



# IEEE Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks

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## IEEE Standards Coordinating Committee 41

Sponsored by the  
IEEE Standards Coordinating Committee 41 on  
Dynamic Spectrum Access Networks

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# **IEEE Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks**

Sponsor

**IEEE Standard Coordination Committee 41 on  
Dynamic Spectrum Access Networks**

Approved 30 January 2009

**IEEE-SA Standards Board**

**Abstract:** The building blocks comprising (i) network resource managers, (ii) device resource managers, and (iii) the information to be exchanged between the building blocks, for enabling coordinated network-device distributed decision making that will aid in the optimization of radio resource usage, including spectrum access control, in heterogeneous wireless access networks are defined. 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.

**Keywords:** architectural building blocks, dynamic spectrum access, heterogeneous wireless networks, network-device distributed optimization of spectrum usage

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## Introduction

This introduction is not part of IEEE Std 1900.4-2009, IEEE Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks.

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, second and third generation cellular radio access technologies and IEEE 802<sup>®</sup> wireless standards. Last but not least, devices and networks with dynamic spectrum access capabilities that allow the use of spectrum resource simultaneously among different systems are emerging 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 that 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.

The IEEE 1900 Standards Committee was established in the first quarter 2005 jointly by the IEEE Communications Society and the IEEE Electromagnetic Compatibility Society. The objective of this effort is to develop supporting standards dealing with new technologies and techniques being developed for next generation radio and advanced spectrum management. On March 22, 2007, the IEEE Standards Board approved the reorganization of the IEEE 1900 effort as Standards Coordinating Committee 41 (SCC41) on Dynamic Spectrum Access Networks (DySPAN). The IEEE Communications Society and Electromagnetic Compatibility Society are sponsoring societies for this effort, as they were for the IEEE 1900 effort. In February 2007, the IEEE 1900.4 working group was launched, originating from the IEEE 1900.B study group, and entitled “Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks.”

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# IEEE Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks

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## 1. Overview

### 1.1 Scope

The standard defines the building blocks comprising (i) network resource managers, (ii) device resource managers, and (iii) the information to be exchanged between the building blocks, for enabling coordinated network-device distributed decision making that 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.

### 1.2 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 that will facilitate the optimization of radio resource usage, in particular, by exploiting information exchanged between network and mobile Terminals, whether or not they support multiple simultaneous links and dynamic spectrum access.

### 1.3 Document overview

The structure of this document is as follows:

- Clause 2 lists normative references
- Clause 3 lists definitions and abbreviations used in this document
- Clause 4 presents overall system description of IEEE Std 1900.4, comprising system overview, summary of use cases, and assumptions
- Clause 5 specifies IEEE Std 1900.4 requirements, comprising system requirements, functional requirements, and information model requirements
- Clause 6 defines IEEE Std 1900.4 architecture. It is comprised of system description and functional description of an IEEE 1900.4 system
- Clause 7 defines the IEEE Std 1900.4 information model
- Clause 8 describes IEEE Std 1900.4 procedures
- Informative Annex A describes IEEE Std 1900.4 use cases
- Normative Annex B gives class definitions for the IEEE Std 1900.4 information model
- Normative Annex C provides data type definitions for the IEEE Std 1900.4 information model
- Informative Annex D describes the IEEE Std 1900.4 information model extensions and usage example
- Informative Annex E describes IEEE Std 1900.4 deployment examples
- Informative Annex F lists informative references related to IEEE Std 1900.4

## 2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1900.1™-2008, IEEE Standard Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management.<sup>1, 2</sup>

ISO/IEC 8824, Information Processing Systems—Open Systems Interconnection—Specification of Abstract Syntax Notation One (ASN.1).<sup>3</sup>

ITU-T Recommendation X.701, System Management Overview.<sup>4</sup>

Unified Modeling Language (UML), Version 2.1.2.<sup>5</sup>

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<sup>5</sup> The UML is available from the Object Management Group Web site <http://www.omg.org/spec/UML/2.1.2/June 2008>.

### 3. Definitions, acronyms, and abbreviations

#### 3.1 Definitions

For the purposes of this document, the following terms and definitions apply.

**3.1.1 base station:** This term is used to refer to any radio node on the network side from radio interface, independently of its commonly used name in a particular standard. Examples of common name are Base Station in IEEE Std 802.16, Base Transceiver System in cdma2000, Node B in UMTS, Access Point in IEEE Std 802.11, broadcasting transmitter, etc.

**3.1.2 Composite Wireless Network (CWN):** This term is used to refer to a network composed of several radio access networks with corresponding base stations, a packet-based core network connecting these radio access networks, and IEEE 1900.4 entities deployed in this network.<sup>6</sup>

NOTE—This definition does not exclude the case where some broadcasting system or future technology system is part of the composite wireless network.<sup>7</sup>

**3.1.3 context information:** This term is used to refer to any information that together with policies is needed for decision making on radio resource usage optimization in this standard. Radio access network (RAN) context information is distinguished from terminal context information. Also, context information is distinguished from policies.

**3.1.4 distributed radio resource usage optimization:** The distributed optimization of radio resource usage by a composite wireless network to satisfy global network objectives and by terminals to satisfy local device and user objectives (see IEEE Std 1900.1).

**3.1.5 dynamic spectrum assignment:** The dynamic assignment of frequency bands to radio access networks within a composite wireless network operating in a given region and time to optimize spectrum usage (see IEEE Std 1900.1).

**3.1.6 dynamic spectrum sharing:** 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.

NOTE—The IEEE 1900.4 definition of dynamic spectrum sharing is intentionally more specific than the IEEE 1900.1 definition of dynamic frequency sharing (see A.2).

**3.1.7 IEEE 1900.4 compliant terminal:** This term is used to refer to any IEEE 1900.4 compliant radio node on the user side, that is, a reconfigurable terminal containing the Terminal Reconfiguration Manager, Terminal Measurement Collector, and Terminal Reconfiguration Controller IEEE 1900.4 entities.

**3.1.8 multi-homing capability:** This term is used to refer to a capability of a reconfigurable terminal to have more than one simultaneous active connections with radio access networks.

**3.1.9 Network Reconfiguration Manager:** The entity that manages the Composite Wireless Network and Terminals in terms of network-terminal distributed optimization of spectrum usage. This management is

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<sup>6</sup> The IEEE Std 1900.4 definition of composite wireless network is intentionally more specific than the IEEE Std 1900.1 definition of composite network. The IEEE 1900.4 definition describes the components of composite wireless networks in the context of the IEEE 1900.4 system architecture.

