IEEE P1900.4 System Overview on Architecture and Enablers for Optimised Radio and Spectrum resource usage

Soodesh Buljore[1], Vincent Merat[1], Hiroshi Harada[2], Stanislav Filin[2], Paul Houze[3], Kostas Tsagkaris[4], Vladimir Ivanov[5], Klaus Nolte[6], Tim Farnham[7], Oliver Holland[8]

1: Motorola Labs-Paris; Soodesh.buljore@motorola.com, vincent.merat@motorola.com, 2 NICT; harada@nict.go.jp, sfilin@nict.go.jp, 3: France Telecom R&D; paul.houze@orange-ftgroup.com , 4: University of Piraeus; ktsagk@unipi.gr 5: Intel; vladimir.ivanov@intel.com, 6: Alcatel Lucent; , Klaus.Nolte@alcatel-lucent.de 7: Toshiba Research Lab-UK; Tim.Farnham@toshiba-trel.com 8: Kings College London; oliver.holland@kcl.ac.uk

Abstract— **The field of application of the IEEE P1900.4 standard is radio systems forming a composite radio access network, i.e. with multi-Radio Access Networks (RAN) using different Radio Access Technologies (RAT). The end-user terminals are multimode terminals, supporting several RATs, with multi-radio link capabilities and having cognitive radio capabilities, such as operating flexibly on different frequency bands. The composite radio access network is assumed to be operated by either a single or several operators. Within this field of application, the standard provides common means to improve overall composite capacity and quality of service through distributed optimization of the usage of spectrum and radio resources offered by the composite radio access network. Basically, the optimization relies on a collaborative information exchange between the composite network and terminals. For this purpose, two entities are identified to facilitate this collaboration: Network Re-configuration manager (NRM) and Terminal Re-configuration manager (TRM), whilst the communication between NRM and TRM is ensured via a logical communication channel, the Radio Enabler (RE). Accordingly, this paper provides an overview of the IEEE P1900.4 scope and purpose, the reference usage cases wherein the standard would be applicable, including system requirements, architecture, and its reference model with main interfaces linked to the information model that is currently being developed.**

Index Terms—***IEEE standardization, SCC41, dynamic spectrum access, dynamic spectrum assignment, cognitive radio, composite network, network architecture, reconfiguration, heterogeneous radio access networks, distributed radio resource management***

I. Introduction

IEEE P1900 is a new standards series within the IEEE, established in 2005 jointly by the IEEE Communications Society and the IEEE Electromagnetic Compatibility Society. Its objective is to develop supporting standards dealing with new technologies and techniques being developed for next generation radio and advanced spectrum management. In March 2007, IEEE P1900 was reorganized under the Standards Coordination Committee 41 (SCC 41) [1]. Currently, there are five working group within SCC41; namely 1) P1900.1 WG is in sponsor balloting process for *Standard Definitions and Concepts for Dynamic Spectrum Access: Technology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management;* 2) P1900.2 WG for *Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems*, has successfully passed the sponsor ballot and submitted to Revcom;3) P1900.3 WG Project Authorization Request (PAR) has been approved by IEEE SDCOM with a broader scope to support merging of P1900.3 and 1900a study group to define a *Standard for Assessing the Spectrum Access Behavior of Radio Systems Employing Dynamic Spectrum Access Methods*; 4) P1900.4 working group which is the subject of this paper; 5) P1900.5 working group dealing with Policy Language and Policy Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications; and finally a study group on sensing in dynamic spectrum access (DSA) and advanced radio systems working towards a working group creation.

In February 2007, the IEEE P1900.4 WG [1] was launched under P1900, based on the P1900.B study group [3], and entitled “Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks”. This group aims at standardizing cognitive radio access networks and is active in defining radio access network architectures and functions for distributed decision making to optimize radio resource usage [4][5].

Three reference use cases are defined [6]: (i) “Dynamic Spectrum Assignment,” refers to the process and mechanisms, which dynamically assign frequency bands to Radio Access Networks within Composite Wireless Network operating in a given region and time, in compliance with the regulations

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rules. (ii) “Dynamic Spectrum Access,” refers to the process and mechanisms for a type of spectrum access that occurs when different radio access networks and terminals dynamically access spectrum bands which are overlapping, in whole or in part, causing less than an admissible level of mutual interference, according to regulatory rules, and may be done with or without negotiation. (iii) “Distributed Radio Resource Usage Optimization,” refers to the process and mechanisms by which the optimization of radio resource usage is performed by Composite Wireless Network and terminals in a distributed manner. Based on these use cases, system requirements and corresponding system architecture, functional requirements and corresponding enabling functions and corresponding functional architecture, and an information model and interfaces between P1900.4 entities are being developed.

