Cognitive Radio Experimentation World

Project Deliverable D2.4

Definition of internal usage scenarios, federation functionality and the use of federation as applicable to the VESNA-based testbed

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Abstract: This document presents how three internal CREW usage scenarios can be complemented after extending the CREW federation with the VESNA-based testbed. For each of those a general setup of the new testbed is described and more specific details are provided for the relevant use cases. Taking into account the specifics of the VESNA-based testbed also a new use case is defined for horizontal resource sharing in the ISM band in outdoor environment. Next, the description of the basic functionality for creating the federation of cognitive testbeds is extended to incorporate the VESNA-based testbed. Accessibility of the VESNA-based testbed for external experimenters is discussed and example experiments are outlined, that could be performed to obtain the first hands-on experience with the testbed. Finally, the document reviews the functionality of the extended federation in three identified modes of operation from the perspective of the VESNA-based testbed with special attention on the key tools required to create the federation.

Keywords: cognitive radio, cognitive networking, usage scenario, use case, licensed, unlicensed, spectrum sensing, testbed, federation, wireless networks, benchmarking, VESNA, LOG-a-TEC

Revision History

1.0	Mihael Mohorcic JSI	Incorporated internal reviewers' comments, added List of Figures and list of Tables, final formatting	30 Dec 2011

Executive Summary

This document presents the applicability of CREW usage scenarios and use cases, describes the VESNA-based testbed and its role in the CREW federation, and describes the key tools required to create different modes of operation of the CREW federation.

The document first reports on the impact of the additional testbed in the federation on the investigation of five internal usage scenarios that make use of federated testbeds and components. Three usage scenarios are identified as those that could also be investigated using the VESNA-based testbed: context awareness for cognitive networking (US1), horizontal resource sharing in ISM band (US3) and cooperation in heterogeneous networks in licensed bands (US4). For each of these scenarios the previously defined wireless experiments, representing existing use cases, are reviewed and amended where needed. Furthermore, taking into account specific characteristics of the VESNA-based testbed a new use case is defined for horizontal resource sharing in the ISM band in outdoor environment (UC34).

With the addition of the VESNA-based testbed, the CREW federation is the combination of five cognitive radio testbeds in different European academic institutions, as well as two advanced sensing platforms. These testbeds are: the Iris reconfigurable software defined radio (SDR) testbed in TCD, the TWIST wireless sensor network test environment in TUB, the w-iLab.t heterogeneous ISM test environment in IBBT, the EASY-C LTE/LTE Advanced testbed in TUD and the VESNA-based LOG-a-TEC wireless sensor network and cognitive radio and networking test environment at JSI. The two advanced sensing platforms are an imec (SCALDIO/WARP DIFFS) prototype flexible low power sensing platform and a THALES multiple receiver antenna array. This document complements previously provided descriptions of the original four CREW federation testbeds and sensing platforms with the description of the VESNA-based testbed, its capabilities and limitations, as well as accessibility for external users. It also complements the original set of example experiments with an additional two, which could help external researchers to get the first hands-on experience and become familiar with the basic functionalities of the VESNA-based testbed. In particular, one experiment only assumes browsing through the remote configuration possibilities and visualising previously collected and stored spectrum sensing measurements, while the other experiment assumes remote selection of subset of sensor nodes to be reprogrammed/reconfigured and used to detect RF signal transmitted by another sensor node(s) so as to construct a simple geo-location spectrum occupancy database. The document also outlines the research goals we expect to achieve using VESNA-based testbed by the end of the second year of the CREW project.

After the role of VESNA-based testbed in the CREW federation is defined, the document reviews the basic functionality of the federation as a whole from the perspective of its extension. To this end, the key tools required to create the federation in one of the three identified modes of operation, i.e. individual, heterogeneous and sequential usage, are briefly described as applicable to the VESNA-based testbed. These tools include a common portal, an interface supporting mixing and matching of hardware platforms from different testbeds, a common data collection/storage methodology, and a benchmarking framework.

