About this document

This document constitutes a white paper developed within WG6 of WWRF, concerning Management and Control Architecture of Reconfigurable Systems.

Management and Control Architecture of Reconfigurable Systems

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Abstract:

Future wireless communication systems will support multiple access systems on heterogeneous network bases leading to reconfigurable and flexible systems. It is obvious that multiple radios access will have several networking architecture that offer potential flexibility and cost advantages over the current architecture. Dynamic reconfiguration of SDR terminals provides a number of benefits to mobile users, network operators, service providers and equipment manufacturers alike. However, these benefits can only be fully leveraged if appropriate mechanisms for reconfiguration, operation and maintenance of terminals and network entities are utilized. In this contribution the architectural building blocks, such as the multi-band multi-standard base station as well as the radio access network and reconfiguration managers, are grouped into three tiers. Based on the three-tier architecture, several network and radio configurations are described. The functional architecture model described in this document covers all concepts concerning Advanced Radio Resource Management (ARRM), Advanced Spectrum Management (ASM) and Dynamic Network Planning and Management (DNPM). Aside from the functionalities and network architectures for reconfigurability presented in this white paper, a particular research challenge is mobile terminal mass-upgrades. To improve the practicality of mass-upgrades, two network-assist schemes are presented that are able to better the scalability of reliable multicast downloads. These schemes are particularly useful where random packet loss (as occurs in mobile networks) makes reliable multicast scale poorly.

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1. INTRODUCTION

E^{2}R project [1] put substantial effort on definition and design of architecture for Reconfigurable Systems, as initially introduced in [2]. It aims at enabling seamless and transparent communication for users, and flexible and efficient management in operating radio network. Operational interface between mobile players includes service provider, operators, end users, manufactures and regulators.

Reconfiguration is the action of modifying the operation or behaviour of a system, a network node, or functional entity. The end-to-end notion dictates that, in certain cases, user and control plane interactions may occur from source to destination in order to adapt the system, the equipment, applications, services, or content [3]. In order to embed algorithms and functions into B3G-SA, E^{2}R system need to provide common platforms and associated execution environments for multiple air-interfaces, protocols and applications. The emerging network will be equipped with scalable and reconfigurable network elements, being capable to allocate resources to involving radio links with optimal solutions and cost effective network management. Reconfiguration Management Plane (RMP) is the platform proposed to embody the functions and interfaces enabling reconfiguration [4].

A UML model for Reconfiguration [5] describes concepts required to define reconfigurable entities and their behaviour. Reconfiguration is envisioned as a set of policy-driven tasks, which includes the way to efficiently adapt, apply, and upgrade the functionality that an entity supports, to any expected or potential change of its state, situation, and activity. Within this context, such UML model captures concepts required to support reconfiguration functionality, and can be used as a guideline for defining an information model to support reconfiguration, as well as for producing models specific to reconfiguration topics, such as context management and service provision.

E^{2}R started specifying Network Architecture and Support Services for Reconfigurability, by identifying requirements, associations and dependencies of entities implicated in the reconfiguration process. The gatherings served to define a logical functional model for Reconfiguration Systems, later mapped onto physical elements.

The proposal of physical configurations based on concrete network architectures is achieved by mapping the RMP model to a horizontal, multi-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).

Following design principles of IP-based networks, the functions related to wireless connectivity are separated logically and physically. The concept of a common next-generation (i.e. 4G) IP-based core network serving multiple, heterogeneous radio access networks requires the encapsulation of access-specific functions into the R-RSF to allow for the definition of an abstract set of functions being common for all access networks. The R-RSF comprises a separate network element lying within a domain of multi-RAN scope.

In addition to the research challenges posed for mobile network architectures to support the required reconfiguration functionalities, several issues must be solved to facilitate mass-upgrades of mobile terminals. A particular such issue is that of one-to-many downloads. This might be considered in the context where network entities exist supporting one-to-many downloads (e.g. the Multimedia Broadcast Multicast Service—MBMS); however, such work is much more widely applicable across heterogeneous systems when considered in the scope of simple IP networks supporting IP multicast, with leaf-node packet loss characteristics reflecting wireless links. Hence as a final contribution of this white paper, two ‘network-assist’ approaches for reliable multicast downloads are presented, both of which are particularly helpful to solve the scalability issues caused by random leaf-node link packet losses.

2. FUNCTIONALITY OF RECONFIGURABLE SYSTEMS

In the following, RMP, a proposal for integrated reconfiguration provisioning to user devices and infrastructure entities (i.e. network elements and subnets) is overviewed [4]. RMP provides layer abstractions to applications and services on one hand, and to terminal equipment and network devices on the other, as depicted in Figure 2–1. It builds on a network-agnostic protocol-independent logical model, which can be considered as extension to existing Management; Control; and Operation and Maintenance (O&M) planes.

RMP consists of Plane Management and Layer Management functions that cater for reconfiguration-related tasks, such as context management, policy provision, service management, and reconfiguration and download management.

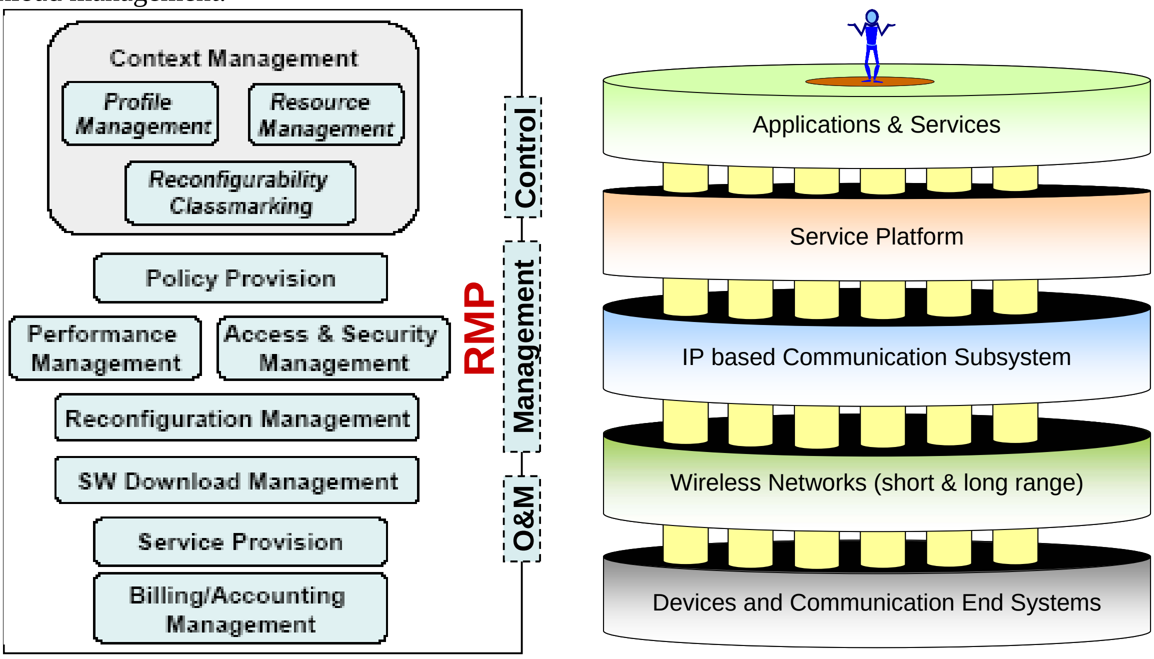


Figure 2–1: RMP and WWI Reference Model

2.1 RMP Functions

As introduced in [2], traditional Plane Management embraces configuration control, resource management, performance management, fault management, access and security management, and accounting management . Traditional Layer Management necessitates the existence of interfaces to all protocol layers, both in the control and in the user plane. Layer management handles Operation and Maintenance (O&M) functions on a per-layer basis. Additionally, Reconfiguration Supporting Functions are found in the Access Stratum as presented in the list below.

Plane Management Functions
- Context Management
- Profile Management
- Reconfiguration Classmarking
- Policy Provision
- Reconfiguration Management
- Service Provision

Layer Management Functions (O&M functions)
- OS-specific
- Network-centric
- RAT-centric
- Device-specific

Radio Reconfiguration Supporting Functions

Terminal
- Available Mode Lookup
  - Mode Monitoring
  - Mode Filtering
  - Mode Caching
- Negotiation
  - Network Capability Negotiation
  - Negotiation Caching
  - Evaluation / Decision-Making
- Handover Management

Base Station
- Service Profile Management
- SW Download Management
- Load/ Traffic Management
- Performance/ Load Monitoring

2.2 RMP UML Model for Reconfiguration

Figure 2–2 highlights the basic reconfiguration scheme: an *Actor* reconfigures a *Reconfigurable Entity*, which is composed of a certain number of discrete *Manageable Elements*. Furthermore, the Actor maintains a "manipulates" relation with each of the Manageable Elements, thus exploiting their functionality.

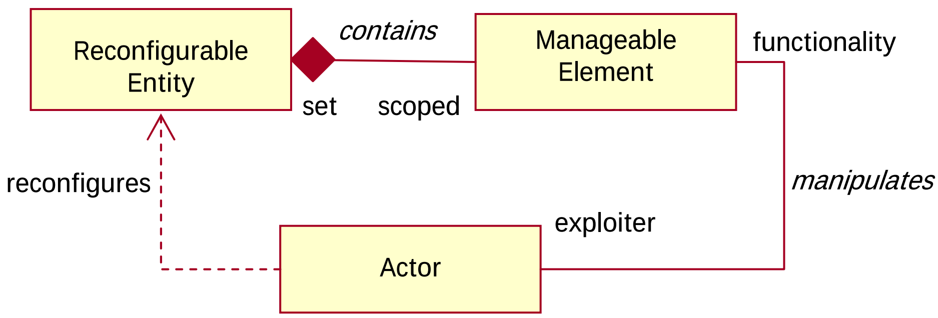


Figure 2–2: Basic Reconfiguration Scheme.