This paper introduces the activities within IEEE P1900.4, based on the latest discussions and contributions submitted thus far, as well as the baseline document [10] of the standard which is in the process of refinement for working group letter ballot. The remainder of this paper is organized as follows. Section II presents the scope and purpose of the approved Project Authorization Request (PAR) of the WG. Section III discusses the main system assumptions and corresponding approaches which are further illustrating the scope, purpose and need for the project. Section IV describes the three reference use cases currently discussed within the group. Sections V, VI, VII present the system requirements, the derived system architecture (entities and interfaces) and the corresponding reference model. A brief overview of the functional architecture and information model that is derived to date is given in Section VIII. In Section IX, procedures related to the reference use cases between the P19004 System entities are presented. Finally Section X concludes the paper and discusses the next steps.

II. Scope and Purpose

This section outlines the scope and purpose defined in the PAR of IEEE P1900.4 [1].

A. Scope

The standard defines the building blocks comprising network resource managers, device resource managers and the information to be exchanged between the building blocks, for enabling coordinated network-device distributed decision making which will aid in the optimization of radio resource usage, including spectrum access control, in heterogeneous wireless access networks. The standard is limited to the architectural and functional definitions at a first stage. The corresponding protocols definition related to the information exchange will be addressed at a later stage.

B. Purpose

The purpose is to improve overall composite capacity and quality of service of wireless systems in a multiple Radio Access Technologies (RATs) environment, by defining an appropriate system architecture and protocols which will facilitate the optimization of radio resource usage, in particular, by exploiting information exchanged between network and mobile terminals, regardless of their support for multiple simultaneous links and dynamic spectrum access.

C. Need for the Standard

Multimode reconfigurable devices are increasingly being adopted within the wireless industry. The choice among various supported air interfaces on a single wireless device is already a reality today, with devices offering, for example, 2nd, 3rd generation cellular radio access technologies and 802 wireless standards. Further, devices and networks with dynamic spectrum access capabilities allowing the use of spectrum resource simultaneously among different systems are emerging (e.g. IEEE 802.22) and will be part of the radio eco-space. There is a need to define a standard addressing the overall system architecture and information exchange between the network and devices, which will allow the devices to optimally choose among the available radio resources and simultaneously use several of these resources such that the overall efficiency and capacity of the resulting composite network is improved.

III. P1900.4 System Assumptions and Approach

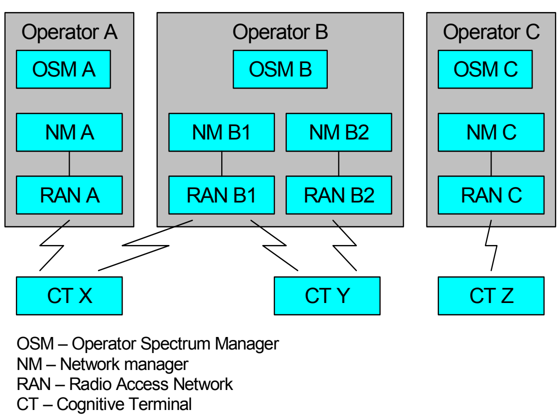
A simplified example of a Composite Wireless Network (CWN), managed by one or several operators in which P1900.4 system will operate, is depicted in Fig. 1(a). The key assumption is that devices (access points and end-user terminals) operating in such composite network (network comprised of several radio access networks: RANs) have multi-mode capability with advanced features, such as support for simultaneous links on different radio access technologies and corresponding spectrum bands/channels.

IEEE P1900.4 considers a heterogeneous wireless environment involving multiple RANs (which may be of different RATs) belonging to different network operators (see Fig. 1(a)). The considered environment may also comprise the case of a “composite network”, consisting of multiple RANs (which again may be of different RATs), under the control of a single network operator (see “Operator B” in Fig. 1 (a)). Cognitive Terminals (CTs), having multi-mode and/or multi-homing capability, facilitate the standard through being able to connect to one or several RANs/RATs of one or several operators. There are, however, foreseeable scenarios in which the standard remains applicable even if CTs are not present.

