Urban planning for Radio Communications

SP 1

GENERIC ARCHITECTURE FOR RESOURCE MANAGEMENT AND ASSOCIATED PROTOCOLS

Task 3

EVOLUTION OF FREQUENCY ALLOCATION TECHNIQUES AND THEIR IMPLEMENTATION

D1.3.2

TITRE DU LIVRABLE

Edition 3 30/04/2008

Editions

Edition	Date	Authors	Comments
ed. 0	01/02/08	P.Tortelier (Orange Labs)	Initial TOC
ed. 1	aa/bb/cc	P.Tortelier (Orange Labs) M. Coupechoux (ENST) H. Kamal (ENST) Ch. Riou (Thales)	First draft of§ 1-4
ed. 2	dd/ee/gg	R. Pintenet (Motorola) Ph. Godlewski (ENST)	
Ed.2.1	10/03/08	Marceau Coupechoux (ENST) Hany Kamal (ENST) Ph. Godlewski (ENST)	
Ed 2.2	19/03/08	P. Tortelier	Defining policies.

Contents

Summary

Among the many flavors of what is called *Cognitive Radio*, policy defined cognitive radio can be said the more pragmatic and/or feasible one. This name emphasizes the importance of a set of rules (policy) governing the behavior of wireless devices, and is of a great importance in situations where the rules are not static or can vary with the location of the equipment. These circumstances call for an implementation of these rules in a machine readable form, and, as a consequence, a language to write them in this understandable form.

The present document aims to give a simple version of such a policy language, not based on XML or existing knowledge description language, but trying to put in evidence that a policy language needs to tell a device the desired behavior on predefined events.

We present some constructs for this policy language, and the possibility to use existing work in a related project, 802.21 which defines an abstraction layer for a media independent handover: most of the features of the policy language we define could be implemented with the primitives of the three services of the MIH function.

A basic example, pertaining to the Dynamic Frequency Selection of WLAN operating in radar bands, shows how to implement this policy in the language.

A more

1 Introduction [FT]

This document aims to introduce the envisioned new schemes of spectrum management based on the use of *policies* and how these policies could be broadcasted to user equipments (terminals). Alongside with the widely known concepts pertaining to heterogeneous wireless access, such as software defined radio (SDR), vertical handover between radio access technologies (RATs) or the new schemes of spectrum sharing designed to alleviate alleged spectrum scarcity, we witness the emergence in the wireless domain of a now mature technology coming from computer sciences: the development of radio related languages taking into account the particularities of the wireless transmission can be traced back to Joseph Mitola's thesis [1] where a Radio Knowledge Representation Language (RKRL) was designed. Later, the same author described Radio XML (RXML), an extension of the widely used XML markup language applied to radio communications [2]. Since then, this topic has belonged to the cognitive radio (CR) stream of research, and is a component of Next Generation Communication (XG) program of DARPA.

Interestingly, the same kind of abstraction of radio communications is performed in the IEEE 802.21 working group, which aims to define a Media Independent Handover (MIH) for heterogeneous access networks; this ongoing work is also based on *ontologies* and uses the web ontology language (OWL). This document proposes to provide a simple description of MIH and to take advantage of this existing work to implement DSA policies.

We shall try to give a simple description of these somewhat intricate strands of research; we think they can be easily seen as solutions to problems arising from the many time scales existing in a wireless network.

1.1 Time scales in a wireless network

The main characteristic of a wireless channel is its space, time and frequency variability. Considered as an impairment decades ago, this variability is now considered as an opportunity through various diversity techniques which are beyond the scope of this paper. If we restrict ourselves to time variability we can underline the existence of many time scales in these channel variations and the need of different techniques to address them. Roughly speaking we shall distinguish fast, low and very low time variations, according to the underlying physical phenomenon or service needed by the user.

- A user moving in a multipath channel experiences fast fading of received signal; we can think of an interference fringes pattern across which is moving the terminal. Speed of variation is given by the Doppler frequency, $f_d = v / l = \frac{v}{c} f_0$. For $f_0 = 900 MHz$ and v = 120 *km/h*, $f_d = 100 Hz$, that is to say, the received level changes 100 times per second.

- Slower variations are caused by variations of the environment: shadowing effect of buildings, moving obstacles (people, cars,…), change in path loss according to the distance between base station and mobile terminal; time scale is about some seconds.
- Slower variations in the environment are related to the movement of the user from a cell to an adjacent one (horizontal handover, HO) in a cellular network. Time scale depends on the cells size and users speed, and is typically some tens of seconds or minutes. The change of cell possibly dictates the change of RAT (diagonal HO), when user leaves the area covered by short range system (hotspot) and must hook to a cellular system (3G). In this category we can include changes of RAT due to requirements of the user service in terms of available rate, delay, required SNR or bit error rate, security level,… the handover is called vertical in this case, we are in the situation of an *heterogeneous access network*.
- At last, time scales of days, months or year have to be taken into account. Intraday variations of traffic due to displacement of users between home and office are an example of hour time scales. Over the air bug correction of terminals, upgrades for software defined radio (SDR) base stations are example of month time scale. Modifying spectrum management could also be of interest, it is a case of low (or very low) time scale.

These manifold time scales, ranging from ms to days or months, are not tackled by a one fits for all technique; however it is possible to identify three main levels as described thereafter:

Quick response to a stimulus (1): réflex	Reasoning in compliance with rules (2)	Change of rules (policies) (3)

Short-term ⟵⟶ Long-term

(1) Link adaptation (transmit power control, adaptive modulation, multiple modulation/coding schemes) is a long used solution to address fast channel variations within a same radio interface (see the MCS of GPRS/EDGE). SDR is an enabler for this technique, allowing the use of various digital baseband processing (such as channel estimation, equalization, synchronization, channel decoding, and their iterative or *turbo* versions), but it cannot be considered as a cognitive radio feature, for it is merely an immediate response to a predefined set of stimuli, without any possibility to manage unexpected changes of environment. We could see link adaptation as an equivalent of reflexes of living beings: an immediate response to an event is sometimes vital, there is no time for reflexion.

(2) The inputs (or metrics) used for link adaptation (for instance: received signal level, estimate of Signal/Noise ratio, any indication from sensors) exhibit time correlations or trends, allowing some form of prediction of their evolution from past samples. For instance if measurements indicate a decrease of re-

ceived signal level we can predict that the current link is likely to break down due to a fading or because we are too far from the current base station. It is then possible to anticipate this event in compliance with existing rules and prepare for a handover. More generally a terminal with various sensors would be able to make a big picture of its environment (indoor/outdoor, its speed, the user behaviour or required service,…). This is the real domain of cognitive radio, more precisely Policy defined Cognitive radio, to emphasize that at any time the radio communication must obey to a set of rules based on regulation, or on operator strategy (for example: terminal should rather use RAT1 than RAT2 for an optimized use of operator's licensed spectrum), and possibly on user preferences.

(3) The third time scale is the long term evolution of the rules. The long term consequences of current rules can be anticipated or observed, as well as the need to change some of them. It is the main topic of this deliverable. This possibility of changing the rules is a major change with respect to the current situation, with two foreseeable consequences:

- As the rules may change they must be implemented in a machine readable (and understandable) form. This is the domain of *ontologies*, an active field of research, including for CR studies. Without going further we can remind the following components of ontologies (from S. Mangold : http://www.comnets.rwth-aachen.de/home/smd/stefanmangold_research.html):

  - *Classes (general things) and instances (particular things) in the domains of interest*
  - *Relationships among things*
  - *Properties (= attributes) of things*
  - *Functions of and processes involving things*
  - *Constraints on and rules involving things*

- The second consequence is the need to broadcast new policies (or changes of current policies) in a network.

Cognitive Radio can thus be considered as the junction of many streams: SDR as an implementation technology providing some flexibility, sensors and detection theory as a means of awareness of the surrounding environment, representation of knowledge and rules (ontologies) and inferences from these rules (reasoning), and last learning from past experience, with the possibility of definition of new rules, modification of existing ones, refinement of knowledge... This is summarized by the following scheme from MITRE research:

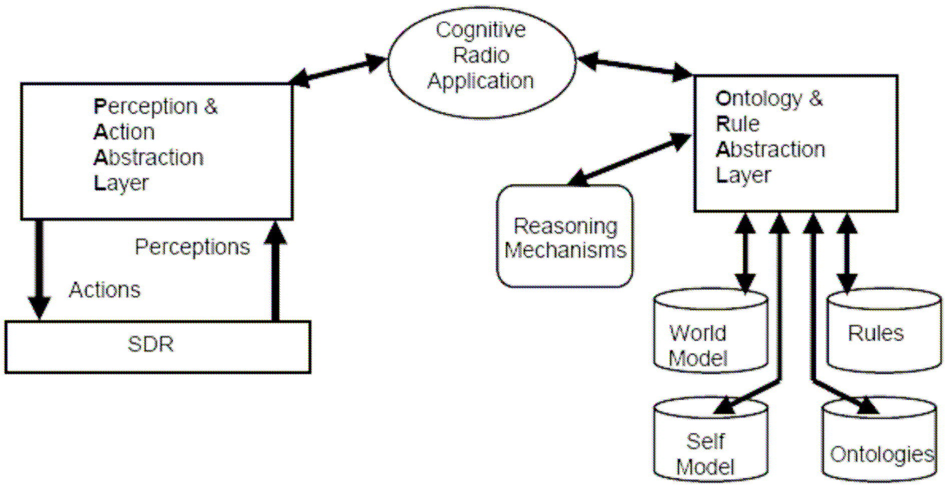


Figure 1: Cognitive radio architecture (A. Ginsberg, W.D. Horne, MITRE)

We can already notice that the main thrust to this new vision is mainly related to the ongoing work on the way spectrum is managed, with the assumption that it is currently underutilized because of a static regulation.

1.2 The role of policies

We now give some examples of circumstances that call for varying policies. Some will be more thoroughly analyzed in section4.2..

It may happen that a network is not well dimensioned because of unexpected behaviour of users; we may remind the problems that arose from unexpected uplink traffic in ADSL resulting from peer to peer usages that were not taken into account in the dimensioning of the core network. The observation of the way a network is functioning can lead to the conclusion that current rules must be changed. This is a first scenario of varying policies coming from the need to optimize the resources of a network, especially spectrum, for wireless networks. The modification of CSMA/CA with a Request-to-Send (RTS) and Clear-to-send (CTS) to tackle the hidden node problem is such an example.

Exceptional events are an obvious cause for changing policies. Moreover we could refine this vague idea if we remark that there are at least two kinds of such events: some of them are perfectly predictable: Olympic games, world cups … Operators are then able to prepare the network to manage expected surge of traffic and the corresponding policy changes. Events of the second kind are expected but we are not able to predict the time they will happen: people from Japan or California for instance know that an earthquake will happen in their respective areas, with a quasi certainty, but they ignore at what moment. Telecommunication infrastructure will be destroyed in such disasters and a temporary wireless infrastructure will have to be deployed immediately for emergency relief. Cognitive Radio base stations have interesting features in such a scenario: first, their flexibility provides interoperability between various communication systems (rescue workers, firemen, police…). Another advantage is that they can be quickly deployed in an ad-hoc manner (i.e. they are composed of nodes of a mesh network), with the consequence that an automatic procedure for allocating them frequencies (for avoiding interferences between base stations) is needed.

Somewhat related to the previous example is the ongoing FCC's auctions of frequencies in the 700 MHz band [3]. Block D is an interesting case: a single license will be issued for a public safety wireless network with a national coverage. A partnership between public safety and commercial carriers is envisioned: a secondary use of these frequencies is allowed with the constraint that public safety will have priority to access the band in emergency periods. The need for some form of varying rules in such situations is obvious; it is also a good example of a secondary market for spectrum usage. Depending on the geographical coverage of the disaster area it is also an indication that policies could be time and location dependant.