Figure 2–2 presents a new lightweight UML Profile that is built using the standard UML extension mechanisms: tagged values, constraints, and stereotypes. The model describes any association between reconfiguration concepts, which are notated into certain items such as stereotypes, abstract classes and meta-classes, dependencies and specific constraints. Such items are semantically interrelated by introducing association roles.

The model can be segmented into three discrete reference models, namely:

- The Context Information Model;
- The Service Provision Model;
- The Reconfiguration Plane Model.

2.2.1 *Reconfiguration Model*

The reconfiguration model consists of the concepts: Provision, Reconfiguration, Classmark, Profile, Policy and Trigger. There is a dependency, the so-called 'Reconfigurability' that associates any Reconfiguration concept to another one, according to the 'manager' and 'reconfigurable' roles.

The Profile stereotype is attached with specific tagged values. The ‘specializer’, which denotes the individual of that profile data are modelled, the ‘local’, which denotes whenever such profile data are stored locally or are distributed with certain consistency rules, and, finally, ‘static’ tag, which denotes whenever such profile data are updated into well-defined temporal constraints. The Policy stereotype is attached by the ‘isDescriptive’ tag denoting whenever polices can be modelled as set of decidable rules or not. The ‘type’s Classmark tag denotes the certain clusters of the classification of the corresponding reconfigurable entity according to contextual information. It is worth mentioning that, a reconfigurable component may be classified to more than one reconfiguration Classmark. This consideration may draw the inference space into inconsistency. The Provision and Reconfiguration stereotypes describe secure, mobility aware and transparent application of service provision and reconfiguration respectively. Finally, the Trigger stereotype describe its intention whenever to convey or not events that are generated by certain object (i.e., notifiers) and if such triggering lead to a sound and complete decision, related to consistent contextual information (Figure 2–3).

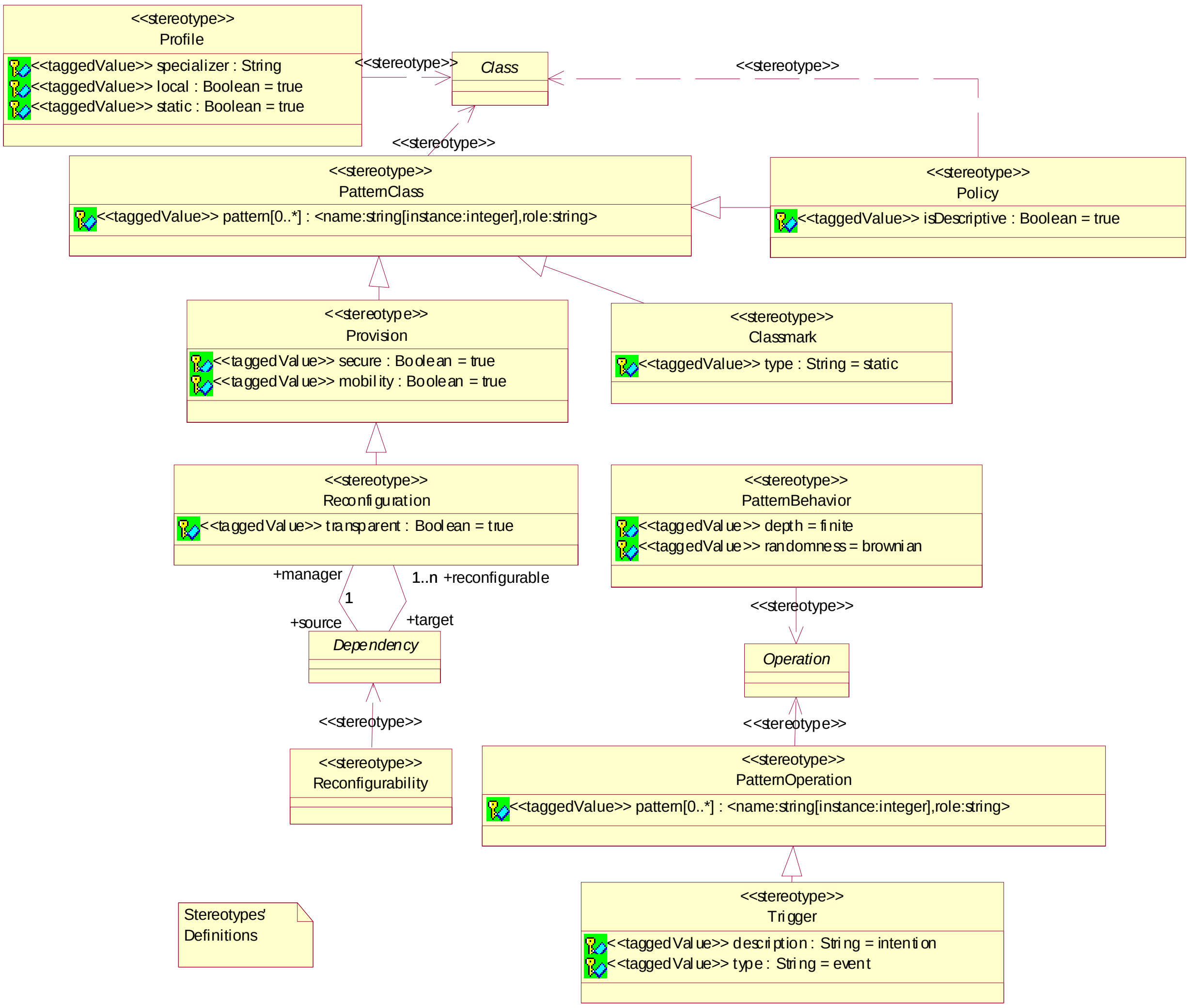


Figure 2–3: UML Model for Reconfiguration (stereotypes)

2.2.2 Context Information Model

Reconfigurable Context is referred as the contextual information available for conclusion and reasoning about when the Actor has to reconfigure a Reconfigurable Entity. The whole telecommunication environment may form such contextual reconfiguration information, in terms of profiles of the various entities (e.g., terminal capabilities, service features, user preferences, network profiles, charging policies) and their semantic interrelations (i.e., subsumption, disjointness and equivalence). The Reconfigurable Context may be modelled by ontologies involving complicated data models.

The classes that model such concept are the Policy, Profile and Classmark stereotypes. The manageable concepts in the model that make uses of such information are the so-called PolicyAwareness, ProfileAwareness and ClassificationStub concepts. The later just classifies the terminal capabilities profile to certain clusters of reconfiguration in order to ease the reconfiguration process to take place (Figure 2–4).

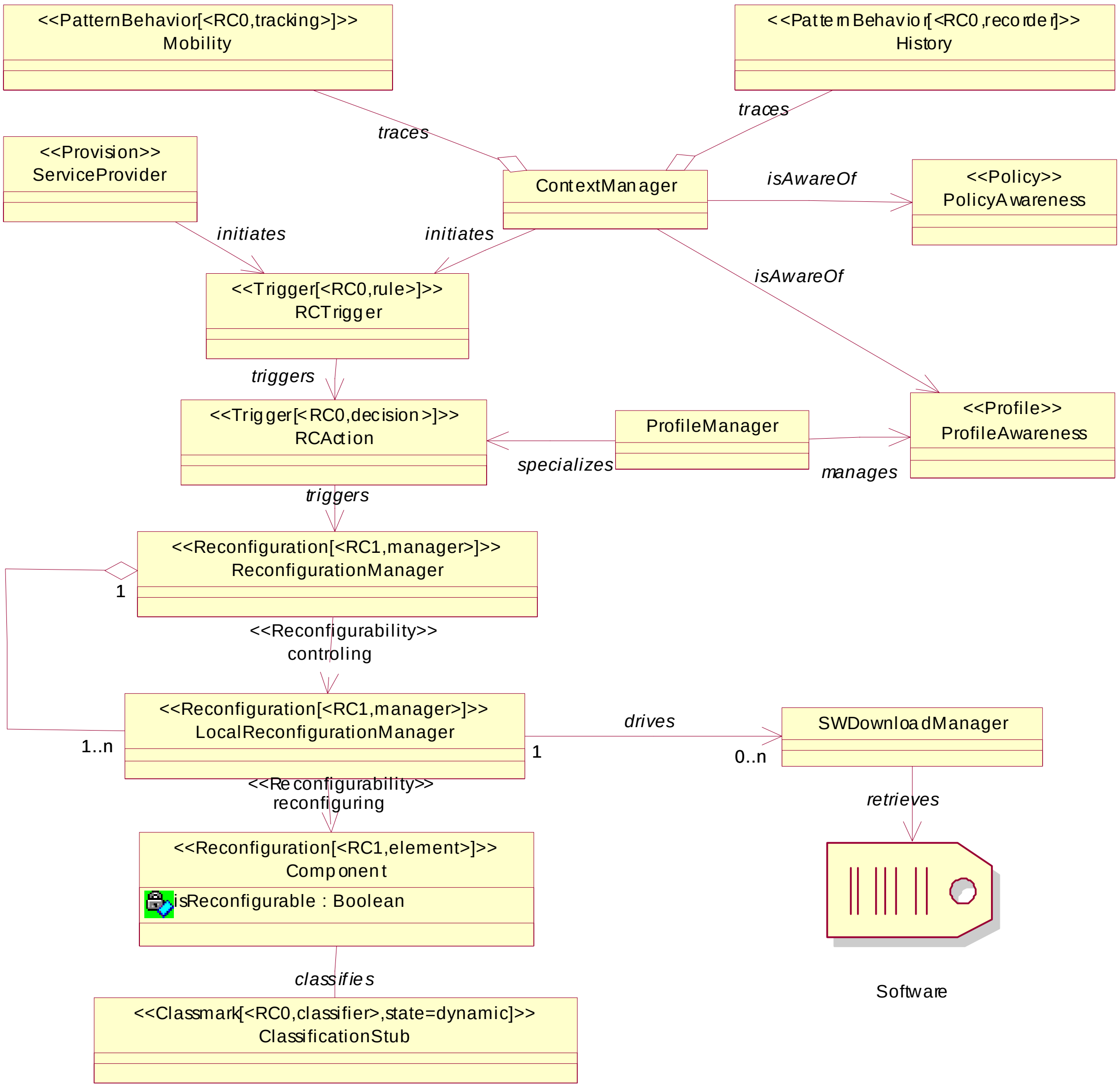


Figure 2–4: The Reconfiguration Model

The Trigger concept, which is modelled as stereotype in the model, is aware of any contextual change (i.e., information alteration). The Reconfigurable Context may be subsumed into Profile and Policy classes. Profile, in a mobile environment, is the abstraction of the contextual information of the different entities that are involved in a mobility scenario. For reconfigurable environments, four different entities are declared, namely, the User, the Service, the Equipment and the Network. Such concepts may be subsumed by the former concepts. For instance, the *Profile* concept is specialized by the classes User, Service and Equipment that manage the corresponding profiles. The Net*work* Profile specializes the *Equipment* Profile and acts as an aggregation of Equipments. Additionally, the *Network* Profile maintains the profiles of the various reconfigurable network elements (routers, base stations, gateways, software controllers). The *static* tagged value holds the corresponding profile mode. Dynamic and static values for the profile mode comprise basic values.

