator has been partitioned into “radio resource pools”. A Common Radio Resource Management server (CRRM Server) is introduced as a new logical node in UTRAN and GERAN. These radio resource pools are controlled by two different types of functional entities:

- RRM entity, which is responsible for RRM inside one radio resource pool (one pool may include one RAT, or one/more cell layers or one/more operating frequencies);
- CRRM entity, which is responsible for coordinating a certain number of RRM entities, to balance the traffic between the overlapping/neighbour radio resources pools.

CRRM should direct users in idle and connected mode to the cell and resource pool which is the most suitable. What is the most suitable may depend on several aspects, e.g. on the user’s service and network constraints such as minimizing interference, load balancing, etc. This new CRRM entity is introduced to
allow some kind of coordination among different radio resource pools whose radio resources are linked to the same geographic area in the network.

![Diagram](image)

**Figure 11.-Coordination among different radio resource pools (CRRM).**

Where

- **rc-i/f**: between RRM and CRRM,
- **cc-i/f**: between two CRRM entities.

The functional relationships between the entities of the functional model are based on two types of functions:

- Reporting Information,
- RRM Decision Support.

While rc-i/f supports both types of functions, cc-i/f only supports “Reporting Information” and can thus be regarded as a subset of the rc-i/f. In the 3GPP specs, the two functions on these interfaces are described in more detail.

Different architectures are possible to enable CRRM and several solutions for the mapping of functional entities into physical entities have been proposed in [12]:

- **“CRRM server” approach**: this approach implements RRM and CRRM entities into separate nodes, CRRM is a stand-alone server. All the interfaces among RRM and CRRMs are open. The CRMS (Common Resource Management Server) first gathers measurements from cells under its coverage. Then, for each specific operation (handover, cell change order, etc.), the RNC/BSC sends to the CRMS the list of candidate cells, including the mobile measurements for these cells and information about the QoS required by the UE. The CRMS, after applying some algorithms, returns the prioritised list of candidate cells. The load of each cell can be considered in the prioritisation process, but other aspects (to be defined) can be included.

- **“Integrated CRRM” approach**: this approach integrates the CRRM functionality into the existing UTRAN/GERAN nodes. The Iur and the proposed Iur-g (between BSC and RNC) already include almost all the required ingredients to support the CRRM functionality. The main benefit of this integrated CRRM solution is that with limited changes and already existing functionality it is possible to achieve optimal system performance.
The Release 5 work only allows for transferring load information among RNC/BSC, but does not allow a common strategy to be set up in RNC/BSC from different vendors, since nothing is stated about the way CRRM entities may affect the RRM decisions. Therefore to enhance the release 5 solution, a work item was accepted by 3GPP, to define a more efficient solution for release 6 CRRM [13]. In this WI, the CRRM strategies and architecture will be discussed to find precise answers to the following questions:

1. What kind of CRRM topology used?
   - Centralised in new physical nodes
   - Integrated in existing nodes.
2. Which entity is the master of decision?
   - CRRM only advises the RRM entity (RRM is the master)
   - CRRM decisions are binding for the RRM entity (CRRM is the master)
3. How tight is the coupling between CRRM and RRM?
   - Tight coupling: CRRM is involved in each RRM decisions (e.g. in each IS HO)
   - Loose coupling: CRRM defines the policies for the RRM entities and updates them. Policy is valid for every ISHO until the policy is changed.

These questions will be further analysed in the context of the WINNER project. It should be noted that the tight and loose coupling defined by the 3GPP is different from the definition related to inter-working between WLAN and UMTS, and should not be mixed up.

[34] proposed to 3GPP a “policy-based CRRM approach” for release 6 CRRM as an attempt to standardise an open interface between RRM and CRRM entities. This would allow a centralised CRRM entity to provide policies to the RRM entities, thus enabling the traffic situation to be dynamically adjusted in the network on the basis of a common strategy.

The CRRM Server can act as a policy manager for the access to the cells and the radio bearer resources within UTRAN and GERAN, by performing the RRM algorithms that are based on dynamic status information per cell from all the cells in the system. The CRRM Server is also connected to other radio access network than UTRAN/GERAN in the future, allowing dynamic intersystem RRM.

With the introduction and integration of several systems with several modes and several layers, resource management becomes a more and more complicated task. For example handover and load sharing algorithms must not only maintain the connection at a reasonable quality, they should also consider whether it would be beneficial to move the connection to another system/layer/mode. This decision is not solely based on changing radio propagation, but also on system load, operator priorities and service quality parameters.

An alternative approach to a CRRM functionality is to use the existing Iur and Iur-g interfaces, i.e. the CRRM functionality is integrated into the existing UTRAN nodes (tight CRRM). The Iur-g interface is used between GERAN BSC and the UTRAN RNC is considered in 3GPP Rel-5 to be used in signaling to transfer information between BSC or the BSC/RNC. The Iur-g is an interface containing a control plane and no user plane. Here, both tight (different RANs offer access to the same core network) and very tight coupling can be considered.

Many CRRM functionalities, such as Intra-RAT/Inter-frequency Handover, Directed retry, Service Handover, etc. are already supported in the current standard. The Iur and the proposed Iur-g
interfaces already include almost all the required ingredients to support the CRRM functionality. Therefore, a natural approach is to continue this path and improve the existing CRRM functionality. The main benefit of the Integrated CRRM is that optimal system performance can be achieved with limited changes and already existing functionalities. Most importantly, this is achieved without introducing additional delay, which will deteriorate the delay sensitive procedures at call setup, handover and channel switching. Furthermore, the additional delay will have adverse impact on the trunking gain, especially for the bursty traffic, which will cause reduced radio resource utilisation. In addition, delayed handover decision and execution will have negative impact on power control and thus reduced system capacity. The delay requirement on the channel switching would in practice limit the possibility to interrogate the external CRMS, thus reducing the possibility to achieve a optimal system performance. Whereas, in the Integrated CRRM, the SRNC or BSC, based on its intra and inter system knowledge and the capacity, makes decision on whether to perform channel switching, inter-layer, inter-frequency or inter-RAT handover.

Finally, 3GPP considers that the RRM algorithms cannot be completely moved to an external CRRM. Some part of functionality will anyway reside in the RNS and BSS. This means that that all three systems need to be tuned to achieve optimal performance, making the system tuning more cumbersome.

**Coupling Approaches for CRRM**

In 3GPP two main approaches are considered to support CRRM in UTRAN and GERAN: tight (integrated) CRRM (TR 25.881) and loose RRM (TR 25.891). Loose architectures are based in a CRRM server linked by open interfaces to the RNC (UMTS) and BSC (GERAN). The CRRM server establishes CRRM policies and each RAT executes RRM algorithms according to the CRRM server policies. Within this approach, CRRM may contain updated and ordered information from the different RATs. Tight CRRM incorporates the RRM functions into the existing UTRAN nodes, therefore, proprietary interfaces are needed and non-radio dependent messages get through to each RAT air interface.

So far, no standard RRM entity exists to manage WLAN access. Loose coupling, however, is a preferred solution for managing WLAN and 3GPP (TS 23.234) (note that the tight and loose coupling defined by the 3GPP is different from the definition related to inter-working between WLAN and UMTS)

CRRM requires deeper investigations, from standardisation and suppliers, to define more precisely what information can be exchanged and how, to define the impact of CRRM on RRM entities and to determine an architecture to support this functionality.

**4.1.2.2 Joint RRM**

JRRM [14] aims at the support of intelligent interworking between different RATs using a central controller to manage the overall capacity of the subnetworks. The architecture of JRRM is quite similar to the one of CRRM, except that JRRM is not restricted to UMTS and GSM only. Moreover, JRRM complements the CRRM approach by several modifications and additional features. A very tight coupling allows this joint managing of traffic streams between the involved networks and the terminals. Joint radio resource scheduling and admission control are therefore required to optimize spectral efficiency, handle various traffic types and QoS constraints and schedule traffic adaptively. In particular, optimal QoS can be achieved with traffic splitting supported by adaptive radio multihoming, which provides multiple radio access for a single terminal in order to allow the terminal to maintain simultaneous links over RATs. The major issues in JRRM are:

1. Traffic prioritization and splitting whereby the incoming traffic is split over two or more substreams. The important information goes through a reliable RAT, the rest through other RATs.
2. Synchronization whereby packets belonging to a substream are multiplexed back to original traffic stream in the receiver based on proposed synchronization schemes.
3. Buffer management whereby jitter and average delay parameters are controlled by the buffer size and synchronization approaches. The static terminal and user profiles stored on the network side will be retrieved by the RNC to determine the calculation power and buffer size of the terminal, and to evaluate the user preference and cost. The synchronization methods are used mainly to compensate average delay, whereas buffers are used to compensate for jitter.

The JRRM architecture is based on the assumption of co-existing of different RATs with different profiles and is illustrated in Figure 13. Each RAT needs an efficient interworking between traffic volume, measurement function, traffic scheduler, load control and admission of control function. The Traffic Estimation module (TREST) informs the administrative entity Session/Call Admission Control (SAC) in every subnetwork on the predicted traffic and planned traffic information in order to update the priority information of each connection and the admission decision within the network.
The main JRRM functionalities are [15]:

- The load controller in charge of evaluating the traffic carried at a given moment considering its characteristics (real/non real time).

- The evaluation of the system performance so as to have at each time a good approximation of the system performance. To do this, the statistics are updated considering a long-term and a short-term value. The long-term value represents the mean value considering a long period of time whereas the short-term value represents the current situation. The combinations of these give a good evaluation of the system performance for a given load.

- The computation of the intersystem handover success probability so as to avoid the triggering of unnecessary handover, which will degrade the system performance of the hosting RAT. To obtain this value, two components are considered. First, the probability that the user performing an intersystem handover will receive the expected QoS has to be maximised. Second, the impact of this intersystem handover on the hosting system performance has to be minimised: i.e. no degradation has to be observed. In particular, the triggering of an intersystem handover could be initiated by the fact that a user is not receiving the desired or expected QoS and no further solution is available in the current RAT or the RAT is overloaded. The indicators that monitor the system are: the load of each RAT, the performance of each RAT under the present load depending on blocking probability, dropping probability, poor FER probability or Bad Quality Call (BQC). After computing all these values the JRRM will notify the user and the concerned RATs of its decision of accepting or refusing the intersystem handover.

- A joint call admission controller is also mandatory to direct immediately a new user/application to the most adapted RAT related to his request (most adapted meaning in terms of offered QoS, load conditions, current performance). Without such an entity, the probability that the user would have to perform an intersystem handover is not minimised. The Joint Session Admission Control (JOSAC) takes the neighbouring RAT system load into account. JOSAC is one JRRM approach. It does not offer detailed traffic splitting to subnetworks, but only alternatively diverts traffic into different sub-radio-networks. The traffic stream is routed through the cooperating systems according to the restrictions and advantages of each system. From the service point of view, different levels of service calibration can be identified to meet the user’s satisfaction. In particular, the reasons to split the traffic through subnetworks are: to reduce the traffic load over individual networks and to provide higher QoS to the user according to his profile, demands and network architecture. For joint admission control, the traffic and the session/messages cannot be split over different networks, but can be admitted alternatively to a different one if the packet switched scenario is getting involved. In particular:
  - mobile users can alternatively access to RATs during a call
  - coexisting RATs are jointly cooperated together
  - network and terminal do not support simultaneous connections over RATs
  - network does not support traffic split and traffic prioritization

- A traffic optimiser which would be responsible for finding a solution to specific big issues taking into account the global radio network. Those issues could be for instance a mass upgrade scenario, or an increasing demand for video during a sport event.

- A joint scheduler in order to keep same QoS in individual RATs as well as the synchronisation to ease the higher layer multiplexer/decoder. The joint resource scheduler (JOSCH) is important for terminals working with simultaneous connections to different networks. JOSCH is responsible for scheduling traffic streams being split over more than one RATs. It helps to optimise utilization of radio resources in the whole system. It also synchronizes the stream being split, e.g. video stream with basic layer and enhancement layer being transmitted over different air interfaces individually or separated main object and inline objects of HTTP service belonging to the same session, etc. This approach is supported by the adaptive radio multi-homing (ARMH) protocols.
The Adaptive Radio Multihoming Concept

Adaptive radio multi-homing (ARMH) concept is a term extended from ‘multi-homing’ concept. It provides multiple radio access for single terminal in order to allow terminal maintaining simultaneous links with the radio network. From the radio resource point of view, traffic splitting supported by joint scheduling under the concept of adaptive radio multi-homing, will increase the system capacity and provide better user QoS. The Multihoming concept manages IP traffic that is being routed through different RATs. From the radio resource point of view, traffic splitting will increase the system capacity and provide better user QoS. Besides that, the advantage of having parallel streams is manifold. If one bearer service has a high availability in the network (low data rate bearer services result in high coverage, e.g. a 16 kbps service is available in 99% of the cases), this link would be used for transferring important information to the terminal, but it cannot fulfil the requirements for multimedia traffic. A higher QoS for the user is obtained if the traffic is intelligently split into rudimentary and optional information streams.

For example the video traffic can be split into base and enhancement layers, where the base layer consists of the most important low frequency information. HTML traffic can be split into main and inline objects of an HTML page; control signalling and highly required security information could be transmitted through UMTS and normal user data through WLAN. The user combines both streams whenever this is possible in order to achieve a higher QoS. Due to the higher availability of a lower data service in UMTS, a minimal QoS can be fulfilled to the user otherwise.

Suppose that a user with a reconfigurable terminal demands a scalable video service from a remote server through tight coupled subnetworks (UMTS, WLAN), which are controlled by one RNC. The procedure that will be followed is:

1) RNC receives an application from a mobile terminal. After estimating the available radio resource in controlled subnetwork, the RNC will apply to the remote server for traffic splitting indicating average rate in each sub-link.
2) Traffic is split and sent to RNC. The sub-streams are labelled differently.
3) RNC receives traffic with labelled packets to further map to tightly coupled sub-networks. Possible services: video and audio, HTTP, scalable video traffic, real time traffic and its control signals.
4) Synchronization mechanism in RNC remedies delays generated by sub-radio-networks due to different TTI value for bearer services, ARQ actions due to different connection qualities, different processing power of different BTS.