In a presentation, Mark McHenry (from the "Shared Spectrum" company) gives a more comprehensive list of envisioned policy types ("Dynamic spectrum use, Briefing to: COMMITTEE ON RADIO FREQUENCIES", April 25 2007). This presentation does not address operator related policies (operator preferences, for instance) but is a good start point for our reflections:

- Listen-Before-Talk (LBT) based types: Various schemes aiming to avoid collisions, in fact it corresponds to modified Carrier Sense Multiple Access (CSMA) schemes, with Request to Send/Clear to Send (RTS/CTS) mechanisms for instance. We can include Detect and Avoid (DAA) mechanism for UWB devices in this category.
- Spatial types: for example spatial reuse of TV frequency, e.g. reuse of DTV spectrum by wireless regional networks (802.22)
- Temporal type: time of day restrictions, finite duration licenses …
- Device based types: the idea is to take into account the device capabilities to grant access to the spectrum; some years ago, publications mentioned a possible standardization of receiver to improve spectrum efficiency, for a good receiver (a receiver with a good RF frontend and implementing high performance receiving algorithms) allows a correct reception with more interference. Iterative receive algorithms (aka turbo schemes) are the key solution, at the expense of a greater receiver complexity (and power consumption). An other possibility (for the base station only) is the use of high temperature superconductor (HTS) filters with excellent out of band rejection.
- Connectivity based type: a beacon reception is required to use the band. The device must be connected to a spectrum manager to request transmission…
- Group behavior based types:
    - Abandon channel if any node within given range detects a non cooperating node.
    - Determine transmit power based on estimated interference probability.

  - o Node identity restrictions (e.g. use while airborne is forbidden, use only in fixed applications, Red-Cross use only)

- Distributed control based types: automated policy updates if feedback indicates that existing policy is insufficient for non interference operations. Automated policy updates notification, or policy revocation, or update by policy authority.

Another classification of possible behaviors can be found in a MITRE presentation at TPRC2003[†]: four high-level behabiors are defined with their associated mechanisms or parameters, as in the following table:

High-level behavior	**Mechanism/parameter**	**comments**
Prohibited	Limit access through defined spectrum space regions (frequency band, time, location, directionality, etc.)	May be used to protect existing systems during introduction of adaptive systems or for protecting critical systems
Casual (if-then)	Given location in the spectrum space (e.g., physical location and frequency), access may be permitted with specific constraints	May require mandated existence and availability of databases
	Given measured environment, access may be permitted with specific constraints	- Requires system to measure environment and react accordingly (e.g., DFS) - May also include limits based on the overall environment (e.g., "interference temperature")
	Given signal identification, access may be permitted with specific constraints	Use of both databases and measured environment to determine actions
Interactive (negotiated or shared control)	Negotiated access using spectrum space dimensions (e.g., request access to x band during y timeframe in location z)	- Such behavior enables regulatory constructs like secondary markets - Less interactive mechanisms, such as beacons, can also be used to define access
Dynamic	Rather than pre-defined actions, systems can automatically determine what criteria and actions are needed based on measurements, shared information, and requirements (e.g., interference levels)	Enables innovative concepts based on dynamic system needs and conditions

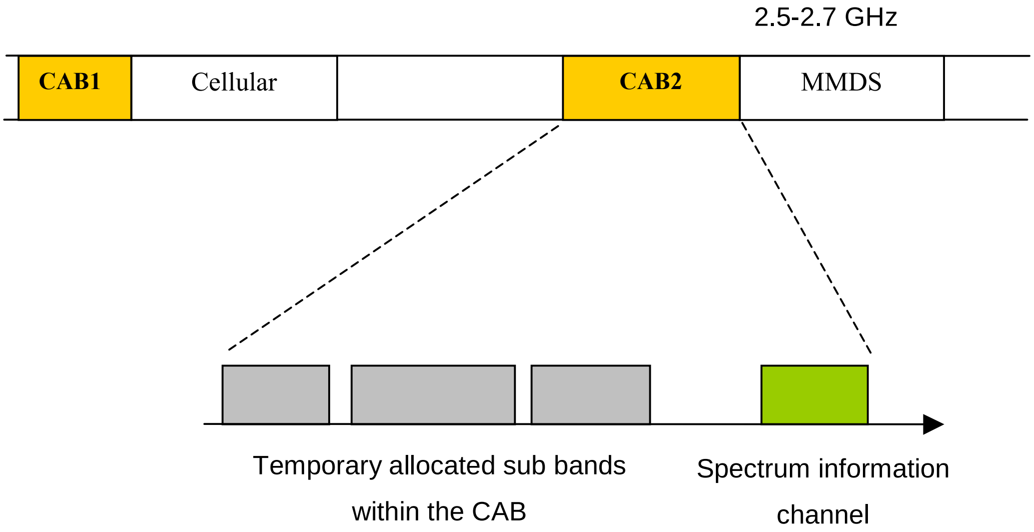
[†] W.D. Horne: Adaptive spectrum access: using the full spectrum space, Telecommunication Policy Research Conference (TPRC), 2003.

1.3 How to broadcast policies in the network (CPC, RE)

As it was already stated we are studying scenarios of possible evolutions of spectrum management where the rules that must be obeyed can evolve in time or space; as a consequence these rules can no longer be hard coded in devices or in network. As we want them to be immediately applied by devices they need to be written so that they can be understood by a machine and broadcasted to all devices. A key component of future networks implementing new DSA protocols is thus an information channel connecting network side to terminal side in order to broadcast policies or change in policies. This idea is already envisioned in some ongoing works, such that:

- The Cognitive Pilot Channel (CPC) of the European project E2R-II, continued in E3.
- The radio enabler (RE), as defined in IEEE P1900.4 working group
- The spectrum information (SPI) channel, defined in the US project DIMSUMnet

There are possibly some other similar studies we are not aware of, but the key idea is present. The two first schemes (CPC and RE) are very often given as an example, being developed in a standardisation body (IEEE) or in the European project E3. This is why we shall focus on the less known Spectrum Information Channel (SPI) from the DIMSUMnet project (Dynamic Intelligent Management of Spectrum for Ubiquitous Mobile Networks) which was a NSF funded project in the framework of the ProWiN program (Programmable Wireless Networks) [5]. The goal of this project was to improve spectrum utilization by the means of new sharing techniques. Besides the usual dichotomy licensed vs. unlicensed spectrum was introduced the concept of Co-ordinated Access Bands (CAB): CAB is a frequency band reserved by the regulation authority (FCC) and adjacent to an existing licensed bands; it is dynamically managed (on a market basis) by a *spectrum broker* which grants access to all or part of CAB to requesters for a limited time duration (in fact, it can be said that it is a kind of short time license).



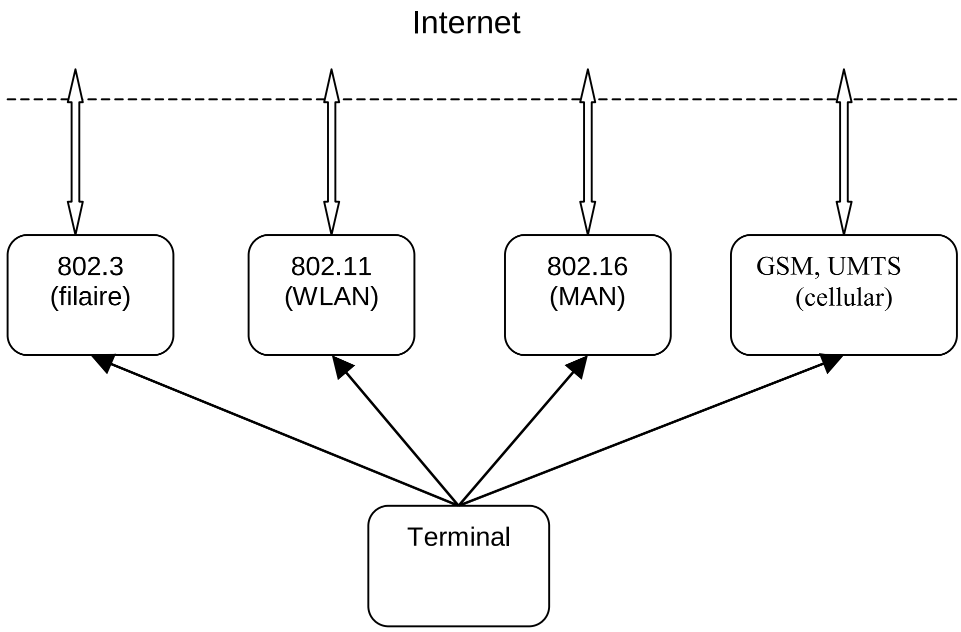
The license is granted by an automated <u>machine driven protocol</u>, this is the link with the topic of the present document. Predefined part of a CAB is reserved for the transmission of a spectrum information channel. In the simplest version of CAB where request for pool spectrum can be made only by network operators, the SPI is a broadcast channel (from base stations to mobile nodes), more precisely an out of band channel because a dedicated physical resource is reserved. The data that might be transmitted by the SPI could include some parameters like frequency band to use from the CAB, time duration of the license (from time t0 to time t1), the licensee (what operator is granted access to this part of the CAB), location (in what place is the license granted), the waveform (GSM, 3G,…); this is indeed an information channel as defined below.

2 A short description of the Media Independent Handover (MIH) [FT]

We give a (not so) short description of the Media Independent Handover (MIH) which is developed within the IEEE 802.21 working group [13] [14]. We should like to stress the possible use of MIH in a dynamic spectrum allocation (DSA) context, or more generally, in a cognitive radio context. Indeed, the Information service defined in MIH could form the basis of an information service which is part of a cognitive pilot channel (CPC) or a radio enabler (RE) in the P1900.4 terminology. Moreover it could be used to implement and broadcast policies in a wireless network, taking advantage that the representation of radio knowledge (that is to say: a radio ontology) has already been carried out in MIH and can obviously be used to build new features related to DSA; the main idea is that DSA protocols could be seen as MIH *users*, where *user* means a level 3+ protocol using MIH interface.

MIH is intended to enable a seamless connectivity to internet through a heterogeneous access network: a multimode terminal accesses internet across wired networks (Ethernet), or wireless networks from the 802 family (such as Wifi, Wimax) as well as non IEEE cellular networks (GSM, UMTS). According the user location or link quality some handover between these access networks will be necessary. The handover is said *seamless* if the internet connection is not lost.

MIH can be seen as an abstraction layer between PHY/MAC layer and L3 and above layers, providing a set of commands, events and information exchange between upper layers and the various PHY layers of the access network in order to enhance handover between various RAT (vertical HO, but it seems it could also be used for horizontal HO).



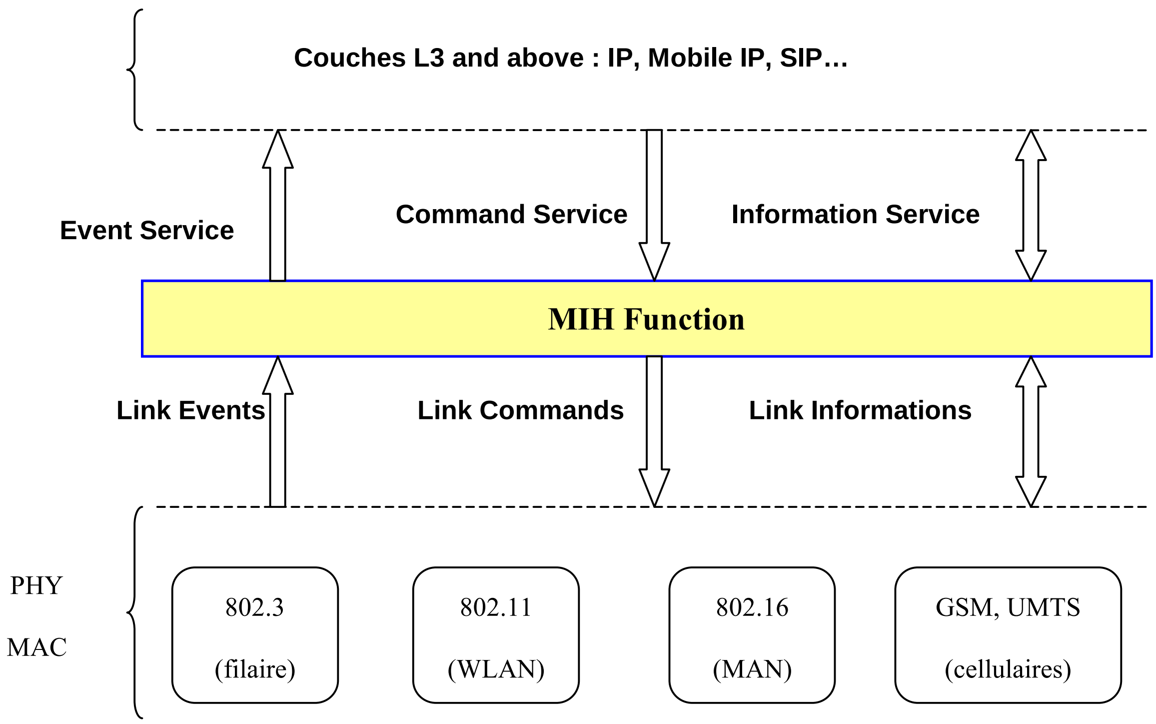
Although related to HO, MIH is not a handover protocol; it addresses only the two first phases of the HO:

1. HO Initialization: network discovery, network selection, resources negotiation
2. HO preparation: seamlessly, as a background task (*make before break*); the number of dropped packets is expected to be significantly reduced, this prevents the connection to be broken.