The stereotype Profile is attached to the ProfileAwareness where there is a association with the ContectManager concept. The ProfileManager stores, and retrieves the appropriate profile while the ContextManager concept tries to draw the ontology space, which maintains the profile data, into a consistent state according to several rules. The stereotype Policy is attached to the PolicyAwareness concept. Such concept updates the policies that are applied over the profile information. The policies, in this context, are modelled as a set of rules (decidable rules that bring the ontological space into consistency). ContextManager traces the History model of a certain object (e.g., user behaviour) and whenever policy-rules hold then the former initiates event messaging towards the Trigger implementer.

Finally, the ContextManager traces the mobility behaviour of the monitored object. Such behaviour is modelled by the concept Mobility. Thus, the History data, the Mobility data, the rules related over the context of the profiles, and, the profile data, that are updated and maintained in a consistent ontological space, draw the ContextManager to a initialisation of any triggering action, whenever axioms in the rule engine hold.

2.2.3 Service Provision Model

The Service Provision concept is modelled by the notion of the Service Provider and its provided content and applications. Such physical objects are represented in the Reconfigurable Context as Multimedia Content Features and Service Features. This kind of information is indispensable for the ContextManager to reason about whenever a service or content, eventually, adaptations hold for several periods of time and location. Such spatial-temporal reasoning may be modelled into set of rules and maintained in the ontological spaces corresponding to the PolicyAwareness concept. The Service Provider, thus, constitutes the initiator of the Reconfiguration Trigger, whenever rule related to service adaptation hold. In the case when the service provision cannot be completed via certain reconfiguration actions (e.g., a user’s terminal is not reconfigurable or the network cannot support such actions), a service adaptation must be performed. The Service concept stands for each individual service and acts as software and content aggregator. The Content concept (which can be bound parameter) stands for the content to be displayed or processed via any service provision.

2.2.4 Reconfiguration Plane Model

In the Reconfiguration Plane Model, the Reconfiguration stereotype is attached to the ReconfugrationManager, to LocalReconfigurationManager and to Component. The ReconfigurationManager is an overall observer of the capabilities (i.e., profile data) and states (i.e., situation aware) of the different network nodes and terminals. In this context, The RCAction is the decision making engine for implementing the reconfiguration actions. Such engine captures the events by the RCTrigger and according to several criteria (i.e., beliefs or probabilistic reasoning) sends command to the ReconfigurationManager to implement the specific reconfiguration action. The latter conveys the appropriate contextual information to its supervisees (i.e., LocalReconfigurationManagers). Such manager carries out part or the whole reconfiguration monitored by their supervisor (i.e., ReconfigurationManager individual). The type of the ReconfigurationManager is the major deduction product decision-making mechanism, which observes, monitors, coordinates and manipulates a set of LocalReconfigurationManagers (LRMs). A LRM can exist and operate for each individual ReconfigurableComponent or for each set of such components aggregated according to their role/operation.

The reconfigurable *Classmark* is a main indicator describing the appropriate knowledge (e.g., such knowledge may be modelled as certain cluster of reconfiguration peer) of any reconfiguration event; thus, any reconfiguration activity for a certain reconfigurable component is based on and driven by its corresponding Classmark. The Classmark is a means of bridging the knowledge context of the ReconfigurationManager and with the ReconfigurableComponent.

A LocalReconfigurationManager has the responsibility to reconfigure a ReconfigurableComponent according to its Classmark; this is achieved in cooperation with the ReconfigurationManager that provides its local specializations with contextual information regarding the whole telecommunication environment. Furthermore, the ReconfigurationManager maintains any contextual information of the LocalReconfigurationManagers. The *SWDonloadManager* acts as a means of downloading the appropriate software upgrade having the responsibility to download and to compose the reconfigurable protocol that works as a compound entity. The decision for the Protocol composition is made by the Local*ReconfigurationManager*, which maintains an activator association role (i.e., the association "drive" in the schema).

2.3 Wireless Resources Management Functions

The Wireless Resources Management Architecture is described in detail in White Paper 4 '*Cognitive Radio and Management of Spectrum and Radio Resources*', pointing out the major building blocks for Dynamic Network Planning and Management (DNPM), Advanced Radio Resource Management (ARRM), and Advanced Spectrum Management (ASM) functionalities, as depicted in Figure 2–5.

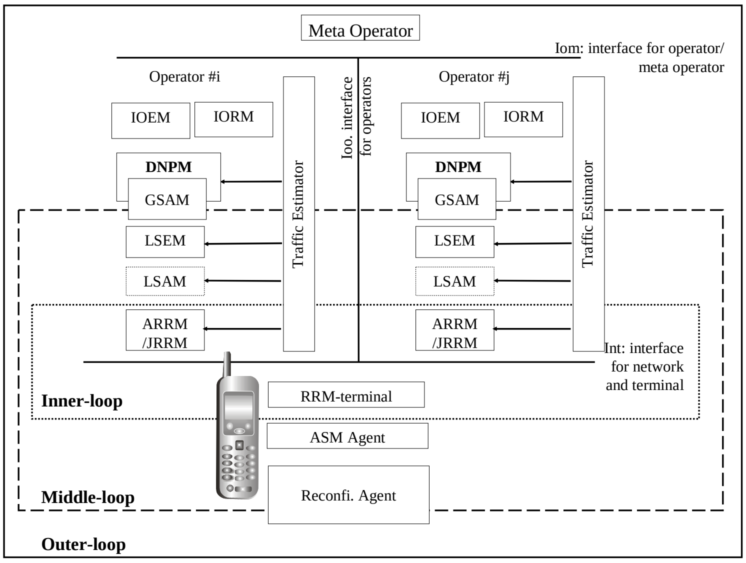


Figure 2–5: Wireless Resources Management Functional Architecture Model

In elucidating the most appropriate distribution of functionality, we first look at foreseen interactions between logical entities that compose the model.

2.3.1 Single Administrative Domain

2.3.1.1 Traffic Estimator

In existing cellular systems, several network monitoring servers of the O&M subsystem monitor the traffic in the radio access networks and core network. This is required to check the status of the network resource utilization and to detect network congestions. Typically, traffic data is stored in databases and this information can be used to anticipate future traffic demand based on past traffic fluctuation trends [6]. For Wireless LAN systems, commercial products also provide traffic monitoring tools to improve the security of the network (e.g. detection of intruders) but also to facilitate the installation of new access points based on past network traffic usage.

In the context of reconfigurable radio networks, the Traffic Estimator predicts future traffic demand for several RATs in a specific region (i.e. spanning several kilometres). **Error! Reference source not found.** presents the various interfaces and procedures involving the Traffic Estimator.

Procedure	Sender	Receiver	Message	Parameters	Comments
I	DNPM	Traffic Estimator	Request an estimation of future traffic demand	Time period, region considered	This procedure is applicable to basestation reconfiguration scenarios (See section 2.3.1.2)
	LSEM / GSAM	Traffic Estimator	Request an estimation of future traffic demand	Time period, region considered	This procedure is applicable to flexible spectrum usage scenarios between RATs (See section 2.3.1.3). The time period is short (seconds/hours) in the case of LSEM and long (hours/days) in the case of GSAM
	IOEM	Traffic Estimator	Request an estimation of future traffic demand	Time period, region considered	This procedure is applicable to flexible spectrum usage scenarios between operators (See section 2.3.2)
II	Traffic Estimator	O&M traffic monitoring servers	Request past network traffic usage information	Time period, region considered	-
III	O&M traffic monitoring servers	Traffic Estimator	Transmit past network traffic usage information	Past network traffic usage information	One or more traffic monitoring servers provide information depending on the region considered
IV	Traffic Estimator	DNPM	Transmit an estimation of future traffic demand	Estimation of future traffic demand	-
	Traffic Estimator	LSEM / GSAM	Transmit an estimation of future traffic demand	Estimation of future traffic demand	-
	Traffic Estimator	IOEM	Transmit an estimation of future traffic demand	Estimation of future traffic demand	-
V	Spectrum Policy Server	Traffic Estimator	Notify changes of spectrum allocations	Changes of spectrum allocations in the country	This procedure is lengthy and includes regulatory bodies and coordination activities
	LSAM	Traffic Estimator	Notify local changes of spectrum allocations and assignments	Local changes of spectrum allocations and assignments in the region considered	This procedure can be done on a daily basis

Table 2-1: Procedures and Interfaces Involving the Traffic Estimator

2.3.1.2 Dynamic Network Planning and Management (DNPM)

DNPM is a framework dealing with planning and managing reconfigurable networks [7]. It consists of two phases:

- Radio network planning phase. The requirements of network operators in terms of coverage, quality of service, and interference management shall be considered at this phase. One option for reconfigurable systems will be to incorporate network planning tools within the O&M subsystem. These tools shall provide guidance on the location of network equipments (during deployment phase), and on the reconfiguration possibilities of network equipments (during the operation phase).

