MOBILITY MANAGEMENT FOR BEYOND 3G RECONFIGURABLE SYSTEMS

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Keywords: Reconfiguration Management Plane, session setup, handover.

Abstract: Reconfiguration is the action of modifying the operation or behaviour of a system, a network node, or functional entity when specific events take place. This paper describes an integrated control and management plane framework for end-to-end reconfiguration, and maps this model to a Beyond 3G mobile network architecture. Emphasis is provided on the reconfiguration actions that take place when a session setup or a handover are executed in a heterogeneous mobile network.

1 INTRODUCTION

Evolution of 3G cellular mobile systems and interworking with off-the-shelf products (e.g., WLAN cards and access points) in conjunction with the progress on broadband wireless IP-based networks (e.g., IEEE 802.16 series, IEEE 802.20) and digital broadcasting (e.g., DVB-T, DAB) raises new research challenges for the control and management of such Composite Radio Access Networks (RANs). On the other hand, the trend towards All-IP mobile networks, with IP routing, mobility, and Quality of Service (QoS) mechanisms in addition to recently adopted bare IP transport, necessitates further research on the efficient application of IT temperament in evolving telecom world networking (3GPP TR 22.978, 2004).

Reconfiguration spans across end-user devices, network equipment, software, and services. Target reconfigurable elements include, in the mid-term, the User Equipment (UE) and Base Stations or Access Points. Signal-processing modules in the UE as well as firmware enhancing the Hardware Abstraction Layer (HAL) can be upgraded. Operational and non-operational software can be downloaded (The Software Defined Radio Forum). Service and content adaptation have already gained attention in the mobile world, promising on-the-fly playout adaptation via, for example, download of upgraded codecs. In the long-term, interior network nodes such as routers and switches or even (parts of) the network itself could be reconfigured, especially for large user groups requesting specialized treatment.

In order to accomplish flexible service offering and to cope with complex systems, the need for end-to-end reconfigurable architectures, systems, and functions raises. (Dillinger 2003, IST Project E²R)

End-to-end reconfiguration dictates the design and specification of an integrated control and management plane for coordinating the interactions between the involved entities, and for enabling the decision-making and enforcement of mechanisms supporting reconfiguration in a dynamic fashion. In (Alonistioti 2005), the Reconfiguration Management Plane (RMP) was introduced, whose main task is to provide layer abstractions to applications and services on one hand, and to terminal equipment and network devices on the other. Furthermore, the RMP is responsible for the coordination of the reconfiguration process and for the provision of the required resources. In this paper, we augment the identified plane management modules with layer management functions. We also demonstrate a possible operation of these functions during the

Alonistioti N., Kaloxylos A. and Maras A. (2005).
MOBILITY MANAGEMENT FOR BEYOND 3G RECONFIGURABLE SYSTEMS.
In *Proceedings of the Second International Conference on e-Business and Telecommunication Networks*, pages 5-12
DOI: 10.5220/0001410400050012

execution of a session establishment or the execution of a handover in a beyond 3G heterogeneous mobile system.

The rest of the paper is organized as follows: the design goals of modelling control and management functions for end-to-end reconfiguration are sketched in Section 2. The constituent RMP modules and the mapping of the RMP logical model to evolved physical configurations are described in Section 3. The challenge for end-to-end reconfiguration differentiation is elaborated in Section 4. We conclude and describe future work on accomplishing the differentiation of reconfiguration services in Section 5.

2 DESIGN GOALS

End-to-end reconfigurability necessitates an integrated framework to address all management aspects related to composite reconfigurable environments. The ITU FCAPS topics, i.e., Faults, Configuration, Accounting, Performance, and Security, comprise traditional management areas, along with resource management and access and security management. The 3GPP has introduced additional management areas tailored to the management domains and areas of a 3G PLMN, including roaming management, fraud management, software management, User Equipment Management (UEM), QoS Management, Subscription Management, and Subscriber and Equipment Trace Management (3GPP TS 32.101, 2004).

The Reconfiguration Management Plane comprises a network-agnostic protocol-independent model for specifying operations and notifications. The RMP comprises a logical model, i.e., an expression of an abstract view of a network element or subnet by means of functional entities incorporating specific functionality to realize physical implementation independent control and management tasks. The Reconfiguration Management Plane can be considered either as extension to existing control and management planes or as a new intermediary plane between legacy control and management planes for dedicated reconfiguration-related tasks, such as context management, policy and profile definition and provision, service management, and native reconfiguration and download management. In addition, the RMP incorporates layer management functions tailored to the O&M needs of reconfigurable network elements and subnets (e.g., Composite RANs). The above design considerations are fulfilled by the RMP modules described in the following section.