The HO execution is not in the scope of MIH. To achieve the enhancement of HO, MIH presents a unified view of PHY/MAC layers to level 3 and above layers and three means to access them through *services*, according to the main direction of messages: from L3 down to L1-L2 (commands), from L1-L2 up to L3 (events, results of measurements), and bidirectional (exchange of informations). These services are described thereafter.

2.1 MIH services (event, command, information)

Three services are defined: Media Independent Event service (MIES), Media Independent Command service (MICS) and Media Independent Information service. (MIIS).



- **Event service** is used to report link events from PHY/MAC layer to upper layers. For instance **MIH_Link_Going_Down** says that the current link is becoming bad and is expected to be soon unusable: Another access network must be found, this event is a trigger for a handover. The corresponding signal implemented in each technology of the access network (*link event*) is **Link_Going_Down**[‡]. A complete list of *events* and other commands is given in the draft version of the standard 13, and the 802.21 tutorial 14 is very useful to get an insight of MIH. Interestingly, we can find in this document indication of events coming from the network (and not from the PHY layer), they seem to be related to some functionalities such that load balancing between adjacent cells or access points, or *operator preferences*; they could be used to implement operators' spectrum management policies through an heterogeneous access network, MIH acting as an adaptation layer with the different PHY layers. This point will be further discussed.

Table 1: some MIH primitives for event service.

Primitive	Short description
MIH_Link_up	L2 connection is established, link is available for use.
MIH_Link_down	L2 link is broken
MIH_Link_Going_Down	Current L2 link is predicted to be down

[‡] More generally, to each primitive **MIH_event-xyz** between the MIH function and upper layers is associated a primitive **event-xyz** between MIH function and the different L2 layers. There is the same distinction for MIH commands and link commands.

MIH_Link_Detected	Link of a new access network has been detected
MIH_Link_Event_Rollback	Previous expected event do not occur.
MIH_Link_Parameters_Report	Link parameters have crossed pre-specified thresholds.
MIH_Link_Handover_Imminent	L2 handover is imminent
MIH_Link_Handover_Complete	L2 link handover to a new PoA has been completed.

- Commands sent by network to L2 layers are transmitted through the **Command Service**. For instance, to initiate handover a **MIH_Handover_initiate** command is sent, followed by a list of available networks near the terminal and their characteristics; this list is part of the information service, and prevent the terminal to perform a scanning which is a time and resource consuming task, especially as the number of available systems increases. A second example is the command **Link_Get_Parameters** which is sent to get some quality parameters from the PHY/MAC layer (received signal strength (RSSI), SNR, bit error rate, packet error rate…).

Table 2: some MIH commands

Primitive	Short description
MIH_Link_Get_Parameters	Get the status of a link.
MIH_Link_Configure_Thresholds	Configure link parameter thresholds
MIH_Link_Actions	Control the behavior of a set of links

- The Media Independant **Information Service** allows exchange of informations between network and terminal, especially informations on available networks in the neighborhood of the terminal, and their characteristics, the aim is clearly to avoid excessive scanning by the terminal which is an energy consuming task. The following example from [14] says that there are 3 available networks : a cellular network (GSM), a 802.11n access point and 802.16e. Informations range from operator's name to security protocol used , and some quality informations on PHY layer, such that data rate, but other parameters could be included (kind of modulation) the terminal can ask for these informations through a request to a server:

Primitive	Short description
MIH_Get_Information	Request to get information from repository

Network Type	SSID/ Cell ID	BSSID	Operator	Security	EAP Type	Channel	QoS	Physical Layer	Data Rate
GSM	13989	N/A	Oper-1	NA	NA	1900	N/A	N/A	9.6 Kbps
802.11n	Enterprise	00:00:…	Oper-2	.11i	EAP-PEAP	6	.11e	OFDM	100 Mbps
802.16e	NA	NA	Oper-3	PKM	EAP-PEAP	11	Yes	OFDM	40 Mbps

The standard draft [13] provides a comprehensive list of informations provides by the information service ; they are stored in a central server as depicted below [14]

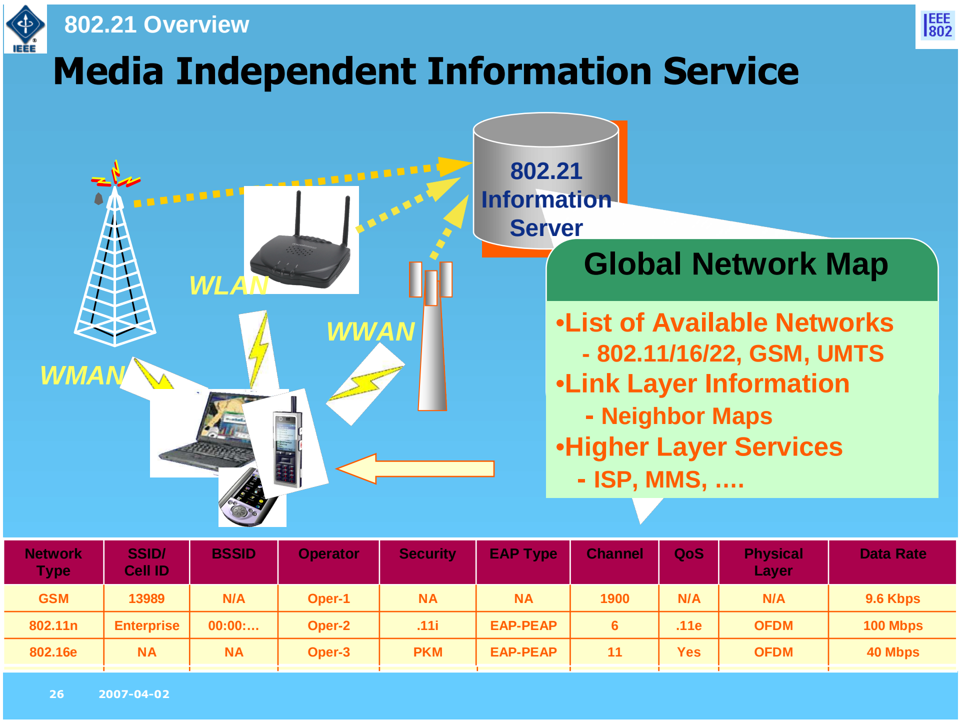


Tableau 3: some MIH information elements

primitive	Short description
IE_NETWORK_TYPE	Link types of the access networks that are available in a given geographical area.
IE_OPERATOR_ID	The operator identifier for the access network/core network.
IE_SERVICE_PROVIDER_ID	Identifier for the service provider.

IE_ROAMING_PARTNERS	Roaming Partners: Network Operators with which the current network operator has direct roaming agreements.
IE_COST	Indication of cost for service or network usage
IE_NETWORK_QOS	QoS characteristics of the link layer.
IE_NETWORK_DATA_RATE	The maximum value of the data rate supported by the link layer of the access network.
IE_POA_MAC_ADDR	MAC Address of PoA
IE_POA_LOCATION	Geographical location of PoA. Multiple location types are supported including coordinate-based location information, civic address, and cell ID.

2.2 MIH and IEEE P1900.4

Somewhat related to the information service of MIH is the ongoing work of IEEE SCC41 (Dynamic Spectrum Access Networks), and more precisely its working group P1900.4 whose scope, according to a presentation from this working group, is:

Scope: This 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 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 information exchange will be addressed at a later stage.

Among these three entities (the Network Resource Manager, or NRM, the Terminal Resource Manager, or TRM, and the Radio Enabler, or RE) RE is an information channel with a function which is very similar to the MIIS (information service of MIH) or the Spectrum Information Channel (see section 1.3 above). Indeed we could broaden the scope of the Media Independent Information Service if we consider that a *user* of MIH (in the 802.21 terminology) could be any L3 protocol, not only handover protocol as initially designed in 802.21, but also resource management protocols or policy implementation and broadcasting, especially in a heterogeneous access network.

We could thus envision a reuse of the information service of MIH as an implementation solution of the radio enabler. Of course some modifications (some extensions, for instance spectrum related informations) seem possible or necessary to account for spectrum management specific features. Moreover this reuse should avoid defining a specific channel with its own spectrum resource (as would be the case for an out of band CPC[§]).

3 Policy languages [FT]

The US XG (next Generation communications) program, funded by the DARPA, addresses opportunistic spectrum access, and many cognitive radio studies have their origin in this endeavour, especially the concept of policy defined CR. A first Request For Comment (RFC) to define a policy language was issued in [23] and some implementations complying with it are already described, such that CoRal (Cognitive Radio Language) (see section 7.4).

For the purpose of URC project, time and resources are not adapted for a definition and an implementation of such a policy language, especially because we do not have the relevant software skills (ontologies for instance). We shall restrict ourselves to introduce key concepts and give a very simple yet interesting example, not intended to give all details of a policy language.

3.1 A basic example: DFS

Cognitive radios will be capable to operate in compliance with given policies (or within the framework of a predefined set of rules). At a first glance, policies come down to a set of if-then-else rules, this perspective will be précised further in the document. The first example of policy we can give is about Dynamic Frequency Selection (DFS), a feature that allows unlicensed users (802.11a devices) to access parts of 5 GHz band in which radars operate, namely 5.25-5.35 GHz and 5.47-5.725 GHz bands. DFS can be considered as a basic mechanism of opportunistic access in which secondary users seek to access a licensed band without creating interference to primary users (for instance meteorological radars in the band 5.60-5.65 GHz). This is not a purely academic research, as many experimental evidences of interference from 802.11a devices on meteorological radars had been reported, for instance in Poland and Hungary, and led to the DFS mechanism.

[§] Nevertheless, if any radio technology can be used in a frequency band (technology neutrality) an out of band CPC remains necessary when switching on a terminal, for the allocation of frequencies to different RATs is unknown to the terminal.

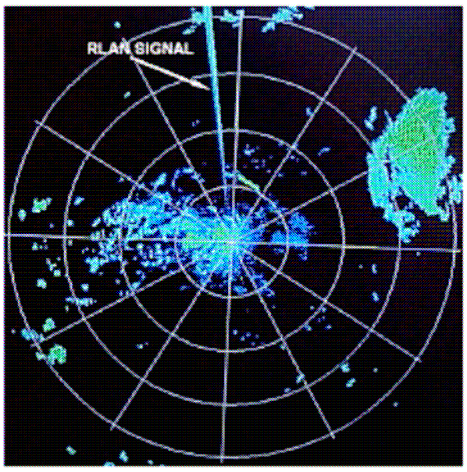


Figure 2: Example of WLAN interference on a meteorological radar. Ref.: A.L. Brandao, J. Sydor, W. Brett, J. Scott, P. Joe, D. Hung: "5 GHz RLAN interference on active meteorological radars", IEEE-VTC 2005-spring.

A high level description of DFS can be given with common English phrases, especially if we remind its description from ETSI EN 301 893:

The operational behaviour and individual DFS requirements that are associated with these modes are as follows:

Master devices:

a) the Master device shall use a Radar Interference Detection function in order to detect radar signals with a level above the Interference Detection threshold in the frequency ranges 5250 to 5350 MHz and 5470 to 5725 MHz. Radar detection is not required in the frequency range 5150 to 5250 MHz.;

b) the Master device initiates an RLAN network by transmitting control signals that will enable other RLAN devices, to associate (participate in a wireless network) with the Master device;

c) before initiating a network on a channel, the Master shall perform a Channel Availability Check for a certain duration (Channel Availability Check Time) to ensure that there is no radar operating on the channel, using the Radar Interference Detection function described under a);

d) during normal operation, the Master shall monitor the operating channel (In-Service Monitoring) to ensure that there is no radar operating on the channel, using the Radar Interference Detection function described under a);

e) if the Master device has detected a radar signal, during In-Service Monitoring as described under d), the operating channel of the RLAN is made unavailable. The Master shall instruct all associated devices to stop transmitting on this channel, which they shall do within the Channel Move Time. The Aggregate Transmissions during the Channel Move Time should be limited to the Channel Closing Transmission Time;

f) the Master shall not resume any transmissions on this channel during a period of 30 minutes after a radar signal was detected, using the Radar Interference Detection function described under a). This period is referred as the Non-Occupancy Period in figure 9.

