IEEE 1900.4: Standard for Optimized Radio Resource Usage in Composite Wireless Networks

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Abstract— **Newly published IEEE 1900.4 standard is the subject of this article. The field of application of the IEEE 1900.4 standard is radio systems forming a Composite Wireless Network (CWN), i.e., comprising multiple Radio Access Networks (RANs), which may be use different Radio Access Technologies (RATs). This composite wireless network is assumed to be operated by either a single or several operators. End-user terminals in 1900.4 are generally assumed to be multimode/ multihoming, supporting several RATs and with multi-radio link capabilities, also possessing some cognitive radio capability such as flexible operation in different frequency bands. This effort covers the scope and purpose of the standard, reference use cases for which the standard is applicable, system requirements, and system and functional architectures.**

Keywords— ***IEEE standardization, cognitive radio, reconfiguration, heterogeneous radio access networks, composite networks, distributed radio resource management.***

I. Introduction

The IEEE 1900 Standards Committee was established within the IEEE in January 2005 jointly by the IEEE Communications Society and IEEE Electromagnetic Compatibility Society. The objective of 1900 projects is to develop standards in the areas of dynamic spectrum access (DSA), cognitive radio (CR), interference management, coordination of wireless systems, advanced spectrum management, and other areas related to new technologies and techniques being developed for next generation radio and advanced spectrum management. In March 2007 the 1900 series was placed under the newly formed IEEE Standards Coordinating Committee 41 (SCC 41), "Dynamic Spectrum Access Networks (DySPAN)" [2].

Currently, there are three standards and four Working Groups (WGs) within the remit of SCC 41.

The IEEE 1900.1 entitled, "Standard Definitions and Concepts for Spectrum Management and Advanced Radio System Technologies," was completed in September 2008. This standard provides technically precise definitions and explanations of key concepts in the fields of spectrum management, policy defined radio, adaptive radio, software defined radio, and related technologies.

The IEEE 1900.2, "Recommended Practice for Interference and Coexistence Analysis," was approved by the IEEE Standards Board in March 2008. This recommended practice provides technical guidelines for analyzing the potential for coexistence or in contrast interference between radio systems operating in the same frequency band or between different frequency bands.

The 1900.3 WG is working on a standard entitled, "Conformance Evaluation of Software Defined Radio (SDR) Software Modules." This standard will provide technical guidelines for analyzing Software Defined Radio software modules to ensure compliance with regulatory and operational requirements.

Two recently added WGs are 1900.5, "Policy Language and Policy Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications," and 1900.6, "Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and Other Advanced Radio Communication Systems."

In February 2007, the IEEE 1900.4 WG was launched, originating from the IEEE 1900.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 standard was published by the IEEE Standards Board in February 2009. From April 2009, 1900.4 Working Group works on two projects:

- *1900.4a:* Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks - Amendment: Architecture and Interfaces for Dynamic Spectrum Access Networks in White Space Frequency Bands.
- *1900.4.1:* Standard for Interfaces and Protocols Enabling Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Networks [2].

IEEE 1900.4 standard discusses Coexistence Support for Reconfigurable, Heterogeneous Air Interfaces in close cooperation with the European IST-E2R II integrated research project. This effort is complementary to other beyond-3rd-Generation (B3G) system concepts such as 3GPP LTE (Long-Term-Evolution), IEEE 802.21 proposing vertical hand-off related mechanisms, etc. In particular, 3GPP LTE and IEEE 802.21 are expected to provide means for efficient vertical hand-off between licensed and unlicensed band technologies as well as functionalities related to maintaining two links in parallel in order to access to different services in parallel (e.g., low-latency and low-data rate service for VoIP, high-data-rate moderate latency services for video-streaming, etc.). In contrast to these efforts, IEEE 1900.4 is focusing on a wireless data network evolution where enhanced QoS (increased throughput, improved availability, etc.) is available due to reconfigurable multi-homing capabilities in the MTs maintaining numerous heterogeneous links simultaneously [3], [5].