- Radio network management/optimisation phase. The aim of this phase is to optimise the usage of network resources, assuming that network equipments are subject to be reconfigured. In this section, the reconfiguration degree of basestations/access points may be partial (e.g. change of antenna configuration, change of emitted power) or complete (e.g. addition of new mode such as 802.16e). The specific problem of optimising the usage of spectrum will be further discussed in section 2.3.1.3.

Table 2-2 presents the various interactions and procedures involving the DNPM.

Procedure	Sender	Receiver	Message	Parameters	Comments
I	DNPM	Traffic Estimator	Request an estimation of future traffic demand	Time period, region considered	-
	DNPM	JRRM	Request Key Performance Indicators (KPIs)	Region considered	-
II	Traffic Estimator	DNPM	Transmit an estimation of future traffic demand	Estimation of future traffic demand	-
	JRRM	DNPM	Transmit KPIs	KPIs	KPIs include information such as drop call rate, session throughput, etc.
III	DNPM	Basestations, Access Points	Notify configuration changes	Change of antenna configuration, emitted power, addition of new mode	Configuration changes have to be implemented by basestations and access points

Table 2-2: Procedures and Interfaces Involving the DNPM

2.3.1.3 Advanced Spectrum Management (ASM)

In E^{2}R, Advance Spectrum Management (ASM) aims at optimising the usage of radio spectrum. In this section, it is assumed that the spectrum resources owned by a network operator can be dynamically reallocated for one or more Radio Access Technologies. This means that end users are dynamically assigned a number of Generic Resource Elementary Credits (GRECs) per Radio Access Technology. Thus, some coordination has to be supported by the network to enable the sharing of spectrum and avoid harmful interference between users. Three main functional blocks have been identified so far in WP5 on the network side: The Global Spectrum Allocation Manager (GSAM), The Local Spectrum Economic Manager (LSEM), and the Local Spectrum Allocation Manager (LSAM).

- Global Spectrum Allocation Manager (GSAM)

The Global Spectrum Allocation Manager (GSAM) calculates the optimised frequency bandwidth for the Radio Access Technologies and the inter-RAT guard bands. Typically, in a dynamic spectrum usage scenario, the bandwidths of the RATs are a function of time and location. One candidate Radio Access Technology is the evolved UTRA defined by 3GPP. One of the evolved UTRA requirements is to support scaleable frequency bandwidth (1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz). Thus, such system will propose to end users flexible peak data rates (up to 100 Mbps for the downlink and up to 50 Mbps for the uplink) [8] depending on the bandwidth assigned to them.

Another important function of the GSAM is to fix the cost for spectrum usage of licensed systems. This issue is closely related to radio regulations. In Europe, spectrum trading and liberalisation are two topics discussed by regulators. Spectrum trading and liberalisation would allow operators to define various and sustainable pricing models for their licensed systems. Moreover, if regulators agree to award new spectrum licenses by auctioning methods on a technology and service neutral basis as proposed by OFCOM in a consultation document [9], operators could deploy new or successful technologies and services on unused areas of their spectrum and apply more competitive pricing models. **Error! Reference source not found.** presents the various interactions and procedures involving the GSAM.

Procedure	Sender	Receiver	Message	Parameters	Comments
I	GSAM	Traffic Estimator	Request an estimation of future traffic demand	Time period, region considered	-
	GSAM	JRRM	Request Key Performance Indicators (KPIs)	Region considered	-
	GSAM	LSAM	Request an estimation of future spectrum demand	Time period, region considered	-
	GSAM	DNPM	Request reconfiguration possibilities of network equipments	Region considered	-
II	Traffic Estimator	GSAM	Transmit an estimation of future traffic demand	Estimation of future traffic demand	-
	JRRM	GSAM	Transmit KPIs	KPIs	-
	LSAM	GSAM	Transmit an estimation of future spectrum demand	Estimation of future spectrum demand	-
	DNPM	GSAM	Transmit reconfiguration possibilities of network equipments	Reconfiguration possibilities of network equipments	-
III	GSAM	LSEM	Notify the cost of spectrum usage	Cost of spectrum usage	-
IV	GSAM	Basestations, Access Points	Notify spectrum allocation changes	Spectrum allocation changes, guard bands	Spectrum allocation changes have to be implemented by basestations/access points

Procedure	Sender	Receiver	Message	Parameters	Comments
V	GSAM	Charging/ billing system	Notify pricing model changes	Pricing model changes	-

Table 2-3: Procedures and Interfaces Involving the GSAM

- Local Spectrum Economic Manager (LSEM)

The data rates and bandwidth requirements of a group of users in the same location are different. In order to optimise the use of the spectrum resources, the users trade with the Local Spectrum Economic Manager (LSEM) the spectrum resources using auctioning methods. Thus, the LSEM acts as the auctioneer, receiving spectrum bid offers from users and decides the price and the number of Generic Resource Elementary Credits (GRECs) for each user.

- Local Spectrum Allocation Manager (LSAM)

After the auction procedure between users and the LSEM, the Local Spectrum Allocation Manager (LSAM) assigns the bandwidth requests negotiated with users. If the spectrum demand is higher than the current resources of the RATs, either a spectrum reallocation procedure is triggered, or the Joint Radio Resource Management function is consulted by the LSAM and an inter-system handover for one or more users is performed.

2.3.1.4 Advanced Radio Resource Management (ARRM)

Advanced Radio Resource Management (ARRM) defines a set of controlling mechanisms whose goal is to optimise the usage of radio resources and to maximize the system capacity. ARRM includes Joint RRM (JRRM) functions (e.g. joint admission control, joint load control) for interworking Radio Access Technologies. Thorough information on ARRM architecture can be found in [3]. The interfaces and procedures involving ARRM/JRRM are defined in Table 2-4.

Procedure	Sender	Receiver	Message	Parameters	Comments
I	DNPM / GSAM	JRRM	Request Key Performance Indicators (KPIs)	Region considered	-
II	JRRM	DNPM / GSAM	Transmit KPIs	KPIs	-
III	LSAM	JRRM	Request inter-system handover for one or more users	User equipments classmarks	-
IV	JRRM	LSAM	Accept or reject inter-system handover for one or more users	Assigned RATs for one or more users	-

Table 2-4: Procedures and Interfaces Involving the ARRM/JRRM

2.3.2 Multiple Administrative Domains

This section addresses the flexible usage of spectrum between two or more network operators. A market-oriented approach is considered here where the spectrum usage rights can be transferred from a primary operator to a secondary operator. Spectrum leasing is a typical use case [10]: A secondary operator (i.e. spectrum renter) trades and leases for a certain period of time spectrum unused by the primary operator (i.e. spectrum owner).

2.3.2.1 Meta-operator / Inter Operator Economic Manager (IOEM)

Two business models are defined in E^2R for flexible spectrum usage scenarios between operators: Either the transfer of spectrum usage rights is performed via a meta-operator, or it is performed directly between two operators.

In the first situation, the meta-operator provides the bridge between different spectrum owners and spectrum renters. When auctioning methods are used to trade the spectrum, it acts as the auctioneer, receives spectrum bid offers from spectrum renters, selects appropriate spectrum owners and decides the price and amount of spectrum blocks to be transferred.

In the second situation, both Inter Operator Economic Managers (IOEMs) of the spectrum owner and of the spectrum renter are responsible to trade the spectrum and to negotiate the price and amount of spectrum blocks to be transferred.

2.3.2.2 Inter Operator Resource Management (IORM)

After the trading procedure between spectrum owners and renters, the Inter Operator Resource Management calculates the optimal location of the spectrum (owned and leased) and guard bands. Then it informs the Global Spectrum Allocation Manager of the result of the calculation.

3. NETWORK ARCHITECTURES

The work presented below presents physical realizations of the RMP, namely 1) the RCM, which resides in the core network domain or in a Trusted Third Party (TTP) domain, 2) the R-RSF in the multi-RAN Manager, and 3) local reconfiguration managers (i.e. MSBS, CMM). Radio resource management and the building blocks of the functional network architecture are grouped into three tiers, namely the radio access, switch and O&M control, and policy, service and subscription server tiers. Subsequently, the integration of radio resource and spectrum management functionality is investigated. RMP is modelled as three-tier organization of reconfiguration managers within a single administrative domain. This pair of functional elements is capable of interworking with systems not offering all areas of traditional management and control, such as Wi-Fi islands.

In highlighting important architectural guidelines for building physical configurations, principles and major functions involved in a three-tier control and management configuration are stressed. By doing so, functional distribution to network elements along with detailed description of these network elements is facilitated.

3.1 Architecture Guidelines

With the emerging high throughput based RATs, some legacy interfaces might become over-killed, e.g. Iub interface. In order to reduce the CAPEX and OPEX, we target at a network architecture allowing more open interfaces and peer to peer communication topologies. According to the following principles, we propose three-tier architecture.

Difference of the tiers is mainly due to the hierarchical location settings of the involving entities in the end to end reconfigurable system. The principle is that entities which are physically limited to the cell (radio access level) level are defined in the 1st tier. Functions which must control several cell radio access level entities are set to be the 2nd tier. Functions which control the overall system behaviour and interworking with other organizations (operators) are defined in the 3rd tier.