Figure 13, Functional Architecture of Joint Radio Resource Management and Delay Factors
Due to the heterogeneity of the co-existing networks the performance of a joint scheduling algorithm will be highly dependent on the synchronization. In non-synchronized traffic from different layers, if the delay difference overrides a certain threshold, the user/terminal will not wait until all the information from different sub layers is received. Also, the target of scheduling is to reduce the individual system load in sub-systems. The synchronization mechanism is very important for JRRM, especially for the joint scheduling algorithm, which deals with traffic splitting over radio networks.

4.1.3 Concurrent RRM

Concurrent Radio Resource Management (ConRRM) is a mechanism for the efficient management of radio resources across different RANs. Contrary to the centralized entity in the JRRM concept, Concurrent RRM allocates the resources within each RAN by a local entity. These entities have to cooperate in a distributed manner to come up with an efficient resource utilization. It can be expected that the different RANs are connected via the Internet, which will be based on TCP/IP. Consequently, it is expected (or assumed?) that RRM, e.g. mobility management and QoS control should be addressed using IETF schemes. For example, for the case of H/2 the technical specification produced by ETSI/BRAN focuses on the functionality in the control plane of the AP and the respective interface between the AP and core network, which allows to cooperating with the IETF schemes. The functions that have to be supported in the control plane of the AP comprise the network management, AAA, admission control to ensure QoS across the core and H/2 network, user data forwarding, mobility support (handover and roaming between networks) and location management for location-based services. For network management the task can be split between a network manager located in the core network and a management agent that resides in the H/2 AP. Among the information maintained by the management agent, there could be the QoS provided to the active traffic flows. This information could be stored in a Management Information Base (MIB) [16].

For the network handover, e.g. between H/2 and UMTS, Mobile IP can be used. In addition, respective functions can be foreseen for fast handover, e.g. by means of context transfer. The context transfer may occur before, during or after the handover and avoids transferring information on the radio link between MTs and AP [17] [18].

The efficient cooperation of different networks requires an inter-working between heterogeneous systems. From the description it becomes obvious that the ConRRM fits quite well to the loose-coupling architecture as defined by ETSI/BRAN, resp. 3GPP [9] [18].

One advantage of loose coupling is that it allows flexibility and rapid deployment. This also perfectly fits to the distributed character of ConRRM.

4.1.3.1 Basic Requirements for Concurrent RRM

As described above one key challenge is the interfacing with IETF protocols for an efficient cooperation between different RATs. That means for cooperation between different systems a new convergence layer (CL), or a more generic an IP2W interface [19], have to be added in the control plane to inter-operate with the respective protocols on the network layer. Furthermore, it has to be defined what kind of signaling will be required between RRM entities and where these entities will reside. As one example for a viable approach the client-server architecture for the network management between H/2 and UMTS can serve.

Another challenge will derive from the user requirements for smooth operation without any interception. This requires fast handover. At the same time the resources should be most efficiently be exploited. That means intelligent context transfer procedures might be required to avoid wasting bandwidth and providing relevant information in time to the decision entities for the RRM.

Whereas in the JRRM, resp. CRRM approach the control over resources are centrally controlled and managed, in the concurrent RRM approach the control and management is organized in a distributed manner. However, the distributed approach might have advantages with respect to flexibility, which is paid by a loss in efficiency. This tradeoff between flexibility and efficiency remains to be determined.

4.1.4 Layered RRM

RRM has been extensively studied over the years, as a way of providing maximum resource efficiency for particular air interface technologies, therefore the developed architectures are optimized for a network operating by using a single layer technology. In future heterogeneous wireless networks, 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.

A wireless network can be formed not only of multiple technologies, but also of multiple domains. This indicates four specific cases of interaction, namely, single technology-single domain, single technology-multi domain, multi technology-single domain, multi technology-multi domain. Current RRM solutions consider the first case, where radio resources are managed solely at the link layer (L2). With a single technology but multiple domains it is also possible to have a L2 solution. On the other hand in “native-IP” environment this could cause conflicts with the network layer (L3) interactions that will be taking place. Therefore communication with L3 entities is very important.

When multiple technologies are introduced, different link layers (L2) will interact with each other and there should be a layer, which will be the bridge between the technologies. In [20] the IP layer (L3) is used as the bridge through the IP2W interface. At L3 a decision can be made on the best resource management across the multiple technologies. In the multi technology-multi domain case, L3 decisions are needed not only in order to allow for cross-technology RRM, but also to remove any inter-domain management conflicts at L3.

In Figure 14, a framework for the multi-layered approach is pictured. There we can see entities at both L2 and L3 relating to RRM. It is also obvious where the IP2W provides the generic interface between L2 and L3. The multi-layered approach has a manager function that manages interactions between A-T specific RRM entities, such as coordinating handover.

![Manager Function](image)

**Figure 14: The multi-layered approach [20]**

The layered-RRM architecture proposed in [20] is depicted in Figure 15. Some main characteristics of the RRM architecture proposal are:

- Support self organization functionality (Establishment and re-establishment automatically and lack of a priori network planning). Nevertheless, the RRM parameter can be modified on request by the user.
- Retain functionality such as power control, admission control, etc.
- Provide QoS support based on IP-QoS (user requirement perspective).
- Maintain flexibility/cooperation (different algorithms in RRM or between functions in RRM entities should be able to interwork tightly).
- RRM algorithms in network/upper layer are not heavily depended on air interface technology.

**Figure 15, RRM Architecture [20]**

Principally the RRM architecture proposal contains a measurement entity, Resource Management entity (RM), Admission Control entity, queue and scheduler entity and output conditioner entity. The measurement entity measures the reception strength of the signal. The RM controls and manages all other functions in the RRM architecture. It also acts as a “gateway” to upper layer functions such as routing or handover. An output conditioner conditions the data flow to meet the current radio link and depends on the air interface technology. The queue and scheduler entity manage the fair and efficient distribution of the capacity among the different QoS of the connections. The Admission Control entity contains the AC algorithm for admitting or rejecting new connections, a channel allocation model that is depending on the air interface technology and a classifier model that depends on the network layer service model.

The location of the RRM functions can be divided between the link layer and the network layer, considering the information requirements and functions that are available at other layers. The division of the RRM architecture on each layer is based on the “target object” or “environment” that must be proceeded by the RRM function. However, there are some cases, where the RRM entity is relevant in both layers (L2 and L3). In these cases, the function is divided across both layers with different aspects of the function resident in different places coinciding with different “target objects” or “environment”. For functions of that kind (that split between two layers) there must be close cooperation between layers to ensure efficient RRM control. One approach is to use one function as “gateway” between layers, for example the RM function.

### 4.1.4.1 Layering of RRM Function Entities

- **Measurement entity**
  It is located only in L1 and measures the signal reception strength.

- **Output Conditioner Entity**
  It contains the power control and link adaptation functions. The main aim of link adaptation is to select a suitable PHY-Mode (modulation and coding scheme) depending on the current interference situation, fading and noise. There are differences in the power management functions between different RANS. For example in HIPERLAN/2 the dynamic power control enables the transmitting station to always set it’s
transmit power level appropriately but in IEEE 802.11 power management decides which power modes should be used. Also the IEEE 802.11a system keeps operating power of the carrier once it has selected it and does not apply dynamic power control like in the HIPERLAN/2 system. These differences between these entities indicate that the output conditioner entity must be optimized to a particular link layer technology and should remain in L2.

- **Admission Control (AC) Entity**
  It contains the AC algorithm for admitting or rejecting new connection calls or handover calls based on the current system state, the traffic and QoS requirements of the service that has to be supported, a channel allocation model and a classifier model or other components that depends on the network layer service model.

The admission control entity in L2 contains AC algorithms that are related to radio handover, Dynamic Frequency Selection (DFS) algorithm and Time Division Multiple Access (TDMA) channel allocation algorithm. When a MT moves from one cell to another, which is served by the same APC the network layer is not involved and the handoff connections are accepted or rejected only by the L2 AC algorithm.

At L3 the AC algorithm needs generic information from L2 about allocated and total available capacity, etc. The L3 AC entity gets these informations from the L2 AC entity. In order for this mechanism to work, it may be required a reliable user identification or user administrative permissions to make the request.

There are aspects of admission control that are specific to the link layer and others that require information available only at L3. For this reason the admission control function resides at both the L2 and L3

- **Scheduler and queue entity**
  The network layer scheduler guarantees that all flows receive the desired service. The scheduler and it’s queue in L3 should be aware of the link layer conditions and receive the information about the current state of the L2 scheduler from the RM entity, such as the condition of L2 buffers/queues. The L3 queues and scheduler send their current state to the L3 RM entity. The L2 queues and scheduler send their state to L2 RM entity such as the current PHY Mode allocation, PER (CIR), load of the system as well as error correction/checking mechanisms. This information is used in order to decide when the channels can be used.

It is clear that queuing and scheduling has L2 and L3 aspects and it should be present in both layers, but a very close coordination is required between these functions.

- **Resource manager (RM) entity**
  The Resource Management entity is used to control and manage more efficiently all other functions in the RRM architecture, as well as acting as a “gateway” to upper layer functions outside of the RRM function, such as routing or handover. The RM entity is present in both L2 and L3 and the entities in each layer cooperate very tight.

Some L2 Resource Management functions
- Controlling and monitoring the radio characteristics (e.g evaluate CIR or PER),
- Controlling the power control and link adaptation based on the current radio channel characteristics and QoS requirements,
- Controlling the queue and scheduler L2 based on the current system load in L2, AC algorithm in L3,
- Controlling the current system load in L2 (i.e the unstable conditions may still occur),
- Assisting L2 AC algorithm in accepting or rejecting the radio handoff request (i.e the amount of traffic load accepted in UL, DL and DiL),
- Mapping the IP QoS parameter to the QoS parameter of the L2,
- Informing the current RRM state L2 to other functions, including the L3 RM, such as current available capacity, current system load in L2, CIR (interference measurements).

Some L3 Resource Management functions
- Acting as a “gateway” to the user or to upper layers for interacting with RRM,
- Acting as an input gate for receiving and processing the information from the L2 RM entity,
• Managing the L3 RRM signalling and reporting the current state of the RRM to other functions needing this information, such as L3 routing, network handover, etc,
• Controlling the L3 queue and scheduler entity based on input such as the current capacity of the L2,
• Assisting the AC algorithm in accepting or rejecting new or network handoff connections,
• Controlling the current system load in L3 taking into account the current system load in the L2.

Figure 16 shows the generic layered RRM architecture, with the division of RRM functions between L2 and L3.

Figure 16. The layered RRM Architecture [21]

4.1.4.2 Information passed through IP2W interface
The following is a minimal list of specific information that needs to be conveyed by IP2W primitives.

From L2 to L3:
• Indication on physical interfaces present on the terminal.
• Current physical interface usable (i.e with radio coverage indicating the reachable radio access networks at one given time).
• Radio measurement report relative to the active physical interfaces. The report should have a generic format independent of the radio and the contents depend on the needs of the multi-homing algorithm.
• Radio measurement reports relative to other inactive physical interfaces.
• Acknowledgement of the message sent by upper layer indicating which interfaces to activate depending on the outputs of the multi-homing algorithm.
• Indication of a failure related to one of the active interface.
• L2 should advertise the metrics of the newly discovered links to the upper layers.
• L2 should report on significant changes to link characteristics. The significance might be controlled by specifying tolerance levels to these characteristics.
From L3 to L2:
- Request for knowing the physical interfaces present on the terminal.
- Request to activate a particular interface.
- Request for radio measurements to be performed at the radio layer.

4.1.4.3 Signalling

Signalling in the link layer (L2) is dependent on the radio interface technology that is used and it is mainly concerned about the exchange of information between neighbor cells based on the same technology.

RRM signalling in the network layer (L3) is required for base stations that use different link layer technologies in order to exchange load information between each other or with a centralized resource management entity, in order to aid decisions regarding when and where the mobile should handover. This information cannot be managed at L2 because there is an inter-technology network. Another reason for L3 signalling exists in ad-hoc environments, where the previous scenario becomes even more complex, as each ad-hoc node needs information about neighbor cells and perhaps more remote cells in order to prevent interference as the mobiles are moving.

The signalling is controlled by the RM entity. The information that may need to be exchanged by the L3 Resource Manager protocol includes:
- Information from L2 (link layer), which includes transmission and received power, interference measurements and allocated and total available capacity of the radio interface.
- From the L3 (network layer) the information includes the result of the AC algorithm and the policy control algorithm, which describes the decision of the new user-request or network handover if admitted or rejected by this node/AP/CC/router. The L3 signalling information includes also the current amount of resources available in queues and scheduler at the network layer and the current system load in L3, which can be used for handover decisions.

The link layer information is primarily relevant only between adjacent cells but may need to propagate further in order to help RRM functions to manage interference as terminals are moving.

The signaling protocol may be possible to “piggybacked” RRM information into existing L3 signaling protocols in the network, but it is difficult to guarantee that all the nodes in the network, where the RRM information is required, will process these messages. Otherwise, a dedicated protocol may be developed, with the desirable characteristics for distributing the RRM information to the relevant nodes in the network.

4.2 WINNER RRM Architecture for Cooperation

Current RRM solutions consider mainly the case of a single technology network that is owned by a single operator (single domain). In most cases, these RRM schemes are managed at the link layer, which provides the most efficient resource management avoiding unnecessary interlayer translations, to obtain least delays and data processing. An L2 solution is also possible when having a single technology but multiple domains. However, future heterogeneous wireless networks will be formed not only of multiple technologies, but also of multiple domains. Therefore new RRM schemes are necessary for the cooperation of legacy and new RANs.

When multiple technologies are introduced, different link layers will interact with each other and there should be a layer, which will be the bridge between technologies. The IP layer could be used as such a bridge through the IP2W interface. 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.