List of Acronyms and Abbreviations

6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
API	Application Programming Interface
BEE2	Berkeley Emulation Engine 2
CN	Cognitive Networking
CPC	Cognitive Pilot Channel
CR	Cognitive radio
CREW	Cognitive Radio Experimentation World
DIFFS	Digital Front-end For Sensing
DIP	Discovery and Identification Protocol
DSA	Dynamic Spectrum Access
DVB-T	Digital Video Broadcast – Terrestrial
EADS	European Aeronautic Defence and Space Company
Easy-C	Enablers for Ambient Services and Systems — Part C Wide Area Coverage
ECC	Electronics Communications Committee
FCC	Federal Communications Commission
FPGA	Field Programmable Gate Array
GIS	Geographic Information System
GPIO	General Purpose Input/Output
GPS	Global Positioning System
GRASS	Geographic Resources Analysis Support System
GSM	Global System for Mobile Communications
HTTP	HyperText Transfer Protocol
I2C	Inter-Integrated Circuit
IBBT	Interdisciplinary Institute for Broadband Technology
IEEE	Institute of Electrical and Electronics Engineers
imec	Interuniversity Microelectronics Center
ISM	Industrial, Scientific and Medical
JSI	Jozef Stefan Institute
JSON	JavaScript Object Notation
LOG-a-TEC	Outdoor Wireless Sensor Network testbed in the city of Logatec (Slovenia)
LTE	Long Term Evolution
LTE+	Long Term Evolution Advanced
OEM	Original Equipment Manufacturer
OSA	Opportunistic Spectrum Access
RaPlaT	Radio Planning Tool

RF	Radio Frequency
RSSI	Received Signal Strength Indicator
SCALDIO	Scalable Radio
SD	Secure Digital
SDR	Software Defined Radio
SNC	Sensor Node – Core
SNE	Sensor Node – Extension
SNP	Sensor Node – Power
SNR	Sensor Node – Radio
SPI	Serial Peripheral Interface
SQL	Structured Query Language
ST	STMicroelectronics
SUT	System Under Test
TCD	Trinity College Dublin
TCF	Thales Communications France
TETRA	Terrestrial Trunked Radio
TUB	Technische Universität Berlin
TUD	Technische Universität Dresden
TV	Television
TVWS	Television White Space
TWIST	TKN Wireless Indoor Sensor Network Testbed
UART	Universal Asynchronous Receiver/Transmitter
UC	Use Case
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
US	Usage Scenario
USRP	Universal Software Radio Peripheral
VHF	Very High Frequency (30…300 MHz)
VESNA	VErsatile platform for Sensor Network Applications
WARP	Wireless Open Access Research Platform
WInnF	Wireless Innovation Forum
WSN	Wireless Sensor Network

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1. Introduction

The inherent nature of the wireless medium is that the radio spectrum is shared among all users. With the proliferation of new wireless technologies and the increasing bandwidth demands, radio spectrum for exclusive use became a very scarce resource, calling for the development of new techniques supporting its more efficient exploitation. This motivated the concepts of Dynamic Spectrum Access (DSA), spectrum sharing and cognitive radio networks, where licensed spectrum assigned to primary users can be used under certain conditions by secondary (non-licensed) users with frequency agile radios.

Spectrum sharing and DSA can be exploited by Cognitive Radios (CR) that autonomously reconfigure their transmission parameters based on the status of the environment they operate in and the services to be provided. When CR identifies the spectral opportunity for its communication purposes and in some way agrees with other nodes on seizing that opportunity we refer to Cognitive Networking (CN), which typically involves cross-layer optimisation based on schemes for coexistence and collaboration in a given environment. This environment is extremely dynamic, making analytical and simulation-based approaches to investigation unreliable and highly dependent on basic assumptions. However, experimental platforms for testing and validating CR and CN concepts are not accessible to most of the research community, which is why the CREW project integrated four existing testbeds and two advanced sensing platforms and made them available as CREW open federated platform to broader research community. This platform facilitates experimentally-driven research on advanced spectrum sensing, cognitive radio and cognitive networking strategies in the view of horizontal and vertical spectrum sharing between heterogeneous wireless technologies in licensed and unlicensed frequency bands.