The article provides an overview on IEEE 1900.4. The next section of this article presents the scope, purpose, and motivation of this standard, while the following section discusses the main system assumptions and corresponding approaches within 1900.4. Three reference use cases considered within the project are described in section IV. The following two sections present the system requirements and derived system architecture for the standard, while an overview of the functional architecture is then given. The final section concludes the article.

II. Scope, Purpose, and Motivation

This section outlines the scope and purpose defined in the IEEE P1900.4 standard [1] and discuses need for this standard.

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.

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.

Motivation:

Multimode reconfigurable mobile 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 many devices offering, for example, second- and third-generation cellular radio access technologies (RATs) as well as IEEE 802 wireless standards, among others. Furthermore, user devices and networks with DSA capabilities are emerging, allowing the sharing and/or optimization of spectrum usage among different systems, and such capabilities will play an increasing part in the wireless world in the near future. One good example of such a facet is the developing IEEE 802.22 standard for wireless regional area networks (WRANs), serving broadband communications for remote communities, effectively achieved through a CR idiom.

Based on the above observations, there is a need to develop a standard leveraging the opportunities, and addressing the technical and regulatory challenges brought about by this newfound versatility in the radio environment.

III. System Assumptions and Approach

The field of application of the standard IEEE 1900.4 is a heterogeneous wireless environment that might include the following (see Figure 1):

Multiple operators
Multiple radio access networks (RANs)
Multiple radio interfaces
Multiple Terminals

In Figure 1, the Operator Spectrum Manager (OSM) may help the operator to coordinate the assignment of spectrum to the different RANs it owns in order to optimize radio resource usage within its Composite Wireless Network (CWN). The Network Reconfiguration Manager (NRM) is the IEEE 1900.4 entity (representing a network resource manager) that manages the CWN and Terminals in terms of network-terminal distributed optimization of spectrum usage. This management is done within the framework of spectrum assignment policies conveyed by the OSM and in a manner consistent with available context information. Terminal Reconfiguration Manager (TRM) is an IEEE 1900.4 entity (representing a device resource manager) that manages the Terminal in terms of network-terminal distributed optimization of spectrum usage. This management is done within the framework of radio resource selection policies conveyed by the NRM and in a manner consistent with the user's preferences and the available context information.