<sup>7</sup> Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

done within the framework of spectrum assignment policies conveyed by the Operator Spectrum Manager and in a manner consistent with available context information.

**3.1.10 Operator Spectrum Manager:** The entity that enables the operator to control the dynamic spectrum assignment decisions of the Network Reconfiguration Manager.

**3.1.11 radio access network (RAN):** The network that connects base stations to the packet-based core network or external networks. If not specified, radio access network includes base stations.

**3.1.12 radio access network (RAN) context information:** This term is used to refer to any information that together with policies is needed for decision making on radio resource usage optimization in this standard and has RANs as its source.

**3.1.13 radio access network (RAN) Measurement Collector:** The entity that collects RAN context information and provides it to the Network Reconfiguration Manager.

**3.1.14 radio access network (RAN) Reconfiguration Controller:** The entity that enables the Network Reconfiguration Manager to control reconfiguration of radio access networks.

**3.1.15 radio enabler:** A logical communication channel between NRM and TRM. Radio enabler may be mapped onto one or several radio access networks used for data transmission (in-band channel) and/or onto one or several dedicated radio access networks (out-of-band channel).

**3.1.16 radio interface:** This term is used to refer to an air interface specifications that shall be fulfilled to setup and maintain connection between terminal and base station. Radio interface may be characterized by multiple access method, modulation, etc. Examples are GSM, WCDMA, WiFi<sup>8</sup>, WiMAX<sup>9</sup>, etc radio interfaces.<sup>10</sup>

**3.1.17 radio resource selection policy:** A policy generated by the Network Reconfiguration Manager which guides the Terminal Reconfiguration Managers in terms of their radio resource usage optimization decisions.

**3.1.18 reconfigurable terminal:** This term is used to refer to any radio node on the user side that can reconfigure its hardware and/or software in order to change its operating parameters in the physical and link layers, such as carrier frequency, signal bandwidth, radio interface, etc. A reconfigurable terminal may have multi-homing capability.

**3.1.19 spectrum assignment policy:** A policy generated by the Operator Spectrum Manager that guides the Network Reconfiguration Manager in terms of its radio resource usage optimization decisions.

**3.1.20 Terminal:** This is used as a short version of the term “IEEE 1900.4 compliant terminal.”

**3.1.21 terminal context information:** This term is used to refer to any information that has the user and/or Terminal as its source, which together with policies is needed in order for decision making on radio resource usage optimization within this standard to be possible.

**3.1.22 Terminal Measurement Collector (TMC):** The entity that collects terminal context information and provides it to Terminal Reconfiguration Manager.

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<sup>8</sup> WiFi<sup>®</sup> is a word mark of the WiFi Alliance.

<sup>9</sup> WiMAX<sup>™</sup> is a trademark of the WiMAX Forum.

<sup>10</sup> This information is given for the convenience of users of this standard and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to the same results.

**3.1.23 Terminal Reconfiguration Controller (TRC):** The entity that enables the Terminal Reconfiguration Manager to control reconfiguration of the Terminal.

**3.1.24 Terminal Reconfiguration Manager (TRM):** The entity 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 Network Reconfiguration Manager and in a manner consistent with the user's preferences and the available context information.

**3.1.25 user preferences:** This term is used to refer to input parameters to decision making process on radio resource usage optimization originated from user and expressing his or her preferences. These parameters may describe, for example, preferred operator and radio interface, perceived audio/image/video quality, maximum cost, minimum data rate, etc.

## 3.2 Acronyms and abbreviations

|      |                                      |
|------|--------------------------------------|
| ASN  | Abstract Syntax Notation             |
| BS   | base station                         |
| CWN  | Composite Wireless Network           |
| NRM  | Network Reconfiguration Manager      |
| OSI  | Open Systems Interconnection         |
| OSM  | Operator Spectrum Manager            |
| QoS  | quality-of-service                   |
| RAN  | radio access network                 |
| RMC  | RAN Measurement Collector            |
| RRC  | RAN Reconfiguration Controller       |
| SAP  | service access point                 |
| SMAE | system management application entity |
| TMC  | Terminal Measurement Collector       |
| TRC  | Terminal Reconfiguration Controller  |
| TRM  | Terminal Reconfiguration Manager     |
| UML  | Unified Modeling Language            |

## 4. Overall system description

### 4.1 System overview

The field of application of this standard 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

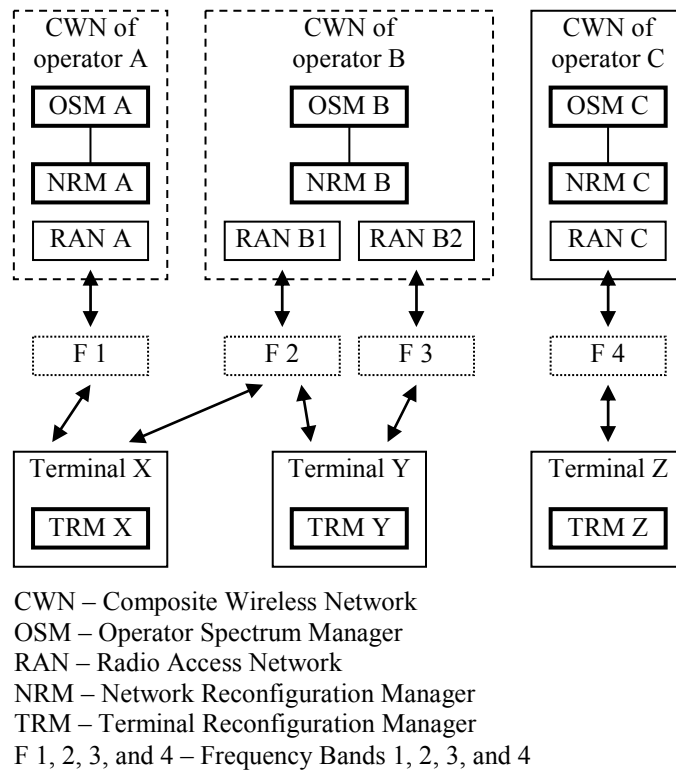


**Figure 1—Heterogeneous wireless environment considered in IEEE Std 1900.4**

Within 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).

Within the stated field of application, the standard provides common means to

- Improve overall network capacity and quality of service
- Facilitate optimization of radio resource usage
- Support reconfiguration capabilities of RANs and Terminals
- Collect RAN and terminal context information
- Support exchange of information between the network and Terminals for radio resource usage optimization related distributed decision making
- Request and control reconfiguration of RANs and Terminals

For this purpose, the standard defines the following:

- Network resource managers
- Device resource managers
- Interfaces between these building blocks

Within Figure 1, 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.