The opening of the 700 MHz frequency band following the shift from analogue to digital television is seen as a unique opportunity for advanced wireless technologies such as cognitive radio. This view has only been reinforced after the decision of the FCC [1] and ECC [2] that terminals without spectrum sensing capability can rely on the use of geo-location and database approach for DSA. Taking into account these developments the CREW federation was proposed to be extended by additional heterogeneous testbed operating in outdoor environment for evaluating a suitability of using custom-developed low-cost Wireless Sensor Network (WSN) platform VESNA (VErsatile platform for Sensor Network Applications) to support experimentally-driven basic and advanced spectrum sensing, focusing on the concept of geo-location spectrum occupancy database approach.

Clearly, extension of the CREW federation calls for a thorough review of previously defined scenarios of using the federated testbeds along with potential amendments of existing and definition of new use cases, representing examples of experiments. A revision of the basic functionality for creating the federation of cognitive testbeds is also needed to incorporate the VESNA-based testbed, identifying new capabilities and limitations as a consequence of federation extension as well as the impact on the modes of its operation. This document thus provides a critical review, from the perspective of the federation extension with the VESNA-based testbed, of previously defined internal usage scenarios and use cases [3], federation functionality [4] and federation use [5].

2. Definition of Usage Scenarios for the VESNA-based testbed

To approach the challenges of research and implementation of cognitive radio and cognitive networking solutions, the CREW project specified five internal usage scenarios for experimentally-driven research that utilize the infrastructure of federated testbeds. These usage scenarios, in Figure 1 graphically mapped to the corresponding frequency bands, have been carefully reviewed for their applicability from the perspective of the VESNA-based testbed. Among the five usage scenarios three are particularly well suited for the VESNA-based testbed:

- US1: Context Awareness for Cognitive Networking
- US3: Horizontal Resource Sharing in ISM bands
- US4: Cooperation in Heterogeneous Networks in Licensed Bands

For each usage scenario, a number of use cases have been identified in [3] in order to address particular aspects of relevance in detail. Those use cases are largely based on characteristics and functionalities of the original four CREW federated testbeds. As discussed in the following, some of them are applicable also to the VESNA-based testbed, while specific characteristics of the latter enable some additional use cases, which are defined in this document under the corresponding usage scenarios.

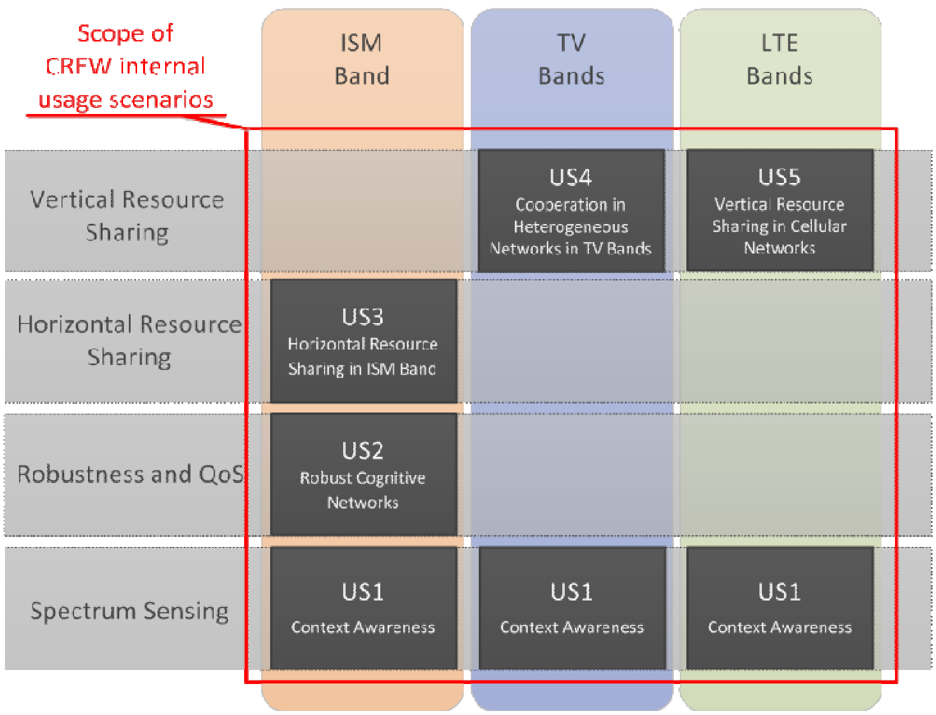

Figure 1: The CREW internal Usage Scenarios [3].