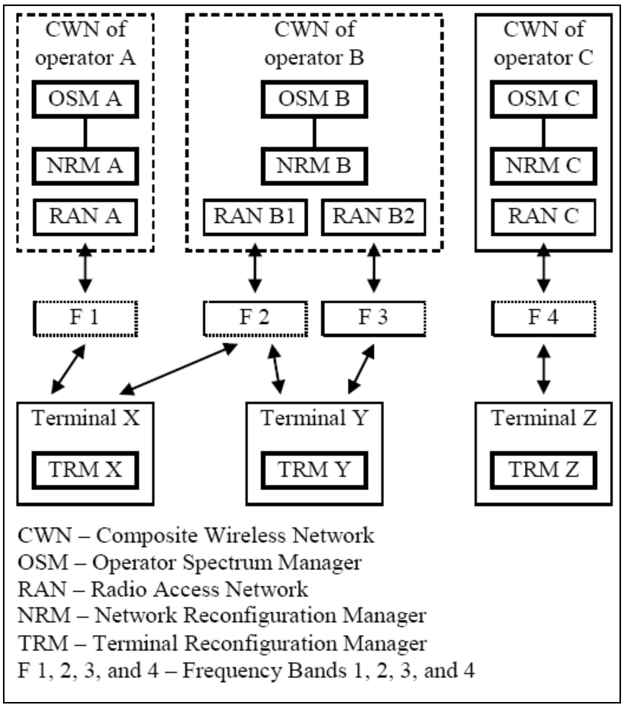

Figure 1: Heterogeneous wireless environment considered in IEEE Std. 1900.4

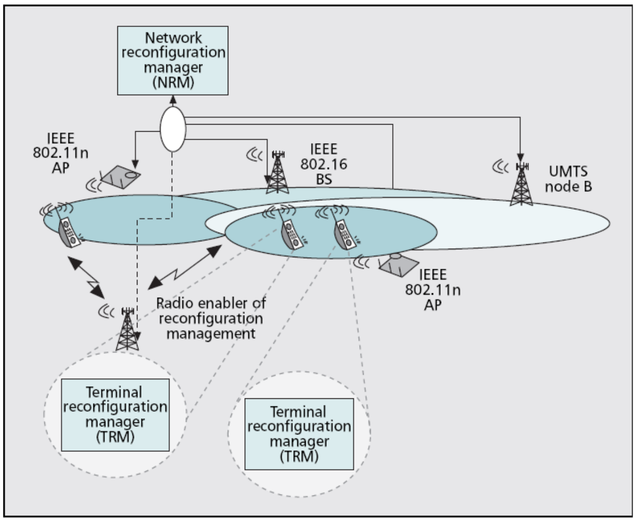

Figure 2: The heterogeneous wireless environment considered within P1900.4.

An example of a composite wireless network, managed by one or several operators in which P1900.4 system can operate, is depicted in Figure 2. 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.

The P1900.4 system 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, depicted in dotted lines in Fig. 2) is called Radio Enabler (RE). The RE may be mapped onto one or several RANs used for data transmission (in-band channel) and/or onto one or several dedicated RANs (out-of-band channel).

IV. Refrence Use Caces

The following three use cases are defined within the standard. We outline the considered use cases as follows:

Dynamic spectrum assignment: 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.

Dynamic spectrum assignment reconfigures network and terminal taking into account changes in the assigned purpose (e.g., operated RAT) for a spectrum band, as made by a composite network or a collaboration of networks as shown in Figure 3. Such changes may occur on timescales on the order of few hours, and/or may be made at any time in reaction to a change in networking context such as network configuration, traffic patterns, QoS requirements, or radio measurements.

OSMs generate spectrum assignment policies expressing the regulatory framework and operators objectives for spectrum usage optimization. The OSMs provide these spectrum assignment policies to the corresponding NRMs.

The NRMs 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 have been made, the NRMs request corresponding reconfiguration of their RANs. Following the RAN's reconfiguration, Terminals need to reconfigure correspondingly.

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 (e.g., IEEE 802.16e).
- The network switches the usage of a spectrum band from mobile broadband wireless access (e.g., IEEE 802.16e) to a wireless LAN (e.g., IEEE 802.11n) if a large number of wireless LAN terminals are suddenly close to the wireless LAN access point.