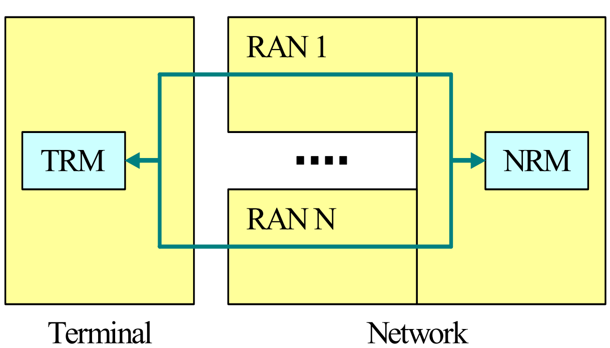
Within Fig. 1(a), the Network Manager (NM) is an existing management entity that supports the RAN by providing functionalities such as initial software downloading, software updating, RAN state monitoring, fault monitoring, RAN reconfiguration, etc. It is assumed that the Operator Spectrum Manager (OSM), in the case of multiple RANs existing per operator, has the role of providing some level of collaboration between RANs, including RAN reconfiguration to change the current spectrum assignment. In case of one RAN existing per operator, the OSM provides the operator an opportunity to express its intentions regarding possible changes to the spectrum assignment. In either case, the OSM manages RANs within one operator only.

Above this heterogeneous wireless environment, IEEE P1900.4 specifies a management system comprised of a Network Reconfiguration Manager (NRM), Terminal Reconfiguration Managers (TRMs), and interfaces between these elements Fig. 1(b). The purpose of this management system is to optimize radio resource usage, including overall capacity and quality of service among the participating networks.

The P1900.4 system (shown in an simplified way in Fig. 1(b) will comprise a logical channel through which network and terminals communicate via their respective reconfiguration managers (Network Reconfiguration Manager: NRM and Terminal Reconfiguration Manager: TRM). This logical channel, is called Radio Enabler (RE). The RE may be mapped onto a) one or several legacy RANs already used for data transmission or b) onto one or several dedicated RANs. While in the former case, the RE can be materialised in conjunction with existing channels e.g. Broadcast Control Channels (BCCH) as defined in GERAN (in-band solution), in the latter one, the logical channel (RE) is mapped onto a newly defined, dedicated physical channel and equipment. (out-of-band channel). This is also the case that is selected to be depicted in the figure by using the dotted lines.



(a)



(b)

Fig. 1. (a) Composite Network wherein P1900.4 system is deployed (b) main building blocks of the P1900.4 system

IV. REFERENCE USE CASES.

As stated in the introductory section, three use cases are defined within IEEE P1900.4:

- Dynamic Spectrum Assignment
- Dynamic Spectrum Access
- Distributed Radio Resource Usage Optimization.

In the **Dynamic Spectrum Assignment** use case, frequency bands are dynamically assigned to the RANs among the participating networks in order to optimize spectrum usage. In other words, the assigned frequency bands are not fixed, and can be dynamically changed. OSMs generate spectrum assignment policies expressing regulatory framework and operators intentions regarding possible changes to the spectrum assignment. OSMs provide these spectrum assignment policies to corresponding NRMs. They analyze spectrum assignment policies and available context information and dynamically make spectrum assignment decisions to improve spectrum usage and quality of service. After the new spectrum assignment decisions, NRMs request corresponding reconfiguration of their RANs, BSs and cognitive terminals. For instance, this use case may cover situations where:

- A new carrier is added for 3G access.
- A frequency band previously used for 3G is assigned to mobile broadband wireless access (802.16e).
- Network switches the usage of a spectrum band from mobile broadband wireless access (802.16e) to wireless LAN (IEEE802.11n), if a large number of wireless LAN terminals are suddenly close to the wireless LAN access point.

Single-operator and multi-operator scenarios are possible within the Dynamic Spectrum Assignment use case. Within the multi-operator scenario, the NRM is considered as being located either inside or outside of the operator.