## 4.2 Summary of use cases

The following three use cases are defined within this standard:

- Dynamic spectrum assignment
- Dynamic spectrum sharing
- 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 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 RANs' reconfiguration, Terminals need to reconfigure correspondingly.

Example manifestations for this dynamic spectrum assignment use case are spectrum sharing, and spectrum renting between RANs. In the spectrum renting example, frequency bands of one RAN are assigned to another RAN on a temporary basis. In the spectrum sharing example, one frequency band is shared by several RANs.

Single operator and multiple operator scenarios are described within the dynamic spectrum assignment use case. Within the multiple operator scenario, there is either one NRM outside of operators CWNs or one NRM inside each operator CWN.

In the dynamic spectrum sharing 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 sharing use case describes how fixed frequency bands are shared and/or used dynamically by RANs and 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 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.

Dynamic spectrum sharing use case includes primary/secondary spectrum usage as a special case.

In the distributed radio resource usage optimization use case, frequency bands assigned to RANs are fixed. Reconfiguration of RANs is not involved in this use case.

Distributed radio resource usage optimization use case considers Terminals with or without multi-homing capability. Decision on Terminal reconfiguration is made by its TRM and is supported by NRM.

NRMs 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 reconfiguration decisions.

TRMs analyze radio resource selection policies and available context information and dynamically make decisions on reconfiguration of their 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 Terminals.

Detailed description of these three use cases and their scenarios is given in Annex A.

## 4.3 Assumptions

### 4.3.1 General

This standard does not specify MAC and PHY layers of RANs and Terminals.

This standard does not specify the way measurements are done on network and terminal side.

A heterogeneous wireless environment exists, including one or several CWNs.

Terminals are present within this heterogeneous wireless environment.

These Terminals are reconfigurable with or without multi-homing capability.

### 4.3.2 Dynamic spectrum assignment

Assignment of spectrum to RANs can be dynamically changed, where spectrum assignment may be characterized by carrier frequency, signal bandwidth, and radio interface to be used in the assigned spectrum.

Concurrently with the new spectrum assignments, RANs can be reconfigured.

Concurrently with RAN reconfigurations, Terminals can be reconfigured.

### 4.3.3 Dynamic spectrum sharing

Assignment of spectrum to RANs is fixed.

Some RANs are allowed to concurrently operate in more than one spectrum assignment for dynamic spectrum sharing.

Some spectrum assignments are allowed to be shared by several RANs during dynamic spectrum sharing.

Some RANs can be reconfigured during dynamic spectrum sharing (maintaining their allocated spectrum assignments).

Some RANs cannot be reconfigured (for example, RANs of primary systems).

Concurrently with RAN reconfiguration, Terminals can be reconfigured during dynamic spectrum sharing.

#### **4.3.4 Distributed radio resource usage optimization**

Assignment of spectrum to RANs is fixed.

Reconfiguration of RANs is not involved in this use case.

Terminals with or without multi-homing capability are reconfigured during distributed radio resource usage optimization.

## **5. Requirements**

### **5.1 System requirements**

#### **5.1.1 Decision making**

There shall be an entity on network side, called Network Reconfiguration Manager (NRM), responsible for managing the CWN and Terminals for network-terminal-distributed optimization of spectrum usage.

There shall be an entity on terminal side, called Terminal Reconfiguration Manager (TRM), responsible for managing the Terminal for network-terminal-distributed optimization of spectrum usage.

The TRM shall manage the Terminal within the framework defined by the NRM and in a manner consistent with user's preferences and available context information.

Decision making in this standard is based on policy-based management framework.

There shall be an entity on network side responsible for generating spectrum assignment policies.

The NRM shall be able to obtain spectrum assignment policies.

Spectrum assignment policies shall adhere to regulations.

Spectrum assignment policies shall express operator needs and/or radio resource usage objectives related to dynamic spectrum assignment.

The NRM shall make dynamic spectrum assignment decisions compliant with received spectrum assignment policies.

The NRM shall provide information on its dynamic spectrum assignment decisions to the entity on network side within the operator's control, which is responsible for generating spectrum assignment policies.

The NRM shall make dynamic spectrum sharing decisions compliant with its spectrum assignment decisions and with received spectrum assignment policies.

The NRM shall generate radio resource selection policies.

The NRM shall provide radio resource selection policies to TRM.

The NRM may have 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 not to overload selected RANs with broadcast. Target set of TRMs to be addressed may be based on combination of the following:

- RAN topology information: TRMs under coverage of list of base station IDs, such as cell IDs, base transceiver station IDs, access points IDs, radio network controller IDs (if any), etc.
- TRMs inside given geo-localized area
- TRMs operating in given frequency bands
- Historical data related to Terminal radio resource usage patterns

The TRM shall make decisions on Terminal reconfiguration compliant with received radio resource selection policies.

If specified by radio resource selection policies, TRM of geo-localization-capable Terminal shall make decisions based on Terminal geo-location.

Several NRMs may collaborate in the process of decision making related to radio resource usage optimization.

If there are several NRMs, there may be interface between these NRMs.

This interface may be used to transmit the following:

- RAN context information
- Terminal context information
- Spectrum assignment policies
- RAN reconfiguration decisions
- Radio resource selection policies

### 5.1.2 Context awareness

There shall be entities on network side and terminal side responsible for context information collection.

Context information collection entity on network side shall collect RAN context information.

RAN context information may include the following:

- 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 the following:

- 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.

### 5.1.3 Reconfiguration

There shall be entities on 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.

If a maximum time interval for reconfiguration is specified by radio resource selection policies, reconfiguration of Terminal shall be performed within this time interval starting from the time when these radio resource selection policies are received.

## 5.2 Functional requirements

### 5.2.1 NRM functionality

The NRM shall have capability to make dynamic spectrum assignment, dynamic spectrum sharing, and distributed radio resource usage optimization decisions.

The NRM shall have capability to request reconfiguration of RANs corresponding to these dynamic spectrum assignment and dynamic spectrum sharing decisions. Actions should be taken by the NRM in the case where reconfiguration is not possible.

The NRM shall have the capability to evaluate the efficiency of spectrum usage under the current spectrum assignment.

The evaluation results shall be made available inside the NRM to assist in improving the efficiency of future dynamic spectrum assignment, dynamic spectrum sharing, and distributed radio resource usage optimization decisions.

The NRM shall have capability to generate radio resource selection policies.

There shall be no conflict in the radio resource selection policies generated by the NRM.