2.1 Usage Scenario 1: Context Awareness for Cognitive Networking

Spectrum sensing represents the core functionality of a true CR, which supports operation over a broad range of frequencies and autonomously adapts transmission parameters to the operating environment. The main motivation for extending the original CREW federation consisting of four testbeds with additional one was to establish a heterogeneous outdoor testbed environment for basic and advanced spectrum sensing in the ISM and TV frequency bands, primarily using the geo-location and database approach, and thus provide part of the context awareness required for experimentally-driven cognitive radio and cognitive networking research.

To facilitate this, the new testbed is based around densely deployed low-cost VESNA sensor node platforms in an outdoor real-life environment, supporting basic spectrum sensing in ISM and TV frequency bands, depending on the used spectrum sensing module. For calibration purposes and as a reference benchmark, these spectrum sensing platforms will be complemented by three Universal Software Radio Peripheral (USRP) modules. Such setup can support different context awareness use cases as outlined in the following, namely spectrum sensing in the ISM (unlicensed) bands and in the TV White Spaces (opportunistic spectrum access – OSA) bands.

The definition of the internal usage scenario US1, summarized in Table 1, remains as originally described in [3].

Title	Context Awareness for Cognitive Networking
ID	US1
Goals	Collect information for cognitive network(s) so that it is possible to adapt to the environment dynamics.
Key Features	Controllable and repeatable context for cognitive networks (for instance the interference environment) and controllable and repeatable ways to obtain this information at run-time by the cognitive network (for instance by spectrum sensing).

Table 1: Internal Usage Scenario 1

2.1.1 Use Case 1.1: Context Awareness in the ISM Bands

The VESNA spectrum sensing platform supports received signal strength indication (RSSI) based spectrum sensing in the unlicensed 868 MHz and 2.4 GHz ISM bands, and can thus provide information about spectrum use or possible interference in the ISM bands. Focus of use case 1.1 remains on sensing of and between two specific technologies used in the ISM band: IEEE 802.15.4 and IEEE 802.11, as specified in [3]. More precisely, in VESNA-based testbed we will investigate the possibility of using low-cost hardware in real-life outdoor environment for RSSI based sensing of the presence of IEEE 802.15 (approach 1 [3]) and IEEE 802.11 (approach 3 [3]) equipment and networks, as well as sensing solutions to differentiate between the technologies. This basic sensing functionality of the testbed will be complemented by fixed USRP software radios for more accurate and advanced spectrum sensing.

The internal use case UC11, summarized in Table 2, remains as originally described in [3], however the VESNA-based spectrum sensing platform will not support the approach 2.

Title	Context Awareness in the ISM Bands
ID	UC11
Goals	Low-cost low power sensing for improved coexistence between heterogeneous technologies.
Approach	*1) Comparing solutions for sensing of 802.15.4 only* *2) Comparing solutions for sensing of 802.11 only* *3) Comparing solutions for sensing of both technologies from 1) and 2)*
Key Features	Sensing Hardware: ISM bands Sensing functionality: detect between heterogeneous technologies Sensing constraints: low cost and low power

Table 2: Internal Use Case 1.1

2.1.2 Use Case 1.2: Context Awareness in the TV White Spaces Licensed Bands

By using appropriate spectrum sensing module, the VESNA platform supports also RSSI based spectrum sensing in licensed VHF and UHF TV frequency bands. Given the limitations in receiver sensitivity for off-the-shelf radio tuners the testbed will make use of distributed sensing techniques further enhanced by the open-source Geographical Information System (GIS) tool GRASS-RaPlaT that incorporates several channel models. This tool will be used for inverse channel modelling to collaboratively detect hidden node, determine the interference region, and construct a geo-location database. Complemented also by fixed USRP software radios for more accurate and advanced spectrum sensing this use case will, in VESNA-based testbed, enable investigation of the trade-off between sensing margins, density of sensing nodes deployment and accuracy of channel modelling.