In the **Dynamic Spectrum Access** use case, frequency bands assigned to RANs are fixed. However, a particular frequency band can be shared by several RANs. In other words, the Dynamic Spectrum Access use case describes how fixed frequency bands are shared and/or used dynamically by RANs and cognitive terminals. NRMs analyze available context information and dynamically make spectrum access decisions to improve spectrum usage and quality of service. NRMs make these spectrum access decisions within the framework defined by spectrum assignment policies. Following these decisions, NRMs request corresponding reconfiguration of their RANs. NRMs dynamically generate radio resource selection policies and send them to their TRMs. These radio resource selection policies will guide these TRMs in their spectrum access decisions.

TRMs analyze radio resource selection policies and available context information and dynamically make spectrum access decisions to improve spectrum usage and quality of service. TRMs make these spectrum access decisions within the framework defined by radio resource selection policies. Following these decisions, TRMs request corresponding reconfiguration of their cognitive terminals.

Distributed Radio Resource Usage Optimization use case demonstrates how the IEEE P1900.4 system can be applied to legacy RANs in order to optimize radio resource usage and improve quality of service. In the Distributed Radio Resource Usage Optimization use case, frequency bands assigned to RANs are fixed. Also, BSs are not capable of reconfiguration. Distributed Radio Resource Usage Optimization use case considers cognitive terminals with multi-mode and/or radio multi-homing capability. Multi-mode cognitive terminals can have only one active connection. However, they can dynamically reconfigure this active connection accessing different RANs with different radio interfaces. Radio multi-homing terminals can have multiple simultaneous active connections with different RANs. Also, they can dynamically reconfigure these connections. Decision on cognitive terminal reconfiguration is made by its TRM and is supported by NRM. They analyze available context information, dynamically generate radio resource selection policies, and send them to their TRMs. These radio resource selection policies will guide these TRMs in their spectrum access decisions. TRMs analyze radio resource selection policies and available context information and dynamically make decisions on reconfiguration of their cognitive terminals to improve spectrum usage and quality of service. TRMs make these reconfiguration decisions within the framework defined by radio resource selection policies. Following these decisions, TRMs request corresponding reconfiguration of their cognitive terminals.

V. System Requirements

Based on the use cases described in previous section, system requirements and the corresponding system architecture are derived and are subject of the next two sections.

A. Context Awareness

There shall be entities on both network and terminal sides responsible for context information collection. The context information collection entity on network side shall collect RAN-related context information, which may comprise RAN radio resource optimization objectives, capabilities, related measurements, transport capabilities and other RAN-related context information. NRM shall be able to obtain RAN-related context information from the context information collection entity on network side. NRM may receive this context information periodically and/or in response to request from NRM and/or on event. Context information collection entity on network side may be implemented in a distributed manner. The context information collection entity on terminal side shall collect terminal-related context information, which comprises of: User's preferences, Required QoS levels, Terminal's capabilities, Terminal-related measurements, Geo-location information, Geo-location based terminal-related measurements and other terminal-related context information. TRM shall be able to obtain terminal-related context information from the context information collection entity on terminal side.

NRM and TRM shall exchange context information. NRM may send this context information to TRM periodically and/or in response to request from NRM and/or on event. TRM shall send the following terminal related context information to NRM. Similarly, TRM may send this context information to NRM periodically and/or in response to request from NRM and/or on event.

B. Decision Making

Decision making in this standard is based on policy-based management framework. There shall be an entity on the network side responsible for generating spectrum assignment policies. NRM shall be able to obtain spectrum assignment policies from this entity. Spectrum assignment policies shall adhere to regulatory framework. Spectrum assignment policies may express operator needs and possibilities related to DS Assignment. NRM shall make DS Assignment decisions compliant with received spectrum assignment policies. The NRM shall provide information on its DS Assignment decisions to the legacy entity on the network side within the operator's control, which is responsible for generating spectrum assignment policies. NRM shall make DS Access decisions compliant with its DS Assignment decisions and with previously received spectrum assignment policies. NRM shall generate radio resource selection policies and shall provide radio resource selection policies to TRM. NRM may have the means to specify geo-location based radio resource selection policies to TRM. Radio resource selection policies and context information should be sent to an optimized set of TRMs in order avoid overloading selected RANs with policy exchanges. The target sets of TRMs to be addressed, for policy distribution, may be based on a combination of RAN topology information (TRM's under coverage of list of Cell IDs, BTS IDs, Access Points, RNC IDs, if any), TRM's inside a given geo-localized area, TRM's operating in certain frequency bands. TRMs shall make decisions on terminal reconfiguration compliant with the previously received radio resource selection policies. If specified by radio resource selection policies, TRMs of geo-localization-capable terminals shall make decisions based on the terminal geo-location. It should be noted that NRM may be implemented in a distributed manner.