The WINNER RAN will implement a multiple-mode RAT in order to provide complete coverage in different deployment scenarios. Layered RRM (see Section…) with its multi-technology/multi-domain concepts is a possible candidate mechanism for ensuring that the WINNER RAN will successfully cooperate with the rest of the legacy technologies. The identified by the trends of mobile communications development specifics, however, imply that a straightforward approach might not be enough. Therefore, it
is more likely, that the WINNER RAN will require a clever combination of a variety of RRM mechanisms if a successful cooperation with other technologies must be guaranteed.

The IST FP6 project Ambient Networks [reference] is defining a cooperative RRM architecture, that includes a Generic Link Layer (GLL) for the connection of wireless networks and an RRM entity for inter-RAN cooperation. This architecture is suitable for the cooperation of heterogeneous networks and, is a candidate cooperation architecture for WINNER. The generic link layer (GLL) should support an easy integration of new air-interfaces into the existing networking infrastructure for cooperation between legacy RANs, and between legacy RANs and new RANs. WINNER should define specific requirements for the GLL to enable the cooperation between the WINNER RAN and legacy RANs.

One concept that could ease the cooperation within RANs is a “convergence layer” that could be a functionality of the GLL, to offer a common appearance to upper entities, the WINNER Cooperative RRM entity. This concept is used in the IEEE 802 protocol suite, where there is only one common LLC sub-layer (defined in IEEE 802.2), common for all IEEE 802 network protocols wired or not (Ethernet (IEEE802.3), 802.11, 802.16, etc) each one with different MAC and physical layer protocols. This allow the use of common layer 3 and 4 protocols (TCP/IP). This eases the interworking, and development of new IEEE networks, because is not necessary to develop new LLC and upper network protocols (TCP/IP).

The cooperation mechanisms will be capable of being activated from the radio access level. Additionally, they will also be activated by other entities of the overall mobile network; for example by a user specified application. In the scope of WINNER the most relevant RRM cooperation mechanisms are considered to be: Mobility management (handover and location based RRM), Joint RRM (admission control and scheduling/load control) and QoS based management.

In the WINNER project, different RRM cooperation schemes will be proposed and analysed; Combined RRM, Concurrent RRM and Layered / Cross Layered RRM. The WINNER cooperation scheme and associated mechanisms will enhance the functionality, performance, flexibility and radio coverage with respect to the current, isolated RANs.

5. Supporting measures for cooperation mechanisms

5.1 Measurements and Triggers

5.1.1 Definition of Triggers

In general, an L2 trigger is understood as a signal of an L2 event. An L2 event regarding the L2 handover may be the early notice of an upcoming change in the L2 point of attachment of the mobile node to the access network. Another possible event is the completion of relocation of the mobile node's L2 point of attachment to a new L2 access point. Although specific L2 information is to be exchanged, an L3 protocol should be kept independent of any specific L2 feature. This means that an L2 trigger that is exchanged with L3 must be generic and technology independent. Apart from that, triggers should only enable performance enhancements and not be used for correct protocol operation.

In most of the cases, an L2 trigger is a kind of notification from L2 (potentially including parameter information) to an adjacent layer that a certain event has happened or is about to happen [22]. In such a way, the process of triggering is related to information exchange and communication between layers. However, this is not necessarily the case. As described further below, a trigger might also be a physical probe, the outcome of an algorithm or the transformation of a requirement, all of which are L2 self-autonomous transactions with no interlayer communication. A trigger may be implemented and applied in a variety of ways. An L2 trigger is not associated with any specific link layer technique but rather is based on the kind of L2 information that is or could be available from a wide variety of radio link protocols. The basic property of a trigger however is that its appearance is closely connected to the handover question. A “traditional” handover is located in L2, since L2 is responsible for the physical and the logical connectivity of higher layers. In fact every L3 handover is usually preceded by a L2 handover. The only problem is that the L3 handover is not aware of the L2 handover due to the independency of the layers. A possible solution to solve this problem is the utilization of link layer triggers. Link layer triggers are objects of information that report a result of a measurement or algorithm.
To show the benefit of link layer triggers, an example is introduced on how link layer triggers may aid an MIP handover:

To detect whether a Mobile Node must change its association point, ARs periodically (e.g. every 2 seconds) broadcast a unique message, a so-called advertisement. If the MN detects a new advertisement, an algorithm to re-associate to the new AR is started. Of course, prior to starting the re-association, the MAC has established a new radio link and removed the old link (for whatsoever reasons), otherwise it would not be possible to detect the new advertisement. With a constant inter-arrival time of 2 s of the advertisements, the Mobile Node will take one second on the average to detect the movement to a new AR. This information is available at the link layer a lot earlier. In fact, it’s available immediately after the link is established by the link layer. The link layer may now send a trigger with this information to the network layer. Hence, on the average the IP handover can be executed 1 s earlier. This would enormously reduce the amount of time for a handover.

This is only one example where link layer triggers may be used.

5.1.2 State of the Art

Triggers have been discussed in the IST project MIND [22] and in the IETF lately. Examples are the activities in the IETF working-groups MIP (Mobile IP) [23] [24], PILC (Performance Implications of Link Characteristics), SeaMoby (Seamless Mobility), or TRIGTRAN (Triggers for Transport). A description of how Mobile IPv6 Fast Handover [14] could be implemented on a link layer conforming to the 802.11 suite of specifications can be found at [25].

PILC: The PILC working group gives advice to link-layer designers from the perspective of best supporting existing IETF protocols (e.g. on link Automatic Repeat reQuest (ARQ)). Of course, triggers may be employed to achieve this goal. Furthermore, the capabilities, limitations and pitfalls of “performance enhancing proxies” (PEPs), are discussed. PEPs are active network elements that modify or splice end-to-end flows in an attempt to enhance the performance they attain in the face of particular link characteristics.

SeaMoby: The Context Transfer Protocol (CTP) is a generic protocol which is currently being specified by the SeaMoby (Seamless Mobility) Working Group of IETF to enable authorized context transfers between PAR (Previous AR) and NAR (New AR) in IP networks. In terms of WLANs an MN corresponds to an 802.11 station and the AR corresponds to a fixed network node connected to one or more 802.11 APs. Hence, the AR provides IP connectivity for mobile nodes.

Two main reasons why context transfer procedures may be useful in IP networks when a mobile node moves to a different access router (i.e., handover or roaming), are defined in [26] as follows:

- There is a need to quickly re-establish context transfer-candidate services without requiring the mobile host to explicitly perform all protocol flows for those services from scratch.
- An interoperable solution that works for any Layer 2 radio access technology is required.

When the state or context transfer between the new and the previous ARs (in conjunction with the mobile station) can be carried out during handover, many important benefits including seamless operation of application streams, performance improvements, bandwidth savings, and reduced susceptibility to errors can be achieved. In particular the IETF Context Transfer Protocol (CTP) described in [27] provides:

- Representation for feature contexts
- Messages to initiate and authorize context transfer, and notify a mobile node of the status of the transfer
- Messages for transferring contexts prior to, during and after handover/roaming

The proposed protocol is designed to work in conjunction with other protocols in order to provide seamless mobility.

TRIGTRAN: This community was recently founded within the IETF (Oct 2002) and emerged from a meeting of the members of the following working groups: PILC, SeaMoby and MIP. The only available information up to now is a so-called problem statement [28]. However, the purpose of this project has already been defined. It should identify interesting link-layer events, define a protocol for event
notifications, and define the usage of notifications by transport layers/applications. Although there is very few information available at the moment on this project, the goal to build a generic framework for L2 triggers sounds very promising.

5.1.3 Types of Triggers
In the following a classification of triggers is presented [22]. We thereby introduce a differentiation in Physical-based L2 triggers, which are physical probes that can be measured and statistically evaluated and Algorithm-based L2 triggers, that are outcomes and decisions of procedures performed within layer 2. Since the main focus of the work is on interworking of WINNER RAN and legacy RAN, we focus on aspects of triggers utilized for the vertical handover.

5.1.4 Physical-based L2 triggers
Similar to the horizontal handover case, the link layer involved in a vertical handover will rely on physical parameters, known from measurements, and their derivatives. The most important ones are explained in the following.

5.1.4.1 Signal Strength
In order to spot a transmitting station, either AP or MT, the receiving station needs to be in the position to detect the corresponding signal. This is only possible if at least a minimum reception level is available. Due to attenuation and pathloss characteristics of the radio channel together with shadowing effects, this minimum reception level is only achieved within a certain range of the transmitting station. The covered area thereby depends on many parameters, e.g. the use of transmission techniques like transmission power control, or hardware arrangements like the deployment of directed antennas, or outer circumstances like topology or even the weather. Thus, there are many reasons why the reception level of a signal weakens. Because of this physical impact, a lower threshold of the reception level is defined, which is higher than the minimum reception level and may not be under-run. The value of this threshold thereby is a standard specific parameter. In order to determine the reception quality of a carrier, L2 (periodically) monitors the reception level with the help of a so called Radio Signal Strength Indicator (RSSI) for, e.g., GSM or Radio Received Signal Code Power (RSCP) for UMTS, whose value is reported from the PHY-Layer.

5.1.4.2 Interference Level
In all communication systems, the primary signal of interest is not solely transmitted. Especially in wireless systems, the signal, respectively its reception, suffers from various disturbances. The generic term for this disturbance is interference or interference level. Interference may be caused by foreign systems, the own system or the environment:

Foreign system caused interference - If multiple systems operate in the same frequency band, their respective transmissions might cause disruption of foreign data. The same is valid if systems operate in adjacent frequency bands (adjacent channel interference), where spurious emissions might have the same effect. Frequency/Network planning and adaptive system behavior (e.g. Dynamic Frequency Selection) are applied to reduce these effects.

Own system caused interference - The aforementioned reasons for interference are mainly due to the coexistence of several systems in the same coverage area. Considering cellular systems, especially inter-cell interference caused by users which are active in neighboring cells of the same system, i.e. which are outside the regarded cell, must be mentioned. Furthermore, the simultaneous transmission of user signals in the same frequency band, which are separated by CDMA-Codes like in UMTS, leads to intra-cell interference. Also within the same system communication on adjacent frequencies will cause adjacent channel interference.

5.1.4.3 Carrier-to-Interference Ratio (C/I)
The aforementioned physical parameters signal strength and interference/noise, need to be put into relation in order to make a decision, whether the need for a handover trigger is given. If, for example, there are much interferences present, but the carrier signal on the other hand is also strong enough, communication still maybe possible though the scenario is very noisy. On the other hand, if there are only minor interferences, the signal needs not to be transmitted with the full power amplitude and a reduction of the transmit power can be ruled (principle of dynamic power control).

5.1.4.4 Bit Error Rate (BER) / Packet Error Rate (PER)
These two indicators are closely connected to the parameters before. A high C/I value usually results in a low BER/PER. The relation between C/I and BER/PER depends on the transmission scheme that is used. In general one can say that more redundant schemes show a better BER/PER performance at the same C/I than less redundant schemes. The latter however feature by a higher data-rate that can be realized. BER
and PER are very important for the handover decision trigger, since their value is directly connected to
the system performance in terms of throughput and delay of data transmission.

5.1.5 Algorithm-based L2 triggers
Complementary to the physical-based L2 triggers, we now summarize further triggers that are involved in
the handover decision making process. One could also classify them as a kind of ‘higher level trigger’
since they are not purely related to L1 issues. In fact, within their appearance, they are taking physical-based
triggers into account and use them within more complex handover decision algorithm processes.
Such, more ‘intelligence’ is connected with the appearance or not appearance of these triggers. Especially
for the vertical handover these kind of triggers offer an extra dimension, namely the cross-system
perspective.

5.1.5.1 HO Ping-Pong avoidance by means of hysteresis
One of the most known HO triggers/decision algorithms, which is usually applied in radio systems is the
here called HO ping-pong avoidance mechanism, which is a good example of a trigger, that prohibits the
initiation of a handover (for further discussion). Especially terminals at the border of two cells have
difficulties in assigning themselves to the one or the other. Due to the overlapping character of the
coverage areas, a MT moving along the cell border would permanently try to switch to the neighbored AP
as soon as the respective signal was a little bit better than the present one. This so called HO ping-pong
effect is prevented by introducing a hysteresis, which means a HO is only allowed, if the signal of the
new AP is remarkable stronger than the present signal. More sophisticated (not-)triggers also include a
time dimension within their decision finding, which means, that either this new, stronger signal must be
present for at least a minimum amount of time before switching is allowed, or the return to an old AP
after HO is not allowed for a certain period. However, this is related to some averaging processes.

5.1.5.2 QoS violation trigger
One more and more important aspect within communication and data transfer is the support of Quality of
Service (QoS). In order to support higher layer demands with respect to delay, throughput, etc, the link
layer should indicate QoS violation, e.g. bandwidth shortage, to the higher layer, that e.g. the network
layer is challenged to choose the most suitable access system, resp. change it by performing a vertical
HO. Fluctuations on the link are partly adjusted by L2 mechanisms like e.g. link adaptation. However if
the current system is not able to satisfy the requested demands anymore, it is up to L2 whether a
(transparent) L2-HO to a neighboring cell of the same system is initiated/triggered (horizontal handover),
changing to a new system is proposed (vertical handover trigger) or a re-negotiation on adapting earlier
agreed QoS parameters is triggered.

5.1.5.3 Connection Admission Control and Connection Forwarding (CAC & CF) trigger
This trigger incorporates the current load condition, the queue length within the buffers and QoS support.
The handover decision depends on actual, requested and expected traffic in such a way, that incoming
requests are not refused straight away if the capacity limit is to be reached. Instead, L2 could indicate that
there is not enough bandwidth available and L3 might in turn give over certain (lower prioritized, less
challenging) connections to another system in order to still be able to accept the incoming request (load
balancing).

5.1.5.4 Location Based trigger
Intuitively one will agree that a mobile close to the AP should not be handed over to another AP unless
there is a promising gain expected. In a horizontal system architecture, this probability is very small, but
for vertical handover scenarios this might be an interesting way to go. However, in most of the cases it
can be assumed that the mobile terminal is the better served the closer it is to the base station. On the
other hand this means that handover prevention mechanisms can be relaxed if the mobile approaches the
cell border. In such a way this trigger consider the distance to the serving AP and can initiate or prevent
the launch of a handover procedure. In this case, especially the prevention of a handover helps to avoid
the aforementioned ping-pong effect. The IST project CELLO [51] considers and investigates such
location aided handover concepts.