Slave devices:

g) a Slave device shall not transmit before having received an appropriate enabling signal from a Master device;

h) a Slave device shall stop all its transmissions whenever instructed by a Master device to which it is associated. The device shall not resume any transmissions until it has again received enabling signals from a Master device;

i) a Slave device which is required to perform radar detection (see table D.3), shall stop its own transmissions if it has detected a radar. The Master device may implement the Radar Interference Detection function referred to under a) using another device associated with the Master. In such a case, the combination should be tested against the requirements applicable to the Master.

We can examine this verbose description. We can straightaway remark that the secondary device must have some knowledge on itself (a *self*) or its environment (perceptions):

1. Is it a *master* or *slave* device?
2. What is its operating frequency?
3. Is a signal above a given level detected?
4. The device has notion of time: a first check for channel availability is performed during 60 s; if a radar is detected a transmitting secondary device must abandon the channel within 10s and must not attempt to access this channel for at least 30 minutes.
5. The sentence (d) above clearly suggests that some processes (here: the channel sensing) are to be performed 'during normal operations', that is: they run in parallel with other processes[**].

Points (1,2,4) refer to the device capabilities and status. This is particularly necessary if some form of reconfigurability is provided by SDR with the consequence that most of radio related parameters are no longer hard coded: operating frequency (frequency agility), transmitted power (power control), modulation, coding and interleaving scheme(s) (in fact, any baseband related parameter, including the receiver processing capabilities: type of equalization, iterative decoding for instance, but there are many others), structure of packets (header, payload, CRC, length), and many other parameters. For example, DFS standard describes the transmit spectral power mask of the secondary devices:

[**] This is a hint that devices like FPGAs which allow the implementation of many parallel processing blocks are possibly more suited to implement such tasks than sequential machines (DSP, general purpose processors). Interestingly, when 'programming' a FPGA, the communication between blocks is more difficult to implement (for instance detecting deadlocks) than the blocks themselves.

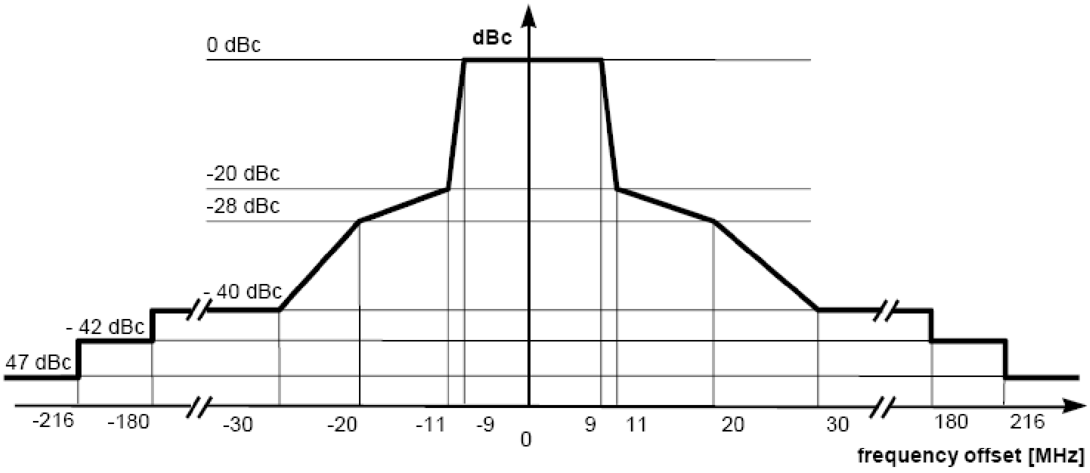


Figure 3: DFS power mask (from ETSI EN 301 893)

In this category we can also mention the energy remaining in the battery as it may affect the choice of a transmission system according to the available resource and what is required by user request.

Point 3 asserts that the device must be able to **sense** its environment in order to detect an existing signal; this means a hardware component (the sensor) and the ability to take a decision from the sensor output. Another possibility would be the ability to know its geographic location (thanks to GPS for example) and access to a server giving the information 'no radar in your neighbourhood'; this kind of information could easily be transmitted via the media independent information service (MIIS, see above).

Last, we understand from this short description of DFS that something more than plain parameters is needed, namely a set of commands; for instance, ***abandon*** current channel within a given time if a primary user is detected; ***perform*** a sensing (with a given period) and consider (***decide***) a user is present if above a predefined level.

PARAMETER	REQUIREMENT
CHANNEL_AVAILABILITY_CHECK_TIME	$\geq 60\,s$
CHANNEL_MOVE_TIME	$\leq 10\,s$
CHANNEL_CLOSING_TIME	$\leq 260\,ms$
INTERFERENCE_DETECTION_THRESHOLD_MASTER	$\begin{cases} -64\,dBm & \text{TRANSMIT\_POWER} \geq 200mW \\ -62\,dBm & \text{TRANSMIT\_POWER} < 200mW \end{cases}$
INTERFERENCE_DETECTION_THRESHOLD_SLAVE	$\begin{cases} -64\,dBm & \text{TRANSMIT\_POWER} \geq 200mW \\ none & \text{TRANSMIT\_POWER} < 200mW \end{cases}$
NON_OCCUPANCY_PERIOD	$\geq 30\,mn$

When thinking to the implementation of this policy we come across a new difficulty; the problem cannot be described as a plain sequence of statements. Some tasks are performed continuously (the channel sensing for instance), and they affect other parts of the global process only when they send some signal (for instance: ***a radar is detected***).

Some parts can de described as a sequence of operations on data or on intermediate results already obtained. This is the case for most signal processing tasks; in our example we could describe the way sensing is achieved by a sequence of successive steps. A very elementary sensing scheme (which does not take into account the fact that a radar signal is to be detected, in particular it does not make use of a pulse repetition factor, or any similar information) could be described as follows:

DO

Step 1: Sample *n* values of incoming signal → $(x_1, x_2, \cdots, x_n)$;

Step 2: Compute $y \leftarrow \sum_{i=1}^{n} (x_i)^2$;

Step 3: $Test \leftarrow (y > THRESHOLD)$; // *Test* is a boolean variable

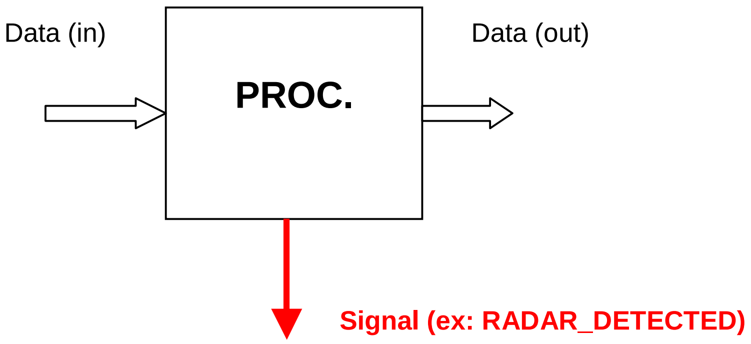
Step 4: if *Test* then **send_signal**(RADAR_DETECTED);

WHILE **true;**

We thus only suppose there is a routine which sends a signal (we could say: throws an exception) when some condition is fulfilled (a variable is above a given threshold).

Other parts of process are to be executed only when this alert is on. They react to some signals. We thus point out the existence of at least two kinds of parts of the global program:

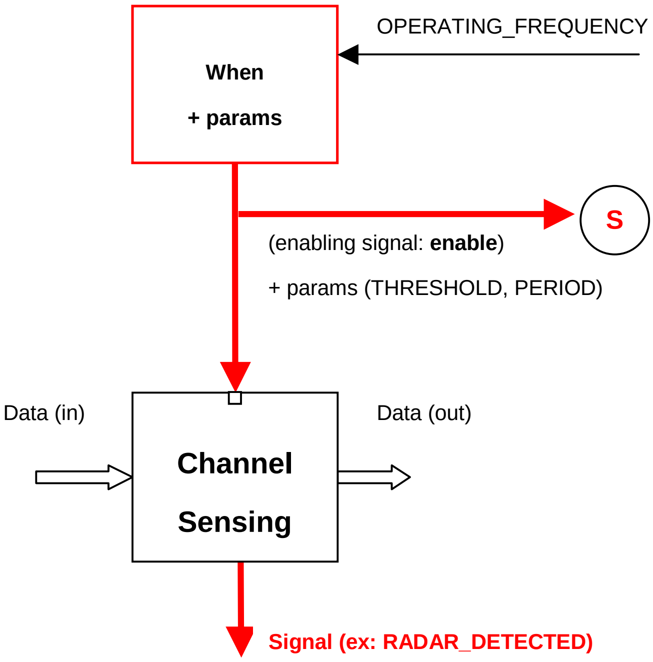
A) A computation parts, where the way data (or variables defined from data) are processed is described. It is merely related to the implementation of data (or signal) processing tasks; these parts are best written with imperative languages, such that C, C++, java, and possibly many others. These languages allow the description of a sequence of statements to be executed by a computer to achieve a computation (in fact the implementation of an algorithm). Imperative programming is well suited for implementing processing blocks which could also trigger an alarm (a signal) on predefined conditions.



B) A reactive part which describes the way signals are handled; this is the relevant part for the implementation of policies because it allows us to describe rules. Here we must be able to describe what has to be done on certain predefined events. For example:

When (OPERATING_FREQUENCY (**units** GHz) **in** [5.25 – 5.35]) **or** (OPERATING_FREQUENCY (**units** GHz) in [5.47 – 5.725]) **enable** Channel_sensing(INTERFERENCE_DETECTION_THRESHOLD (**units** dBm), PERIOD (**units** s)).

Here is emphasised the relation between a condition and the action to be executed upon that condition, no matter the way this action is actually implemented. Moreover the keyword **when** is to be understood as different from a classical **if-then** statement: while the **if-then** is a statement in a predefined sequence of instructions, **when** is rather a kind of statement with the highest priority, enabling a task (channel sensing) on some condition.



In this figure, red boxes and red arrows are related to the control part of the overall process, they are described by the policy language. A **signal** is **false** unless the conditions are fulfilled, giving it the value **true**. <u>It means it always has a definite value</u>. For instance, in the above drawing, **S** is a signal indicating if the operating frequency is in a radar band; it is always available and, when true, enables the block performing channel sensing. With this in mind we can rewrite the previous DFS rule as:

signal OPERATING_IN_RADAR_BAND **=** (OPERATING_FREQUENCY (**units** GHz) **in** [5.25 – 5.35]) **or** (OPERATING_FREQUENCY (**units** GHz) in [5.47 – 5.725]);

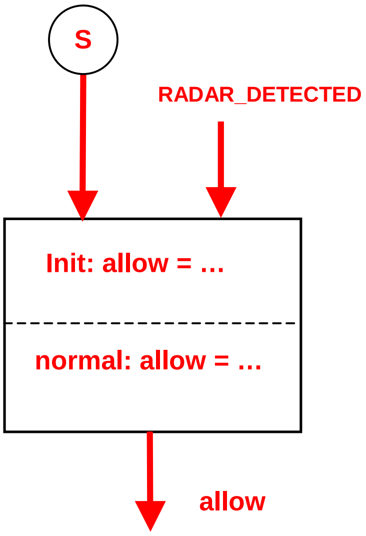
when OPERATING_IN_RADAR_BAND **enable** Channel_sensing (INTERFERENCE_DETECTION_THRESHOLD (**units** dBm), PERIOD (**units** s)).

We now consider the handling of the event RADAR_DETECTED. Item (c) of the verbose description of DFS shows that two cases must be distinguished: initial transmission and normal operations.

When initiating transmission, the master will allow transmission if the operating frequency is not in a radar band or when no radar is detected before *t* = 60s;

allow = **not** (**S** **and** (RADAR_DETECTED **and** (t **<** CHANNEL_AVAILABILITY_CHECK_TIME)))

During normal operation we have **allow** = **not**(RADAR_DETECTED). This difference between initial and normal phases will have to be described in the policy language.



3.2 Building a policy language

In this section we shall give a pseudo language description of the most important elements of the language: frequency bands, power masks, detection of existing transmitters, **rules**…

Boldface words are reserved words from a possible language defining rules.

3.2.1 Data types

We may assume without loss of generality that usual types of programming languages are available in a policy language. Thus the following types are assumed:

integer (or **int**), **float**, **boolean, true, false**;

In order to comply with the usual way of representing values in engineering we can envision the possibility to assign values to numerical variables with a scale factor defined with the keyword **units**. For instance the following statement

float OPERATING_FREQUENCY = 2.5 (**units** GHz);

means that OPERATING_FREQUENCY is a **float** number that sores the transmission operating frequency in GHz, with initial value 2.5. Other units are expected to be useful, such as **dB, dBm**, **dBc**, **MHz**, …

For boolean variables, the usual logical operators are assumed to be available in the language: **and, or, not**., **if, if–then–else**.