Functions/algorithms of user plane and control plane in the radio sub-system, O&M subsystem and switching subsystem are not limited by tier definition. The interfaces between neighbour tiers have therefore multiple definitions crossing the domains. The interworking of the network architecture is envisaged in three-tiers, namely:

Tier 1, radio Access: here radio subsystems are considered including MSBS. The following functions are typical examples of tier 1 radio access:

- Some JRRM Functions: Channelisation code in CDMA, Joint Power control between interfering RATs, Vertical Handover (intersystem handover), Joint Scheduling: the scheduler could even work over multiple RAT/frequency layers, e.g. HSDPA with two frequency layers supporting RMH, Joint load control, when this function is combined with LSAM, spectrum allocation over selective multi-carrier is involved, Diagonal Handover (handover between RATs and also with dynamic frequency reallocation) in a distributed manner,
- Some Spectrum Management Functions: Auctions through radio access for cognitive radios, e.g. LSEM, LSAM, Secondary spectrum usage between operators and negotiations are through radio protocol,
- Some DNPM functions: Network Elements, Power proportion setting for HSDPA, Antenna angel, Reconfiguration between RATs in MSBS, Spectrum allocation for RAT.

Tier 2 Switching and Routing: Soft switches or relays, we can envisage the RAN manger with enhanced functionality of SGSN, typical examples of tier 2 functions are:

- Some JRRM Functions: IP based handover (FMIP and HMIP), Joint radio admission control by selecting active set and candidate set for the involving RATs operated in the MSBS,
- Network Management and Planning Functions: Traffic database, Policy on reconfigurability, e.g. angel of antenna and minimum guard band requirement for inter-RATs spectrum allocation, Ontology between element managers, Inter-operator economic manager (IOEM) in mid term, Inter-operator resource manager (IORM) in mid term, GSAM.

Tier 3 Subscriber/Services Server: In this level O&M functionality is embedded, the functions encompassed in this tier are:

- Some policy functions: AAA, Billing, Roaming Control for end users, Spectrum access policies for end users,
- Operator and supplier specific functions: Meta Operator, IOEM in long term, IORM in long term, Roaming agreement, HRM (home reconfiguration manager), Manufacture server, EIR (equipment identity register),
- Server for Services: IMS, HSS/HLR, Software download server,
- Some radio domain functions enabling RRM: Open interfaces for policy based ARMH (e.g. scalable video codec, scalable HTTP services, in-online and main objects), Home agent for mobile IP.

3.2 System physical elements

Future mobile and wireless communication systems will support multiple access on heterogeneous networks. For multi-radio access, several networking architectures that offer potential flexibility and cost advantages over the current RAN architecture have been identified. In [11], new distribution of RAN functionalities between existing nodes e.g. moving radio related protocols closer to radio interface which leads to shorter delays for users, necessary interface enhancements, improvements in protocol stacks and enhancements of UTRAN procedures to support the evolved UTRAN architecture has been studied. In this section we propose network architecture suitable for heterogeneous radio access technologies (RAT) in which the radio functionalities are distrusted moved down to the access nodes (e.g. Node B). The proposed network architecture facilitates efficient use of resources, access to all-IP core network, while it aims at minimizing the CAPEX and OPEX by simplifying the existing network hierarchy and evolving towards multi radio and all IP networks.

The E^2R network architecture should include the following points:

- Reduced latency and provision of high bursty throughputs due to fast spectrum allocations and JRRM schemes
- Integration of reconfiguration and download support functions based on RMP for intelligent MSBS and terminal

Main building blocks of the E^2R network architecture shown in Figure 3–1 are described below.

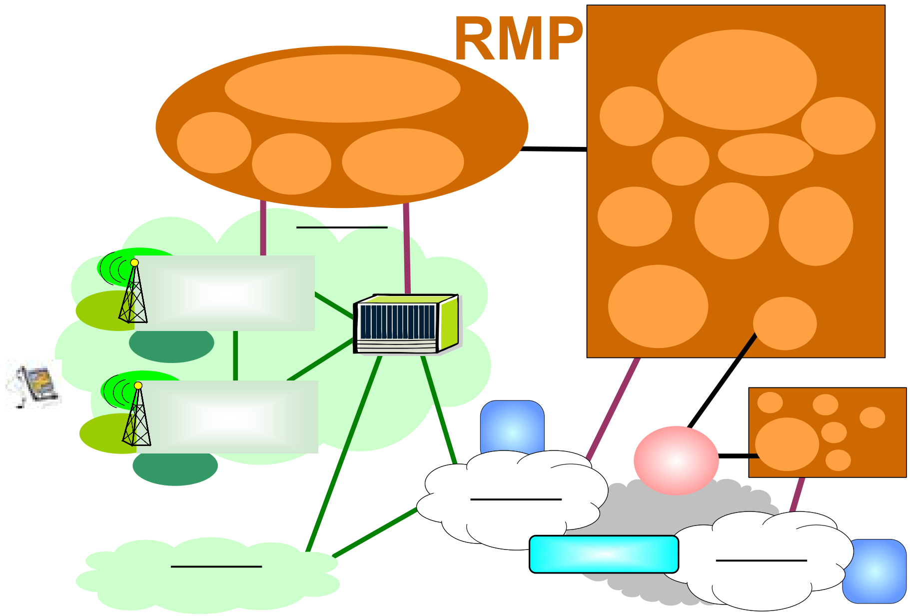


Figure 3–1: E²R Network Functional Architecture

3.2.1 The Reconfiguration Manager

The main RCM modules are responsible for the control and management of terminal and base station reconfiguration are the Reconfiguration Management Module and the Policy Provision Module.

The *Reconfiguration Management Module (RMM)* initiates network-originated and coordinates device-initiated configuration commands, by communicating with Reconfiguration Support Functions at the User Equipment (i.e., the CMM), 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 signalling 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 *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.

3.2.2 Radio Reconfiguration Support Function

This RAN manager/server is the anchor point towards CN managing the data flow to/from the CN. It acts as policy servers for higher layer JRRM, DNPM & Spectrum Management within one intra-domain - multi-standard operator. Parts of the R-RSF functions are distributed in this node such as inter standard functions, i.e. Mode/RAT discovery and mentoring, handover, negotiations. The RAN manger includes also some of the RNC mobility related functions, e.g. micro mobility (paging and MSBS reallocation).

This concept fits well in a system incorporating Joint Radio Resource Management (RRM) and Dynamic Network Planning and flexible network Management (DNPM). The R-RSF implements interfaces to a variety of radio access protocol suites, in dependency of the composition of the heterogeneous RAN.

Examples of Radio Network System controlling entities in a Composite RAN are the BSC/RNC for a GERAN/UTRAN access network, the WAG/PDG for a WLAN/Wi-Fi hot spot, and the Access Point Controller (APC) for a WiMAX or DxB access network.

Terminal-oriented R-RSF functionalities span RMP down to the composite RAN to support seamless service continuity, by enabling fast environment scanning when managing the context of the multi-access network. The R-RSF assists the terminal by interacting with Radio Network Layer elements of available RANs, implementing interworking functions where needed. The translation mechanisms occur in the access stratum towards Radio Elements in different RANs and/or operator domains. Therefore, the terminal reconfiguration process benefits from rapid detection, identification, monitoring, negotiation, and selection of the most suitable RAN. Furthermore, traffic management for spectral efficient downloads is enhanced in that interworking is closer to the radio resource controlling servers.

The apportionment of responsibilities between the R-RSF and the terminal depends on the capability to instantiate simultaneously radio links to other RANs. Hence, the terminal can also process mode monitoring, negotiation and selection on its own. Such feature requires the terminal to embed most of the functionality of the process, implying heavy local processing. Following modular architectural approach, R-RSF incorporates terminal and base-station-oriented mechanisms, either common to both types of reconfigurable equipment or tailored to specific requirements of terminals and base stations.

Discovery and Monitoring in the R-RSF facilitate interaction with Positioning, Initial Access and Information Broadcast. At Radio Network Layer, the Discovery and Monitoring module requests information from the surrounding radio layer controllers (i.e. RNC, BSC, APC); this data refer to system information such as deployed technologies, frequencies of transmission and timely service availability in dependency of load. In addition, Handover and Mobility functions are enabled and supported by the R-RSF, including functions such as Policy, QoS, HO, and Profile management. The Mode and Service Negotiation Management in the R-RSF consists of Mode Negotiation and QoS Mapping functions.

The inclusion of the most advanced RRM functions in wireless communication systems will depend on the evolution of radio regulations, the definition of new air interfaces, etc. Nevertheless, it can be roughly estimated that a time frame of 10 to 15 years is realistic. Thus, it is of high importance to align the WP3 architecture with existing 3GPP work on system architecture evolution.

3.2.2.1 Mapping of Wireless Resource Management (WRM) functions to Network Control and Management Architecture

DNPM and GSAM may be distributed in the evolved RAN subsystem and in the O&M subsystem if information can be exchanged between basestations/access points. In such a case, a decentralized optimisation strategy can be adopted and basestations/access points decide autonomously appropriate reconfiguration

LSAM and LSEM are located within the evolved RAN (i.e. near the basestations/access points) since the time interval between two spectrum auctions is assumed to be short (e.g. seconds)

IOEM and IORM are located within the evolved O&M subsystem (RCM) as the time interval between two auctions is assumed to be long (e.g. several hours to several days/months).

The mapping of WRM functions to the network support architecture is shown in Figure 3–2.