5.1.5.5 Velocity based trigger
Handover are mostly connected with mobility and mobility refers to velocity. Therefore one important
aspect for handover triggers is the speed with which the user moves. Considering the velocity that a user
is running makes it easier to predict the necessity for the next handover. Thus it is not necessary to only
rely on e.g. RSSI measurements in order to determine that the border of a cell approaches. This makes it
possible to mainly execute planned handovers, which means that there is enough time to exchange
necessary information data via the backbone, such that a forward handover (horizontal handover) can be
realized. Additionally, the consideration of the actual speed allows to take a decision whether a vertical handover should be envisaged or not. A good example is a train scenario, the user moves with high speed and there is no access to an AP inside the train, he probably is triggered to attach to a wide-area covering system like UMTS. If the train is reaching a station (where it probably even stops for a longer period), a trigger to switch to H/2 can be expected. In such a way, the velocity is an important indicator or trigger, since it is closely connected to the covered area of a single AP/BS.

5.1.5.6 A priori-knowledge based trigger
Often the MT holds information that is not based on measurements of received information data. For example, if a MT is attached to a micro-cellular system like H/2, it implicitly knows that the covered cell size is much smaller than the one of UMTS. This information alone is not sufficient for triggering any handover, but in combination with other triggers, e.g. velocity, it becomes useful information to be used. The same is valid, if the mobile makes use of information that possibly could be provided by ROM, e.g. on the SIM-card. This could be a street map or a map of positions of APs or information concerning areas with handover problems or areas where MT's have worse connectivity to certain systems. Again, this a priori knowledge could be interesting to be used for handover triggers. Beside this, the MT could record periodically recurring events and use this information for future HO triggers. For example, if a user takes the same way to his work every day, there will be the same sequence of HO's to serving APs every day. If this sequence somehow is stored, it can be used the next time to predict HO's, which again allows for executing planned and forward HO's. The learning aptitude of MTs and its intuitive appliance of knowledge to satisfy the user's demands is also referred to as Cognitive Radio.

5.1.5.7 Service availability trigger
Although it is no L2 trigger, the service availability trigger is worth to be mentioned here. The current system does not (any longer) support a certain service or does not support a requested service at all. Thus a HO trigger to another system that offers the service is initiated.

5.1.6 Combination of different triggers
The previously described triggers are all indicators that might cause a (V)HO. A more effective usage of those triggers is achieved by combining them in their evaluation. This was already indicated in the presentation of the algorithm-based triggers, which make use of the physical-based triggers with their HO proposal.

5.1.7 Collection of triggers
The previous sub-chapters concentrated on the description of triggers and their appliance. Somehow, their origin, especially the one of the physical-based triggers, was not covered.

An important point is therefore how the information is gained that is carried by the respective trigger. This will be described in the following.

Basically, there are the following possibilities:
- Self-organized information provisioning (Scanning)
- Information exchange within the same or with other systems
- Out of band communication signal (common information channel)
- Coupling with other systems
- A priori knowledge

The most common way to gather the required information surely is to perform a scanning of the air-interface, i.e. gaining information from the physical layer to detect possible systems to switch over. The advantage of this method is that it can be realized self-autonomously by the MT, which is important for newly switched on devices or terminals that suddenly have lost their old connection. Furthermore, especially for the HH-case, the MT does not need to possess additional hardware components, since the same device can be used in different cells of the same type (roaming). The disadvantage of this approach is that the scanning procedure needs special coordination and resources like additional battery power consumption. Also, the scanning takes time, which usually cannot be used for communication.

Another way to gather information is to exchange information within the same or with other systems. Information gathering within the same system is required for HHO, whereas for VHO information gathering between different types of systems is needed. This approach offers a great economic potential since the scanning procedures can be minimized. Each system collects data about the current state within the covered cell and provides this information on request to MTs that are willing to change their connection within the same system (HHO) or different systems (VHO). For the HHO case this is partly already realized by means of broadcast channels that a BS periodically transmits. However, these
broadcast channels do not include information about neighbouring or different systems. Thus, the new topic is that this information will be provided as well. Especially, for the VHO-case this means a remarkable gain. One alternative and novel solution to gain information of the target system is explained in the section 6.1.2.1 which is a position-aided vertical handover. Another way to organize the data-transfer is via a common information channel (Out of band communication signal) supported by all different systems. This solution is close to the broadcast proposal with the difference that the data is directly obtained from the new system without the in-between step over the old AP. Thus it is time saving and not affected by sudden break downs of the old link. A clear disadvantage is that there is no spectrum available for an extra control channel. Additionally, an extra standard would be needed, agreed and supported by all parties.

5.1.8 Introduction to Measurements

For mobile controlled HO (MCHO), the mobile device has the responsibility selecting the “best” RF channel to use. However, there are two issues to address. First, the mobile device must possess the necessary data to make a valid decision. Unfortunately, much of this data is not directly accessible by the mobile device. The network infrastructure must pass the pertinent data to the mobiles. The second issue is one of efficiency. Since the mobile is required to always operate on the “best” channel, it must frequently compare the current channel with possible alternate candidates. Unfortunately, most, if not all mobile devices will only have a single receiver, which means that when a mobile is assessing an alternate channel, it is unable to receive data broadcast on its normal data channel. Therefore, the algorithm must contain mechanisms to improve the efficiency of alternate channel scanning.

Some of the aforementioned is also valid for the network controlled HO (NCHO) with the difference that now the network needs to be aware of possible other systems where it can request the mobile to attach to. In order to get these information, a BS/AP can either trigger a MT to provide respective information, or it performs measurements on its own. For the latter case one can assume that a BS is generally equipped with multiple entities compared to a MT, i.e. several transceivers to allow for parallel scanning and active transmission. On the other hand central scanning at the BS might not be very useful, since this kind of information, e.g. about the interferences on a certain frequency might strongly differ from the interference situation a MT is facing at the edge of a cell. However, in both cases a logic separation between information gathering and evaluation, respectively decision taking has to be taken. The usual case will be that some entities mainly located within layer 1 and 2 will collect the respective information and forward them to one central instance, that takes over the evaluation. The location of this central entity that finally decides whether a handover shall be initiated or not, most probably but not necessarily will operate within layer 3.

Measurements in UMTS

In this section it will be elaborated on the measurement facilities defined in WCDMA. While the following part focuses on the UE based measurements, similar facilities exist for measurements performed by the node B.

UEs may not be capable to measure on other frequencies and or RATs in parallel to operating a dedicated connection. In such cases UTRAN may configure gaps in the transmission on the current dedicated connection. Different methods have been defined for this purpose including the use of compressed mode and the introduction of databases for the collection and exchange of measurements within the same or different systems.

**Measurement identity:** A reference number that should be used by the UTRAN when setting up, modifying or releasing the measurement and by the UE in the measurement report.

**Measurement command:** One out of three different measurement commands.

- Setup: Setup a new measurement.
- Modify: Modify a previously defined measurement, e.g. to change the reporting criteria.
- Release: Stop a measurement and clear all information in the UE that are related to that measurement.

**Measurement type:** One of the types listed below describing what the UE shall measure. The different types of measurements are:

- Intra-frequency measurements: measurements on downlink physical channels at the same frequency as the active set.
- Inter-frequency measurements: measurements on downlink physical channels at frequencies that differ from the frequency of the active set and on downlink physical channels in the active set. The measurement quantities are measured on the monitored primary common pilot channels (CPICH) of the cell defined in the measurement object.

- Inter-RAT measurements: measurements on downlink physical channels belonging to another radio access technology than UTRAN, e.g. GSM.

- Traffic volume measurements: measurements on uplink traffic volume.

- Quality measurements: Measurements of downlink quality parameters, e.g. downlink transport block error rate. A measurement object corresponds to one transport channel in case of BLER. A measurement object corresponds to one timeslot in case of SIR (TDD only).

- UE-internal measurements: Measurements of UE transmission power and UE received signal level.

- UE positioning measurements: Measurements of UE position.

The measurements are performed by the node B or the UE and can be either periodic or event triggered. In particular, a trigger can be:

- a notification from one to an adjacent layer that a certain event has happened or is about to happen
- a physical probe
- the outcome of an algorithm
- a higher layer requirement

In case of periodic measurements, the node B/UE periodically reports certain quantities. The advantage of using periodic measurements is that UTRAN always has a good overview of the current system status. However, the use of periodic measurements may involve a significant amount of signalling, leading to the consumption of scarce resources. As a result, event triggered measurements have been defined to reduce the amount of signalling. In case an event triggered measurement is used, the node B/UE only provides a measurement report when a specific event has occurred eg. a measured quantity has reached a certain threshold. Although this may greatly reduce the signalling load, the UTRAN does not have as good an overview as when using periodic reporting. Moreover event triggered measurements are less flexible as only the events defined in the standard can be reported. A summary of measurements events and their use is depicted in Table 1.

As different measurement quantities are specific for each RAT, it is difficult to assess which RAT connection is best at each time. To overcome this problem, in WCDMA the radio technologies are not compared with each other but against thresholds that are specific for each technology. For example, to accommodate a handover to GSM, the UTRAN may configure a UE in CELL_DCH state to report event 3a (Table 1); the estimated quality of the currently used UTRAN frequency becomes below a certain threshold and the estimated quality of the other system is above a certain threshold. The problem of measurement comparison between different RATs can also be solved by defining functions for mapping one quantity on to the other. Although this functionality was initially included in [1] it was later considered not to be needed.

Another technology specific aspect that should be considered when evaluating measurements is the use of soft handover, as supported in WCDMA. When soft handover is employed, all of the radio links that are used (active set) contribute to the quality of the radio connection. To accommodate this, a formula has been defined for determining the quality of a certain frequency. This does not only apply for the currently used frequency; when comparing the current frequency with another WCDMA frequency also the different radio links on the other frequency should be accounted for. This is not only accommodated in the measurement events, but also procedures have been defined for controlling the radio links on the other frequency that the UE should consider (the virtual active set).
<table>
<thead>
<tr>
<th>Event</th>
<th>Description</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intra frequency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A</td>
<td>A primary CPICH enters the reporting range</td>
<td>Soft handover, add radio link. Applies when room for adding radio links</td>
</tr>
<tr>
<td>1B</td>
<td>A primary CPICH leaves the reporting range</td>
<td>Soft handover, remove radio link</td>
</tr>
<tr>
<td>1C</td>
<td>A non-active primary CPICH becomes better than an active CPICH</td>
<td>Soft handover, replace radio links. Applies when no more radio links can be added</td>
</tr>
<tr>
<td>1D</td>
<td>Change of best cell</td>
<td>Best cell to be used as reference and/or to accommodate certain service eg. HSDPA</td>
</tr>
<tr>
<td>1E</td>
<td>Primary CPICH becomes better than absolute threshold</td>
<td>Soft handover (alt), add radio link</td>
</tr>
<tr>
<td>1F</td>
<td>Primary CPICH becomes worse than absolute threshold</td>
<td>Soft handover (alt), remove radio link</td>
</tr>
<tr>
<td><strong>Inter-frequency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>Change of best frequency</td>
<td>Hard handover</td>
</tr>
<tr>
<td>2B</td>
<td>Estimated quality of the currently used frequency is below a certain threshold and the estimated quality of another frequency is above a certain threshold</td>
<td>Hard handover eg. when using another frequency for macro and micro cells (HCS)</td>
</tr>
<tr>
<td>2C</td>
<td>Estimated quality of a non-used frequency is above a certain threshold</td>
<td>Hard handover (alt.), move to more demanding measurement scheme</td>
</tr>
<tr>
<td>2D</td>
<td>Estimated quality of the currently used frequency is below a certain threshold</td>
<td>Start inter-frequency and/or inter RAT measurements</td>
</tr>
<tr>
<td>2E</td>
<td>Estimated quality of a non-used frequency is below a certain threshold</td>
<td>Move to less demanding measurement scheme</td>
</tr>
<tr>
<td>2F</td>
<td>Estimated quality of the currently used frequency is above a certain threshold</td>
<td>Stop inter-frequency and/or inter RAT measurements</td>
</tr>
<tr>
<td><strong>Inter Radio Access Technology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>Estimated quality of the currently used UTRAN frequency is below a certain threshold and the estimated quality of the other system is above a certain threshold</td>
<td>Handover from UTRAN (typical)</td>
</tr>
<tr>
<td>3B</td>
<td>Estimated quality of the other system is below a certain threshold</td>
<td>Move to less demanding measurement scheme</td>
</tr>
<tr>
<td>3C</td>
<td>Estimated quality of the other system is above a certain threshold</td>
<td>Handover from UTRAN (alt), move to more demanding measurement scheme</td>
</tr>
</tbody>
</table>

Table 1. Measurement events and their use.

The measurement facilities defined in WCDMA can be regarded as a toolbox including a large number of options and parameters which UTRAN may apply when configuring measurements e.g. hysteresis, time to trigger, cell individual offsets, reporting interval, amount of reports, reporting deactivation threshold. For further information, see [1] especially sections 14.1-14.3.

5.1.8.1 State of the art

In order to decide to perform an intersystem handover and to allow choosing the most suitable radio access technology, a fundamental aspect is to define a set of parameters in order to assess the quality that different RATs will provide to the terminal. This quality indication is basically obtained by performing measurements from the current and possible target networks and comparing the different values obtained. The IST SCOUT project has provided a deliverable whose subject is "Analysis of inter-system handover measurements and criteria" [29]. In this document, measurements and criteria able to trigger inter-system handover have been identified and analysed, in order to provide a general framework that allow handover to any technology.

In [29], 4 groups of radio link measurements have been identified:

- **Signal level:** This must allow concluding on the reception quality of the actual configuration and the possibility (or the necessity) of doing a handover to other radio access technology. These measurements are used to compare the cells independently from radio parameters.
Measurements for UTRAN FDD cells are classically CPICH RSCP or CPICH Ec/Io ([30]). Measurements for UTRAN TDD cells are classically P-CCPCH RSCP ([31]). Measurements for GSM cells are RXLEV (or GSM carrier RSSI in UMTS terminology), which is the received signal strength. Pathloss measurements can also be performed, but however not directly.