The proposal of physical configurations based on concrete network architectures is achieved by mapping the RMP model to a horizontal, two-tier organization of reconfiguration managers within a single administrative domain. These managers are hereafter called the ReConfiguration Manager (RCM) and the Radio Reconfiguration Support Function (R-RSF). This pair of network elements is capable of interworking with systems not offering all areas of traditional management and control, such as Wi-Fi islands. This design decision is further elaborated in the following section, which sketches the network support architecture for end-to-end reconfiguration.

3 THE RECONFIGURATION MANAGEMENT PLANE

The Reconfiguration Management Plane accommodates the following plane management and layer management modules (Fig. 1).

A. Plane Management Modules

The RMP plane management consists of the Context Management, Policy Provision, Performance Management, Access and Security Management, Reconfiguration Management, Software Download Management, Service Provision, and Billing and Accounting Management modules.

The *Context Management Module (CMM)* monitors, retrieves, processes, and transforms contextual information. Contextual information affects the service provision phase, and provides input to policy decisions and reconfiguration strategies. Contextual information includes profile information as well as resource-specific information. Profile composition and provision is handled by the CMM *Profile Management Module (PrMM)*, which manages and combines the different profiles. Profile information originates from different parts of the system, and includes user profile, network profile, application/service/content profile, terminal profile (the so-called Reconfigurability Classmark), charging profile, and security profile. The *CMM ReSource Management Module (RSMM)* handles resource-specific data regarding the reconfiguration progress, such as the operational mode, state information, and congestion indication. In addition, the CMM *Reconfigurability ClassMarking Module (RCMM)* assigns and retrieves the *Reconfigurability Classmark*, which characterizes any mobile terminal and specifies the level of dynamism regarding reconfiguration, as well as the capabilities of the terminal (e.g., enhanced MExE/WAP classmark). The calculated value of the classmark depends on the type of reconfiguration requested and negotiated, on the type of software to be downloaded, on business incentives, and on individual or operational chains of stakeholders involved in the reconfiguration process.

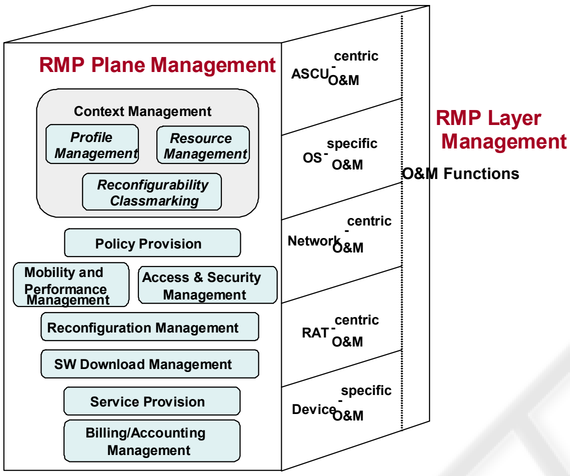

Figure 1: The reconfiguration management plance.

The *Policy Provision Module (PPM)* is the main decision-making entity for reconfiguration, by comprising the entry point for reconfiguration-related system policies. Furthermore, it exploits contextual information and redefines policy rules and reconfiguration strategies. This module produces an up-to-date decision about the feasibility of a reconfiguration as well as respective actions to be triggered. In addition, the PPM caters for inter-domain issues, interacts with Policy Enforcement Points (e.g., in the GGSN), and facilitates the mechanics for the differentiation of end-to-end reconfiguration services.

The *Mobility and Performance Management Module (MPMM)* is responsible for mobility management, triggering and controlling inter/intra system handovers and also collects performance measures, usage data, and traffic data, and estimates performance and cost constraints, which can be exploited for network-initiated element reconfiguration.

The *Access and Security Management Module (ASMM)* participates in the mutual authentication of the user / reconfigurable terminal, verifies the authorization to download, and determines the security control mechanisms (e.g., agreement on security keys) prior to download transfer.