Radio resource selection policies shall be defined in a way that they correspond to a targeted group of Terminals (could be composed of any number of Terminals).

The targeted group of Terminals should be defined based on the needs of CWN radio resource usage optimization objectives, Terminal location, and radio resource usage patterns of the Terminals.

Radio resource selection policies shall guide TRMs in Terminals' reconfiguration decisions.

The NRM may specify radio resource selection policies referring to specific geo-location-based terminal measurements.

The NRM shall have capability to specify and control the time interval within which Terminal reconfiguration shall be performed.

The TRM shall perform Terminal reconfiguration within this time interval.

The NRM shall have capability to evaluate the efficiency of current radio resource selection policies.

These evaluation results shall be made available to the NRM to assist in improving the efficiency of future radio resource selection policies.

The NRM shall have capability to receive, process, and store the following context information:

- RAN context information (see 5.1.2)
- Terminal context information (see 5.1.2)

The NRM shall have the capability to use this context information for radio resource usage optimization purposes.

The NRM should have the capability to select RANs for exchanging radio resource selection policies and context information between the NRM and the TRM, that is, to map radio enabler onto specific RANs.

The NRM functions should have capability to perform the following in cooperation with each other:

- Make dynamic spectrum assignment, dynamic spectrum sharing, and distributed radio resource usage optimization decisions
- Request reconfiguration of RANs
- Evaluate the efficiency of spectrum usage
- Generate radio resource selection policies
- Evaluate the efficiency of current radio resource selection policies
- Select RANs for exchanging radio resource selection policies and context information between the NRM and the TRM

If there are several NRMs, there may be an interface between these NRMs.

This interface shall be used to exchange the following:

- RAN context information
- Terminal context information
- Spectrum assignment policies
- RAN reconfiguration decisions
- Radio resource selection policies

### 5.2.2 TRM functionality

The TRM shall have the capability to make dynamic spectrum sharing and distributed radio resource usage optimization decisions, as well as, to support dynamic spectrum assignment decisions received from the NRM.

The TRM shall have the capability to request reconfiguration of its Terminal corresponding to these decisions. Actions should be taken by the TRM in cases where reconfiguration is not possible.

The TRM shall have the capability to receive, process, and store the following context information:

- Terminal context information
- RAN context information

The TRM shall have the capability to use this context information for radio resource usage optimization purposes.

The TRM shall have the capability to select RANs for exchanging radio resource selection policies and context information between the NRM and the TRM.

TRM functions should have the capability to perform the following in cooperation with each other:

- Make dynamic spectrum sharing and distributed radio resource usage optimization decisions
- Request reconfiguration of its Terminal

- Select RANs for exchanging radio resource selection policies and context information between the NRM and the TRM

### 5.3 Information model requirements

Information model shall provide a specified representation of information within the scope of this standard.

Information model shall consider two sets of managed objects, that is, CWN and Terminals.

CWN-related classes shall abstract operator, RAN, BS, and cell concepts within the scope of this standard.

Terminal-related classes shall abstract user, application, Terminal, frequency channel, and active connection concepts within the scope of this standard.

Information model shall abstract policy concept within the scope of this standard, including spectrum assignment policy and radio resource selection policy.

Information model may include time/duration reference related to the validity of the provided information. For instance the time at which measurements were made or the valid period in which they are to be taken.

Information model should provide geo-location related information items.

## 6. Architecture

### 6.1 System description

According to system requirements, the following system architecture is defined in this standard (see Figure 2).

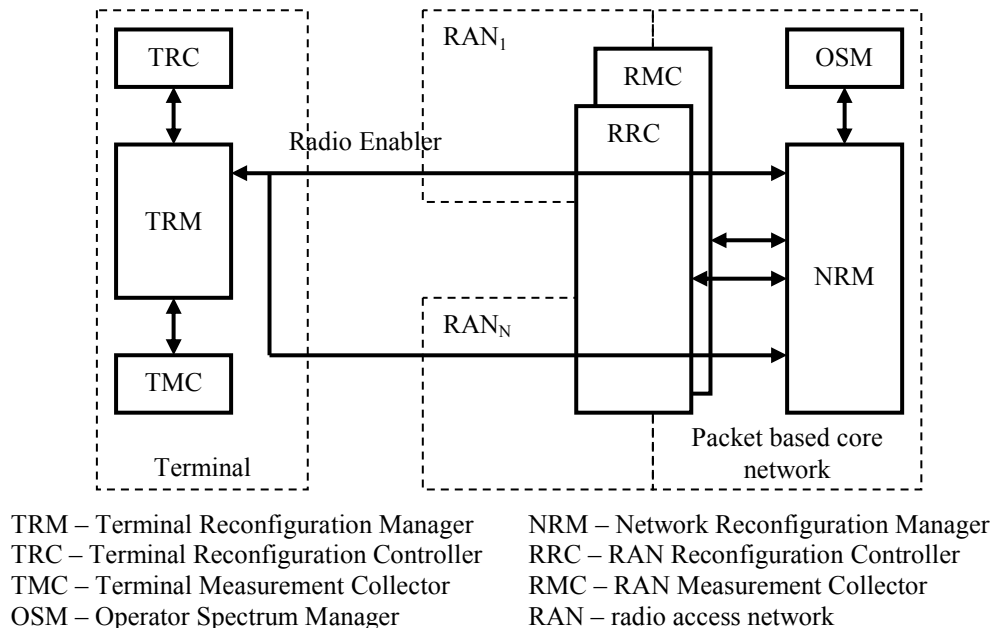


Figure 2—System architecture

### 6.1.1 Entities

The following four entities are defined to represent network resource managers (see Figure 2):

- 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 (see Figure 2):

- 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).

### 6.1.2 Interfaces between entities

The following key interfaces are defined (see Figure 2):

- 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

#### **6.1.2.1 Interface between the NRM and the TRM**

Interface between the NRM and the TRM is used to transmit the following:

- From NRM to TRM:
  - Radio resource selection policies
  - RAN context information
  - Terminal context information
- From TRM to NRM:
  - Terminal context information related to Terminal of this TRM

#### **6.1.2.2 Interface between the TRM and the TRC**

Interface between the TRM and the TRC is used to transmit the following:

- From TRM to TRC:
  - Terminal reconfiguration requests
- From TRC to TRM:
  - Terminal reconfiguration responses.