Likewise, the usual comparisons of numbers (integer or float) are available because they will naturally be involved in some rules, especially to establish numerical constraints, for instance:

if RSSI > THRESHOLD **then** …

is a test comparing the received signal strength (RSSI) to a given threshold; these comparisons will involve relational operators such as:

== , **>, >=, <, <=,** # (not equal, or **!=**)

The DFS example above shows that it is useful to define ranges of values, lists of values, and the logical test that a variable belongs to a given range or list of values. For instance:

DIST **in** [1.0, 5.0] (**units** km)

This is a boolean quantity, true if the variable DIST (in kilometers) is in the range 1.0-5.0. This is a more convenient way to express the condition **(**(DIST **>=** 1.0) **and** (DIST **<=** 5.0)**).**

Likewise, the following statement

if CURRENT_MODULATION **in {**BPSK, QPSK, 16-QAM**} then** …

is a test for the current modulation being in a list whose elements are BPSK, QPSK or 16-QAM.

The possibility to pack many variables in a record (an object, in the meaning of object oriented programming, but possibly without methods) is clearly a useful feature of any language, including a policy language as shown by the power mask of the DFS example above, it could be described as follows:

```
DFS_POWER_MASK = record
  // the mask is symmetric with respect to the carrier frequency
  Boolean Symmetric = true;
  // frequency offset from carrier in MHz; inf is a keyword, it means infinity
  Float Offset = {0,9,11,20,30,180,180,216,216,inf} (units MHz);
  // attenuation with respect to carrier freq, in dBc
  Float Attn    = {0,0,-20,-28,-40,-40,-42,-42,-47,-47} (units dBc)
  End; // record
```

Many parameters related to the device will be used throughout the examples, and in the real world policies; it is convenient to pack them in a particular record, called STATE (or any equivalent name); for instance

```
STATE = record
  float OPERATING_FREQUENCY = …;
  coord CURRENT_POSITION = …; // geographical position of device
  int BATTERY_LEVEL; // a gauge of the device's battery
```

signal BATTERY_LOW **= (**BATTERY_LEVEL **<** LEVEL_MIN**);**
End; //record

The Annex B of the 802.21 draft standard [13] provides a list of the data types used in the standard. We find the INTEGER(**size**) or UNSIGNED_INT(**size**) in the basic data types, **size** is the length of the data in bytes. Moreover, a set of general data types is also described. It does not contain a **float** type; this is not a real problem since we do not need a so great accuracy if we represent values with the keyword **units** (they generally will be rounded up to nearest integer).

Type name	Derived from	definition
ENUMERATED	UNSIGNED_INT(1)	An enumerated attribute. Valid Range: 0..255
BOOLEAN	ENUMERATED	Represents a boolean. 0: FALSE, 1: TRUE
OCTET_STRING	LIST(CHAR(1))	An array of octets.
PERCENTAGE	UNSIGNED_INT(1)	Represents a percentage. Valid Range: 0..100
STATUS	ENUMERATED	The status of a primitive execution. 0: Success 1: Unspecified Failure 2: Rejected 3: Authorization Failure 4: Network Error

All these data type can thus be reused in a policy language.

A data type for **location** is defined (annex B.3.6 of the draft standard); it is a variant record as they are many possibilities to define location (geo coordinates, cell id, XML description of position…).

3.2.2 Signals

The policy language is expected to allow the description of **signals** as boolean equations, and the way a device must behave on some signal. As a result rules handling events will be a major component of any policy language. The most obvious example is of course the **When** statement which describes what to do on the occurrence of some event or signal, but we can envision the possibility of a bundle of rules.

We recall hereafter the example of a **signal** definition and its handling with a **when** statement:

signal OPERATING_IN_RADAR_BAND **=** (OPERATING_FREQUENCY (**units** GHz) **in** [5.25 – 5.35]) **or** (OPERATING_FREQUENCY (**units** GHz) in [5.47 – 5.725]);

when OPERATING_IN_RADAR_BAND **enable** Channel_sensing (INTERFERENCE_DETECTION_THRESHOLD (**units** dBm), PERIOD (**units** s)).

The **when** statement could also be directly used without a signal definition:

When OPERATING_FREQUENCY **in** [2.4,2.5] (**units** GHz) OUTPUT_PWR = 10 [††](**units** mW);

There is no equivalent of a **signal** type in the 802.21 draft standard, nor possibility to define it. Nevertheless the event Link_Going_Down can be considered as a signal, all the more that a reason code is associated with this event, and a number of reason codes (4 to 127) are reserved for a future use, this is a solution to define new kinds of signals. Likewise reason codes from 128 to 255 allow operators to define their own reason codes (or signals).

Tableau 4: Link Going Down reason code [13]

Reason code	reason	description
0	Explicit disconnect	The link is going to be down because explicit disconnect procedures will be initiated either by MN or network. For example, when a BS has decided to shutdown for administrative reasons or an operator of the terminal has decided to execute a handover manually, a Link_Going_Down trigger may be sent to the MIHF.
1	Link parameter degrading	The link is going to be down because broadcast messages (control frames such as beacons) could not be received by mobile node.
2	Low power (Equivalent to our BATTERY_LOW signal above)	The link is going to be down because the power level of the terminal is low and the current link will not be maintained in such a low power level. Mobile terminals usually have limited battery supply, and when the battery level of the terminal is low, a terminal may choose a link that has lower power consumption for handover according to the received Link_Going_Down triggers with the reason code RC_LOW_POWER. This will lengthen the usable time for the terminal.
3	No resource	The link is going to be down because there will be no resources to maintain the current connection. For example, a BS may have too many users and send Link_Going_Down indications to terminals when the links with them can not be kept because of insufficient resources. An another example is that the users with higher priority may preempt the ones with lower priority when no more resources can be allocated in 3GPP, and this also may cause a Link_Going_Down indication with RC_NORESOURCE reason code.

[††] Here we should carefully make a difference between the statements "OUTPUT_POWER = 10" which assigns a value to a variable, and **set** OUTPUT_POWER = 10 which is intended as a command on the RF part of the transmitter; in this case the keyword **set** should be included in the policy language.

4 to 127	**Reserved** (possibility to define new events or signals)	Reserved for IEEE 802.21 future use.
128 to 255	**Vendor specific reason codes** (operator specific events or signals)	Vendors may specify their own specific reason codes in this range.

The various signals we envisage in our example have thus a counterpart in MIH or there is possibility to define an equivalent via the operator specific reason codes.

3.2.3 Defining a policy

Many policy types can be defined, with the consequence that we need a construct to tell the device that we are defining a new policy. We make a difference between the way the policy interacts with the rest of the software (we call it the **interface** part), that is the various signals (or events) used by or defined by the policy; signal used by the policy are declared with a **requires** statement, signals defined by the policy are declard with a **defines** statement.

The **implement** part describes the way signals are handled or generated. The DFS example above shows that we could find useful to have a way to differentiate two phases of a process: an **init** phase that takes place at the onset of a process, and a **normal** phase which corresponds to the normal part of the process. We keep in mind the posibility of a third phase corresponding to the end of a process (an **exit** phase).

```
policy DFS_master = {
-- interface
    requires signal RADAR_DETECTED; // coming from detection block
    defines signal OPERATING_IN_RADAR_BAND;
-- implementation
    defines signal allow; // a local variable!
  OPERATING_IN_RADAR_BAND = (OPERATING_FREQUENCY (units GHz) in [5.25 – 5.35])
or (OPERATING_FREQUENCY (units GHz) in [5.47 – 5.725]);
    case phase of
      init: allow = not (OPERATING_IN_RADAR_BAND and (RADAR_DETECTED and (time <
CHANNEL_AVAILABILITY_CHECK_TIME)));
      normal: allow = not(RADAR_DETECTED);
    endcase;
    if not(allow) transmit "abandon current channel"; // to all slave nodes
  }
```

We should describe likewise all the blocks involved in the policy; for instance the channel sensing block could be described as follows:

```
Block Channel_sensing = {
-- interface
    requires signal OPERATING_IN_RADAR_BAND;
    defines signal RADAR_DETECTED;
-- implementation
    RADAR_DETECTED = false;
    when OPERATING_IN_RADAR_BAND do {
    // call to the C/DSP/FPGA implementation of channel sensing
    RADAR_DETECTED = sense(THRESHOLD (units dBm) , PERIOD (units ms))
      }
  }
```

Only the interface and the implementation of signals (events) are described; the hardware or software implementation of the sensing operation is not described for it is irrelevant with respect to the policy.

A policy can thus be described as a collection of blocks sending and/or receiving signals (events), with well defined behaviours upon these events. One of these blocks is the main block, it defines the rules, it is declared with the **policy** keyword.

The policy for a slave device is simpler to describe; we need only to describe what happens when receiving a message from master device saying that we must abandon the current channel.

```
Policy DFS_slave = {
-- interface
-- implementation
     when receive "abandon current channel" do…
       // stop emission in current frequency channel
  }
```

There is no equivalent of the **policy** type in MIH. If we remind the viewpoint of this document it no surprising: 802.21 does not define a handover protocol, nor does it define policies to be implemented. It only provides a unified interface between L2 layers and L3 and above layers. So, definition of policy is not in the scope of MIH, but we can reuse its components to implement policies.

3.2.4 Other operations on policies

It may happen that more than one policy co-exist at the same time in a terminal, with the possibility of conflict when they lead to different behaviors. Imagine a PDA with a WLAN peripheral (it implements the DFS policy above); it is known that the use of wifi will quickly dry out the battery of the PDA. We can thus envision a second policy which prevents using WLAN when battery level is below a given level or when the application is energy consuming (video). Under this circumstance, the second policy precedes the DFS policy we have seen above: if the battery level is low we must obey to this policy and not consider the indication of the DFS one.

We declare this possibility with a **precedes** statement:

```
policy Manage_energy = {
```

```
  -- interface
      requires signal BATTERY_LOW;
  -- implementation
      when BATTERY_LOW  … // use any RAT except WLAN
  }
precedes Manage_energy DFS_slave;  (or equivalently: manage_energy > DFS_slave)
```

Other potential operation on policies are:

remove P1; to remove a policy P1

if we remind that one of the arguments that led us to introduce policies was the need to change or update existing rules we can infer that we could update a policy or replace a policy by another one; this could be done by a statement like:

replace P1 P2; // replace policy P1 by policy P2

The DFS example we have chosen has the property that policy is valid anytime and anywhere. But it may happen that a policy is valid only in some circumstances depending on a particular day, or for a given geographic region, or even on the type of terminal. It makes sense to add a third part (after the interface and the implementation parts) describing the condition(s) of validity of the policy under consideration. We could thus have:

```
policy my_policy = {
-- interface
    requires signal S1;
    defines signal S2;
-- validity
    valid = (date == dd/mm/yyy) and location in RANGE_LOCATION;
-- implementation
    case phase of
      init: …
      normal: …
    endcase;
  }
```

The exceptional event scenario will illustrate this validity field.

3.3 Spectrum policies in URC scenarios (=exemples de politiques dans URC)

See section 4.3.

4 DSA contexts, paradigms and scenarios [Thales, ENST]

In this section, we give a brief reminder of DSA contexts, classification and paradigms and we provide some examples of spectrum policies related to URC scenarios.

4.1 DSA Contexts and paradigms [Thales, ENST]

4.1.1 Reminder on DSA classification and attributes

We give here a brief reminder to the classification done in [6] on spectrum management techniques. There are four main classes in this classification: Command and Control, Operator Sharing, Primary and Secondary Usage, and Commons. The first class is not in the scope of URC project.

The second class involves a limited number of entities, which are the operators. These operators are usually competing entities; each one has a license provided by the regulator for the usage of the spectrum band.

In the third class, there is a primary user (operator) who has a license for the considered band and has priority to his band. However secondary users can access the band in an opportunistic manner (overlay), or using a very low power (underlay) providing that they do not to disturb the primary user.

In the fourth class, there is a common spectrum band, where all devices can communicate. All entities have an equal access to the band provided that some basic rules (etiquette) are respected, e.g. low output power. In the last three classes, regulation policies have to be enforced for a proper operation.

Let us recall some DSA attributes essentials for policy definition:

- Centralised / decentralised DSA;
- Operator centric / user centric;
- Cost and utilities (or revenues) of each actor (end user, operator, regulator, meta-operator);
- Long term / short term DSA:
  - Long term: DSA algorithms work on operating bands or channels (e.g. FCA, DCA);
  - Short term: DSA algorithms work per packet call (for bursty traffic); it is often known as Dynamic Spectrum Access instead of Allocation.