The *Reconfiguration Management Module (RMM)* initiates network-originated and coordinates device-initiated configuration commands, by communicating with Reconfiguration Support Functions at the User Equipment (U-RSF), as well as at interior network nodes (e.g., the R-RSF handling a Composite RAN). In order to accomplish the supervision of end-to-end reconfiguration, the RMM incorporates the signaling logic, including negotiation and capability exchange services. In the case of scheduled software download, the Reconfiguration Management Module hands-over the control of the residual reconfiguration steps to the Software Download Management Module. Finally, the RMM undertakes the necessary session management and Mobility Management (MM) context transfer and translation in cases of inter-domain handover, e.g., from a 3GPP System to a WLAN/Wi-Fi access network.

The *Software Download Management Module (SDMM)* is responsible for identifying, locating, and triggering the suitable protocol or software for download, as well as for controlling the steps during, and after download.

The *Service Provision Module (SPM)* is responsible for the interaction between the RMP and the application/service. This entity accepts and processes service improvement requests from the service providers. In addition, the SPM can initiate a reconfiguration command on behalf of the application. For example, it can initiate network configuration changes or selection of different settings by the users, or it can launch mobility-induced events. In addition, the Service Provision Module may trigger service adaptation actions based on network or device capability modifications, or based on updated policy conditions. Finally, roaming issues for service provisioning are also tackled by the SPM.

Finally, *the Billing and Accounting Management Module (BAMM)* collects charging records from the additional network elements supporting reconfiguration (i.e., the R-RSFs), processes these records, and apportions the reconfiguration-induced revenues to the involved business players.

B. Layer Management Functions

Layer management functions handle Operation and Maintenance (O&M) tasks per protocol layer. The number and scope of these layers depends on the managed environment. In environments supporting end-to-end reconfiguration, layer management functions can be introduced in order to support the service provision stage, and should be adapted based on input related to the definition and enforcement of reconfiguration policies. End-to-end differentiation of reconfiguration services should also take into account the outcome of reconfiguration functions for O&M, such as monitoring reports and capabilities of network elements.

Reconfiguration-oriented O&M functions can be classified to five categories: Application-, Service-, Content- and User-centric (ASCU) functions; Operating-System-specific; Network-centric; RAT-centric; and Device-specific.

Provision of customer care information is a typical example of *ASCU-centric O&M* function. Logging is an important feature, offering the history of reconfiguration actions (e.g., recent over-the-air upgrades), statistical information on the latest faults and alarms reported to the user, etc.

OS-specific O&M functions should coordinate the auditing, testing, and validation procedures at the reconfigurable terminal. Network-centric O&M functions estimate the impact of mobility and QoS on the software download process. In addition, dynamic network planning and its impact on traffic split comprise important O&M functions for reconfigurable network elements.

RAT-centric O&M functions manage RAT-specific issues for a single Radio Access Technology or guarantee efficient collaboration of multiple RATs. The Composite Radio Environment Management function handles stability, conflict resolution, and certification issues, and ensures proper collaboration between network infrastructure manufacturers and terminal providers. The Radio Element Management function cooperates with the RMP Performance Management Module. Analysis of RAT-specific performance data is an example of performance management, which may in turn affect real-time reconfiguration. The Function Partitioning and Reallocation entity coordinates coupling issues as well as distribution of functional entities for multi-RAT environments owned by a single administrative authority. Finally, the Interworking function verifies the correct operation of control plane functionality between radio elements owned by different operators, as well as network sharing scenarios. RMP RAT-centric O&M functions communicate with the R-RSF for efficient management of composite multi-RAN environments.

*Device-specific O&M function*s include, for example, functions for User Equipment Management. Remote equipment diagnosis assists in the remote identification of equipment faults, taking into account security threats. Finally, coordination with Hardware Abstraction Layer configuration modules can also be accomplished through device-specific RMP O&M functions.

C. The RMP in a Beyond 3G Mobile Network

The provision of end-to-end reconfiguration services and management in Composite RAN environments, coupled with scenarios of evolved core network architectures (S. Uskela, 2003), should be accommodated via a two-tier control and management architecture depicted in Fig. 2. From a high-level perspective, the architecture consists of two managers, i.e., the ReConfiguration Manager and the Radio Reconfiguration Support Function.