C. Reconfiguration

There shall be entities on the network side and terminal side responsible for reconfiguration. NRMs shall send reconfiguration requests to reconfiguration entities on the network side. Following received reconfiguration requests, reconfiguration entities on the network side shall request and control reconfiguration of RANs. Reconfiguration entities on the network side may be implemented in a distributed manner. TRMs shall send reconfiguration requests to reconfiguration entities on the terminal side. Following received reconfiguration requests, reconfiguration entities on the terminal side shall request and control reconfiguration of terminal

VI. System Architecture

Following the system requirements described before, Fig. 2 shows the current architecture of the P1900.4 system, which is

subject to ongoing refinement. The main objective is to define the overall design of the P1900.4 system, the relationship between various building blocks and the corresponding interfaces associated with the functional architecture and introduce reference points and illustrative mapping to selected standards (such as 3GPP, IEEE802.11x, IEEE802.16x, etc.). This acts as an important requirement, in order to be able to implement the standard in a real context, at a later stage.
Therefore, the following entities are identified. NRM is the entity that manages the Composite Wireless Network and terminals for network-terminal-distributed optimization of radio resource and spectrum usage. TRM is the entity that manages the terminal for network-terminal-distributed optimization of radio resource and spectrum usage. This is performed within the framework defined by the NRM in a consistent manner with user preferences, available context information and radio resource usage constraints.

RAN Reconfiguration Controller (RRC) is the entity that enables NRM reconfiguration of RANs. RAN Measurement Collector (RMC) is the entity that provides RAN-related measurement results to NRM. Terminal Measurement Collector (TMC) is the entity that collects terminal-related measurement results and provides them to TRM. Radio Enabler (RE) is the logical communication channel between NRM and TRM. Radio Enabler may be mapped onto one or several RANs already used for data transmission (in-band channel) and/or onto one or several newly defined, dedicated RANs (out-of-band channel).

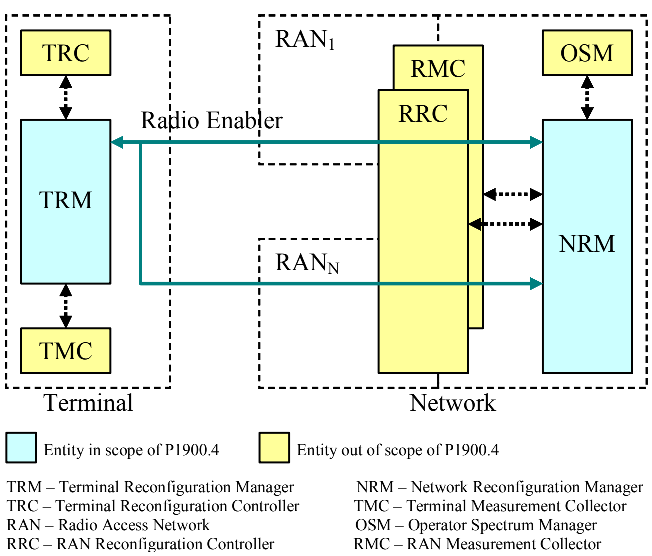


Fig. 2. **System architecture for distributed radio resource and spectrum usage optimization**

Interfaces are defined between NRM and TRM, NRM and RRC, NRM and RMC, TRM and TMC, and TRM and TRC. Table I shows type of information to be exchanged via each these interfaces.

Interface	Direction	Information
Interface between NRM and TRM		
	From NRM to TRM	• Radio Resource Selection policies • RAN related context information
	From TRM to NRM	• user's preferences • context information [1]
Interface between NRM and RRC		
	From NRM to RRC	• RAN reconfiguration requests
	From RRC and NRM	• RAN configuration status information
Interface between NRM and RMC		
	From NRM to RMC	• RANs-related measurement requests
	From RMC to NRM	• RANs-related measurement results
Interface between TRM and TMC		
	From TRM to TMC	• terminal-related measurement requests
	From TMC to TRM	• terminal-related measurement results
Interface between TRM and TRC		
	From TRM to TRC	• terminal reconfiguration requests
	From TRC to TRM	• terminal reconfiguration responses

Table I. Information to be exchanged via interfaces

VII. REFERENCE MODEL

IEEE 1900.4 system comprises Reconfiguration Manager, Reconfiguration Controller, and Measurement Collector (see Fig. 3). It is represented by Reconfiguration Management Entity (RME) as an integral management object.