- **Signal quality:** This must allow concluding on the quality offered and perceived by the UE and to compare it with the required quality. So it is necessary to do some measurement on user data flow in order to define QoS indicators. QoS indicators could be: BER (bit error rate), Residual BER or BLER (block error rate), retransmitted block rate or bit rate at different layers level (for example layer 1 with instantaneous bit rate, layer 3 with throughput or applicative layer level).

Measurements for UTRAN FDD and TDD cells are classically transport channel BLER performed by the mobile, and also measurements performed by UTRAN, such as SIR, transport channel BER or physical channel BER [30] [31]. Measurements for GSM cells are classically the RXQUAL measurements, measured either at the mobile or the BTS (bit error rate).

- **Cell load parameters:** This shall provide information on the actual cell load, cell load can be measured with radio transmitted and received power (these measurements are available for UMTS FDD and TDD cells for example) or it can be derived from bit rate, number of users, etc. The cell load corresponds to the currently used active connections, but other important information is the cell capacity, which corresponds to the maximum number of active connections.

- **Handover statistics:** This must allow indicating if handovers are well performed or not. Typical parameter could be: handover success or failure rate, time to perform handover… A bad quality with this measurement could be investigated with the other measurements like cell load parameters or signalling level.

Contrary to the case of intra-RAT measurement for which two measurements performed on two different cells could directly be compared, the evaluation and comparison of two measurements performed on two cells of two different radio access technologies is based on different quantities. For example, the comparison between GSM carrier RSSI measurement on a GSM cell and measurement on the UTRAN cell cannot directly be done. 3GPP specifies standardized mechanisms to compare cells owning to different RANs. The determination of best cell is done by comparing separately the measurements of different radio access technologies to absolute thresholds. On the other hand, in order to allow a direct comparison between different RATs measurements, it may be interesting to define some sort of mapping functions or to derive some abstract parameters common to every RAT, but this point has to be investigated further. One can notice that pathloss measurements are common for all RATs since it gives the attenuation of the radio signal regardless of the output power used.

Within 3GPP, work on CRRM [12] resulted in the introduction in GSM and UMTS of the possibility to exchange cell load information between RNC and BSC.

More precisely, two types of measurements that can be exchanged have been defined:

1. Measurements on cells controlled by a distant entity (RNC or BSC), *i.e.* dynamic information
2. Static information on cells controlled by a distant entity (RNC or BSC).

The measurements, such as load information of the neighbouring UMTS and GSM cells, are an important input of the CRRM algorithm. In release 4, all the necessary procedures have been developed over the Iur to allow a RNC to obtain cell load measurements on cells controlled by other RNC. For CRRM, the measurements between RNC and BSC could be transferred in different ways: via Iur-g if existing, via the Iu and the A interfaces or via a new interface. The following common measurements have been identified [12]:

- 2G cell load in CS domain (*i.e.* percentage of 2G cell capacity for CS domain)
- 2G cell load in PS domain (*i.e.* percentage of 2G cell capacity for PS domain)
- 3G cell load (*i.e.* percentage of 3G cell capacity, already available in RNSAP)
- UMTS-specific measurements, such as those already available in RNSAP, can be provided to the BSC, as the transmitted carrier power, the received total wide band power, etc.

Concerning static information, the following information has been identified [12]:

- Cell relation, *i.e.* overlapping between cells (macro/micro cells, HCS structure),
- Cell capability for the GSM cells, *i.e.* GPRS, EDGE, HSCSD, etc.
- Cell capacity and QoS parameters:
  - 2G cell capacity for CS domain (e.g. number of available time slots)
  - 2G cell capacity for PS domain (e.g. number of available time slots)
To exchange the measurements information, different architectures are possible, whether a CRRM server or an integrated CRRM can be used, as described previously in a previous section. In addition to these solutions for the exchange of measurements, another possibility is to reuse existing procedures transferring information between BSC/RNC such as handover and relocation procedures. The messages included in these procedures can be easily extended to include the additional measurements that are required, without the additional complexity of new nodes/interfaces.

5.1.8.2 Measurements requirements for inter-system mobility

This section aims at providing a guideline for the definition of the WINNER radio interface so as to facilitate the handover with the legacy RANs.

The following is only based on the inter-system mobility mechanisms that are available in the UMTS standard to balance the traffic between an UMTS network and another RAT and on document [33]. This section will be updated with requirements related to interworking with other legacy RANs. Besides, this section aims at giving guidelines to WP2 workpackage, which is in charge of the definition of the WINNER radio interface, but can be modified according to the work performed in this work package, as the WINNER radio interface will be more precise. Interactions between WP2 and WP4 are required on this topic.

The following defines some first requirements to enable handover between WINNER RAN and UMTS networks.

The inter-system handover procedure between UMTS and another RAT is already specified by the 3GPP. Some of the specifications are applicable to any RAT while others are RAT specific (e.g. specified measurements on GSM are applicable to GSM only). Therefore, the WINNER design must fulfill all the requirements that are mentioned in the 3GPP specifications for every RAT and the 3GPP will need to do some specifications dedicated to the WINNER system.

Before going into details, the overall principle of inter-system mobility mechanisms can be described with a few steps.

1) The user is connected to an initial serving cell (either UMTS or WINNER cell)
2) The cell broadcasts the list of neighbouring cells (from the Beyond3G system and from the UMTS), with their attributes and the information necessary to demodulate their signal. For example, if the user is in a WINNER cell, this serving cell must broadcasts the frequencies, the scrambling codes of the UMTS neighbouring cells.
3) The cell signals to the user that it has to perform measurements on the other system. This is triggered by various criteria.
4) The cell signals to the user how to perform measurements for each neighbouring cell.
5) The user performs measurements on the other system cells of the list.
6) If given criteria are fulfilled, the transfer is performed accordingly to the inter-system mobility procedures.

We can notice that the triggering criteria, the signalling and above all the measurements constitute some important steps in the inter-system mobility process. The mentioned quantitative criteria must be based on comparisons between WINNER and UMTS current link qualities. However, the WINNER system is not developed enough to define precisely these criteria.

Two approaches are possible to design a bi-mode terminal able to measure two different RATs:

- The dual receiver approach.
- The scheduling approach

A dual receiver can use separately dedicated receivers for each source at the same time. However, there may be some technical difficulties of implementation depending on the frequency bands of each RAT, and duplication of hardware components might increase the cost of the mobile equipment. In addition it is not optimal as each receiver is not busy during all the communication periods.

In the case of the scheduling approach, a single receiver is capable of alternating operation on the resources. This approach has the following advantages: lower complexity in the hardware at the receiver level and possible integration of UMTS and the Beyond3G receivers.

There are two cases to study: the user is initially connected to the UTRAN and will perform a transfer of its connection towards the WINNER RAN, or the user is initially connected to the WINNER RAN and will perform a transfer of its connection towards the UTRAN.
Measurements on WINNER RAN performed by a UE connected to UTRAN

When the user camps on a UMTS TDD cell, or on a FDD cell in idle mode or connected mode for all states except the Cell_DCH state, it does not need to interrupt a dedicated communication to perform measurements. Therefore, no special requirements on the WINNER system have been identified for this case.

On the contrary, for a user that initially has a dedicated connection with a UMTS FDD cell (in the Cell_DCH state of the connected mode), the user must interrupt its dedicated communication, and use the "compressed mode" to perform measurements. In order to facilitate the transfer of the connection, the WINNER system design must fulfill some requirements.

The user will perform measurements on neighbouring WINNER cells using the "compressed mode". The compressed mode consists in introducing silent periods (called gaps) during which the user does not transmit nor receive dedicated signal, so as to listen to other frequencies cells (WINNER cells in our case).

These gaps must be of minimum duration and minimum frequency as they imply a loss of capacity and also a too large amount of interference. Indeed, the compressed mode has a bad impact on the system performances (capacity and coverage are decreased).

Depending on the WINNER radio interface, different cases must be considered, whether WINNER network is a frequency planned network with frequencies to discriminate cells or a single frequency network with scrambling codes to discriminate cells. The constraints will not be the same: for example, in the first case, a similar procedure to the measurements of GSM cell can be used, provided that an equivalent to the BSIC is periodically broadcasted by the WINNER cells. Or in the second case, a similar procedure to the measurements of TDD cells can be used, provided that WINNER cells transmit equivalent primary and secondary synchronization codes. This should be further investigated when the WINNER RAN will be more defined.

Hence, in order to facilitate measurements, the WINNER system should fulfill the following requirements:

- The broadcast information of the WINNER system should require a short demodulation window time, because if the window necessary to demodulate the broadcast information is large, then the required gap of the compressed mode will be large.
- The period of the broadcast information of the WINNER system should be a compromise between a short period and a large period. Indeed, if the period of apparition of the broadcast information is too low, then the user will manage to catch the broadcast information only after a very long period. Nevertheless, if the broadcast information has a too short period then it will create too much overhead.
- The WINNER system should have a time structure that is near from the one of the UMTS FDD time structure, in order to facilitate the parameters setting of the UMTS FDD compressed mode.

Measurements on UTRAN performed by a UE connected to WINNER RAN

Whether the WINNER RAN will be a TDD or FDD system will impact the way the UE may perform measurements on other RATs. There are many different solutions that are compatible with the scheduling approach. For instance, the WINNER user could insert silent periods (idle slots), or it could even listen to the UMTS frequency during the period of UL WINNER transmission, or it could require compressed mode to perform the measurements on legacy systems.

There are two cases to consider: the WINNER idle mode and the WINNER connected mode since the requirements may differ.

In order to facilitate measurements on UMTS FDD (respect. TDD) cells by users being in a WINNER cell, some general requirements for the WINNER RAN can be assumed, but they need to be refined when the WINNER radio interface will be more precise:

- having a time structure near from the UMTS FDD (respect. TDD) time structure
- having the same accuracy of measurements than those performed by a user in a UMTS TDD cell on a UMTS FDD (respect. TDD) cell.
- having synchronized networks would allow to optimise the gap distribution: it could be possible to be sure that broadcast of information from WINNER corresponds to a gap in compressed mode. It would facilitate a lot the cell search procedure.

Some first requirements that the WINNER system should fulfill in order to facilitate the inter-system handover with UMTS are summed up below:

- The procedures for the transfer of one user-network connection, between UTRAN and another RAT are already partly specified by the 3GPP. They require some signaling: about UMTS cells transported by the WINNER radio interface, or signaling about WINNER cells transported by the UMTS radio interface.
- In the case of a single receiver, a scheduling approach might be adopted. In order to facilitate inter-system measurements, the time structure of the WINNER system must be near from the UMTS time
5.2 Location techniques

The method for determining positions is called localization or positioning. The position of a MT can be utilized to support a VHO if the location of the AP/BS or the coverage of the target system is known. Alternatively, the position can be utilized and can be compared with a foreign-based measurement report that indicates the link conditions in the target system, as this is proposed in section 6.1.2.1 via the position-based HO approach. Another context in which localization plays a role already today is the support of location-based services, which were introduced by GSM operators in Europe in 2001. Further context information related to mobile computing and location awareness is related to positioning, navigation, guidance systems, route tracking, goods logistics and others. So, there is a strong interest in proper localization for a various number of reasons even today. Appropriate techniques originally worked out for one of those neighboring localization backgrounds thus may be overtaken and adapted to allow for information gathering in mobile radio systems.

From a physical localization point of view, in principle there are three techniques to be distinguished as mentioned in the following:

1. Triangulation:
   Here, trigonometric methods are used for the position determination. Within triangulation, it can be differentiated between distance-based **lateration** (example: Global Positioning System, GPS) and angle- or direction-based **angulation** (example: phase-sensitive antennas) methods. For the distance based lateration, the position of an object is computed by measuring its distance from multiple reference points. Possible methods for measuring comprise direct measurements by physical actions or movements, time-of-flight measurements by taking the time it takes to travel between the object and a certain point at a known velocity and attenuation measurements by exploiting certain pathloss properties.

2. Proximity:
   Determination of the place of an object, which is ‘close’ to a well-known place. Here, again one distinguishes three fundamental sub-methods:
   - Recordation of a physical contact, for example piezoelectric pressure or contact sensors, capacitive transducers etc.
   - Monitoring of access points of a WLAN. Here, it is indicated, if a terminal is in the range of one or several APs (example: Active Bat Location System by AT&T).
   - Monitoring of automatic authentication systems such as credit card terminals, access systems, bar-code scanner, system logins etc.

3. Pattern Recognition
   Within methods that apply pattern recognition, a further separation into optical pattern recognition (scene analysis) and non-optical pattern recognition can be done.
   With the scene analysis, simplified views of an observed scene are used for the representation and the comparison of pictures, for example the horizon line captured with a camera. With the static scene analysis an allocation to pre-defined database objects takes place and thus to certain places. In contrast to this, a comparison of sequential pictures takes place for the differential scene analysis, in order to determine the current position of an object. The differences of the pictures correspond to the movements of the object that is observed. Due to well-known pixels of the photographs the relative position of the object can be determined in each case. The advantage of this method is in the bare observation, without need for determination of angle- or distance parameters. However, changes of the actual scene (e.g. objects or landscape) require a change or a new modeling/update of the underlying database scheme.
   Non-optical pattern recognition techniques also apply mapping techniques of dedicated parameters to well known samples stored in a database. Contrary to the scene analysis, the input usually does not consist of pictures taken by a camera, but any arbitrary other physical quantity to be evaluated.
   For both recognition techniques, optical and non-optical, dedicated mapping schemes are applied such as the Database Correlation Method based on Hidden Markov Models.

**Classification**

Four different categories can be distinguished according to the active elements in localization.

- Network – based
- Mobile - based
• Mobile-assisted
• Foreign system-based/assisted

The first three methods rely on system inherent signal exploitation, whereas the last category applies additional non-specific mobile radio communication system techniques to perform localization.