#### **6.1.2.3 Interface between the TRM and the TMC**

Interface between the TRM and the TMC is used to transmit the following:

- From TRM to TMC:
  - Terminal context information requests
- From TMC to TRM:
  - Terminal context information

#### **6.1.2.4 Interface between the NRM and the RRC**

Interface between the NRM and the RRC is used to transmit the following:

- From NRM to RRC:
  - RAN reconfiguration requests
- From RRC to NRM:
  - RAN reconfiguration responses

#### **6.1.2.5 Interface between the NRM and the RMC**

Interface between the NRM and the RMC is used to transmit the following:

- From NRM to RMC:
  - RAN context information requests
- From RMC to NRM:
  - RAN context information

#### 6.1.2.6 Interface between the NRM and the OSM

Interface between the NRM and the OSM is used to transmit the following:

- From OSM to NRM:
  - Spectrum assignment policies
- From NRM to OSM:
  - Information on spectrum assignment decisions

#### 6.1.2.7 Interface between several NRMs

If there are several NRMs, a corresponding interface may be defined between these NRMs (not shown in Figure 2).

This interface is used to transmit the following:

- RAN context information
- Terminal context information
- Spectrum assignment policies
- RAN reconfiguration decisions
- Radio resource selection policies

#### 6.1.3 Reference model

In general, each IEEE 1900.4 entity (OSM, RMC, NRM, RRC, TMC, TRM, and TRC) has the reference model shown in Figure 3. IEEE 1900.4 entities are modeled as a system management application entity (SMAE) (see ITU-T X.701 for SMAE specification).<sup>11</sup> The IEEE 1900.4 entity, as SMAE, is located on the application layer and has access to any layer of the OSI model.

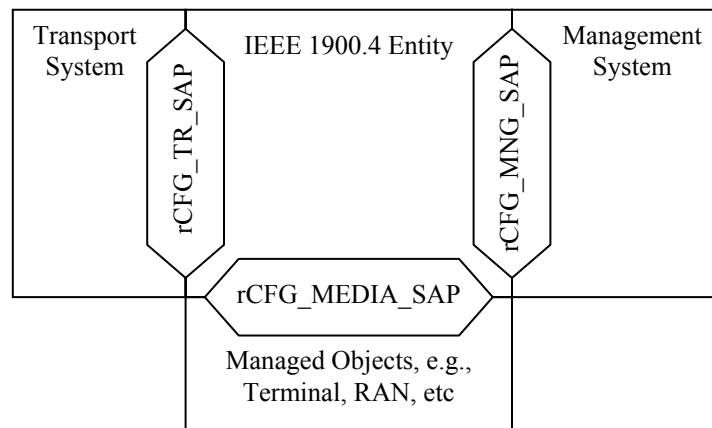


Figure 3—IEEE 1900.4 reference model

<sup>11</sup> Information on references can be found in Clause 2.

Each IEEE 1900.4 entity implements one or more of 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 IEEE 1900.4 entities. It abstracts transport mechanisms from IEEE 1900.4 entities by providing a set of generic primitives and mapping these primitives on transport protocols.

For example, this SAP is used to exchange radio resource selection policies and context information between the NRM and the TRM over radio enabler.

If there are several NRMs and there is interface between them, this SAP is used to exchange context information, spectrum assignment policies, reconfiguration decisions, and radio resource selection policies between these NRMs.

**Reconfiguration and Measurement SAP** provides reconfiguration and measurement services for managing RANs and Terminals. It provides a set of generic primitives for IEEE 1900.4 entities to collect RAN and terminal context information, as well as, to control reconfiguration of RANs and Terminals. These generic primitives are mapped onto specific protocols depending on the managed RANs and Terminals.

**Management SAP** provides management service for managing IEEE 1900.4 entities by legacy management systems. This SAP provides a set of generic primitives for IEEE 1900.4 entities to exchange information with these legacy management systems.

## 6.2 Functional description

According to functional requirements, the following functional architecture is defined in this standard (see Figure 4).

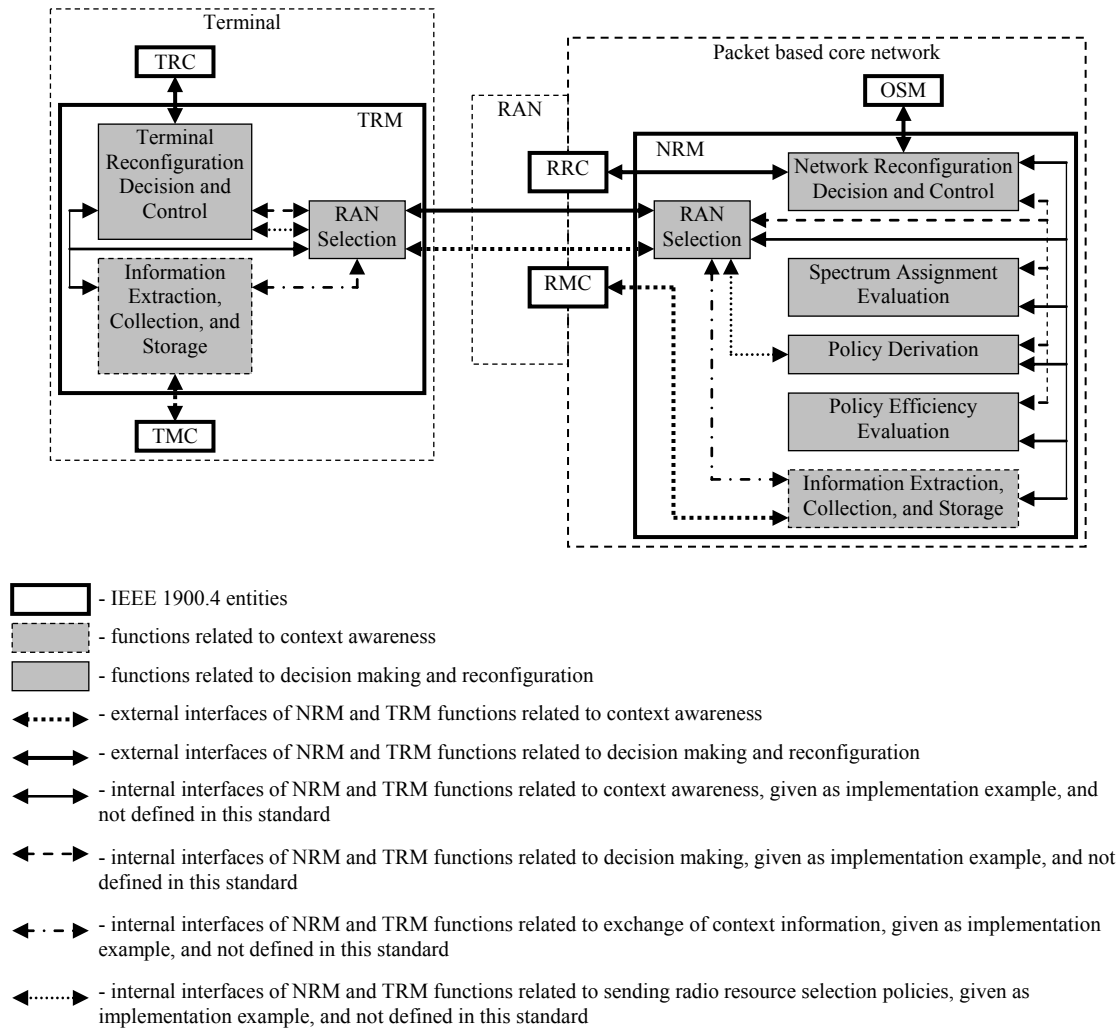


**Figure 4—Functional architecture**

### 6.2.1 NRM functions

The following functions are defined inside NRM (see Figure 4):