The RCM is a realization of the RMP logical model to the heterogeneous network architecture. To cope with complex scenarios, the RCM is located at the highest network hierarchy, i.e., either in the core network domain (e.g., attached to the Gi and/or the Gp interface in a 3GPP System) or in a trusted third party domain. Alternatively, the RCM would be distributed in the core network, with its functionality apportioned to the SGSN and GGSN. The first option facilitates future architectural scenarios. For example, apart from intra-domain connection of RAN nodes to multiple CN nodes currently supported in a 3GPP Release 6 System, inter-domain connection as well as network sharing scenarios dictate the presence of the RCM as a separate network element beyond the GGSN in the network hierarchy. This decision also facilitates independent evolution paths for future all-IP core networks, i.e., with IP routing and IP mobility except IP transport [1]. The second option is more efficient for mobility management purposes; when a User Equipment abruptly de-attaches from a 3GPP System and attaches to a WLAN or Wi-Fi hot-spot, the RCM Reconfiguration Management Module should manage the necessary Mobility Management (MM) context to capture the movement from UMTS to WLAN and vice versa.

The R-RSF manages a single or a Composite RAN, thus, being responsible for functions such as Joint or Common Radio Resource Management, Network Planning, and Spectrum Management [7]. The R-RRSF function in UMTS is placed in the RNC and cooperates closely with RNC's RRC to execute handovers and session establishments.

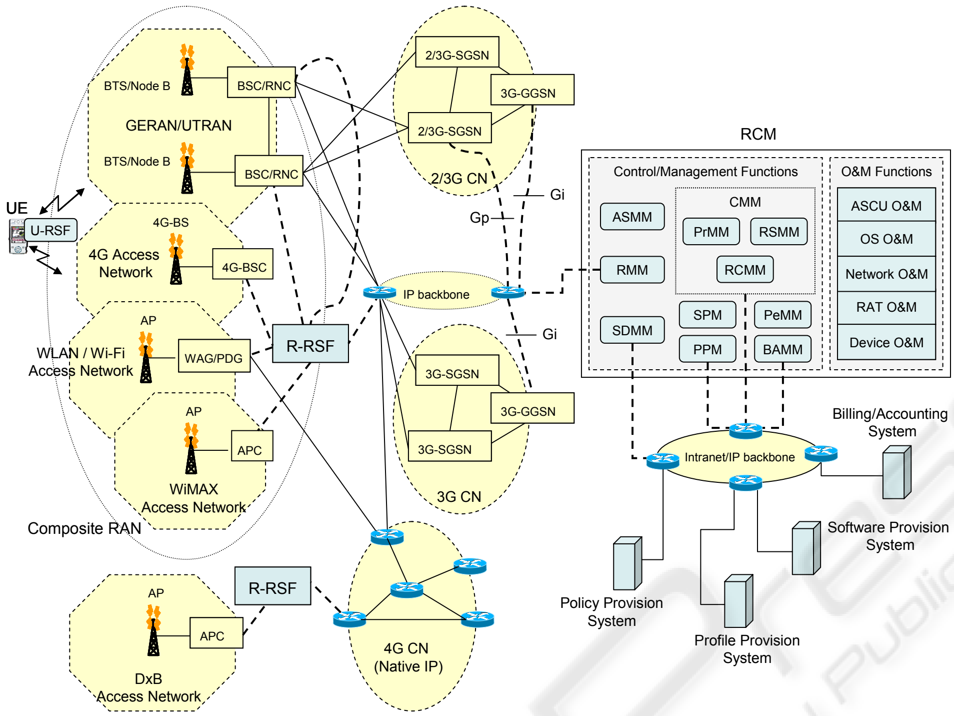

Figure 1. The RMP in a Beyond 3G mobile network architecture.

Fig. 2, also depicts a collection of repositories in the form of four integrated systems. The collection of profile repositories should be viewed as a composite *Profile Provision System (PPS)*. The PPS should apply to an n-tier system capable of disseminating profile management policies into an n-layered architecture. Such multi-tier architecture can be constructed based on topological considerations and/or on semantic aspects. Segmentation and distribution of profile data representation via *profile staging,* should offer performance and flexibility benefits.

Accordingly, the download servers are organized into a *Software Provision System*, whilst the *Policy Provision System* holds reconfiguration policies and strategies. Finally, the *Billing and Accounting System* calculates the revenues induced by reconfiguration operations, both due to signaling and user traffic.

4 SESSION SETUP AND HANDOVER EXECUTION

As a case study we consider a network topology similarly to the one of Figure 2 where a UMTS network is integrated with a WLAN. We consider a tight integration between the two systems in order to achieve a satisfactory performance for the execution of mobility management procedures.

To understand in depth the proposed functionality of RCM and R-RSF we consider the establishment of a session setup and the execution of an vertical handover from UMTS to WLAN. In both cases we make the following assumptions:

1) Both the UMTS and the WLAN infrastructure belong to the same operator.