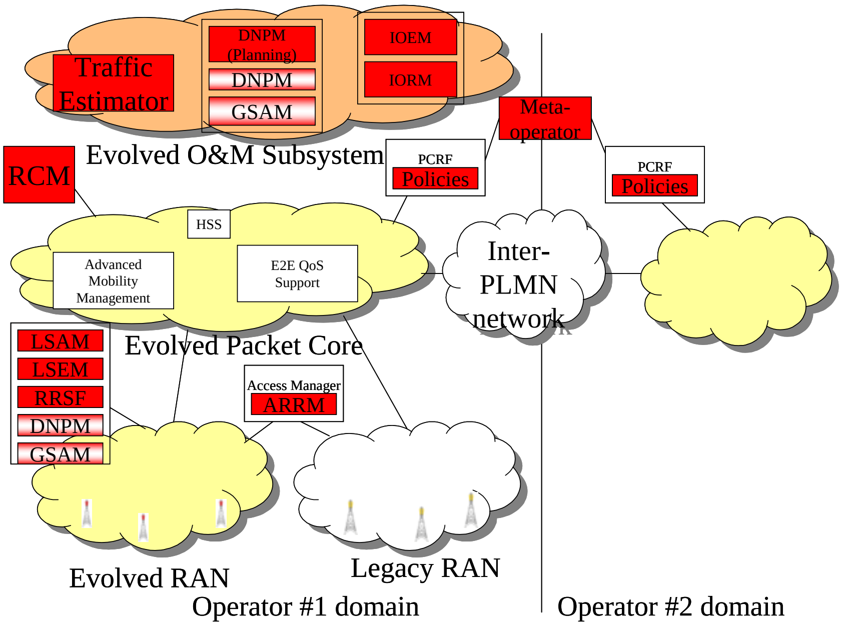


Figure 3–2: Enhanced Network Control and Management Architecture

3.2.3 Multi-Standard Base Station (MSBS)

A reconfigurable base station/or multi standard base station can support more than one standards and radio front-ends at the same time e.g. (3G, 3.xG, 4G, IEEE standards); a typical example of MSBS is the Hotel Base Station concept. Some of the RAN Reconfiguration Support Function (R-RSF) are including in the MSBS. Some of the radio resources management functionality are introduced to this smart node for example lower layer or fast RRM, e.g. Joint Scheduling, spectrum allocation functionality between standards.
Base-station-oriented R-RSF functionalities also fall within the access stratum sphere. The DNPM mechanisms interwork with RMP layer management functions local to Radio Network Subsystems (i.e. RAT-centric O&M functions as presented in [12]). BS Service Profile Management describes the Hardware, Software, and Functional (e.g. air-interface) capabilities; SW Download Management manages the download of additional or new software modules required for a specific configuration; Load/Traffic Management controls the allocation of resources to a specific standard; Performance/Load Monitoring monitors the hardware and software resources within a Base Station.

The interactions between the R-RSF and the RCM RAT-centric O&M functions should be automated for the implementation of the required reconfigurations after the analysis of RAT-specific performance data. In addition, the R-RSF and the RCM RAT-centric O&M should collaborate for the definition of Joint RRM policy rules (e.g. RSSI thresholds, OFDM code generation, admission control, traffic distribution), which are stored in the Policy Provision System. Then, the RCM Policy Provision Module retrieves and delivers these conditions to the R-RSF for policing the Joint RRM procedures.

3.2.4 The Configuration Management Module (CMM)

This section describes the reconfiguration support functionality residing in the equipment. These functions are locally controlled by the different CMMs interacting locally in the terminal but also with R-RSF entities. Focus is precisely on the interaction with the R-RSF for different phases of the reconfiguration process such as monitoring, discover, negotiation, selection, download, etc. More details can be found in [13].

The CMM modules manage all configuration tasks in the equipment according to specific semantics and configuration data, as well as the negotiation of reconfiguration decisions with other entities. The following modules comprise the configuration management architecture:

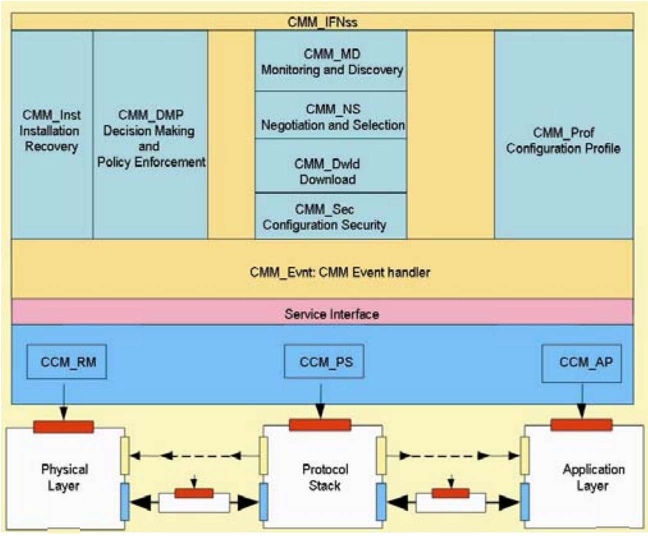


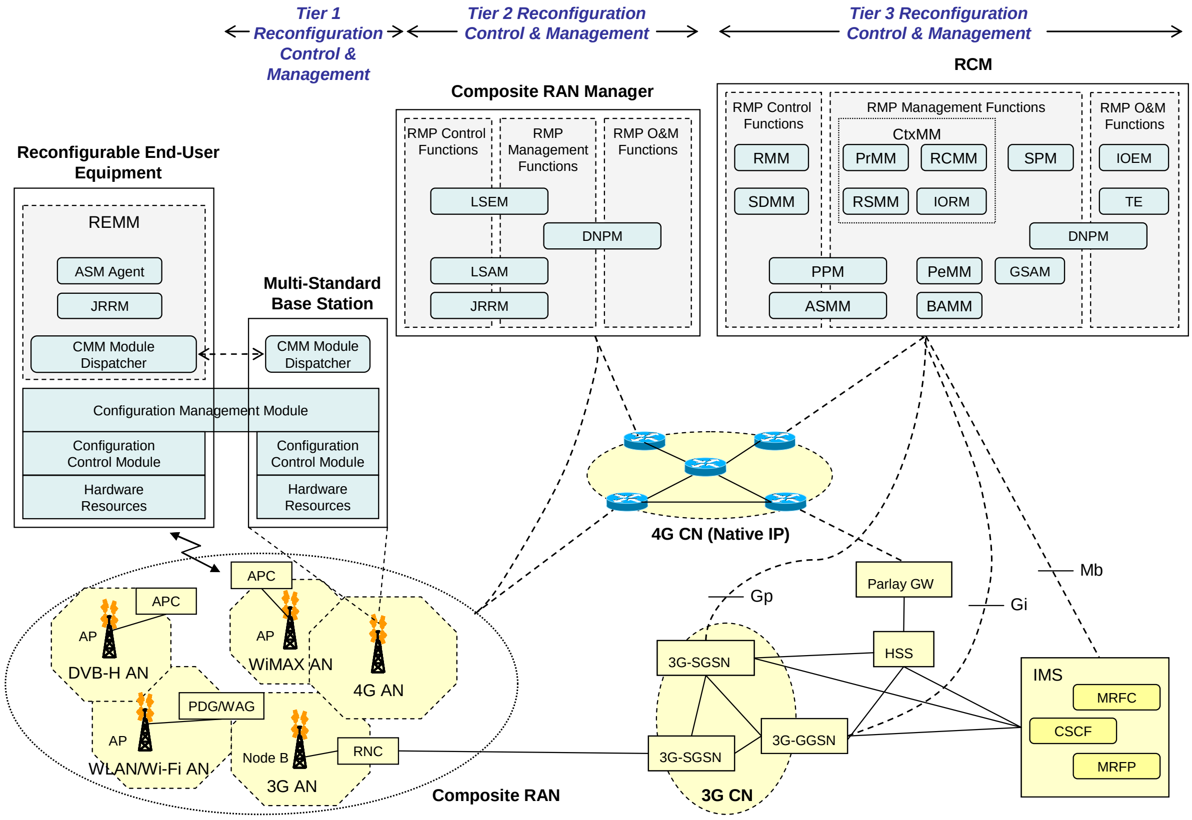
Figure 3–3: The Configuration Management and Control Architecture

3.3 Distribution of RMP functional architecture

The building blocks distribute in Reconfigurable System in Plane and Layer Management planes as depicted in Figure 3–4. The RCM comprises a realization of the RMP logical model to the heterogeneous network architecture. In order to cope with complex and interleaved 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 (TTP) 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.

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 Wi-Fi or WiMAX hot-spot, the RCM-RMM should undertake the transfer of the necessary MM context from the source SGSN to the target Wi-Fi/WiMAX Access Gateway / Packet Data Gateway (WAG/PDG). Mapping the MM context to the target MM information elements should be performed by the RCM-RMM as well, thus achieving hard and soft handover scenarios.



3G	Third Generation
4G	Fourth Generation
AN	Access Network
AP	Access Point
APC	Access Point Controller
ASM	Advanced Spectrum Management
ASMM	Access and Security Management Module
BAMM	Billing and Accounting Management Module
CMM	Configuration Management Module
CN	Core Network
CSCF	Call-Session Control Function
CtxMM	Context Management Module
DNPM	Dynamic Network Planning and Management
DVB-H	Digital Video Broadcast – Home
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSAM	Global Spectrum Allocation Manager
GW	Gateway
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
IORM	Inter-Operator Resource Manager
IOEM	Inter-Operator Economic Manager
JRRM	Joint Radio Resource Management
LSAM	Local Spectrum Allocation Manager
LSEM	Local Spectrum Economic Manager
MRFC	Multimedia Resource Function Controller
MRFP	Multimedia Resource Function Processor
O&M	Operations and Maintenance
PDG	Packet Data Gateway
PeMM	Performance Management Module
PPM	Policy Provision Module
PrMM	Profile Management Module
RAN	Radio Access Network
RAT	Radio Access Technology
RCM	ReConfiguration Manager
RCMM	Reconfigurability ClassMarking Module
REMM	Reconfigurable Equipment Management Module
RMM	Reconfiguration Management Module
RMP	Reconfiguration Management Plane
RNC	Radio Network Controller
RSMM	ReSource Management Module
SDMM	Software Download Management Module
SGSN	Serving GPRS Support Node
SPM	Service Provision Module
TE	Traffic Estimator
WAG	WLAN Access Gateway
Wi-Fi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Network

Figure 3–4: Functional architecture for Composite Reconfigurable Systems

4. Novel 'Network-assist' Solutions for Reliable Multicast Reconfiguration Downloads

Having discussed important network entities for reconfiguration in some detail, in this section we outline two simple 'network-assist' functionalities useful for mass reconfiguration downloads (mass-upgrades) in generic IP networks supporting IP-multicast. Both schemes relate to improving the scalability of reliable multicast. Note that both schemes are also useful to improve the scalability of a solution presented in [2], dynamic switching between one-to-many download methods, in multicast mode of the download.