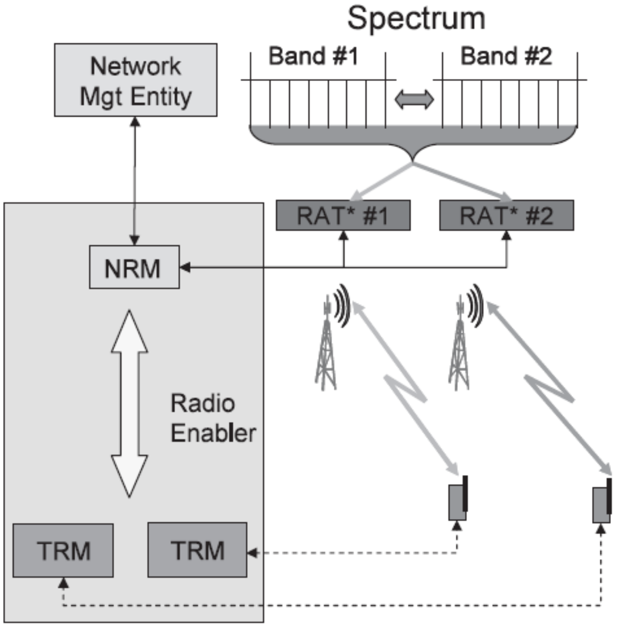

Figure 3: Dynamic spectrum assignment

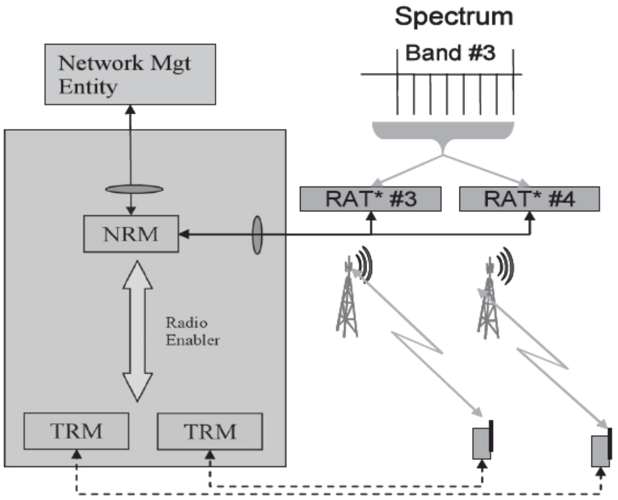

Figure 4: Dynamic spectrum sharing

Dynamic spectrum sharing: Frequency bands assigned to RANs are fixed. However, a particular frequency band can be shared by several RANs. In other words, the dynamic spectrum sharing use case describes how fixed frequency bands are shared and/or used dynamically by RANs and Terminals. Dynamic spectrum sharing use case includes primary/secondary spectrum usage as a special case. Figure 4 demonstrates this use case.

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 these radio resource selection policies and the available context information and dynamically make spectrum access decisions to improve spectrum usage and quality of service. These spectrum access decisions are made within the framework of the radio resource selection policies. Following these decisions, each TRM requests corresponding reconfiguration of its Terminal.

Following examples are related to this use case:

- Unlicensed secondary systems (e.g., IEEE 802.22) accessing licensed but locally unused VHF/UHF spectrum bands in an opportunistic fashion
- Unlicensed wireless LANs (e.g., IEEE 802.11 in a possible future CR-like variant) accessing licensed but locally unused VHF/UHF spectrum bands in an opportunistic fashion.

Distributed radio resource usage optimization: Covers the process and mechanisms by which the optimization of radio resource usage is performed by the CWN and terminals in a distributed manner (Figure 5). Frequency bands assigned to RANs are fixed. Reconfiguration of RANs is not involved in this use case.

Optimization is done at two levels: the network and terminals. The NRM, at the network level, derives radio resource usage constraints and evaluates them in order to meet a global objective (e.g., global network power minimization or load balancing). These radio resource usage constraints are conveyed from the NRM to the TRM via the RE. At the second level of optimization, end-user terminals optimize their use of radio resources (radio links, spectrum bands, and channels) by selecting in turn the optimal (or optimal combination) of resources, say, to yield maximal throughput or required quality of service (QoS), and/or satisfy user preferences. These choices also have to be compliant with policies derived at the first level (the NRM) and must respect a “time constraint” provided by the NRM within which the policies must be executed.

One of the example scenarios for this use case is optimization triggered by a network context change. When a network context changes, for example, in case of users’ connection and disconnection, end user terminals select better resource usage strategy, thus adapting to the change independently of the network side.

Another example for this use case is mobile scenario when a mobile terminal selects appropriate access point and corresponding RAT based on network policy and context information.

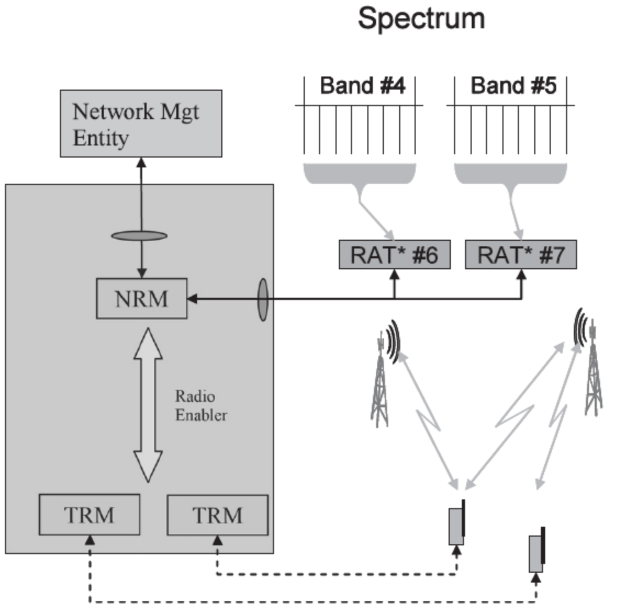

Figure 5: Distributed radio resource usage optimization.