- Policy Derivation
- Policy Efficiency Evaluation
- Network Reconfiguration Decision and Control
- Spectrum Assignment Evaluation
- Information Extraction, Collection, and Storage
- RAN Selection

Policy Derivation function generates radio resource selection policies that guide TRMs in Terminals reconfiguration decisions.

The radio resource selection policies are derived according to 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 may be used by the Policy Derivation function during generating radio resource selection policies.

The Network Reconfiguration Decision and Control function makes decisions on the RAN's reconfiguration compliant with spectrum assignment policies received from OSM. After making these decisions, Network Reconfiguration Decision and Control function sends corresponding reconfiguration requests to the RRC. Also, the Network Reconfiguration Decision and Control function sends information on the decisions that have been made to the OSM.

The Spectrum Assignment Evaluation function evaluates the efficiency of spectrum usage under the current spectrum assignment.

Evaluation results may be used by the Network Reconfiguration Decision and Control function while making decisions on the RAN's reconfiguration.

The Information Extraction, Collection, and Storage function receives, processes, and stores the following context information:

- RAN context information
- Terminal context information

RAN context information is received from the RMC periodically and/or by request and/or on event-basis.

Terminal context information is received from the TRM periodically and/or by request and/or on event-basis.

The Information Extraction, Collection, and Storage function provides information to functions inside the NRM.

The Information Extraction, Collection, and Storage function forwards RAN context information to the TRM.

The Information Extraction, Collection, and Storage function may forward terminal context information, related to other Terminals, to the TRM.

The RAN Selection function selects RANs for exchanging radio resource selection policies and context information between the NRM and one or several TRMs. Radio resource selection policies are sent from NRM to TRM. From NRM to TRM, RAN context information is sent and terminal context information may be sent. From TRM, NRM receives terminal context information related to Terminal managed by this TRM.

Policy Derivation, Policy Efficiency Evaluation, RAN Selection, Network Reconfiguration Decision and Control, and Spectrum Assignment Evaluation functions cooperate during their operation. They represent different aspects of decision making and reconfiguration. During their operation, these functions use information from the Information Extraction, Collection, and Storage function.

## 6.2.2 TRM functions

The following functions are defined inside TRM (see Figure 4):

- Terminal Reconfiguration Decision and Control
- Information Extraction, Collection, and Storage
- RAN Selection

The Terminal Reconfiguration Decision and Control function makes decisions on Terminal reconfiguration. After making these decisions, the Terminal Reconfiguration Decision and Control function sends corresponding reconfiguration requests to the TRC.

The Information Extraction, Collection, and Storage function receives, processes, and stores the following context information:

- Terminal context information
- RAN context information

Terminal context information is received from the TMC periodically and/or by request and/or on event-basis.

Terminal context information regarding other Terminals is received from the NRM periodically and/or by request and/or on event-basis.

RAN context information is received from the NRM periodically and/or by request and/or on event-basis.

The Information Extraction, Collection, and Storage function provides information to functions inside the TRM.

The Information Extraction, Collection, and Storage function forwards terminal context information to the NRM.

The RAN Selection function selects RANs for exchanging radio resource selection policies and context information between the NRM and the TRM through the radio enabler. Radio resource selection policies are sent from NRM to TRM. From NRM to TRM, RAN context information and terminal context information are sent. From TRM to NRM, terminal context information is sent.

The Terminal Reconfiguration Decision and Control and the RAN Selection functions cooperate during their operation. They represent different aspects of decision making and reconfiguration. During their operation, these functions use information from the Information Extraction, Collection, and Storage function.

The Terminal Reconfiguration Decision and Control function makes reconfiguration decisions within the framework determined by the received radio resource selection policies.

## 6.2.3 Interfaces of NRM and TRM functions

### 6.2.3.1 NRM interfaces

The following interfaces between the NRM and other IEEE 1900.4 entities on network side are defined (see Figure 4):

- Interface between Network Reconfiguration Decision and Control function and OSM

- Interface between Network Reconfiguration Decision and Control function and RRC
- Interface between Information Extraction, Collection, and Storage function and RMC

Interface between Network Reconfiguration Decision and Control function and OSM is used to transmit the following:

- From OSM to Network Reconfiguration Decision and Control function:
  - Spectrum assignment policies
- From Network Reconfiguration Decision and Control function to OSM:
  - NRM spectrum assignment decisions

Interface between Information Extraction, Collection, and Storage function and RMC is used to transmit the following:

- From Information Extraction, Collection, and Storage function to RMC:
  - RAN context information requests
- From RMC to Information Extraction, Collection, and Storage function:
  - RAN context information

Interface between Network Reconfiguration Decision and Control function and RRC is used to transmit the following:

- From Network Reconfiguration Decision and Control function to RRC:
  - RAN reconfiguration requests
- From RRC to Network Reconfiguration Decision and Control function:
  - RAN reconfiguration responses

If NRM is implemented in a distributed manner, that is, there are several NRMs, and there is interface between these NRMs, the following interfaces are additionally defined (not shown in Figure 4):

- Interface between Information Extraction, Collection, and Storage functions of several NRMs
- Interface between Network Reconfiguration Decision and Control functions of several NRMs
- Interface between Policy Derivation functions of several NRMs

Interface between Information Extraction, Collection, and Storage functions of several NRMs is used to exchange the following context information:

- RAN context information
- Terminal context information

Interface between Network Reconfiguration Decision and Control functions of several NRMs is used to exchange the following:

- Spectrum assignment policies
- RAN reconfiguration decisions

Interface between Policy Derivation functions of several NRMs is used to exchange the following:

- Radio resource selection policies

An interface between the RAN Selection function in the NRM and the RAN Selection function in the TRM is defined (see Figure 4). The RAN Selection functions distribute on this interface the radio resource selection policies to a specific defined group of Terminals, based on location and/or radio resource usage volume.