This use case, summarized in Table 3, will enable comparison of different solutions for context awareness in the VESNA-based testbed, i.e. local sensing, distributed sensing and database approaches.

Title	Context Awareness in the TV White Spaces Licensed Bands
ID	UC12
Goals	Achieve a reliable sensing to avoid interference to licensed users. Focus on sensing the licensed technology.
Approach	*1) Comparison of different sensing solutions for local sensing* *2) Distributed versus local sensing (for reliability improvements)* *3) Sensing versus Database*
Key Features	Sensing hardware: TV White Spaces Sensing functionality: detect licensed technology Sensing constraints: reliability

Table 3: Internal Use Case 1.2

2.2 Usage Scenario 3: Horizontal Resource Sharing in ISM bands

The number of devices operating in the unlicensed ISM bands, in particularly at the 2.4 GHz, is increasing, especially in indoor environments, but also outdoor. In outdoor environments, including around the house, these are mainly Wi-Fi access points and hotspots, outdoor wireless sensor networks and Bluetooth devices such as wireless earphones.

All these devices are competing for the same limited amount of spectrum in the ISM band, calling for appropriate cooperative algorithms, protocols and networking architectures that will form cognitive networking environments to allow more efficient use of the spectrum resources. In different CREW testbeds both cooperation between heterogeneous networks technologies (e.g. Bluetooth and Wi-Fi) as well as cooperation between different homogeneous technologies (e.g. two independent sensor networks) are considered. In this respect the VESNA-based testbed complements other testbeds that are focusing on cognitive networking experimentation in indoor operating environments (home, office, exhibition) by the outdoor operating environment. To this end it provides a large number of fixed remotely controlled nodes as well as a few advanced sensing nodes, all integrated in the CREW federated platform and evaluated in terms of common CREW benchmarks. The main difference with respect to indoor testbeds is that it may be more challenging to ensure sufficiently stable and monitored test environment and thus repeatability of the experiments.

The definition of the internal usage scenario US3 is summarized in Table 4 and remains as originally described in [3].

Title	Horizontal Resource Sharing in ISM Bands
ID	US3
Goals	Enhance the quality of the wireless networking experience through optimization of the ISM spectrum use. The optimization is achieved by letting different homogeneous and/or heterogeneous networks cooperate more efficiently through the provisioning of cognitive networking.
Key Features	Controllable and repeatable realistic interference environments. Comparability of wireless solutions in different realistic reference scenarios, allowing a correct analysis of multiple candidate solutions or subsequent developments. Stable and monitored wireless test environment, ensuring relevance of the performed experiments. User-friendly tools supporting the experimenter in running experiments, and subsequently collecting and processing results.

Table 4: Internal Usage Scenario 3

2.2.1 Use Case 3.1: Horizontal Resource Sharing in Home Environments

The VESNA-based testbed will not support this use case, however, individual VESNA platforms can be used in other heterogeneous ISM testbeds. In particular, a VESNA-based cognitive networking testbed can be setup for testing semi-automatic and automatic protocol stack composition based on existing implementations of modular abstractions of protocol stacks. To this end, the Rime protocol stack, that can be used on VESNA, has been enhanced to allow automatic generation of a stack (a pipe of modules). Moreover, additional VESNA based wireless sensor network can be set up representing the building automation network.

The internal use case UC31, summarized in Table 5, remains as originally described in [3].

Title	Horizontal Resource Sharing in Home Environments
ID	UC31
Goals	Development of cognitive networking protocols to enhance coexistence of ISM devices in a home environment.
Approach	*1) Cognitive networking protocols, using limited functionality of the nodes (e.g. noise scan, packet loss monitoring)* *2) Cognitive networking protocols, using one or more advanced sensing components located in the wireless environment* *3) Cognitive networking protocols for nodes with advanced sensing support*
Key Features	Wireless technologies under test: heterogeneous 2.4 GHz ISM Wireless environment: - limited, fixed number of devices - limited dynamism - nodes owned by single user

Table 5: Internal Use Case 3.1

2.2.2 Use Case 3.2: Horizontal Resource Sharing in an Office Environment

As with use case 3.2, the VESNA-based testbed will not support this use case, however, similarly, individual VESNA platforms can be used in other heterogeneous ISM testbeds. The same remarks apply.