1. Network-based

If all necessary measurements are performed by the network (base station) itself, this is called network-based localization. Hence, no changes to the UE are necessary and legacy devices can be employed. Nevertheless, this procedure fails if the terminal is in idle mode and beyond that necessary signalization can bring additional load to the network.

2. Mobile-based

In the mobile-based localization approach the terminal holds responsible for the position determination. Therefore, base stations need to transmit on a regular basis. If no active communication is established due to very low load conditions, some kind of beacon signal in a control-like channel needs to be conveyed enabling all users in the cell to perform autonomous localization at arbitrary times. Depending on the sophistication of the mobile-based localization, the base station might need to supply additional information, like its own coordinates. Disadvantages of the mobile-based localization obviously are given by increased complexity due to higher challenges on calculation power and equipment leading to the conclusion that this method is not applicable for legacy terminals.

3. Mobile-assisted

The third category, called mobile-assisted localization is a hybrid solution of the two aforementioned methods. The terminal hereby measures reference signals of incoming BSs and transmits the data back to the network. The final computation can take place in the network, e.g. a central server station. However, this burdens a lot of traffic to the network if explicit measurement signaling is triggered. Additionally, the evaluation of the position is delayed compared to the mobile-based implementation. The major advantage is the possibility to use existing GSM or already specified UMTS measurement reports [52] [53]. Hence this technique can be based on specified standards and only minor changes are necessary. Besides this, if respective reports that are conveyed to the base station anyway, e.g. in the context of power control adjustment, are exploited, the aforementioned disadvantage of additionally introduced overhead is not valid anymore.

4. Foreign system-based/assisted

The last category, foreign system-based/assisted localization, differs from the aforementioned three ones by exploiting additional metrics whose origin is not the actual mobile radio system itself. Methods to be applied here comprise radar location techniques or satellite navigation systems. Also, inter-system solutions incorporating localization based on mobile radio network techniques jointly applied with foreign system techniques belong to this category. Depending on the degree of support, a distinction in foreign system-based and -assisted can be done.

6. Cooperation mechanisms

The rising demand for fast, scalable, efficient and robust data transfer over the air has produced a variety of RATs. The RATs are often divided into the different “generations” of mobile radio networks. 2G systems had their focus on conversational services, but it was possible to use circuit-switched data services as well, though their performance was not satisfying. As an extension to GSM the General Packet Radio Service (GPRS) was invented. With enhanced data rates up to 60 kbps and its packet switched nature this service solved the weaknesses of circuit-switched systems. However, having a look at the systems of 3G that are currently to be established, one will notice that these are still far away from the goals of WINNER.

In recent past a heated debate arose whether WLAN systems like IEEE 802.11x and Hiper-LAN/2 or UMTS will be more efficient in terms of costs for planning, building and operation. Sometimes these systems are said to be an extension to UMTS. Hence, two or more of these systems may peacefully coexist in such a way, that the user will always be served with the best possible QoS at the lowest possible price. UMTS will be available area-wide within the next five to ten years. At areas with high volume of traffic, so-called “Hot Spots” or “Hot Areas”, systems with high data rates will be deployed and are currently rarely setup. In addition, a new RAT covering a wide range of services and operating in different deployment concepts will be developed that complement the existing systems. These
heterogeneous systems must be capable of forwarding data streams and session context among each other and a (vertical) handover should happen seamlessly.

Within WINNER WP4 respective mechanisms are studied that support the cooperation of legacy systems with the new defined 4G system, as well as mechanisms for cooperation of systems using the newly defined air-interface and that will be deployed in different scenarios. The intention is an efficient inter-working between future wireless systems to exploit the scarce resource spectrum in an optimal way and to satisfy the user requirements at the same time. For that purpose different cooperation mechanisms have to be studied and new solutions have to be found and developed.

General requirements that arise out of this challenge cover the minimizing of signaling between the systems, an optimized radio resource management, e.g., seamless handover, joint or distributed scheduling, etc.

6.1 Mobility management

Due to the tremendous popularity of the Internet protocol suite it is very likely, that future services will be built on top of this protocol suite. Unfortunately, the current version of IP (version 4), was not intended for being used in a wireless environment. TCP and IP suffer from the characteristics of wireless links. Mainly three problems can be figured out for wireless links:

1. A wireless link is not as reliable as a wired link in terms of BER/BLER (physical layer).
2. The cellular structure of today’s mobile radio networks requires the mobile terminal to quickly change the terrestrial radio Access Point (AP) with which it is communicating (link layer).
3. The route between two nodes in a network is not known a-priori and may change during a connection between two nodes. (network layer)

The last two requirements will be challenging tasks in the near future, when operators want to offer handover between their different networks and aim at optimal utilization of their resources. The duration of a disruption of a service caused by handover varies. It depends first of all on the system itself. Which procedures are defined to execute a handover? How long do these procedures take? Is there really a disruption at all? GSM for example defines procedures for a handover in a break-before-make manner. First the old link is dropped and afterwards a new link is established. However, the disruption is not noticeable, since the handover was carefully optimized for this purpose. In UMTS the handover is performed in a make-before-break manner. New links are established before old links are dropped. That means, there should be no disruption at all. For IEEE 802.11b no handover procedures at all are defined. But with the mobile extensions of IPv4 and IPv6 a handover is said to be possible in IEEE 802.11b and every other mobile radio system. However, the duration of the interruption of the service for this kind of handover is very long.

The fast handover within the same and between heterogeneous systems is not the only challenging requirement. Mobility management comprises also roaming, paging and routing. Closely related to the mobility management is also the localization of users. For example, a handover to another RAT can be initiated based on the position of a user. Or based on user profiles, i.e. the time-variant densities of users, the temporarily allocation of resources can be managed to offer the limited resources where they are needed. There are numerous applications imaginable if the position of a terminal is known and different mechanisms to exploit these information and their respective requirements are explained in the next section.

6.1.1 Handover

The Internet protocol was designed with a focus on connectivity rather than mobility. Hence, the mobile extensions of IPv4/6 had to introduce mechanisms for roaming while not interrupting the established connections. Therefore, L3 mechanisms like IP handover and Mobile IP (MIP) protocol solutions had been introduced. To ensure the independency of the layers, these mechanisms are purely L3 based.

A “traditional” handover is located in L2, since L2 is responsible for the physical and the logical connectivity of higher layers. In fact every L3 handover is usually preceded by a L2 handover. The only problem is that the L3 handover is not aware of the L2 handover due to the independency of the layers.
In order to offer a good quality of service to the user, the handover management should come up to the following aims:

- Minimise packet loss and delay during a handover (seamless handover);
- Make use of any “triggers” available (e.g. information from the mobile host or from the network that a handover is imminent), in order that action can be taken in advance of the actual handover (planned handover);
- Allow the possibility of transferring context (QoS, security, header compression state, link layer states) but also any buffered packet (tunnelling) from the old to the new access router;
- Ensure that a planned handover can fall back gracefully to an unplanned one (in case it fails), and that the same actions can happen (transferring buffered packets and context);
- Allow inter-technology handover if the mobile host supports different technologies (vertical handover).

The possibility for a vertical handover means that an additional dimension of choice is introduced since the two system types might also offer complementary services. Therefore, a MT might be triggered to perform a vertical handover, though the link quality on the current system has not decreased. Consequently, further intelligence is necessary to decide, which kind of handover shall be performed and when.

6.1.1.1 Definition of Handover Schemes

**Hard Handover**

In the hard handover scheme the MT changes its point of attachment with a short interruption of service. The old link is released and a new one created with the new BSs. The time the system needs to set up the path is referred to as the network response time. If the old radio link is broken up before the network completes the setup, the connection is dropped even if there are channels available in the cell. To make sure the interruption is as short as possible the path to the new BS is established in advance through the network before the device changes over. Switching to the new path and rerouting of the transmitted information are performed simultaneously. At any time there is only a single connection to a BS per MT. Hence no scarce resources are wasted and the data overhead is minimised since data does not have to be duplicated. However, excessive service interruption when changing over would result in a dropped call.

**Seamless Handover**

During the seamless handover the MT changes between cells by using the old and the new connection simultaneously with only one of them being active. Data is broadcast via both links. The old link stays active as long as the new path is activated through a switching action in the network, based on the quality perception of the mobile device. In comparison to the hard handover the seamless approach is more reliable since the old link is release after a new one has been established. However the utilisation of two links during the handover phase degrades the number of available channels, which has a negative impact on the number of users that can be carried.

**Soft Handover**

The soft handover allows a transient phase during which multiple links can be used for communication simultaneously with all of them being active. This concept – which has the advantage that if one link fails the MT can communicate using the remaining links - is referred to as simulcasting. Hence the link transfer is not sensitive to the elapsed link-transfer time. Soft handover can be used to extend the time that is available to make a handover decision without any loss of QoS. This allows reduction of the service interruption to a minimum when changing between cells. However in addition to limiting the efficient use of the frequency spectrum, resulting in high data overhead since packets are transmitted on all links. To enhance the performance of the soft handover scheme variations have been suggested.

**Predictive Rerouting Handover**

The Predictive Rerouting Handover Scheme predicts the new potential BSs based on the information stored in the location management system. These BSs then join a group of BSs that form a multicast tree, which is set up initially when a mobile device registers with the network. The group is updated as the device moves through the coverage region of the network. In this group, the serving BS is called active and the remaining BSs inactive. A handover is triggered when a MT fails to receive the beacon signal of its serving BS several times. When this happens the new BS becomes active and updates the multicast tree. The multicast tree can be used in two different ways to send data packets: either packets are only sent to the active BS or to the whole group of BSs. In the latter case the BSs which are not active buffer
the packets and drop them when they are outdated. In both cases the advantage of the scheme is that a link is already established before the handover occurs. Since the tree is updated after the handover response the handover latency is minimised (the aim of this scheme). A negative aspect of the scheme however is the signalling overhead involved in updating the multicast tree, as well as the data overhead in case duplicate data packets are sent to all members.

Reservation Handover
Reservation handover schemes are based on the idea to prioritise handover requests over new calls. This is achieved by reserving resources exclusively for handover requests, which can be done in a predictive or non-predictive manner. While predictive reservation schemes reserve channels at potential BSs prior to the arrival of MTs based on future path prediction using probability values and mobility pattern on individual MTs, non-predictive reservation schemes (Guard Channel Schemes) reserve a set of channels solely for handover requests. By doing this handover requests and new calls are allowed to compete for the remaining channels. Guard Channel (GC) Schemes can be split up into static and dynamic reservation types depending on whether the set of reserved channels is fixed or varies according to the traffic conditions. The static scheme uses a threshold in each cell. If the number of channels currently being used is below that threshold, both new calls and handover request are accepted. If the number of used channels exceeds the set threshold, incoming calls are blocked and only handover request are served. The basic problem of this approach is that the threshold value must be chosen carefully otherwise the available spectrum of the system might be under utilised and hence the total amount of carried traffic limited. Dynamic Reservation Schemes try to avoid the problem by varying the set of reserved channels according to the traffic condition and the position of users. This has the advantage that the scheme overall results in a better utilisation of the available frequency spectrum. In order to allow dynamic adjustments, some method for monitoring the traffic situation is required, which results in signalling and computational overhead.

Queuing Handover
Handover queuing schemes represent a further technique of handover prioritisation. These delay handover instead of denying access if the potential new BS is busy. Queuing handover requests is possible due to the time a mobile device spends in the overlapping service region of cells. In this region the MT can communicate with both the serving and the new BS. Once a handover has been initiated, if no idle channels are available in the new cell, the request is placed in a queue to wait for a certain time for channels to become available. No new calls are granted channels before queued handover requests are served, which generally results in a decrease of carried-to-admitted traffic. Queuing schemes can be categorised as static and dynamic schemes. While the static scheme serves handover requests in a first-come-first-served manner, dynamic schemes take into consideration the rate of degradation in the current radio channel, and dynamically reorder handover requests in the queue to reduce the probability of forced termination. Therefore the system ensures that the MT first to leave the handover area will be assigned the next available channel. In order to enable the system to adapt to the new traffic situation it requires information, which can either be obtained by the MT or the BS. Both cases result in computational or signalling overhead. The concept of queuing request has also been taken up by the so-called channel exchange scheme, which holds the potential to further improve the performance properties of the prioritised queuing approach.

Channel Carrying Handover
In the Channel Carrying Handover Scheme if there are no channels in the new BS the MT is allowed to keep on using its current channel and carry it into the new cell. Communication is now maintained via the BS in the new cell using the old channel. By doing this, the scheme ensures that an ongoing call is not forcibly terminated due to an unavailability of channels. Since channels do not need to be reserved in advance the efficiency of the system is increased. This is achieved without any requirement of global communication. However, carrying a channel into a new cell results in an increased signalling overhead due to communication with the neighbouring cell to negotiate the channel use. This is presumed to be insignificant.

Channel Sub-Rating Handover
The Channel Sub-rating Scheme is able to carry more offered load than any other scheme. It achieves this by creating a new channel on a blocked port for a handover attempt by sub-rating an existing connection. Sub-rating means that in the case of non-availability of channels a full rate channel is temporarily divided into two channels at half the original rate. By doing this one half can be used to serve the existing connection and the other to serve the handover request so that the forced termination of calls can be
virtually eliminated. However this enhancement is achieved at the expense of a degradation of QoS, which makes the scheme only suitable for low bandwidth requirements such as voice transmission.

Adaptive Handover Priority
The Adaptive Handover Priority Scheme has been tailored for the requirements of multimedia services. Since these are mostly able to adapt and trade off QoS with changes in bandwidth usage the scheme provides two classes of services: the wideband class, able to deal with a degradation of QoS in the form of channel sub rating, and the narrowband class unable to accept any adaptation in QoS. Calls belonging to both classes are only accepted if the call can secure the full bandwidth requirements. If a new call cannot obtain full bandwidth it is blocked. In the case of an adaptive handover request with insufficient bandwidth to meet the normal QoS, the call will handover successfully if the new BSs is able to provide a smaller amount of bandwidth adequate to meet a lower, but tolerable level of QoS. The new BSs can then deliver the required bandwidth to support the call by adapting the QoS level of one or more existing adaptive calls that it is already serving. If this is not possible the handover fails. If the handover is of the non adaptive type, it will only be successful if the new BSs can provide the bandwidth needed. This may be obtained in the same way as for the adaptive call. The adaptive handover priority scheme secures reduced probability of handover failure and hence achieves a smaller handover dropping probability. Furthermore it improves the QoS perceived by users. This does involve signalling to negotiate and indicate the bandwidth requirements of a connection. In general the scheme is only suitable for limited environments and is non-applicable for most systems.