4.1.1 Aggregation of Bitmapped NAK Feedback Packets

Each source-receiver path in a reliable multicast session commonly has a unique lossy profile. Packet losses on each source-receiver path must therefore be monitored, and this necessity often makes feedback volume an issue. Although the use of negative acknowledgements (NAKs) somewhat improves the situation, for medium- to large-scale reliable multicast sessions the risk of a *feedback implosion* [14] is still such that a number of mitigating techniques have been heavily investigated by the research community, among which prime contenders are feedback suppression [15][16][14] and the use of proactive Forward Error Correction (FEC) [17]. However, a technique that is often appropriate, and that is perhaps underused, is to relay packet success information in a bitmap form for each transmission group of download packets. This would greatly reduce feedback load through lowering the mean header overhead per feedback notification for each download packet.

Aforementioned approaches to feedback reduction are all end-to-end, meaning that they do not require any multicast supporting technology (or 'multicast-assist') in routers aside from the default IP Multicast. Although these schemes are promising, and other options largely based on the effective administration of parity coding [17][18][19] further improve prospects, scalability will ultimately always be an issue if indeed it is to be ensured that 100% reliability is preserved. Alternatively, approaches exist that are not truly end-to-end, but that through the use of *optional* router-assist functions are able to improve the scalability of multicast downloads in a more robust manner. *Feedback aggregation* is one of the most prominent of these router-assist schemes.

The objective of feedback aggregation (sometimes termed feedback 'elimination') is simply to store feedback packets (or information about them) in routers for a certain time period, and to discard any matching incoming feedback packets within that time, thereby reducing repetition in the collective feedback packet array [15]. Unfortunately however, no technique has thus far been suggested for performing aggregation of bitmapped feedback packets, despite bitmapped feedback being far more efficient as previously indicated. Here we suggest such a scheme.

4.1.1.1 Bitmapped NAK Feedback Aggregation Architecture

Our bitmapped feedback aggregation scheme is conceived to be easily incorporated into present routers with few changes to their functions. Although by necessity such a scheme must be stateful in approach, we ensure that state storage requirements are minimal.

The algorithm for a simplified IP router, ignoring optional capabilities such as QoS provisioning, is depicted in Figure 4–1(a). Evolved from that, our updated router algorithm incorporating the option of bitmap NAK aggregation is shown in Figure 4–1(b). Upon the arrival of a packet at the router, our scheme progresses as follows:

Step 1

The IP header checksum/length/version are verified as per normal. The packet is dropped if any of these are incorrect.

Step 2

The port field is inspected and compared to entries in the *offsetTable*, as applies for bitmapped NAK aggregation (Table 4-1). If the port is matched to a known port for which bitmapped feedback should apply, the incoming packet is passed through our feedback aggregation process. Otherwise, the router acts on the packet as per normal.

Step 3

The position of the multicast feedback sequence number (seqno) *s* in the feedback packet is found from the offsetTable. Note that the multicast feedback seqno generally represents the transmission group of the download for which the bitmap NAK applies. There is always a field in bitmapped feedback packets that corresponds to this information, although it might take a range of names dependent on the utilized protocol.

Step 4

The algorithm checks to see if there is a packet already stored for seqno *s*.

(a) If there is a packet stored, the bitmaps of the incoming packet and the stored packet are logically ORed together in a bitwise fashion, and the resulting bit pattern replaces the bitmap in the stored packet. The incoming packet can then be discarded.

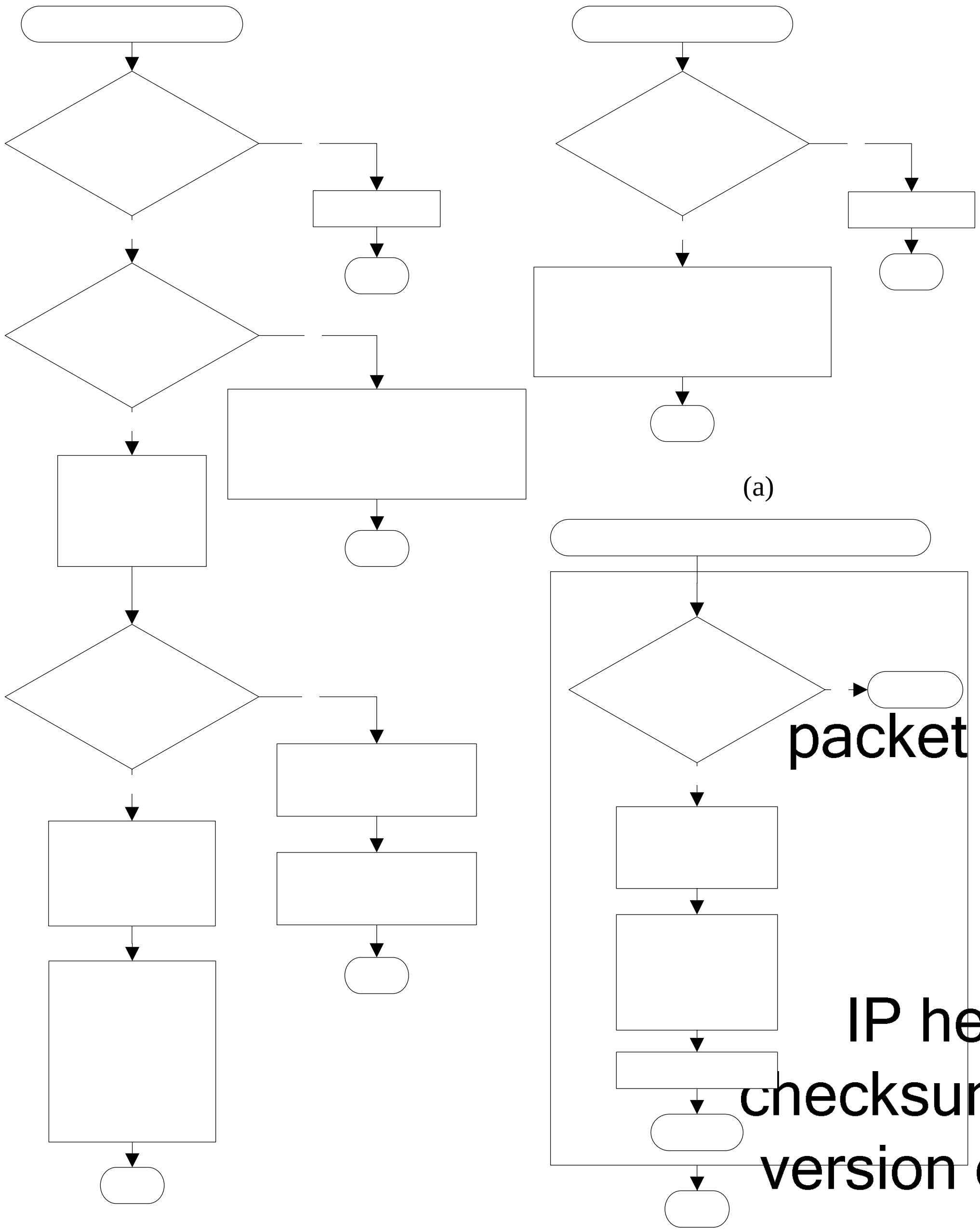
(b) If there is not a packet stored, the incoming packet is stored in the router. A feedback aggregation timer T_s is invoked, and any further incoming packets for seqno *s* within the aggregation period T_A are aggregated with the new stored packet.

In addition to the above, it is necessary to detect when feedback timers have exceeded the aggregation period T_A, and to act accordingly. Timer expiration checks therefore are triggered periodically through timer interrupts. As indicated in Figure 4–1(c), if the timer T_s has expired, the simple tasks are to forward the stored (aggregated) bitmapped feedback packet for sequence number s upstream, and to delete the timer T_s.

To achieve the bitmap aggregation process across a range of different multicast protocol types, we must define a mapping between packets and their multicast transport protocol, hence the position (offset) of necessary information within these packets. For our purposes, this necessary information comprises the feedback seqno (typically the block number of the download packet array), and the actual bitmap that is to be aggregated. It is safe to assume that the port number uniquely identifies the underlying reliable multicast transport protocol as used by the associated application. Hence port numbers must be read and mapped to known protocol offsets using the *offsetTable*, an example of which is provided in Table 4-1 for the case of bitmapped NAK aggregation. This offsetTable is intended to be updatable in routers upon the design of new multicast transport protocols, hence should be maintained in a writable storage medium.

	Port Number	Seqno. field offset (bytes)	Bitmap field offset (bytes)	Bitmap field size (bytes)
Protocol 1	1332	2	4	2
Protocol 2	4355	4	6	8
Protocol 3	14334	6	8	4
.	.	.	.	.
.	.	.	.	.

Table 4-1: Example of an offsetTable for bitmapped NAK feedback aggregation



(a)

(b) (c)

Figure 4–1: Simplified functioning of an IP router, (b) an updated router supporting the proposed bitmap NAK aggregation process, and (c) the timer expiration check routine

4.1.2 Constrained Multicast Retransmission Forwarding under Bitmapped Feedback Packets

In scenarios where retransmissions are sent 'end-to-end', to the same multicast group as original data packets, constrained retransmission forwarding (see e.g. [15]) is far more efficient than retransmissions to the whole group. Moreover, as discussed previously, the use of bitmapped packets is preferable to convey feedback to the source, because the feedback packet header overhead is shared among feedback notifications for a number of multicast download packets. Hence in this section, we suggest a scheme for using constrained retransmission forwarding in routers, which is operable in cases where feedback is sent in a bitmapped form. Such an approach has yet to be conceived by the research community, despite the far superior multicast scalability that it would achieve.