This interface is used by the NRM to transmit the following to the TRM:

- Radio resource selection policies
- RAN context information
- Terminal context information

This interface is used by the NRM to receive the following by the TRM:

- Terminal context information

### 6.2.3.2 TRM interfaces

The following interfaces between TRM and other IEEE 1900.4 entities on terminal side are defined (see Figure 4):

- Interface between Information Extraction, Collection, and Storage function and TMC
- Interface between Terminal Reconfiguration Decision and Control function and TRC

Interface between Information Extraction, Collection, and Storage function and TMC is used to transmit the following:

- From Information Extraction, Collection, and Storage function to TMC:
  - Terminal context information requests
- From TMC to Information Extraction, Collection, and Storage function:
  - Terminal context information

Interface between Terminal Reconfiguration Decision and Control function and TRC is used to transmit the following:

- From Terminal Reconfiguration Decision and Control function to TRC:
  - Terminal reconfiguration requests
- From TRC to Terminal Reconfiguration Decision and Control function:
  - Terminal reconfiguration responses

Interface between RAN Selection function in TRM and RAN Selection function in NRM is defined (see Figure 4). The RAN Selection functions distribute on this interface the radio resource selection policies to specific defined group of Terminals, based on location and/or radio resource usage volume.

This interface is used by the TRM to transmit the following to the NRM:

- Terminal context information

This interface is used by the TRM to receive the following from the NRM:

- Radio resource selection policies

- RAN context information
- Terminal context information

The system architecture defined in this standard can be deployed in different ways. Concrete deployment examples are given in Annex E, showing IEEE 1900.4 entities, interfaces, and SAPs.

## 7. Information model

### 7.1 Introduction

IEEE 1900.4 uses an information model based on an object-oriented approach, whereby given that CWN and Terminals are controlled by an IEEE 1900.4 system, they are viewed as the two sets of managed objects.

To this end, the terminal-related classes abstract the user, application, device, and radio resource selection policy concepts, for instance structuring different profiles, capabilities, and measurements related to the Terminal.

The CWN-related classes present an abstract view of the CWN, capturing the operator and RANs, where operator concept includes assigned channels, regulatory rules, and spectrum assignment policies and RAN concept includes BSs and cells.

It must be noted that the presented conceptual abstraction is fully aligned to the scope of this standard. For example, **Application** class in the hierarchy of terminal-related classes does not incorporate generic application attributes; rather, it only incorporates those that have been identified within the standard scope.

Policy information as represented/abstracted by policy classes is a fundamental part of this standard ensuring the communication of policies to NRMs and TRMs to define framework of their operation. This standard therefore presents a concrete representation of events that trigger policies activation and execution, the conditions within which policies must act, and the precise actions that must be undertaken should, for example, a Terminal is found to be violating a policy.

In summary, the information model classes are grouped into the following categories:

- Common base class
- Policy classes
- Terminal-related classes
- CWN-related classes

For each of these categories, the simplified UML (see UML Version 2.1.2) diagrams are described in this clause. Detailed UML diagrams, as well as, attributes and methods of each class are given in precise detail in Annex B and Annex C. Annex D defines utility classes.

The rest of this clause is organized as follows. Subclause 7.2 specifies information modeling approach used in this standard, while 7.3 describes information model classes.

## 7.2 Information modeling approach

In order to fulfill the requirements, to keep the necessary level of information abstraction, to be prepared for future extensions, and to be easily used by different tools, the following properties have been taken into account for the information modeling:

- a) The information model is developed in an extensible form in order to accommodate future radio access technologies and allow for custom extensions to existing data models.
- b) The information model uses an object-oriented approach.
- c) The information model supports sufficiently simple relationships between different classes.
- d) The information model allows for inclusion of both uniform and non-uniform data structures (e.g., lists).
- e) The information model allows for definition of new abstract data types to describe the information model items.
- f) The information model allows providing information items allowing for specification of precision and accuracy.
- g) The information model includes exclusivity or consistency relationships between objects to determine conflicts (for instance whether two different channels or radio technologies can be monitored at the same time).
- h) The information model provides means for unique identification of managed objects.
- i) The information model utilizes platform-independent unambiguous information/data type definitions.
- j) The information model allows for inclusion of information about information objects distribution (e.g., to identify the targeted nodes in a multicasting case).
- k) The information model is open to incorporate
  - Corresponding information elements towards developing a shared knowledge framework about the information objects themselves. Such framework may include information about the updates, status etc.
  - A notifications list, such as configuration changes, threshold crossings etc to align the shared knowledge framework.
  - Additional information elements to ensure alternative information retrieval for supporting an efficient retrieval mechanism to obtain performance, quality-of-service and related information and measurements data.
  - Information elements that can provide value (instantiate) through mechanisms such as statistical operations to reduce data transfers.
  - Managed objects in order to coordinate the measurements scheduling.

## 7.3 Information model classes

The IEEE 1900.4 information model classes are depicted together with the relations among them in order to present the breaking down of the conceptualization in the adopted several levels of abstraction/details. The corresponding cardinality information has been also included.

### 7.3.1 Common base class

Common base class is shown in Figure 5.

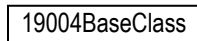


Figure 5—Common base class

The following common base class is defined:

- **19004BaseClass**  
This class comprises basic properties to be supported by all objects of the IEEE 1900.4 information model. It is considered as an abstract class that is only used for inheritance. The properties supported are, e.g., an attribute representing the class name of an instance, and three generic events that an instance of this class can report to a managing system. These three events are: creation of a new instance of this class, deletion of an instance of this class, change of an attribute value in an instance of this class.

### 7.3.2 Policy classes

Policy classes are shown in Figure 6.

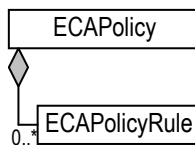


Figure 6—Policy classes

The following policy classes are defined:

- **ECA Policy**  
This class is used to describe policies of type Event-Condition-Action (ECA). An instance of this class comprises a set of Event-Condition-Action rules that have to be obeyed when applying the policy.
- **ECA Policy Rule**  
An instance of this class describes (in terms of three attributes)
  - a) an event that triggers the evaluation of the policy condition
  - b) a condition that shall be fulfilled before applying the policy action
  - c) the action that has to be performed if the event has occurred and the condition is fulfilledAll these attributes refer to information entities that are available in the system that applies the policy.