2) There is global UMTS coverage but WiFi islands also exist.

3) The MT has always a UMTS signaling connection through which it initiates all procedures. It can however choose to pass a number of its new or established data connections through a WLAN for reasons of cost and bandwidth availability.

4) The session establishment and the execution the handover are executed in two phases. Initially, the MT gathers dynamic network information (e.g., SNR status) and combines this information with static information such as the user profile (e.g., preferences in execution efficiency and cost, subscription status), the terminal capabilities, the service profile and builds a prioritized target list of RAT to be used. This list is send to the network where the operator will enforce its policy based on the current traffic load of the targeted RATs and the subscription class of the requested user.

5) The overall system guarantees seamless service continuity (Kaloxylos, 2005) and we

consider multi-mode terminals (i.e., they can be concurrently attached to two different RATs).

4.1 Connection setup through a WLAN

Figure 3 illustrates the signalling message exchange when a data connection is configured to pass through a WLAN access network. Before any service is executed, the MT needs to attach to the network and initiate an RRC signalling connection. Then, the MT scans the signal strength of the neighbouring Node Bs and APs. When a service is to be executed, it decides that a PDP connection is required, and issues an Activate PDP Context Request Message towards the SGSN.

The SGSN-RCM checks the user’s subscription, selects the Access Point Name (APN) and performs the host configuration. It then sends a Create PDP Context Request to the target GGSN. The GGSN creates an entry to its context table to enable the packet routing with the external packet data networks and returns a confirmation message to the SGSN (Create PDP Context Response).

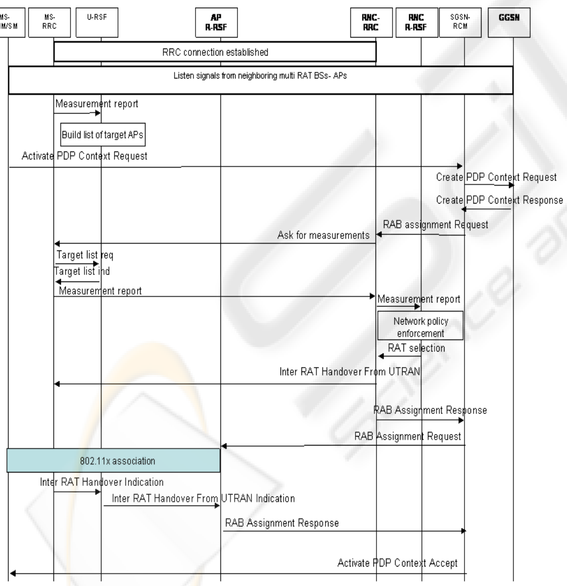

Figure 3. Outgoing connection setup through WLAN

After receiving the *RAB assignment request* and before activating the Radio Access Bearer, the RNC’s RRC asks for the current measurements from the MT. The U-RSF entity replies with the MT’s prioritized list of target access networks based on the reachable APs or Node Bs, the service requirements, the user preferences and the terminal profile. The RNC’s R-RSF will process this list and will decide, based on the traffic load and the policy of the operator, whether this connection should be served by a WLAN or the UMTS.

In our scenario we assume that WLAN is preferred and thus the RNC a) notifies the MT with an *Inter RAT Handover from UTRAN* message to associate with the WLAN and b) notifies SGSN-RCM *(RAB Assignment Response)* that resources should be allocated in the WLAN for the specific PDP context. The first message may also contain information or protocols that the MT will need in case this is the first time it will connect to a WLAN.

Right after the receipt of *Inter RAT Handover from UTRAN* message, the MT will be reconfigured to send all session related packets through the WLAN interface. U-RSF is the responsible entity to accomplish the reconfiguration. When the 802.11 association and the reconfiguration are completed then the AP’s R-RSF is notified. This entity in its turn will notify the SGSN-RCM entity.

At the same time, when the SGSN-RCM is notified by RNC’s RRC, it sends to the AP’s R-RSF a *RAB Assignment Request* message. Upon receipt of this message the AP’s R-RSF reserves resources and it will notify the SGSN about the completion of all radio resource management procedures and the MT’s reconfiguration. Finally, SGSN-RCM receives the *RAB assignment Response* and it will notify the MT that the connection is active and communication can begin (*Activate PDP context accept)*.