The internal use case UC32, summarized in Table 6, remains as originally described in [3].

Title	Horizontal Resource Sharing in an Office Environment
ID	UC32
Goals	Development of cognitive networking protocols to enhance coexistence of ISM devices in an office environment.
Approach	*1) Cognitive networking protocols, using limited functionality of the nodes (e.g. noise scan, packet loss monitoring)* *2) Cognitive networking protocols, supported by one or more advanced sensing components located in the wireless environment* *3) Cognitive networking protocols for nodes with advanced sensing support*
Technical Parameters	Wireless technologies under test: heterogeneous 2.4 GHz ISM Wireless environment: - large number of nodes, large node density - increased network dynamics and a changing number of users - most nodes under single administrative domain, but also visiting nodes

Table 6: Internal Use Case 3.2

2.2.3 Use Case 3.3: Horizontal Resource Sharing During an Exhibition

As with use case 3.2 and 3.3, the VESNA-based testbed will not support this use case, however, similarly, individual VESNA platforms can be used in other heterogeneous ISM testbeds.

The internal use case UC33, summarized in Table 7, remains as originally described in [3].

Title	Horizontal Resource Sharing During an Exhibition
ID	UC33
Goals	Development of cognitive networking protocols to enhance coexistence of 2.4 GHz ISM devices during an exhibition. Development of fast network deployment mechanisms.
Approach	*1) Cognitive networking protocols, using limited functionality of the nodes (e.g. noise scan, packet loss monitoring)* *2) Cognitive networking protocols, supported by one or more advanced sensing components located in the wireless environment* *3) Cognitive networking protocols for nodes with advanced sensing support*
Technical Parameters	Wireless technologies under test: heterogeneous 2.4 GHz ISM Wireless environment: - very large node density - high network dynamics, a changing number of users - high number of co-located networks operated by different administrative domains

Table 7: Internal Use Case 3.3

2.2.4 Use Case 3.4: Horizontal Resource Sharing in Outdoor Environment

This use case is a further evolution of the use cases UC31, UC32 and UC33 defined in [3]. The outdoor environment is probably the most challenging since the scale of the network is larger and not bounded by the building; there may be several outdoor wireless sensor networks in place belonging to different organizations; devices with Wi-Fi and Bluetooth radios are belonging to different users, also mobile, and therefore out of testbed control; the number of devices can vary significantly; there may be notable effect of indoor deployed networks and devices on the outdoor operating environment due to open/closed windows and doors. All these characteristics also depend on the type of outdoor environment, i.e. urban, suburban, rural or industrial.

As in the other use cases under the usage scenario US3, the goal of this use case is to develop and analyze cognitive networking solutions that will help the different wireless nodes and systems to better coexist in the ISM band. This use case is in its essence more dynamic and prone to random events, so the test environment is also less stable and not entirely controlled. The testbed infrastructure will be used to recreate the network environment under evaluation as much as possible in outdoor environment, as well as to support experiment execution and analysis. This will include determining traffic patterns common to an outdoor environment to be replayed in the testing environment.

During the development of the cognitive networking solutions, the impact of different available sensing components on the cognitive networking protocols can be investigated and compared, from nodes with only basic sensing functionality, to nodes with the access to the information of more advanced sensing solutions, and eventually to nodes with integrated advanced sensing solutions.

For the execution of various test cases in the ISM bands the VESNA-based testbed will also provide USRP software radios integrated with VESNA platforms to serve as interferers.

The new internal use case UC34 is defined in Table 8.