4.1.2 DSA vs. JRRM

Let us now remind the fundamental differences between joint radio resource management (JRRM) and DSA. Taking an example of one cellular operator, who is deploying more than one RAT (Radio Access Technology) infrastructure, (i.e. GSM, UMTS, and/or WiMAX). In a non-DSA network context, each of these technologies/networks is deployed using its specific frequency spectrum band according to the standards specification. One of the major tasks of the operator is to optimally use the available radio resources to offer the required services to the end users. This operation is referred to as radio resource management (RRM). The operator has two options regarding the RRM techniques:

- Managing the radio resources of each of the different RATs separately.
- Mutually/jointly managing the resources between the heterogeneous networks. This is known by JRRM (Joint RRM).

Regarding the RRM techniques themselves, they are mainly divided into static and dynamic management.

Static radio resource management methods involve all the fixed radio network planning techniques starting from the spectrum band planning done by the national regulators, passing by the base stations installation, antenna systems and sector directions decisions, in addition to the techniques used to maximize the utilization of the band between the users such as FDMA, TDMA, etc…

The dynamic RRM is used to accomplish better spectral efficiency practice of the available resources using adjustable methods to the variations of the different networks parameters, i.e. number of users, QoS requirements, etc.

The main examples of dynamic RRM are: power control techniques, adaptive antenna methods (e.g. beam forming), adaptive modulation techniques, DCA (Dynamic Channel Allocation (DCA). It's worth mentioning that DCA techniques are not the same as the DSA we are investigating in this document. DCA is mostly known as the selection method for a sub-channel in a certain technology that is using a fixed spectrum band (i.e. DECT).

In JRRM techniques, although the resource management is jointly done by the operator, each RAT has a fixed spectrum band. In a DSA network context, we could then consider the DSA technique used by the operator to maximize its system spectral efficiency an extension to the classical/known RRM methods. But in this case, the operator is also able to assign variable size of spectrum bands to the different RATs. In this context, RATs can for example exchange spectrum bands or access to a common spectrum pool.

4.1.3 Operator sharing DSA

In this section, we detail the operator sharing class that we see more related to the URC research project work. This sub-classification is focusing on the DSA for cellular systems, and adopting the URC project point of views.

We divide the DSA networks into two main types in case of operator (or intra-operator case) and multi-operator (or inter-operator case) sharing. The first type sees the DSA as extension of the classical RRM techniques (as described above). For this type, the competition between operators (or simply the competition concept) is not applicable since in most of the cases this model consists of one cellular operator, optimizing his spectrum resources.

Nevertheless the second type is an inter-operator DSA, or an operator sharing DSA system. We will discuss in more details those two types in the coming sections. Fig. 1 illustrates our DSA networks sub-classification.

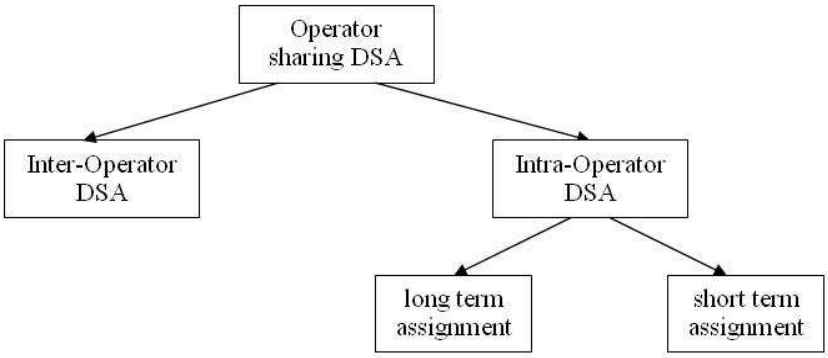


Figure 4: DSA classification for operator and multi-operator systems

4.1.3.1 Intra operator DSA

In a DSA context, each of the RATs could be given a different spectrum band other than the band typically known to operate on (i.e. 1900 MHz spectrum band could be assigned to a UMTS network). In this context of one operator, managing his own spectrum bands - after being given to him by the regulations – dynamically between the different RATs, the main difference between DSA and JRRM is the fact that in the former case, spectrum bands can be allocated to different RATs, whereas in the latter case, RATs have a predefined spectrum band.

An important parameter is to be considered when talking about DSA systems: the time duration during which the spectrum is assigned to a specific network element. This duration is referred to as the holding time in [7], while it's defined as the duration of lease in [6]. According to this distinction we would then divide our first DSA type (as extension to RRM techniques) into two sub-types; long term assignment and short term assignment.

Long term assignment

The assignment of a spectrum band to a certain RAT could be for hours, seconds, or m-seconds. If the assignment last for hours, we refer to as long term assignment. The Drive/OverDrive projects mentioned in [6] report employed the load variations over space and time in order to maximize the utilization of spectrum. Drive/OverDrive projects implemented their idea on UMTS and DVB-T technologies, in a context where the spectrum bands are not fixed for each RAT. Two examples could illustrate the concept of the long term assignment:

- Drive/OverDrive projects;
- Simulator developed in deliverable 2.1.3 [**8**].

Drive/OverDrive projects are examples of the DSA networks applying a long term assignment. We could consider this type of assignment close to FCA (Fixed Channel Allocation) technique, where a frequency planning process is required. In a long term assignment the channel (spectrum) could be considered fixed during the long period of assignment.

Short term assignment

The spectrum assignment to a certain RAT could also be performed for the duration of a call or for a session. This type of assignment lasts for few tens of seconds, or for the packet call duration varying from 1 ms till 1s. On the contrary to the *long term assignment*, we could consider the short term assignment close to DCA technique. Using DCA, the frequency planning process is avoided.

We give here few examples for a short term assignment DSA networks, where the DSA can be seen as an extension to the RRM methods.

- IEEE P1900.4 standard framework.
- Roke Manor's DSA network. A DSA network architecture proposed by Roke Manor for the British regulator OfCom [9].
- A centralized JRRM model for heterogeneous networks proposed by [**10**].

We will give in the following a brief about each of these models.

The frame work of the IEEE P1900.4 standard aims at building architectural blocks to enable Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks. The idea behind P1900 is to define a distributed decision making policy/process, for a RAT selection, between the mobile terminals and the network. At the same time the different RATs are assigned dynamically a spectrum band according to three proposed scenarios [11].

The following figure Fig. 2 gives the system architecture of the network.

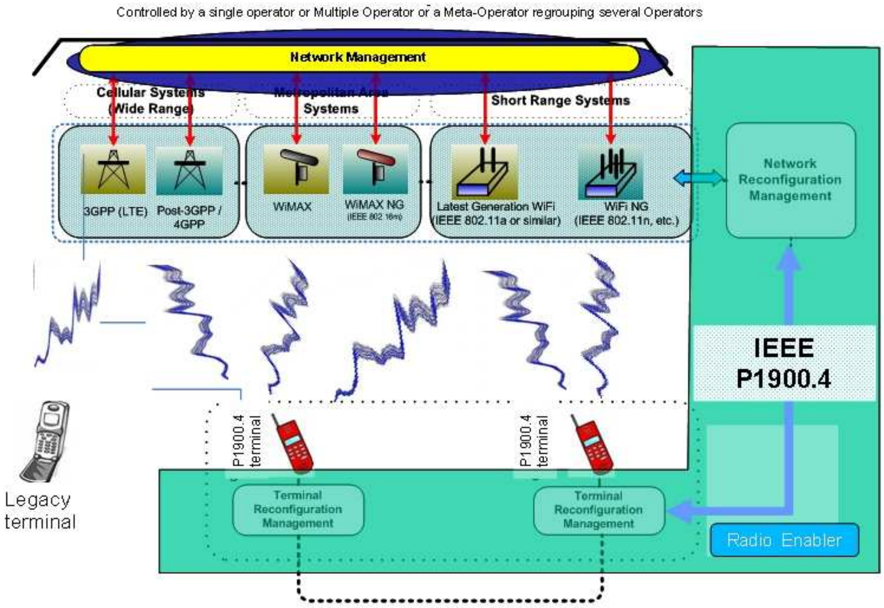


Figure 5: The IEEE P1900.4 system architecture [11]

Roke Manor has proposed DSA network architecture for the British regulator OfCom. Their model is based on dynamic pricing. The idea is to develop a selection criterion where dynamic pricing is used to select the optimum available RAT on the basis of price versus Quality of Service.

The study done by Roke Manor focused on three axes for evaluating the system via simulations: protocol signalling delays, dynamic pricing and the mobility management [9].

It is worth mentioning that we categorize the proposed system more into a dynamic RAT selection system rather than into a DSA system. Each RAT, in the system proposed by Roke Manor, work on a fixed spectrum band. The user selects the suitable RAT mainly according to the price versus the QoS offered by each of the available RATs.

The third example presents a centralized JRRM model for heterogeneous networks [10]. Two co-localized cells of two different RATs, WLAN and HSDPA, are considered. A decision has to be taken by the network, at each new session arrival, to assign a mobile terminal to a RAT (whether WLAN, or HSDPA). In this model an optimal policy is to be found using SMDP (Semi Markov Decision Process) theory.

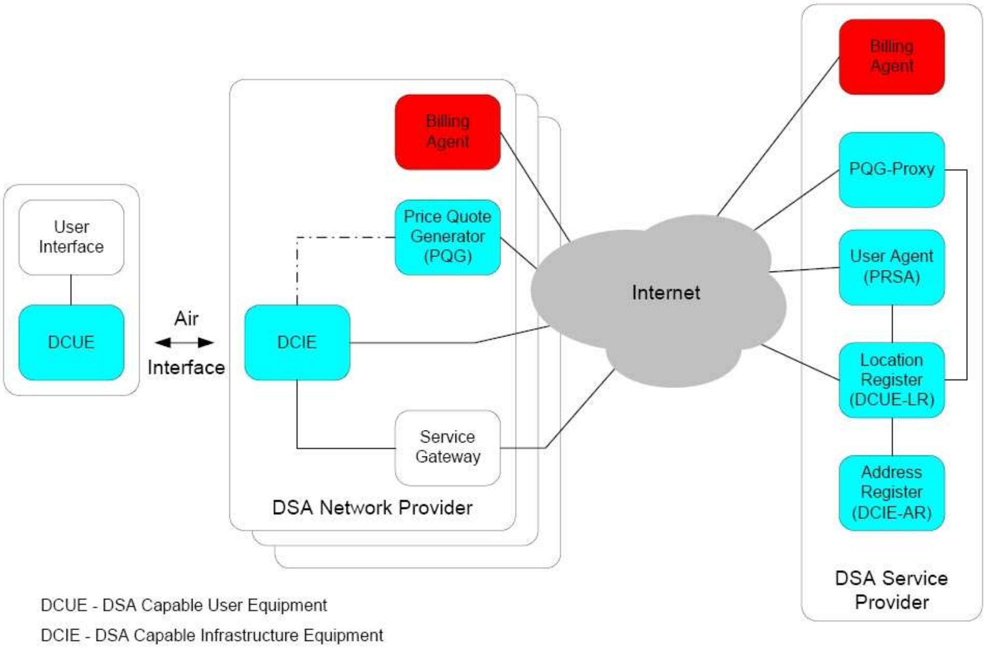


Figure 6: The DSA network architecture as presented in Roke Manor report [9]

4.1.3.2 Inter-Operator DSA or DSA with competition

Now we move to the second type of our DSA networks, the operator sharing DSA. This type we see the most challenging type of DSA systems that would be needed by the market in the actual situation of spectrum crowd. However this model has many paradigms starting from the regulation aspects, going through the technical aspects and ending by the cost and utility aspects seen by the operators who are sharing the same spectrum band.

4.1.4 Secondary use

We give here a brief remind to the primary/secondary usage class as given in the deliverable D1.3.1

In this model, the spectrum band is owned by a primary user, but the band can be opportunistically used by a secondary user with minimum impact on the primary user. In the ideal case, the primary user is not even aware of the secondary user transmissions.

According to the type of technology used by the secondary user, sharing is called **Spectrum Underlay** or

Spectrum Overlay. In the former case, power levels used by the secondary user are so weak that there is no interference for the primary user. The use of UWB falls in this sub-class. In the latter case, access is opportunistic (in time or space) so that this approach can be called “opportunistic spectrum access (OSA)”, “listen-before-talk” (in relation with the type of MAC protocol that can be used), or “cognitive radio”.

4.2 Scenarios [ENST, Thalès]

This section summarizes some of the scenarios defined in the project with respect to dynamic spectrum management:

- Exceptionnel Events
- Crisis period
- Dynamic spectrum access use cases

The two first scenarios have been defined during task 1.2 and are presented in the deliverable D1.2.2. The latter has been added from other contributions. It addresses DSA in a particular context, but may be related to scenarios 3 and 4 as defined in D 1.2.2.