V. System Requirements

The advanced spectrum management considered in IEEE 1900.4 assumes that reconfiguration of some parts of the CWN is possible (e.g., base stations and terminals). Reconfiguration usually involves three phases: obtaining the context information required for decision making, making reconfiguration decisions, and the actual reconfiguration according to the decisions made. These three categories are used to classify the system requirements of 1900.4.

Context Awareness: The standard states that there shall be entities on the network side and terminal side responsible for context information collection. Two types of context information are defined: RAN context information and terminal context information.

RAN context information may include:

- RAN radio resource optimization objectives
- RAN radio capabilities
- RAN measurements
- RAN transport capabilities.

The NRM shall be able to obtain RAN context information from context information collection entity on network side. The NRM may receive this context information periodically and/or in response to request from the NRM and/or on event. Context information collection entity on network side may be implemented in a distributed manner. Context information collection entity on terminal side shall collect terminal context information.

Terminal context information may include:

- User preferences
- Required QoS levels
- Terminal capabilities
- Terminal measurements
- Terminal geo-location information
- Geo-location-based terminal measurements.

The TRM shall be able to obtain terminal context information from context information collection entity on terminal side. The NRM and the TRM shall exchange context information. The NRM shall send RAN context information to the TRM. The NRM may send to the TRM's terminal context information related to other Terminals. The NRM may send this context information to the TRM periodically and/or in response to request from the NRM and/or on event. The TRM shall send terminal context information related to its Terminal to the NRM. The TRM may send this context information to the NRM periodically and/or in response to request from the NRM and/or on event.

Decision Making: According to the standard, there is an entity on the network side, the NRM, which is responsible for managing the CWN and terminals to achieve network-terminal distributed optimization of spectrum usage. There is also an entity on the terminal side, the TRM, responsible for managing the terminal for network-terminal distributed optimization of spectrum usage. The TRM manages the terminal within the framework defined by the NRM, and in a manner consistent with user preferences and available context information.

Distributed decision making in 1900.4 is based on a policy-based management framework. Two types of policies are defined: spectrum assignment policies and radio resource selection policies. Spectrum assignment policies are based on regulations and express operator objectives related to dynamic spectrum assignment. These policies are generated by another entity on the network side and transmitted from this entity to the NRM. Radio resource selection policies guide terminals in their reconfiguration decisions, and are generated by the NRM and transmitted from the NRM to TRMs in terminals. Spectrum assignment policies are mandatory for the NRM, while radio resource selection policies are mandatory for the TRMs.

Reconfiguration: The standard IEEE 1900.4 requires that there are entities on the network side and terminal side responsible for reconfiguration. The NRM shall send reconfiguration requests to reconfiguration entity on network side. Following received reconfiguration requests, reconfiguration entity on network side shall request and control reconfiguration of RANs. Reconfiguration entity on network side may be implemented in a distributed manner. The TRM shall send reconfiguration requests to reconfiguration entity on terminal side. Following received reconfiguration requests, reconfiguration entity on terminal side shall request and control reconfiguration of Terminal.

To ensure stable network operation during reconfiguration, the maximum time interval during which reconfiguration must be performed can be specified by radio resource selection policies. Reconfiguration of the terminal must be performed within this time interval, measured from the point in time at which these radio resource selection policies are received.

VI. System Architecture

According to system requirements, the following system architecture is defined in the standard (see Figure 6).