On terminal side, Reconfiguration Manager corresponds to TRM, Reconfiguration Controller corresponds to TRC, and Measurement Collector corresponds to TMC. On network side, Reconfiguration Manager corresponds to NRM,

[1] Context inforamtion may comprise User's preferences, Required QoS levels, Terminal's capabilities, Terminal-related measurements, Geo-location information, Geo-location based terminal-related measurements etc.

Reconfiguration Controller corresponds to RRC, and Measurement Collector corresponds to RMC.

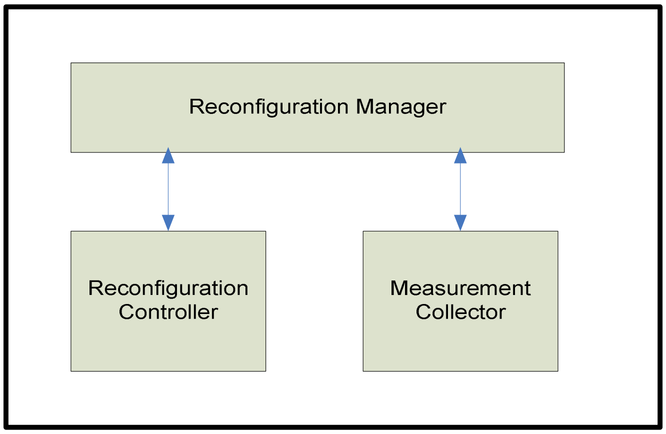


Fig. 3. IEEE 1900.4 system

IEEE 1900.4 system is modeled as System Management Application Entity (SMAE) [7]. The RME, as SMAE, is located on the application layer and has access to any layer of the OSI model. Reference model of RME is shown in Fig. 4.

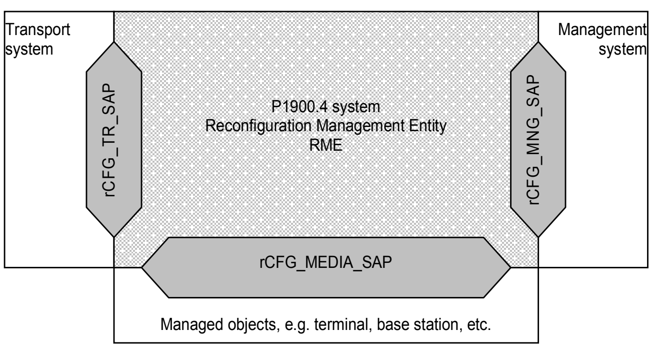


Fig. 4. IEEE 1900.4 Reference Model

The RME includes but does not limit the following service access points (SAP):

- rCFG_TR_SAP - transport SAP;
- rCFG-MEDIA_SAP - reconfiguration and measurement SAP;
- rCFG_MNG_SAP - management SAP.

Transport SAP provides transport service for message exchange between network side RME and terminal side RME. It abstracts transport mechanisms from RME by providing a set of generic primitives for RME and mapping these primitives on transport protocols. Transport SAP is used to exchange radio resource selection policies and context information between one network side RME and one or several terminal side RME.

Reconfiguration and Measurement SAP provides reconfiguration and measurement service for managing RANs and terminals. It provides a set of generic primitives for RME to collect RAN-related and terminal-related context information and to request and control reconfiguration of RANs and terminals. These generic primitives are mapped onto specific protocols depending on the managed RAN and terminals.

Management SAP provides management service for managing RME by legacy management system that can be terminal or network element or network management system. It provides a set of generic primitives for RME to exchange information with these legacy systems.

VIII. Functional Architecture and Information Model and Representation

Based on the functional requirements for the different interfaces (at the system level-between main P1900.4 building blocks and corresponding entities- and at the functional level-between main P1900.4 functions within the building blocks and corresponding sub-functions for the realization of reference use cases in Section 4.) The details of the FA derivation to support the P1900.4 system purpose are given in [10]. The corresponding information model and representation will be defined. The main purpose of an information model is to model managed objects at a conceptual level, independent of any specific implementations or protocols used to transport the data. The information model captures various types of information elements necessary to describe network and terminal reconfigurations, terminal and network context, reconfiguration policies, and radio resource management within the P1900.4 framework. Table 1 shows the type of information under consideration in the P1900.4 baseline draft. A comprehensive detailed description is given in [10].