6.1.1.2 State of the art
6.1.1.2.1 Handover in UMTS
When the UE operates a dedicated radio connection (ie. it is in CELL_DCH state), the network controls the UE mobility i.e. with which cells it shall maintain a connection (radio link). TS 25.331 [35] includes a number of radio interface procedures that UTRAN may apply for this purpose:

- **Active set update**: to perform a soft handover; that is to add and/ or remove links to the set of used radio links
- **Reconfiguration procedures**: to perform hard handover i.e. to a different set of radio links on the current frequency, to another frequency and/ or mode (eg. from FDD to 3.84 Mcps TDD)
- **Handover to/ from UTRAN**: to change Radio Access Technology eg. from WCDMA to GSM. This procedure applies when a signalling connection is established with the CS domain. Furthermore a CS domain RAB and PS domain RAB may be established
- **Cell change order to/ from UTRAN**: to change Radio Access Technology eg. from WCDMA to GSM. This procedure applies when no RABs are established or when the established RABs are only from PS domain.

It is up to UTRAN implementation to decide when it should initiate a handover procedure. Amongst others, UTRAN may apply the following triggers (or a combination of) for handover: change of uplink or downlink quality (e.g. BER, BLER), change of uplink or downlink signal (e.g. RCSP, Ec/N0, Pathloss), traffic load eg. directed retry, change of service type and/ or location.

In order to make sure the radio connection after handover is of good/ sufficient quality, UTRAN typically configures the node B and the UE to perform measurements. UTRAN may however also order the UE to perform handover when measurement information has been provided (blind handover).

In general, the decision when to switch to another system can depend on several reasons, one is the changing link status, another might be the availability of a further system that can better support the requested service. In case of a vertical handover the network layer will be involved and has to be informed about the change of the link-status. Two general approaches have to be distinguished to detect changes in link status at the IP layer: the direct use of L3 mechanisms (MIPv4/6 standard) and the use of L2 trigger to inform L3 about a status change.

In most of the cases, an L2 trigger can be understood as a kind of notification from L2 (potentially including parameter information) to an adjacent layer that a certain event has happened or is about to happen. In such a way, the process of triggering is related to information exchange and communication between layers. However, this is not necessarily the case. As described further below, a trigger might also be a physical probe, the outcome of an algorithm or the transformation of a requirement, all of which are L2 self-autonomous transactions with no interlayer communication. A trigger may be implemented and...
applied in a variety of ways. The basic property of a trigger however is that its appearance (or its failure to appear) is closely connected to the handover question. An L2 trigger is not associated with any specific link-layer technique but rather is based on the kind of L2 information that is or could be available from a wide variety of radio link protocols.

Triggers can be classified as physical-based L2 triggers, which are physical probes that can be measured and statistically evaluated or algorithm-based L2 triggers that are outcomes and decisions of procedures performed within layer 2. Physical-based L2 triggers are, e.g., the signal strength, the interference, the carrier-to-interference ratio, bit error rate (BER), or resp. packet error rate (PER), etc. Algorithm-based triggers can be QoS-violation trigger, connection-admission-control trigger, location-based trigger, velocity based trigger, etc. Furthermore, a combination of the triggers can be imagined.

The challenge that now arises is the appropriate selection and combination of the triggers to define the right time for handover. Moreover, the gathering and collection of the required information will put some demands on the lower layers, since they have to provide some of these information, especially in the case of physical-based triggers. It remains to be investigated, whether there are more triggers that are suitable for the cooperation of different RATs and how the new RAT can support the provision of suitable triggers.

UMTS inter-RAT handover protocol
Standard 3GPP 25.331 includes the protocol and the commands to perform vertical handover to/from UMTS, typically UMTS-GSM handovers. The purpose of the inter-RAT handover procedure is to transfer a connection, of a dual mode UE (UMTS and other) to the other available access technology. UMTS/GSM handovers are network initiated handovers, i.e. the handover decision is taken by the RAN, but based on the terminal measurements.

Handover to UTRAN
This procedure is initiated when the other RAN send to the UE a command HANDOVER TO UTRAN COMMAND to the UE, this message includes all the information that UE need to camp in the objective UMTS cell, in fact it is an UMTS message included in a message used by the other RAN. This message includes; UMTS mode (FDD or TDD), UL and DL frequencies, DL Transport channel, radio resources for uplink and downlink, and maximum CCPCH and UL TX powers.

The UE shall be able to perform an inter-RAT handover, even if no prior UE measurements have been performed on the target UTRAN cell and/or frequency. Also is possible that UE had a set of radio predefined configuration parameters.

After the reception of this command UE should initiate configuration of signalling connections, capabilities, network identification, etc.
If the UE succeeds in establishing the connection to UTRAN, it shall transmit a HANDOVER TO UTRAN COMPLETE message on the uplink DCCH channel, now to the UMTS network.

If the UE receives a HANDOVER TO UTRAN COMMAND message, which contains a protocol error, the UE shall perform procedure specific error handling according to the source radio access technology. The UE shall transmit an RRC FAILURE INFO message to the source radio access technology.

If the UE does not support the configuration included in the HANDOVER TO UTRAN COMMAND message, e.g., the message includes a pre-defined configuration that the UE has not stored, the UE shall continue the connection using the other radio access technology; and indicate the failure to the other radio access technology.

If the UE does not succeed in establishing the connection to UTRAN, it shall terminate the procedure including release of the associated resources, resume the connection used before the handover; and indicate the failure to the other radio access technology.

Upon receiving a HANDOVER TO UTRAN COMPLETE message, UTRAN should consider the inter-RAT handover procedure as having been completed successfully and indicate this to the Core Network.

**Handover from UTRAN**

The purpose of this handover procedure is to, under the control of the network, transfer a connection between the UE and UTRAN to another radio access technology (e.g. GSM). This procedure may be used in CELL_DCH state. This procedure is applicable to CS domain service.

The UE shall establish the connection to the target radio access technology, by using the contents of the IE "Inter-RAT message". This IE contains a message specified in another standard, with information about the candidate/ target cell identifier(s) and radio parameters relevant for the target radio access technology. Two “System type” are considered CDMA 2000 and GSM 1900/1800.

![Dual mode UE UTRAN Other RAN diagram](image)

**Figure 18.- UTRAN to other RAN handover**

Upon successfully completing the handover, UTRAN should release the radio connection; and remove all context information for the concerned UE.

If the UE does not succeed in establishing the connection to the target radio access technology, or the message is incorrect, it shall perform a cell update procedure and transmit the HANDOVER FROM UTRAN FAILURE message.
6.1.1.2.2 Handover in IST project SCOUT

In the IST SCOUT document [29], to avoid specification of handover to and from every possible technology, a generalized scheme has been investigated that allows handover to any technology. SDR allows the possibility for the network to download a specific handover measurement and decision algorithm to the terminal. This could include base-band measurement algorithms and signalling protocols to cope with the available technologies in a particular location.

From the figure below, it can be seen that different RAT’s measurements are conducted that yield different quantities, which should be mapped into a common parameter independent from the RAT being used. After investigating/collaborating, the needed information from the different actors in the mobile scenario (terminal, network, service and user), these information or attributes are classified into static and dynamic features and include attributes such as the level of interworking and the required QoS for the intersystem handover: this information will be fed as an input for the HO decision Manager that will describe/derive a procedure. This procedure, which will carry on with handover, would be selected with the associated protocol. In general, the handover protocol of different RATs does not differ too much; therefore, it is possible to identify similarities and differences between all protocols and extract then a generic intersystem handover protocol.

![Figure 19 - Generic handover framework](image)

The handover procedure proposed in [29] is being initiated by reception of an event triggering a handover decision. Such an event may be created by components residing in the terminal or in the network. Together with the event, the handover decision should take into account other information. Indeed, intersystem handovers may imply changes that are relevant for services and applications used in the terminal. This suggests including application/service layer parameters (e.g. the subscribed services by the user, the supported services in a particular network) in the handover decision process, and also user preferences and profiles (cost related preferences, provider related preferences, RAT preferences, etc.) have to be considered. Other parameters that can be taken into account in the handover decision are terminal capabilities and resources (e.g. available battery capacity, supported RATs, etc.).

Different handover decision strategies can be defined and the most suited to a particular situation must be chosen. This is not simple however, and a policy based strategy selection could be one solution. Two main types of strategy can be highlighted:
User oriented strategies: the user may want to minimize costs, or to be "always on" for example
Operator oriented strategies: the operator may apply different strategies according to the user class
(some RAT may be reserved in priority for some users), may want to minimise the number of
handovers, may need to balance the load between different networks, etc.
Document [29] gives some guidelines to define a generic handover protocol, but does not go any further
into the definition of a generic inter-system handover.

6.1.1.3 Handover based on CRRM
In release 99, procedures for inter-system handover between UMTS and GERAN have been defined, but
they could result in a failure due to high load in the target cell. This situation resulted in the interest for
the standardization of cell load information exchange between systems in Release 5 and in CRRM
functionalities.

In the literature [34] [36] [37], the most widespread approach for CRRM is to consider CRRM as a policy
manager for the access to the radio resources, i.e. as an advisor for RRM entities. The main task of
CRRM in this case is the prioritisation of the candidate target cells in handovers and call set-ups. The
CRRM receives load and QoS measurements from each cell, either periodically or on event, or on
demand. Based on this information, the CRRM is able to adjust the radio network parameters involved in
RRM algorithms.

In inter-system/inter-layer handovers for example, CRRM can dynamically set handover triggering load
thresholds per cell: load reason cell changes are triggered only when the cell load is above this threshold.
This threshold can be tuned by CRRM depending on the load of the neighbouring inter-RAT/layer cells,
as proposed by Nokia in [37]: the existing threshold in each cell is compared to the average load of inter-
RAT/layer neighbour cells and adjusted accordingly. The higher the neighbouring inter-RAT/layer cell
load is in a cell, the higher the load threshold should be set in order to avoid unnecessary handovers when
all layers are equally or more loaded than the current cell.

Once the decision of triggering a load based handover is taken by the RRM entities, the second step
involving CRRM is the choice of the target cell. Two approaches are possible, giving more or less
influence to CRRM:
- Siemens’ approach [34]: the RRM entity takes the final decision, but to choose the best
target cell, further information about the load of the possible candidates is provided by the
CRRM entity. The information can be a relative ranking of the cells or precise
measurements.
- Nokia’s approach [36] [37]: RRM entity sends to CRRM candidate cell list, together with
measurements and QoS requirements, and the CRRM entity selects the best target cell.

Additionally, CRRM can direct the incoming call to the most suitable system also in the initial access
phase by a similar procedure.
Concerning the CRRM benefits, they are discussed within 3GPP. Nokia claimed that CRRM can improve
the capacity by 11% for 144kbps services (conversational or streaming) and up to 140% for interactive
packet data services, assuming 4 systems/layers (e.g. UTRAN, GERAN, macro, micro cells) [36] [37]. It
should be noticed that these results are very depending on working assumptions and required more
investigations.

6.1.2 Location-based RRM

6.1.2.1 Position-based HO
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. If this procedure shall take place during an ongoing connection, two transceivers are required,
which enhances the complexity of a MT in a not acceptable way and therefore is not regarded in further
detail here. If no ongoing connection is active, in principle the MT may switch to another network in
order to derive respective measurements at arbitrary times. Nevertheless, to prevent the MT from being
paged from its current system while scanning another one, respective signaling indicating some kind of
sleeping and temporary non-availability is necessary. If the MT demands for up to date information on
other networks in order to guarantee best QoS to the user, the aforementioned signaling/scanning
procedure needs to be repeated on a regular basis resulting in transfer overhead that does not even pay off if the conditions in the possible destination network are too bad and thus no handover takes place.

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 20. 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 20.

![Figure 20: Exchange of HO reports between systems](image)

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 interworking between heterogeneous systems.

### 6.2 Admission control

#### 6.2.1 State of the art

Admission control is responsible for controlling the load of the system so that the available capacity can be exploited without compromising system stability. Before admitting a new UE or modifying the connection of an already admitted UE, admission control checks whether these actions will sacrifice the planned coverage area or the quality of the existing connections. When a new UE is admitted or an existing connection is modified, admission control is also in charge of setting the parameters for the new connection, e.g., the initial downlink (DL) transmission power. This process is described in Figure 21 for the case of UMTS.

Figure 21 shows the logical network elements, the names of different interfaces and the manner in which the RRM algorithms are distributed among the network elements.
Recently, policy-based admission control mechanisms have been described in [38] aiming at providing policy-based control over admission control decisions for ensuring certain QoS level. Admission control is the key RRM algorithm to use for investigating the capacity gain when adaptive antennas are deployed at the node-Bs, since it is in charge of controlling the load of the system. In general, admission control algorithms are attractive as they offer trade-offs between capacity and coverage, while taking advantage of the soft capacity offered by WCDMA systems [39]. In the uplink, admission control will prevent the system from entering an unstable situation by blocking all connection requests that are estimated to lead the system into such situation. Thus, the consequence of deploying admission control is a certain increase of the call blocking probability but a substantial decrease of call dropping probability. In [40] admission control techniques are classified into throughput and power-based. In throughput-based admission control techniques, the throughput can be delivered by the system is determined according to some dimensioning calculations, assuming some conditions in the system. In power-based admission control techniques, the admission control decisions are based on periodic power measurements of the system.

Throughput based AC techniques have several drawbacks. First, the dimensioning is done for some propagation conditions and it is not valid in other situations. In addition, it is very difficult to take into account the soft capacity gain that can be obtained if the load of the system is not homogeneous. The own cell load factor can be expressed in terms of throughput if the service profile is known. Then the profile for which the system is likely to become unstable strongly depends on the total wideband received power at the node-B. Such techniques are studied in [41], among others, and [42] discusses further enhancements for making the system tolerant to the load variations caused by bursty packet traffic.