Entities

The following four entities are defined to represent network resource managers:

Operator Spectrum Manager (OSM)
RAN Measurement Collector (RMC)
Network Reconfiguration Manager (NRM)
RAN Reconfiguration Controller (RRC)

The OSM is the entity that enables operator to control NRM dynamic spectrum assignment decisions. The RMC is the entity that collects RAN context information and provides it to NRM. RMC may be implemented in a distributed manner. The NRM is the entity that manages CWN and Terminals for network-terminal distributed optimization of spectrum usage. NRM may be implemented in a distributed manner. The RRC is the entity that controls reconfiguration of RANs based on requests from NRM. RRC may be implemented in a distributed manner.

Three following entities are defined to represent device resource managers:

Terminal Measurement Collector (TMC)
Terminal Reconfiguration Manager (TRM)
Terminal Reconfiguration Controller (TRC)

The TMC is the entity that collects terminal context information and provides it to the TRM. The TRM is the entity that manages the Terminal for network-terminal distributed optimization of spectrum usage within the framework defined by the NRM and in a manner consistent with user preferences and available context information. The TRC is the entity that controls reconfiguration of Terminal based on requests from the TRM. Radio enabler is the logical communication channel between the NRM and the TRM. Radio enabler may be mapped onto one or several RANs used for data transmission (in-band channel) and/or onto one or several dedicated RANs (out-of-band channel).

Interfaces between entities

Six interfaces are defined in the standard (Figure 6).

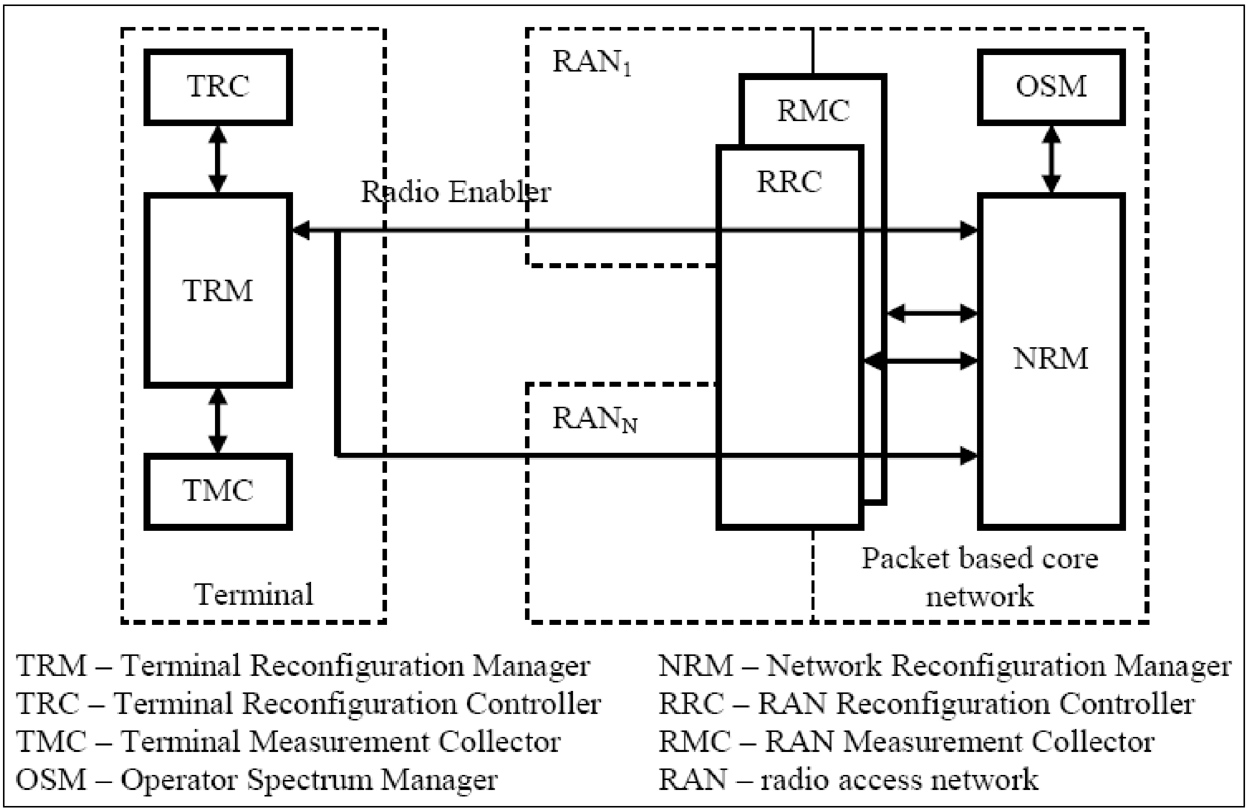

Figure 6: The 1900.4 system architecture

Defined interfaces are listed below:

- Interface between the NRM and the TRM
- Interface between the TRM and the TRC
- Interface between the TRM and the TMC
- Interface between the NRM and the RRC
- Interface between the NRM and the RMC
- Interface between the NRM and the OSM

Functionality of each interface and type of messages exchanged by these interfaces between entities, are defined in detail in the standard.

VII. FUNCTIONAL ARCHITECTURE

The functional architecture defined in the IEEE 1900 standard is shown in Figure 7. The functionalities of the OSM, RMC, RRC, TMC, and TRC are well defined in 1900.4. However, as the NRM and TRM are the key decision making entities in the standard, this article concentrates on the functions of these two important entities in the functional description of IEEE 1900.4. The main functions related to both the NRM and TRM sides depicted in Figure 7.

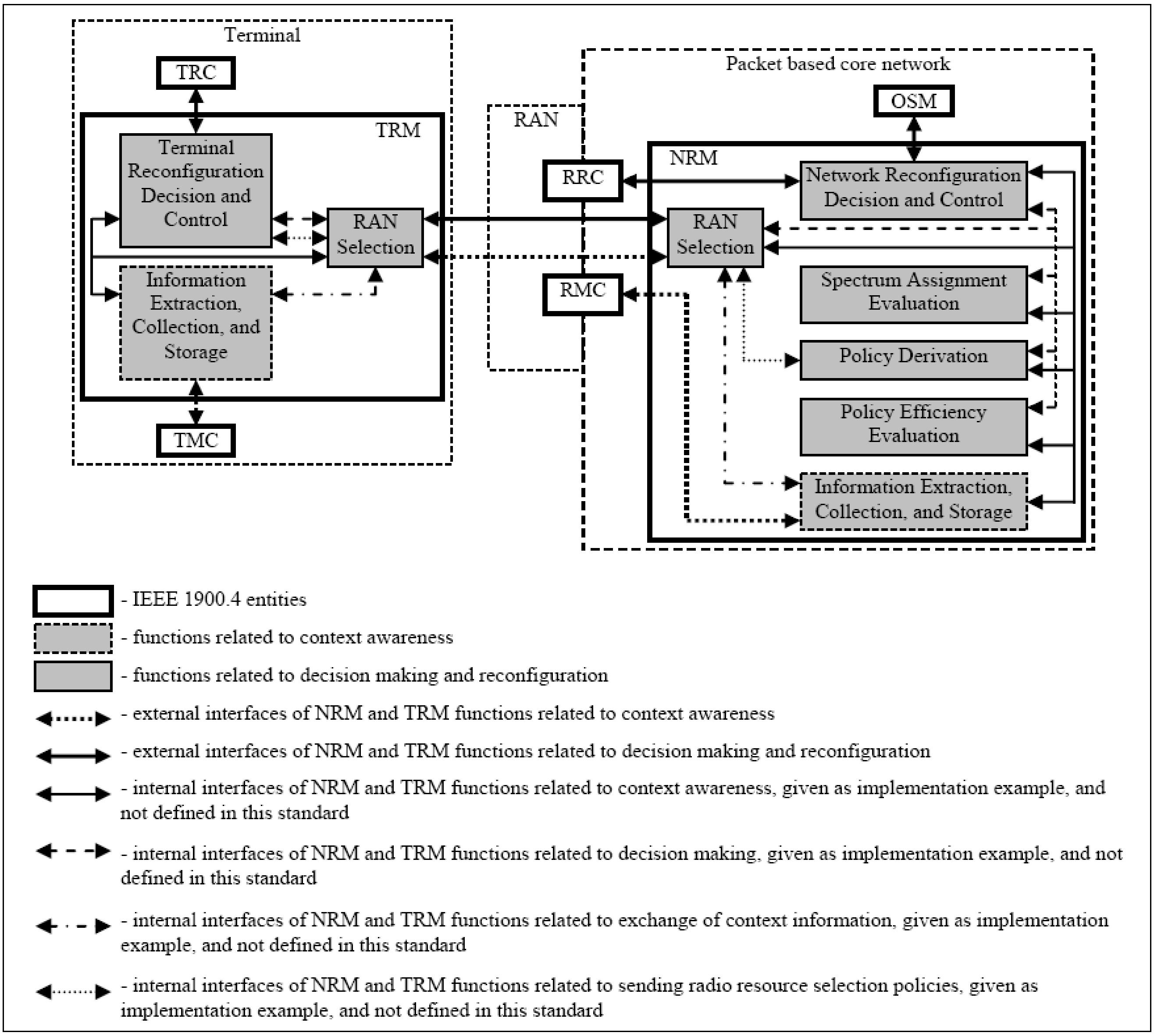

Figure 7: The 1900.4 functional architecture

NRM FUNCTIONS

The standard defines six functions inside the NRM: policy derivation, policy efficiency evaluation, network reconfiguration decision and control, spectrum assignment evaluation, information extraction, collection, and storage, and RAN selection.

The policy derivation function generates radio resource selection policies that guide TRMs in terminals' reconfiguration decisions. The radio resource selection policies are derived using the context information from the information extraction, collection, and storage function. The policy efficiency evaluation function evaluates the efficiency of current radio resource selection policies. Evaluation results are used by the policy derivation function in generating radio resource selection policies. The network reconfiguration decision and control function makes decisions on RANs reconfiguration compliant with spectrum assignment policies received from OSM. After making these decisions, this function sends corresponding reconfiguration commands to RRC. Also, this function sends information on made decisions to OSM. The spectrum assignment evaluation function evaluates the efficiency of spectrum usage under the current spectrum assignment. Evaluation results are used by the network reconfiguration decision and control function in making decisions on RAN reconfiguration.