IX. Generic Procedures Related to the Reference US Cases

DS Assignment procedure describes steps required to make DS Assignment decisions, as well as, to perform corresponding reconfiguration of RANs and cognitive terminals. DS Assignment procedure for Single Operator Scenario is shown in **Fig. 5**

DS Access procedure, shown in Fig. 6, describes steps required to make DS Access decisions, as well as, to perform corresponding reconfiguration of RANs and cognitive terminals. Furthermore, **DRRUO** procedure, shown in Fig. 7, describes steps required to make decisions on cognitive terminals reconfiguration in legacy RANs in a distributed manner. It also describes steps required to perform corresponding reconfiguration of cognitive terminals.

X. Conclusion

This paper has discussed ongoing activities within the IEEE P1900.4 WG, also outlining its purpose, scope, the need for the project, system assumptions and reference use cases. It also gives an overview of the system requirements, architecture and reference model. Finally the procedures related to the reference use cases between the entities of the system architecture are given. These are based on the latest baseline document approved by the WG in the Athens meeting in May 2008. The current status of the draft provides an overall Radio Resource Management System, distributed on the network and terminals with corresponding information exchanges between them. Thanks to the radio resource Selection policies, terminal/RAN context information, being exchanged, the system will provide means to optimize radio resource usage optimization for the reference use cases considered, namely Dynamic Spectrum assignment and Access for next generation wireless systems. Furthermore, the system can also be exploited in legacy wireless systems, where frequency bands assigned to RANs are fixed, in order to optimize radio resource usage and improve quality of service.

The WG is currently progressing in the specifications of its baseline document in order to initiate the internal Letter Ballot process for comments resolution before submission to Sponsor Ballot.