### 7.3.3 Terminal-related classes

A simplified UML diagram of terminal-related classes is shown in Figure 7. A detailed UML diagram of terminal-related classes is available in Annex B.

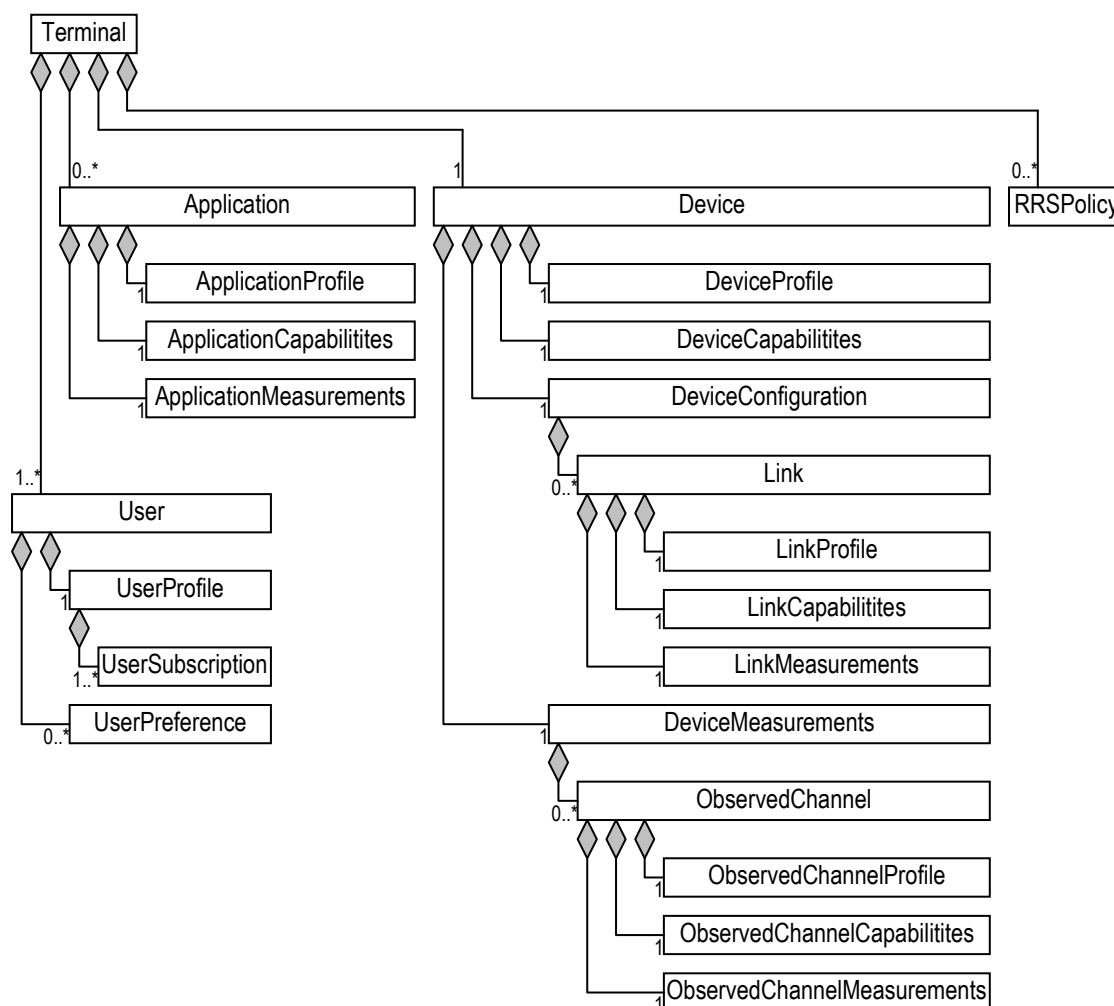


Figure 7—Terminal-related classes

The following terminal-related classes are defined:

- **Terminal**  
The instance of this class contains instances of all terminal-related classes using composition.
- **User**  
This class describes information related to a user of the Terminal. Each instance of **Terminal** class can have one or several instances of **User** class as members.
- **User Profile**  
This class contains general information about one user of the Terminal, for example, user ID. Each instance of **User** class can have only one instance of **User Profile** class as a member.
- **User Subscription**  
This class contains information about one subscription of the user. It describes which RANs/services the user has been subscribed in and what is the associated cost. Each instance of **User Profile** class can have one or several instances of **User Subscription** class as members.

- **User Preference**  
This class describes in a formalized form one preference of the user, for example, preferred operator and radio interface, perceived audio/image/video quality, maximum cost, minimum data rate, etc. Each instance of **User** class can have zero or several instances of **User Preference** class as members.
- **Application**  
This class describes one currently active application. Each instance of **Terminal** class can have zero or several instances of **Application** class as members.
- **Application Profile**  
This class contains general information about the application, for example, application ID, traffic class, direction (downlink or uplink), links used to deliver this application, QoS requirements etc. Each instance of **Application** class can have only one instance of **Application Profile** class as a member.
- **Application Capabilities**  
This class contains information about measurements (instantaneous measurement data and performance statistics derived from this data) supported by this application, for example, delay, loss, and bandwidth measurements. Each instance of **Application** class can have only one instance of **Application Capabilities** class as a member.
- **Application Measurements**  
This class contains measurements (instantaneous measurement data and performance statistics derived from this data) performed by this application, such as delay, loss, and bandwidth measurements. Each instance of **Application** class can have only one instance of **Application Measurements** class as a member.
- **Device**  
This class describes all radio interface related hardware and software of a Terminal, as well as, measurement information related to radio resources within the Terminal. Each instance of **Terminal** class can have only one instance of **Device** class as a member.
- **Device Profile**  
This class contains general information about the Terminal, for example, Terminal ID. Each instance of **Device** class can have only one instance of **Device Profile** class as a member.
- **Device Capabilities**  
This class contains information about Terminal capabilities including both transmission and measurement capabilities, for example, supported radio interfaces, maximum transmission power, etc. Each instance of **Device** class can have only one instance of **Device Capabilities** class as a member.
- **Device Configuration**  
This class contains information about the current configuration of Terminal. Each instance of **Device** class can have only one instance of **Device Configuration** class as a member.
- **Link**  
This class contains information about one active connection between Terminal and RANs. Each instance of **Device Configuration** class can have zero or several instances of **Link** class as members.
- **Link Profile**  
This class contains general information about this active connection, for example, link ID, serving cell ID, channel used, etc. Each instance of **Link** class can have only one instance of **Link Profile** class as a member.