Power based AC techniques have several advantages. First, the different propagation conditions are automatically included in the measured power values. Furthermore, the potential soft capacity gain is also indirectly included in the measurements, since low loaded surrounding cells result in a better power situation, i.e. in less received power at the cell under consideration. However, they have also practical drawbacks. First, they rely on measured power values, which are subject to measurement inaccuracies. Second, they require the specification of thresholds that are used in order to guarantee the system stability while still exploiting the available capacity; in practice, the specification of such thresholds is not straightforward.

When a power based AC algorithm is used in a cell with sector antennas, a UE is admitted if there are enough channelisation code resources and the following condition is estimated to remain true after the admission

\[ P < P_{\text{Target}}, \]

where \( P \) is the total average wideband transmitted power at the cell and \( P_{\text{Target}} \) is a pre-defined threshold.
In general, other RRM aspects also play a significant role, when determining an achievable capacity gain. For example, the use of large soft handover (SHO) margins involves large channelisation code consumption per UE, which contributes to increase of the capacity reduction due to code blocking.

6.2.2 Admission control in the context of WINNER

Admission control schemes are the decision making part of networks with the objective of providing to users services with guaranteed quality by limiting the number of call connections into the heterogeneous networks in order to reduce the network congestion and call dropping probabilities and at the same time to achieve as much as possible resource utilization. The initial assumptions [www.ist-winner.org/IR 4.1] include:

- An accepted call that has not been completed in the current RAT may have to be handed off to another RAT.
- New calls and handoff calls have to be treated differently in terms of resource allocation.
- Handoff calls are normally assigned higher priority over the new calls.
- Traffic will be routed through the cooperating systems according to the restrictions and advantages of each system.
- Different levels of service calibration can be identified for the user.
- Mobile users can alternatively access to RATs during a call.
- Coexisting RATs are jointly cooperated together.

6.3 Scheduling/load control

6.3.1 Packet Scheduling

Packet-data transmission is characterized by the fact that a connection is not necessarily constant during its whole period. Such a connection (based on the request-response model) is shown in Figure 22 for the uplink in UMTS. The scenario assumes that a packet session is already open and that an initial access procedure has been performed and a connection has been established between the UE and the network. After a connection is established, signaling messages can be exchanged between the UE and the network. Because of the bursty nature of packet data traffic, a constant data rate per connection would lead to a waste of resources. This requires a dynamic control of resources that is performed by an entity called packet scheduler (PS). The PS is located in the radio network controller (RNC) and hence packet scheduling cannot be performed on a packet-per-packet basis. The main reason for this is the delay imposed by the interfaces between the UE and the RNC [43]. Therefore, the uplink packet scheduling consists in allocating a list of data rates to the UEs for a certain period.

In the uplink the resource to schedule among users is the total received power in the node B. Upon data burst arrival, UEs send capacity requests (measurement reports) to the PS. At each scheduling interval, capacity requests previously received in the PS are ranked according to the applied scheduling policy. For each processed request, it is tested whether a possible data rate allocation to the UE results in an estimated total received power above the planned target. The network then notifies the UEs of the granted resources with a list containing all possible formats and data rates allowed during the transmission period. The UE then can start the transmission of data. At each transmission time interval, the UE selects one of the formats in the allocated list.
Packet scheduling in UMTS is a combination of centralized and distributed (UE autonomous) packet scheduling.

From an architectural point of view, the PS is part of the RRM module (see Figure 23). The PS communicates with the radio resource control (RRC) and MAC protocols and other RRM entities. It receives capacity requests from the RRC protocol and then transmits to the RRC the allocated transport format combination set (TFCS) of the users that are allocated power at the end of the packet scheduling. From the load control (LC) module, the packet scheduler receives information regarding the total received power in the cell. The LC communicates with the node B that provides periodically to the LC the mean values of the other entities over an observation window. In addition, it receives the value of the planned target for the received power.

The PS receives from the MAC layer information about inactive users, i.e., for users who have been allocated resources but they are not making use of them. This information is important for the estimation of the available scheduling power.

The packet scheduler operates at each packet-scheduling period. Typically it is much longer than an UMTS radio frame that is equal to 10 ms [43].

Figure 22 Overview of uplink packet data access in UTRAN.

Figure 23.-Packet scheduling environment (in UTRAN)
6.3.2 Load control

Load control (LC) [43] is an RRM mechanism whose task is to ensure that the system does not become overloaded so that stability is not compromised. In principle, when an overload situation occurs, the LC must bring the load back to the targeted levels. Some possible actions include inter-frequency or inter-system handover for some UEs, quality decrease for some connections, throughput decrease packet traffic and controlled dropping of low-priority UEs. These actions are taken at the RNC. Other related actions can be taken at the node-Bs by means of a fast LC algorithm. If the packet scheduling and the admission control mechanisms have been designed properly, the system is supposed to operate within the desired load range. However, the admission control and the packet scheduling are based on estimations and predictions of the load in the system and therefore errors are introduced.

LC is necessary whenever the air interface load (the total received power in the uplink) exceeds a certain threshold. Upon triggering of the load control, the data rates of a number of users are downgraded in order to bring the total received power level in a cell back to the allowed level. The relationship between LC and PS is given in Figure 23.

A possible implementation of LC can include users that are downgraded to the next lower data rate [45]. For each data rate downgrade, the resulting received power is estimated and a power modification estimator is applied. The LC stops when the total received power is set back to the target. Users that have been allocated the highest data rates are downgraded first.

6.3.3 Scheduling Policy

The most common scheduling policies are: the fair throughput scheduling, the best C/I and the time scheduling [43]. In the fair throughput scheduling, the available throughput is divided equally to the users. When best C/I scheduling is performed, users that experience the best C/I ratio are the ones with higher priority on data rate allocation. In time scheduling, resources are allocated to a single user for a time period.

![Figure 24.-Building blocks of a predictive scheduler [47].](image-url)
Based on these main groups of scheduling policies, other, specific mechanisms have been proposed (e.g., QoS-adaptive scheduling [46], predictive scheduling [47] [48], power-control feedback scheduling [49], and so forth).

Figure 24 shows the building blocks of a predictive scheduler that can be used to support bursty type of communications between node-Bs and between node-Bs and UE in an evolved from 3G type of network.

The following underlying principles have been applied to the predictive scheduler:

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

At the network side two aspects of prediction are considered—hotspot traffic prediction based on the long-term observations and radio-channel prediction for dynamic link adaptation at all network elements. The latter includes layered RRM and traffic/channel predictive RRM.

In order to realise a lean RRM framework, a reduced complexity scheduler can also be designed to support the mechanisms for service differentiation that are to be offered in mixed service environment. The preferred mechanism depends on the desired service: guaranteed service levels, fairness criteria etc.

In such architecture, a mix of Priority Queuing (PQ) and Weighted Fair Queuing (WFQ) [50] can be used. Weighted Fair Queuing is used for reserved data streams, e.g. real-time traffic or voice circuits and the Priority Queuing is used for the users with a relative service level (different service classes), with the best-effort users as the users with the lowest priority. Instead of the priority queuing, threshold dropping can also be used. In that case the behaviour of the scheduler is a different in the sense that with low system load there is no service differentiation between the queues, but at higher traffic levels the users with lower priority levels are pushed out. In the case of priority queuing, the data of the higher priority user always has priority over the other users. This mainly influences the delay performance of the service classes in the system. The choice between the two mechanisms is therefore mainly dependent on the desired delay performance, in case of strict delay requirements Priority Queuing has to be used, in other cases Threshold Dopping can be used which gives a more fairly distributed delay performance. Figure 25 depicts the discussed scheduling structure.

The choice for Priority queuing will be motivated by the presence of delay sensitive data in the system, signaling information being an example of this. If the signaling information is treated as relative traffic of the highest priority, it will always capture a slot in the WFQ and thus effectively it will serve as a random access channel.

![Figure 25.- Simplified coupled scheduler.](image)

### 6.4 QoS based management

The relationship between the core network bandwidth broker (BB) and the RRM entities for the WINNER RAN and the legacy RANs must be investigated in order to support end-to-end QoS in a heterogeneous environment.
In a beyond 3G environment, different wireless access technologies can be cooperating components of a combined heterogeneous infrastructure. In this case, the network provider can rely on diverse radio technologies for an effective, in terms of cost and provisioned quality, coverage of demanding service area regions. The exploitation of a wireless system, operating in such a composite radio context, requires upgraded service and network management capabilities. In the context of WINNER, QoS based management should serve to optimize service delivery and traffic distribution in a composite type of radio environment comprising legacy RANs (as listed in IR4.1) and the WINNER RAN. A QoS-based management scheme should be capable of guiding users to the appropriate quality level of each requested service and the chosen RAN in a transparent manner. By determining the QoS levels that can be offered and the networks that can support this demand, the relevant network and service level performance can be assessed. The design of a QoS management scheme should also target the cost-effective provision of the services through heterogeneous environments of cooperative RANs.

6.4.1 QoS-based management applied to WINNER and legacies RANs cooperation

Description of how the QoS-based management scheme can enable the cooperation between the legacy RANs and the WINNER RAN; and at the same time can optimize the available resources.

A possible QoS management scheme can be based on the Combined RRM approach (see Figure 10). A short-term functionality (the session manager) and a mid-term functionality (the network manager) can collaborate to handle requests from the user plane and a hot-spot area. In a possible scenario, the IMU can identify a situation 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 as a response to act upon requests from cooperating networks to handle the arisen situation. Such requests can contain capacity or cost-related information. Based on the networks status, a global functionality can decide on the assignment of services or traffic to the corresponding network. During the acceptance phase, 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. The optimization process can rely on the input data including the set of services the user is interested in at a specific time point, the required QoS levels the elements of the network policies, etc [54] and the optimization should result into allocation of the requested services to the quality levels and corresponding RANs. These allocations will help optimize an objective function, associated with the quality levels at which each service will be provided. In this process, the technology capabilities of the UE and coverage in the area where the user is located are of importance. This process can be described in Figure 26.

![Figure 26 QoS allocation in a cooperative RAN environment.](image)

To enable interconnection of the various RANs and facilitate the sharing of resources, some network management functionality is also needed. Such functionality can help increase the network performance and maximize resource usage of the underlying networks by monitoring each RAN, by predicting congestion situations, by allowing for roaming between cooperating RANs, and so forth.
6.4.2 QoS-based Adaptive Scheduling
Packet transmission over wireless links makes it possible to achieve a high statistical multiplexing gain. Packet flows generated by mobile users can be classified to several traffic classes. Each of these classes has its unique traffic characteristics and QoS requirements. The order of packet transmissions for multimedia traffic has a great impact on the efficiency and performance of the wireless system. Therefore, packet scheduling is an important issue. The design of a packet scheduler, however, involves balancing a number of conflicting requirements. Some of the common criteria include maximization of throughput, QoS provisioning, scheduling according to predefined priority structure as well as low implementation complexity (in the case of packet scheduling implementation in real-time) [55]. For efficient resource usage, a QoS-based scheduling strategy is necessary in order to provide QoS guarantees in terms of bit error rate (BER), packet delay, and packet loss and to maximize the system’s resource utilization. A significant challenge when applying such algorithm in a cooperative environment of various RANs will be limited capacity (because of interference) that will prevent that the packet is delivered with certain accuracy and within a certain time frame. If there is a bandwidth limitation but a high demand for it, then the system resources cannot accommodate the resource demands of the admitted users and packets will be dropped. Two objectives can be defined to prevent this and at the same time to maximize resource sharing:

- Design an algorithm that allows for sharing of packet losses among users (and networks)
- Maximize the number of supported users with a guaranteed QoS.

For example, the bandwidth can be shared in such a way, that when QoS requirements are guaranteed for one user, they will be guaranteed for all other users at the same time and no user will be allocated more resources than really needed. Optimisation of the time slots usage will also lead to better resource sharing. Here, it must not be forgotten that multimedia traffic will load the uplink and downlink in a highly asymmetric way and that the type of transmission will be multirate. Therefore, QoS-based schemes will need to consider as parameters for the QoS the transmission accuracy and delay requirements.

7. Conclusion
In this document different possible network architectures for the cooperation of WINNER RANs with other new RANS and legacies RANs have been presented. Conversely to the currently deployed RANs, WINNER RAN should incorporate flexible, multi RAN supporting radio access technology. Cooperation between RANs can be done, in a centralized way by a network element that will manage the individual RRM entities (Common RRM), or the cooperation element could be distributed between the different RANs (Concurrent RRM) and other option is distribute RRM between layers (Layered RRM), and to use a convergence layer (GLL or IP2W) to harmonize the communications and protocols of different RANs’ lowers layers towards upper layers. The aim of these architectures is to coordinate the individual RRM activities, associated to each RAN. The degree of coupling of wireless networks determine which integrated network services can be offered (e.g. inter-RAT handover, Accounting, Authorization, Authentication). A promising approach is to use a convergence layer to harmonize different RANs and a Cooperative RRM entity (distributed or centralized).

The different types of triggers and measurements have been described since they are the basic inputs of cooperation RRM algorithms, in particular of inter-RAT handovers. Triggers can be classified as L2 triggers (signal strength, C/I, BER, PER) and algorithm L2-based triggers (process L1 information). It has been given the first general guidelines for the definition of the WINNER radio interface so as to facilitate the handover with the legacy RANs. Specific requirements for the WINNER RAT have been proposed to enable measurements on UMTS and to be consistent with the already defined inter-RAT handover procedures in UMTS. The next steps will define requirements for cooperation with other legacy RANs and more details will be given. An alternative to measurements on each RAT by the terminal is also proposed in this document and is based on location information. For this purpose location techniques have been described.

In the scope of WINNER, the most relevant Radio Resource Management (RRM) cooperation mechanisms have been described, in particular: Mobility management (handover and location based RRM), Admission control, Scheduling/load control and QoS based management.
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