4.1.2.1 Constrained Retransmission Forwarding Algorithm

Upon the arrival of a packet at the router, the constrained retransmission forwarding algorithm progresses as follows (see Figure 4–2):

Step 1

The IP header checksum/length/version are verified as per normal. The packet is dropped if any of these are incorrect.

Step 2

The port field is compared to entries in the *offsetTable* as applies for constrained retransmission forwarding (Table 4-2). If the port is matched to a port for which constrained retransmissions apply, the packet is passed through the constrained retransmissions process. Moreover, if the port also matches one for which bitmapped NAKs apply, the constrained retransmissions process with bitmapped NAKs is used.

Step 3

(a) Constrained retransmissions:

The position of the multicast download sequence number (seqno) *s* in the feedback packet is found from the offsetTable. This seqno is then matched to the multicast group *g* and the incoming interface of the feedback packet, and a state is stored for that seqno/group combination denoting the incoming interface. If a state for the seqno/group combination already exists, the new incoming interface of the feedback packet is added to that state, unless that interface is already specified in the state.

(b) Constrained retransmissions with bitmapped NAKs:

The Transmission Group (TG) for which the feedback packet applies is found from the offsetTable. This TG is then mapped to its multicast download seqno range. The bitmap range in the feedback packet is obtained from the offsetTable, as well as the endianness of the bitmap, and the bits in the bitmap are correspondingly matched to multicast download seqnos. The feedback packet's incoming interface is therefore linked to each download seqno/group combination within the bitmap range, and a state is created for the seqno/group combination (denoting the incoming interface) if the seqno's corresponding bit is set such to indicate a lost packet.

Step 4

Multicast download packets with ports for which either form of constrained retransmissions apply have their seqno/group combination compared with stored seqno/group states (as obtained in step 3 (a)/(b) above). If a matching stored seqno/group combination state is found, that packet is forwarded only on the downstream interfaces indicated by the stored state.

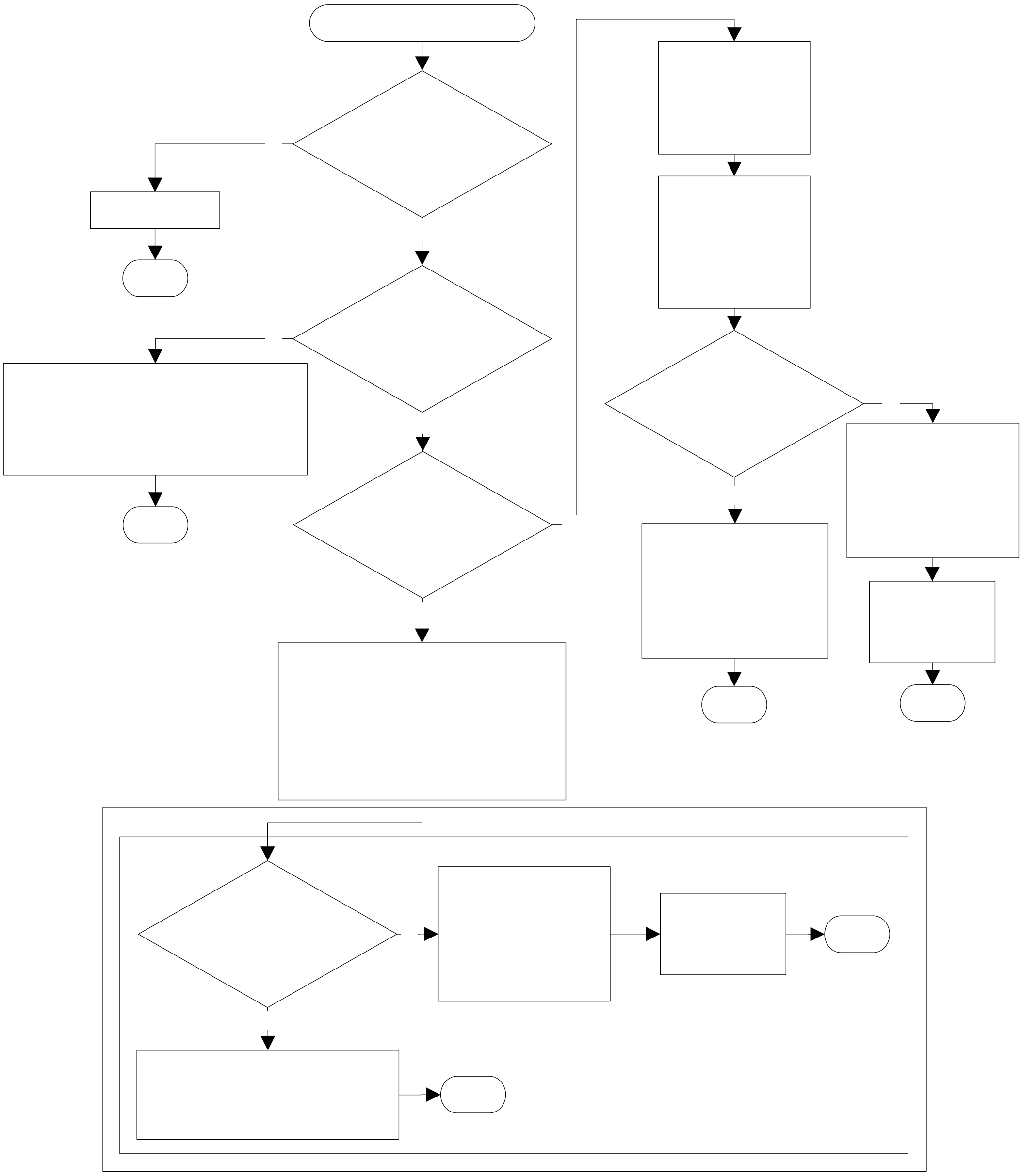


Figure 4–2: A router algorithm supporting our proposed constrained retransmissions scheme

In addition to the prior methodology, it is necessary to set timers for seqno state storage in routers in order to limit router loads. A timer is created immediately upon instantiation of each seqno state, which must also be identified with the multicast group for which it applies. Timer expiration checks are triggered periodically through timer interrupts, upon which all current timer objects are tested. If the timer $T_{s,g}$ has expired, the seqno/group combination state for $T_{s,g}$ and the timer itself are simply deleted.

To achieve the process across a range of multicast protocol types, we must define a mapping between packets and their transport protocol, thence the position (offset) of necessary information within these packets. For our purpose, this necessary information comprises the feedback seqno or the multicast TG number, the size of this field, the location of the bitmap field, the size and endianess of the bitmap field, and an indication as to whether ‘1’ or ‘0’ bit value is used to signify a lost packet, possibly among other information. It is safe to assume that the port uniquely identifies the underlying reliable multicast transport protocol as used by the associated application. Hence port numbers must be read and mapped to known protocol offsets using the *offsetTable*, an example of which, as applies for constrained retransmission forwarding, is provided in Table 4-2. The offsetTable is intended to be dynamically updatable in routers upon the design of new multicast transport protocols, so must be maintained in a writable storage medium.

	Port Number	**Seqno/TG field offset (bytes)**	**Seqno/TG field size (bytes)**	**Bitmap field offset (bytes)**	**Bitmap field size (bytes)**	**Bitmap endianess (1=little, 0=big)**	…
Protocol 1	1396	2	2	4	2	1	…
Protocol 2	2232	4	2	8	8	0	…
.	.	.	.	.	.	.	
.	.	.	.	.	.	.	

Table 4-2: Example of an offsetTable for constrained retransmission forwarding

5. CONCLUSIONS

While a number of promising mechanisms for management and control of reconfigurable networks in various areas have been suggested, a lot more research has to be performed to identify and understand the underlying common principles and thus gradually approach the far-reaching goals of design of architecture for Reconfigurable Systems. While long-term research should be focussed on adaptive algorithms to realize smartness and self-optimizing behaviour, the next steps should be ventured in the areas of radio context awareness and cognitive networks. In this paper the radio resource management and the building blocks of the functional network architecture is presented. These blocks are grouped into multiple tiers. Subsequently the integration of radio resource and spectrum management functionality is investigated. The Reconfiguration management plane is modelled as horizontal, multiple-tier organization of reconfiguration managers within a single and multiple administrative domains. Summarizing the new trends for system architecture evolution and management reside on defining and designing the architecture that scaleable and distributed, i.e. provide network operators the ability to expand specific functions within the network without unnecessary expansion in other functions, and support the decomposition of monolithic functionality into a distributed IP based system, thus enabling a far more scaleable, open network, with open, standardized interfaces. Moreover a plane management and layer management functions as an extension to the traditional legacy plane that cater for reconfiguration-related tasks, such as context management, policy provision, service management, and reconfiguration and download management is proposed in this paper.

Pioneering network architectures supporting reconfigurability are extremely important for their ability to satisfy a range of requirements of terminal reconfiguration in mobile networks. However, progress in the field of reconfigurability can also be made on the level where minimal assumptions are made about network entities, aside from supporting IP and other basic functionalities such as IP-multicast. In this context, two simple network-assist schemes for reliable multicast downloads have been introduced, thus making mass-upgrades of terminals in heterogeneous networks easier. The first of these, aggregation of bitmapped multicast feedback packets, greatly reduces the risk of a 'feedback implosion' due to feedback load in a large-scale reliable multicast download. The second of these schemes, a constrained retransmission forwarding approach which is operable where bitmapped feedback packets apply, reduces the *transmission inefficiency* inflicted by the need to retransmit lost packets to the multicast group. Operating in tandem, these solutions might improve the scalability of a mass-upgrade (in terms of number of receivers) by many orders of magnitude, even under severe random (wireless) packet loss scenarios.

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