In this section, we simply remind the main characteristics of each scenario, as a complete description has already been provided, and we rather emphasize on the different roles which are related to each practical use case. The main objective is to depict each role in order to build architecture which are relevant with the issues raised by the scenarios.

4.2.1 Exceptional Events [Thales]

4.2.1.1 Description of the context of the scenario

During exceptional (but non dramatic) events (match, concert …) the use of radio resources has to be adapted to cope with a strong increase in the traffic.

Different situations, involving one or several operators, and several RATs, are considered. Please refer to D1.2.2, scenario N°4, for a complete and detailed d escription.

4.2.1.2 Description of practical use cases and identified roles

1/ intra-operator DSA scenario: The operator changes the repartition of frequencies allocated to the RATs he operates (between GSM and UMTS) in order to optimize the radio resources allocations and solve the global capacity congestion problem. In particular the new repartition (RAT versus Frequency) should not create compatibility problems (intra + extra). The study consists in identifying the elements of the methodology and related algorithms.

2/ advanced JRRM scenario: An anticipated "load balancing" process is prepared prior to the event and groups of users are redirected to the relevant RATs without impacting the QoS. The new situation is able to avoid the bottleneck situation due to the exceptional event. The study consists in identifying the target situation and building the algorithms to reach it.

For the use cases defined above, we identify the following roles:

- Users and terminals: the ones who uses the different services through assigned resources. Terminals may be characterized by the RATs it can access, or we may assume all terminals can access all RATs.
- Per operator:
  - RAT networks: the different access networks which are available (GSM, UMTS, WIMAX, WIFI, …
  - Services and resources assignment: in typical cellular networks, this is the role which handles the assignment of such communication/service to such a bearer. (*we consider this to be the main role of an operator : to be discussed with partners*).
- Regulators: three roles are to be considered.
  - Respect of the licence conditions
  - Efficient use of the spectrum
  - Effective QoS for end-user

4.2.2 Crisis period [Thales]

4.2.2.1 Description of the context:

This scenario is related to crisis management and the use of radio communications. Here, crisis may include tsunami, earthquake, terrorism … In such a situation, the main actors using radiocommunications are the PPDR. Today they operate in defined PMR frequency bands (around 400 MHz), but we consider they may require additional spectrum, either because of the seriousness of the crisis, or simply because of an increase in data transfer due to new, multimedia oriented, applications.

Please refer to D1.2.2, scenario N°5, for a complet e and detailed description.

4.2.2.2 Description of practical use case and identified roles

1> Possibilities of band sharing of PPDR used systems with radioastronomy, 406 - 408 MHz, in delimited geographical areas. As radioastronomy is a particular service which requires specific protection, but is usually located far from big cities, it could be possible to share an additional capacity with PPDR networks, when a crisis occurs in an urban region.

2> Introduction of video surveillance equipment, connected to an existing WIMAX or WIFI network, in nomadic or ad-hoc modes, with pre-emption of the resources which are allocated to non professional users. (This track could be implemented in the scenario N°2, with the WIMAX technology). Here, the is sues are related to the capacity to deploy quickly such equipment, using a network a priori unknown by PPDR. Local authorities could play a significant role at this point, managing the information of existing networks to handle it to PPDR representatives, and reserving an acceptable QoS level for users (non PPDR).

3> Introduction of global monitoring solutions, based on the use of UAVs, with terrestrial links. This requires the use of either 2.3 – 2.4 GHz band, or 4.4-4.99 GHz band, according to D1.1.1. Both are today devoted to government use, for the military. In our case, for a civil government use, we could foresee the introduction of command and control links in the PPDR band, because :

  i. The UAV is operated from a location close to the area which is to be monitored, but it is an aeronautic link : spatial filtering, beam forming, should reduce significantly possible interference.
  ii. Command and control of such equipment does not require a wide bandwidth, and its design may be “short packet oriented”, to reduce the duration of each transmission. This of course is probably less applicable in the phases of takeoff and landing, which may require a special approach.

4> Use of UWB as a transmission technology to collect information form sensors on the site (or around the site) of the crisis. In this case, the frequency bands in which UWB could operate are to be defined. This could be done depending on the area of operation, following a predefined procedure: sensors are activated using a narrowband channel (pilot channel?). Then a local spectrum monitoring operation allows defining the wideband channel which may be used to collect data from sensors. This operation includes measurement as well as coordination with local existing networks, and may include some local authority.

For the use cases defined above, we identify the following roles:

- Users and terminals: the ones who uses the different services through assigned resources. Terminals may be characterized by the RATs it can access, or we may assume all terminals can access all RATs. Here we have two classes of users: PPDR and others. PPDR are requesting services and resources on the area for a short duration, while others are typical users who should impact as less as possible by PPDR users.
- PPDR authorities: they are responsible for handling the crisis, and have to set up the required communication solutions for their teams. They are the interface to operators
- Per operator:

  - RAT networks: the different access networks which are available (GSM, UMTS, WIMAX, WIFI, …
  - Services and resources assignment: in typical cellular networks, this is the role which handles the assignment of such communication/service to such a bearer. (in this use case, local authorities operating a muni-wireless network are to be considered as an operator).
- Regulators: three roles are to be considered.
  - Respect of the license conditions: the re-attribution of portion of spectrum due to some “force majeure” situation shall be implemented under the authority of a regulator
  - Efficient use of the spectrum
  - Effective QoS for end-user: in these use case, PPDR users are prioritized w.r.t. other users.

4.2.3 FCC Bloc D

This paragraph intended to presents some additional elements regarding the particular sharing proposed for the so-called Bloc D of spectrum by the FCC. Unfortunately, it appears the US regulator had to step back from its original position, as the results of the auction process was not as expected: the only auction of 472 M$ was far from the reserved price of 1.33 Md$

Here are some information regarding this D bloc:

- Bloc D: 758-763 MHz, 788-793 MHz, with a national coverage, and PPDR entities are defined as the primary users.
- Set up of a Network Sharing Agreement between the winner of the auction process and the delegate authorities.
- Delegate authorities: Public Safety, Homeland Security Bureau, Wireless Telecommunications Bureau.

The possibility of commercial secondary use was indeed considered by a private company, as an auction has been placed, but the value of this auction was about a third of the minimum price set by the FCC. This is probably due to a high level of constraints which have been pointed out by many.

Anyway, as the process is suspended and bloc D will be considered lately in a separate way, we will not emphasize on this point.

4.3 Spectrum policies in URC scenarios [ENST, Thalès]

In this section, we give some examples of policy constraints for some URC scenarios. Examples of policies and policy constraints are given in [25], and [26] presenting CoRal language. Note that examples are based on the secondary usage technique in which the secondary user accesses the spectrum in an opportunistic manner. Spectrum policy is originally given by the regulator. However, in this section we extend the notion to the intra-operator case. In this kind of scenario, an operator is able to use the radio enabler in order to broadcast spectrum policies related to its bands and terminals.

A policy is a sequence of constraints concerning the accessibility to the spectrum. Examples of constraints are:

- What is the level of the detected signal that could be considered as background noise?
- For how long the user should wait till he confirms that the band is empty (not used by the primary user)
- What is the power level allowed for the secondary user?

Spectrum policy constraints are described by using the following types of information:

- Frequency band(s) considered by the policy constraint,
- Time and duration of the policy constraint,
- Location (GPS coordinates or less accurate indications like “indoor/outdoor”, or radio indication like path-loss) of terminals concerned by the policy constraint,
- Capabilities of concerned terminals (accessible RATs, frequency bands, accessible MCS, multi-slot capabilities, terminal class, terminal priority, etc),
- Power levels (maximum or average figures for transmitted powers, received levels, interference and noise levels),
- Operation modes (listen-before-talk, underlay/UWB, secondary/primary usage, spectrum pool),
- RAT information (technology, operator, cell ids, location areas, etc),
- Service concerned by the policy constraint (voice, MMS, SMS, etc).

4.3.1 Examples of policy constraints for exceptional event scenario

Let us take the exceptional event scenario described in D1.2.2 document.

1) There is a mass downloading from a server through WLAN or UMTS before the beginning of the match.

- “For terminals with WLAN interface <u>and</u> located in city 1 <u>and</u> in coverage of a WLAN hot spot <u>and</u> on day D between 8am and 12am: choose in priority WLAN 5GHz rather than UMTS 2GHz”.

- “On day D between H hour and H+5 <u>and</u> for terminals in city 1: GSM band XMHz-X+5MHz is not accessible for GSM calls”.

- “On day D between H hour and H+5 <u>and</u> for terminals in city 1: the frequency band X-X+5MHz is accessible for UMTS calls”.

2) Operator 1 moves UMTS users who are using voice services to GSM network.

- "For terminals with GSM interface and located in city 2 and on day D between H and H+10 and for a voice call: use in priority GSM network".

3) Some Operator 2 GSM bands are considered as a GPRS/EDGE spectrum pool in city 2.

- "GSM bands X-YMHz on day D between H and H+10 are under the GPRS/EDGE spectrum pool mode of operation".

- "All GSM terminals on day D between H and H+10, if access to the operator band fails, check the pool".

4) JRRM rules: choose HSDPA or WLAN according to the distance to the access point or base station.

- "For all terminals of operator 1 with HSDPA and WLAN interface, if CPICH received level > CPICH min, choose in priority HSDPA network, otherwise choose WLAN access".

- "For all terminals of operator 1, if UMTS access is blocked N1 successive times, try to access to WLAN".

- "For all terminals of operator 1, if WLAN throughput is less than X bps and terminal multi-slot class is more than class number C, try to access to EDGE network".

4.3.2 Examples of policy constraints for crisis event scenario

Taking the crisis event scenario described in D1.2.2 document, we can imagine three types of communications needed in a crisis situation:

- Communications between the safety team members (firemen, police, etc…).
- Communications between people in the crisis zone who are asking for immediate help from the safety teams.
- Communications needed by the authorities for monitoring the crisis zone and consequently sending orders for immediate help to the different safety teams.

The goal of the spectrum policies development in this section is to provide reliable communications in crisis situations.

In a crisis situation we see the geographical division as shown in Fig (6). The crisis zone is the zone where the crisis has occurred. In the crisis zone the infrastructure sites are most probably one destroyed.

The "near zone" is the first surrounding area to the crisis zone. In this zone the GSM/UMTS/WiMAX sites are supposed to be functional and hence they will be used of for the rescue operations.

The neighbour zone is the zone surrounding the ""near zone".

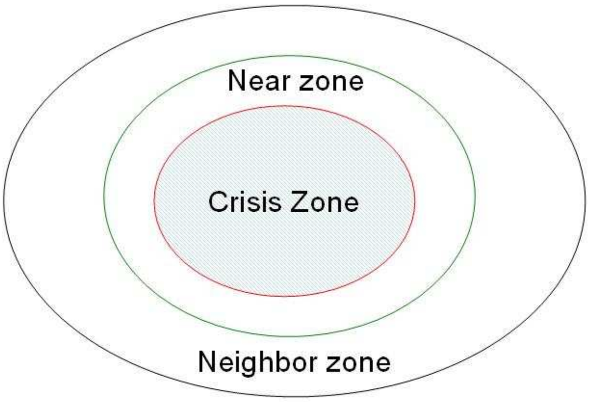


Figure 7: Crisis zones

1) In the first set of actions during the first hours of the crisis immediate safety operations and field information gathering about the crisis are needed.

-"On the crisis time and for all PPDR (Public Protection and Disaster Relief) terminals, an extra band is available in the 406-408MHz range".

-"On the crisis time and for all PPDR terminals, if the access to the PPDR band fails, check the extra band".

-"On the crisis time: STOP all the commercial use of WiMAX sites in the "near zone", these sites are to be controlled by the authorities for monitoring using the surrounding video surveillance systems".

-"On the crisis time: If UAV are to be used, with their command and control links in the PPDR frequency band, these links are operated as primary users in this band"

2) In the second set of actions organizing the control and the management of the crisis zone.

-"On the crisis time: for the GSM sites located in the "near zone": extra bands are available using a part of the neighbour zone's bands".

-"On the crisis time: for the GSM sites located in the "near zone": automatic antenna tilting directs the antennas towards the crisis zone (Providing more capacity)".

- "In the crisis zone, check if legacy RAT is available (GSM/UMTS/WiMAX etc), if not use ad hoc networking on 5GHz band using listen-before-talk mode of operation".