Handover from UMTS to WLAN

The execution of handover from UTRAN to WLAN is illustrated in Figure 4. A MT with active connections monitors periodically for events that can trigger a vertical handover (e.g., the signal received by neighboring APs and Node Bs, battery level, etc.), either for a specific PDP context or for all PDP contexts. In case a MT moves from the coverage area of one RNC to another, then any active PDP context will be switched either to a target RNC or a target AP. In this section, the single PDP-context transfer case to a target AP is discussed.

When a handover initiation criterion is met, the U-RSF checks the different profiles (i.e., service, user, terminal) and builds a prioritized list for the service that needs to be handed over to a different radio access technology. This list is sent with the message *Measurement Report* to the RNC’s RRC. This message is the standard RRC message enhanced with the appropriate parameters and their semantics.

Based on the policy of the operator and the traffic load measurements, the received list is processed by the R-RSF based on the operator's policy for the current traffic load and the user's subscription status.

In our example the target AP is selected and the RNC's RRC is notified (*RAT Selection)*. In its turn the RRC will notify the SGSN's RCM that the PDP Context will be relocated to the AP. In the next step the MS's RRC will be notified (*Inter RAT handover from UTRAN)*.

The RNC's RRC will also notify AP's R-RSF to start receiving packets from the serving RNC (*Relocation Commit)*. The MT, upon reception of the *Inter RAT Handover from UTRAN*, it reconfigures the protocol stack to exchange all session related packets through the WLAN interface. It also establishes an 802.11 association with the AP.

The AP's R-RSF notifies the SGSN that a handover is under execution (*Relocation Detect).* Upon reception of this message, the SGSN configures the GTP-U protocol to switch the flow of the specific PDP Context towards the AP.

When the MT finishes the WLAN association, it communicates with the AP (*Inter RAT Handover From UTRAN Indication).* In case reservation of resources is needed at the WLAN, this is done at this point using standard IP-based QoS provision methods, such as RSVP. This clearly requires proper mapping of UMTS QoS parameters to IP-based QoS parameters at the MT and ERNC. After that, the SGSN is notified (*Relocation Complete)* to release resources (*Iu Release Request/Complete*) in the UMTS.

In case there are no resources to serve the connection, then the relocation process fails. The AP notifies the SGSN to try the next candidate in the list of target RATs, if there is one left.

5 CONCLUSIONS

We presented an integrated plane management and layer management framework for the support of end-to-end reconfiguration, and elaborated on the constituent modules for control and management operations. The introduced Reconfiguration Management Plane comprises a network-agnostic protocol-independent model for specifying operations and notifications, viewed as extension to existing control and management planes or as a new intermediary plane for dedicated reconfiguration-induced tasks.

Envisaging the major challenges for end-to-end reconfiguration differentiation, we identified the requirement of communication between reconfiguration-aware and unaware nodes, and the necessity to offer transparent reconfiguration services.

To prove the feasibility of our proposal we demonstrate how the overall architecture would operate in the case of session establishment and handover execution in tightly coupled UMTS-WLAN network. The proposed procedures are based on existing protocols and mechanisms which we enhance to support the required reconfigurable functionality. The result is a network that can support advanced services which are future proof since they are easily modified and extended.

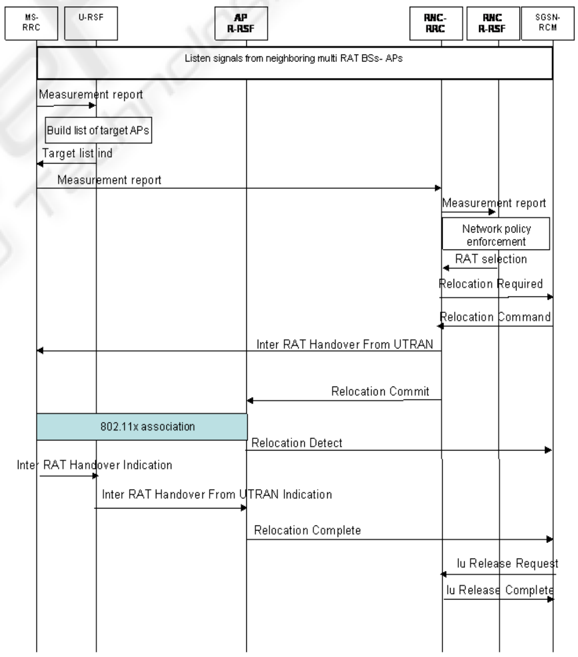

Figure 4: Handing over a connection from UMTS to WLAN

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