The NRM information extraction, collection, and storage function receives, processes, and stores RAN context information and terminal context information. RAN context information is received from the RMC, while terminal context information is received from the TRM. The NRM information extraction, collection, and storage function provides information to functions inside the NRM. It forwards RAN context information to the TRM and may forward terminal context information, related to other terminals, to the TRM.

The NRM RAN selection function selects RANs for exchanging radio resource selection policies and context information between the NRM and TRM. This is done to minimize signaling overhead, and ensure timely and reliable delivery of radio resource selection policies and context information.

TRM FUNCTIONS

The standard also defines three functions inside the TRM: terminal reconfiguration decision and control, information extraction, collection, and storage, and RAN selection functions. The terminal reconfiguration decision and control function makes decisions on terminal reconfiguration. These decisions are made within the framework determined by the radio resource selection policies received from the NRM. After making these decisions, this function sends corresponding reconfiguration commands to the TRC.

The TRM information extraction, collection, and storage function receives, processes, and stores terminal context information and RAN context information. Terminal context information is received from the TMC. Terminal context information regarding other terminals may be received from the NRM. RAN context information is received from the NRM. The TRM information extraction, collection, and storage function provides information to functions inside the TRM. Also, it forwards terminal context information to the NRM.

The TRM RAN selection function selects RANs for exchanging radio resource selection policies and context information between the NRM and TRM.

VIII. CONCLUSIONS

This article has presented an overview on IEEE 1900.4, outlining its purpose, scope, reference use cases, system assumptions, system architecture, and functionality architecture of the standard. The information presented is based on the published standard in 2009.

IEEE 1900.4 is the first stage in this type of standards. Work on development of this standard is continued within 1900.4 WG. Currently two projects, 1900.4.a and 1900.4.1, are defined related to IEEE 1900.4. These new areas are complementary works to the published standard.

REFRENCES

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