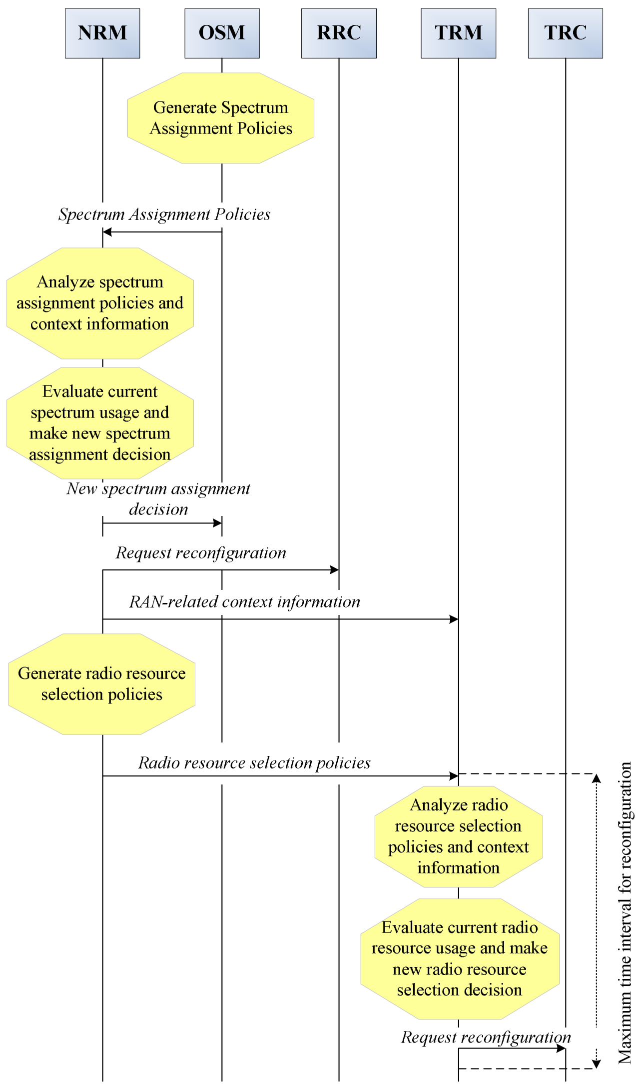


Fig. 5. DS Assignment procedure for Single Operator Scenario

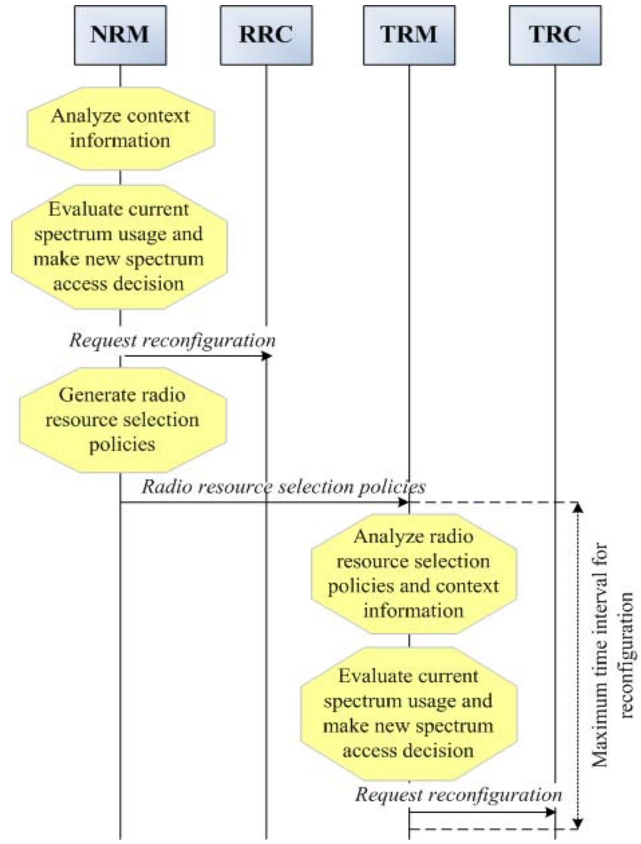


Fig. 6. DS Access procedure

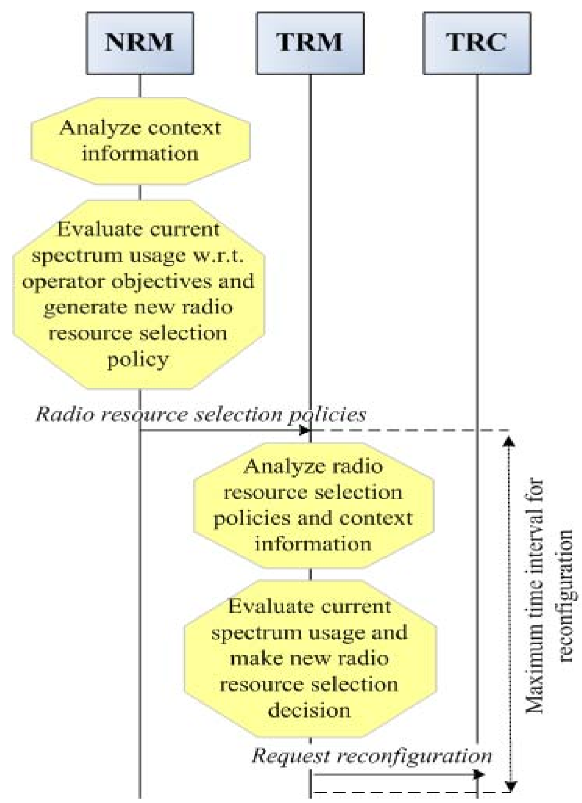


Fig. 7. DRRUO procedure

ACKNOWLEDGMENTS

The Chair of P1900.4 WG and the authors would like to acknowledge the contributions of our current voting members to the derivation of the current draft D1.5: 1.Alcatel-Lucent, 2.BAE Systems, 3.BitMeister, 4.Cosmo Research, 5.France Telecom, R&D, 6.Hitachi, 7.Intel Corporation, 8.ISB Corporation, 9.Kings College London, 10.KDDI R&D, 11.Kozo Keikaku Engineering Inc, 12.Motorola Labs, 13.NCSR/Demokritos, 14.NICT, 15.Pultek Corporation, 16.Tokyo University of Science, 17.Toshiba Research Labs, 18.University of Athens, 19.University Polytechnic of Catalunya, 20.University of Pireaus, 21.Willnet, 22.Worldpicom Corporation, 23. NEC.

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