-"In the crisis zone, for PPDR sensors: UWB transmission is allowed for short distance communications provided that output power is less than X dBm".

4.3.3 Examples of policy constraints for secondary usage scenario

In the secondary usage scenario we have the overlay and the underlay modes of operation. We will give policy examples for each of them.

Considering the underlay method, a policy constraint example is:

-“In any location and at any time, all UWB users are allowed to transmit, in the band 5 GHz-5+Y GHz, with a maximum power level of X-dBm” (knowing that X-dBm is the considered as background noise by the primary users on this band).

Considering the overlay method, policy constraint examples are:

-“In any location and at any time, all secondary users have to sense the spectrum band X MHz, for T seconds before transmitting”.

-“In any location and at any time, all secondary users have to use CSMA/CA in the spectrum band X MHz, with DIFS parameter equal to T micro-seconds”

-“In any location and at any time, all secondary users have to scan the band X MHz while transmitting, if primary user is detected: STOP transmission”.

5 Description of these scenarios in the above defined policy language [FT]

We should like to stress the difference between a policy and an algorithm; our analysis will use DSA as an example because it is directly related to the topic of new spectrum management schemes, and is of potentially interest in some scenarios already developed in URC.

Real time optimization of a wireless network with several hundreds of devices in several cells would be a too huge problem to be managed with to-day technology. Off line simulation are daily used by engineers or researcher to find good algorithms to improve performances of wireless networks. The results of these algorithms tell the good solutions to, for instance, roll out a network, or good rules concerning the access of multiple users to a shared resource. CSMA/CA and its modifications (RTS/CTS) is such a protocol; it can be said a policy with the main difference that it is hard wired in current devices. Policies are to be seen as rules whose validity has been checked by off line simulations and which are broadcast to network elements. As simulations commonly use models of the real world, and as these models do not completely take into account all the peculiarities of the real world, there will be discrepancies between predicted and observed performances. We can thus envision a feedback from the observation of the network in order to search a new and better policy.

Therefore, in a DSA scenario, policies are not to be confused with the algorithm used to implement a spectrum allocation. The DSA algorithm is a sequence of computational steps whose result is a spectrum allocation to RATs under consideration and satisfying some constraints on interferences. The corresponding policy will only tell user equipments in which frequency bands they can find RAT1, RAT2…

The exceptional event scenario assumes that operators #1 et #2 have GSM and/or UMTS networks covering city1 and city2. The scenario assumes that the user equipment has some information on its location. We can use the data types used for location in 802.21, more specifically the data type used for storing information on the cell where is the device in a cellular network. The 802.21 draft standard defines several data types to represent cell identifier according to the network type, they can be seen as variant record with a field containing the cell identifier, called CI for a 2G network and CELL_ID for a UMTS network. For a WLAN we can use the MAC address of the access point as an location information, it is also an information available in 802.21. We shall use these data for user's location in our scenario (instead of geographical coordinates for instances).

To test the user's location we therefore compare the current cell identifier or (MAC address for an access point) to a predefined list of cell ids (or MAC addresses), for they are known before the event. The corresponding block of the policy could be written as follows:

```
Block Where_am_I = {
-- interface
  Defines signal ville1;
  Defines signal ville2;
  Defines signal stade;
-- implementation
  // lists of cell identifiers
  GSM_Cell_Ids_city1 = {cei1, cei2};
  GSM_Cell_Ids_city2 = {cei3, cei4,cei5};
  GSM_Cell_Id_stadium = cei6; // we suppose only one GSM cell on the stadium.
  UMTS_Cell_Ids_city1 = {cei7, cei8,cei9};
  UMTS_Cell_Ids_city2 = {cei10, cei11};
  List_of_POA_addr_stadium = {macadr1, macadr2, macadr3}
  If (NETWORK_TYPE = GSM) then {
    // CI = cell identity, derived of CHAR(2), a 802.21 data type
    ville1 = (CI in GSM_Cell_Ids_city1);
    ville2 = (CI in GSM_Cell_Ids_city2);
    stade = (CI == GSM_Cell_Id_stadium);
    }
  If (NETWORK_TYPE = UMTS) then {
    // CELL_ID = cell identity, derived of UNSIGNED_INT(4) , a 802.21 data type
    ville1 = (CELL_ID in UMTS_Cell_Ids_city1);
    ville2 = (CELL_ID in UMTS_Cell_Ids_city2);
    stade = (CELL_ID == Cell_Id_stadium);
    }
  If (NETWORK_TYPE = 802.11) then {
    // POA = point of attachment, ,
    // POA_MACADD, MAC address of a POA,  a 802.21 data type
    // we surely will have many hotspots in the stadium.
    stade = (POA_MACADDR in List_of_POA_addr_stadium);
    ville1= false;
    ville2 = stade; // le stade est dans la ville2
    }
```

```
}
```

The scenario makes a difference between voice calls and data services; 802.21 does seem to have some possibility to take into account the type of service but only for QoS management. We therefore shall implement two blocks, one for voice service, one for data service, and suppose the main block (the policy) has some mean to know what service the user wants.

Voice calls are handled according to the user location. In city1 user is required to use UMTS network in the frequency band [X Mhz, X+5 MHz][‡‡]; in city2 user must use GSM network for voice calls Both cases can be seen as a network initiated handover and thus can be implemented with appropriate command of the MIH Command service MIH_Net_HO_Commit. This command is described in chapter 7.4.21 of [13]. For the purpose of our implementation we shall restrict the list of arguments of this command to the link type (GSM or UMTS) and possible information on the target network (the frequency band to be used for instance). The following implementation aims to show the possibility to use MIH commands for implementing a policy, but is not to be considered as complete.

```
Block voice_service = {
-- interface
  requires signal ville1, ville2;
-- implementation
  If (ville1 and time in [H,H+5] (units hour)) then {
    // use UMTS in a given frequency band.
    Link_Target = UMTS;
    Target Network Info List = { FREQUENCY_BAND = [X,X+5] (units MHz))};
    MIH_Net_HO_Commit.request(Link_Targ, Target Network Info List);
    }
  If (ville2 and time in [H,H+10] (units hour))  then {
    Link_Target = GSM;
    Target Network Info List = {}; // no special info
    MIH_Net_HO_Commit.request(Link_Targ, Target Network Info List);
    }
  }

Block data_service = {
-- interface
  requires signal ville1, ville2, stadium;
-- implementation
  If (ville1 and time in [H,H+5] (units hour)) then {
    // use UMTS in a given frequency band.
```

[‡‡] Apparently for either voice or data services. If true, a user in city1 should use UMTS network for a voice call.

```
    Link_Target = UMTS;
    Target_Network_Info_List = { FREQUENCY_BAND = [X,X+5] (units MHz))};
    MIH_Net_HO_Commit.request(Link_Targ, Target_Network_Info_List);
    }
  If (ville2 and time in [H,H+10] (units hour))  then {
    Link_Target = GSM;
    // initial frequency band for GSM users of operator #1
    Target_Network_Info_List = {OP1_FREQ_BAND};
    MIH_Net_HO_Commit.request(Link_Targ, Target_Network_Info_List);
    MIH_Net_HO_Commit.response(STATUS); // check if connection OK
    // if connection failed, try to use the frequency pool from operator#2
    if (STATUS == false) then {
      // operator #2 frequency band
      OP2_FREQ_BAND = [X,Y] (units MHz);
      Target Network Info List = { OP2_FREQ_BAND };
      MIH_Net_HO_Commit.request(Link_Targ, Target_Network_Info_List);
      }
    }
  If stadium then {
    // download a software patch.
    …… // TBD.
    }
  }
```

The scenario (exceptional event) does not apply anytime/anywhere but only on the day of the football competition and in cities city1, city2 (and in the stadium of city2). This gives the validity condition of the policy, described in its **validity** field which is useful because it avoids writing the conditions in each clause of the policy.

```
policy exceptional_event = {
-- interface
  requires signal ville1, ville2, stadium;
  requires signal voice, data;
-- validity
  // only apply policy on exceptional event date and in cities city1, city2 or stadium.
  Valid = (date == jj/mm/yyyy)  and (ville1 or ville2 or stade);
-- implementation
  when voice do voice_service;
  when data  do  data_service;
  }
```

Interestingly, the scenario we consider involves <u>two</u> policies; one of them, we have already discussed of, applies only on the event date and location, but there is another one about joint resource management

(JRRM) which is not restricted to this event. It is merely another set of rules of operator1 which applies anytime and anywhere, and does not preclude the other policy.

Due to the huge number of 802.21 primitives related to the QoS management we do not, in a first version of the deliverable, give a description of the JRRM policy.

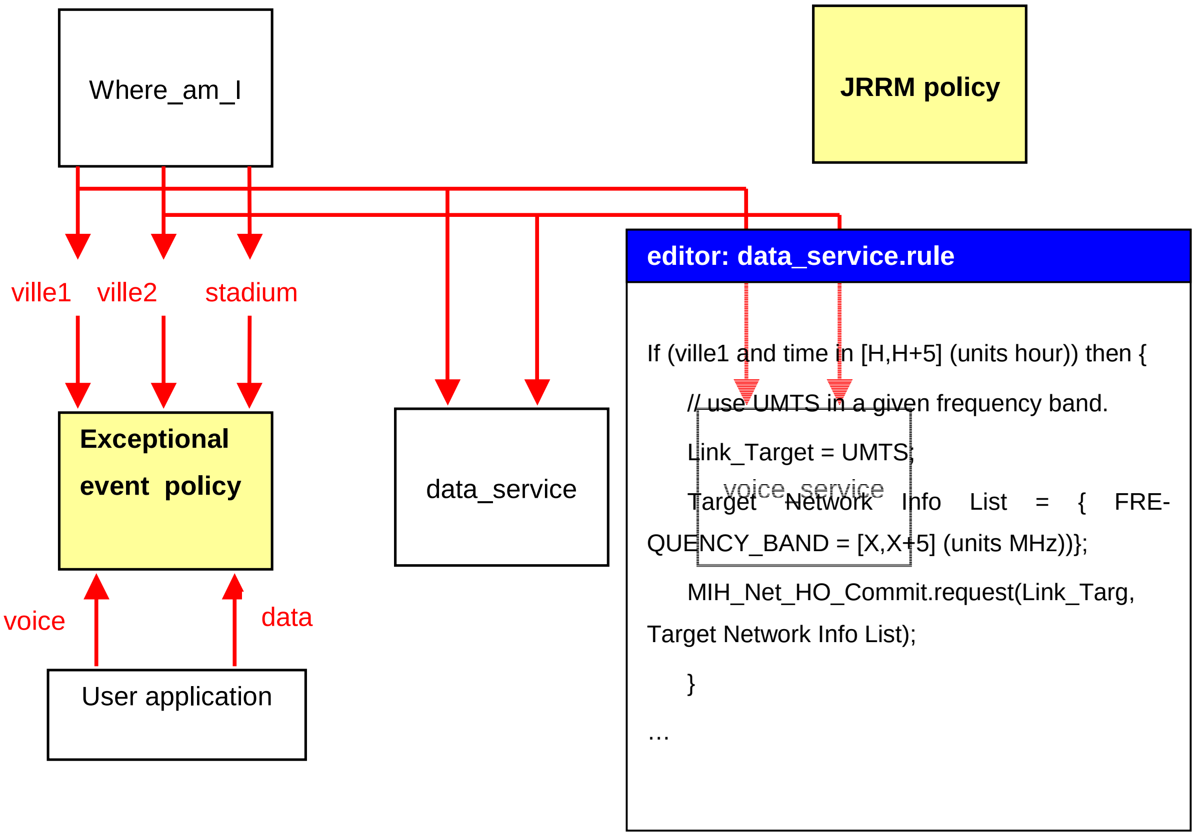
```
policy JRRM = {
-- interface
  requires signal…;
  // valid anytime; valid = true is default value if no validity field.
-- implementation
 // TBD…
  case phase of
    init:
    normal:
    exit:
  endcase;
  }
```

6 A short conclusion

This document provides an overview of a possible policy language for cognitive radios which is very different from the current proposals (Mitola [2], CoRaL [24-29]) which seem to put the emphasis on the reasoning aspect of the language. Our approach is based upon the idea of event and the language is therefore an event based language.

Further work could consist in implementing this language, with two possibilities:

1. A possible graphical description of policies by means of boxes (the various blocks and the main policy blocks) connected by lines representing events. The program could generate the policies (with the above language) corresponding to the graphical description. The scheme below gives an idea of the user generated graphic description, with an example of rule for the box *data_service*.
2. we can also think of an implementation with an existing event based language (Esterel for instance), with the remaining question of a compiler for each type of terminal.



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