Title	Horizontal Resource Sharing in an Outdoor Environment
ID	UC34
Goals	Development of cognitive networking protocols to enhance coexistence of ISM devices in an outdoor environment.
Approach	*1) Cognitive networking protocols, using limited functionality of the nodes (e.g. noise scan, packet loss monitoring)* *2) Cognitive networking protocols, supported by one or more advanced sensing components located in the wireless environment* *3) Cognitive networking protocols for nodes with advanced sensing support*
Technical Parameters	Wireless technologies under test: heterogeneous ISM Wireless environment: - large number of nodes, node density depending on the type of outdoor environment, from large in urban to small in rural - high network dynamics, a changing number of users and access points - high number of co-located networks operated by different administrative domains

Table 8: Internal Use Case 3.4

2.3 Usage Scenario 4: Cooperation in Heterogeneous Networks in Licensed Bands

The CREW internal usage scenario 4 has been defined in order to support the experimentation on cooperation between unlicensed communication devices in heterogeneous networks operating in the VHF and UHF TV frequency bands. By its fixed outdoor deployment, the VESNA-based testbed is well suited for the experiments on primary-secondary coexistence in the TV bands applying database driven regulatory regime. The testbed will support dynamic grouping of sensing nodes in subsets, thus allowing for investigation of the trade-off between densely deployed low-cost spectrum sensing equipment providing basic capabilities and sparsely deployed advanced sensing equipment with high processing power, based on USRP software radios integrated with VESNA modules.

The definition of the internal usage scenario US4 remains as originally described in [3] and is summarized in Table 9, with the addition of integrated USRP-VESNA platforms representing CR enabled secondary users.

Title	Cooperation in heterogeneous networks in TV bands
ID	US4
Goals	To explore the utilization of TV "white spaces" and investigate feasibility of secondary user implementation in the TV bands.
Key Features	Software defined radio – Iris TV band Test and Trial license Geo-location database of spectrum occupancy USRP-based software radios integrated with VESNA modules

Table 9: Internal Usage Scenario 4

2.3.1 Use Case 4.1: Geographical White Space Sensing

In detecting and adapting to the primary spectrum usage, spectrum sensing plays a crucial role. However, contrary to the assumption in many studies that every secondary user terminal will have spectrum sensing capabilities, it is clear after the FCC decision on the document FCC 10-174 [1] and the ECC Report 159 [2] that unlicensed communication devices operating in the VHF and UHF TV frequency bands will be used without sensing capability at least in the initial phase of opening the TVWS. This will make these devices entirely dependent on the use of spatial-temporal spectrum occupancy database for DSA.

Thus, with respect to the VESNA-based testbed, the use case UC41 will explore the capability of low-cost sensing equipment to map the frequencies of the TV bands at different geographical locations and construct a geo-location database. Thus, this use case aims at replacing TVWS spectrum utilization maps obtained in the past trials by complex and highly sensitive laboratory equipment. The detection and determination of the hidden nodes' locations will be performed using collaborative spectrum sensing mechanisms, while interference regions will subsequently be determined by inverse channel modelling using GRASS-RaPlaT tool.

The internal use case UC41, summarized in Table 10, remains as originally described in [3], but when implemented on the VESNA-based testbed, it will give special emphasis on the construction of geo-location spectrum occupancy database, as pointed out the key features.

Title	Geographical white space sensing
ID	UC41
Goals	To create a mapping of a specific geographical area, showing the frequency band availability at key points on the map. Opportunistic use by secondary users can then rely on a geo-location database containing such information.
Approach	*1) Set sensing equipment up at strategic points of a selected geographical area.* *2) Sense the area for a certain frequency for a predetermined period of time.* *3) Repeat for all frequencies of interest.*
Key Features	Multiple sensing platforms Suitable geographical area Construction of geo-location spectrum occupancy database

Table 10: Internal Use Case 4.1

2.3.2 Use Case 4.2: Detection of Wireless Microphones

The VESNA-based testbed will also support potential experiments that attempt to detect transmissions of wireless microphones, which operate as an underlay network in the VHF and UHF bands and are considered licensed incumbent users of TV spectrum.

The internal use case UC42, summarized in Table 11, remains as originally described in [3].

Title	Detection of wireless microphones
ID	UC42
Goals	To detect the presence of wireless mics in TV bands.
Approach	*1) Transmit a sample wireless mic signal.* *2) Use a feature detection algorithm to detect the presence of a wireless mic signal.*
Key Features	Signal generator with wireless mic signal. Feature detection for wireless mics.

Table 11: Internal Use Case 4.2

2.3.3 Use Case 4.3: Transmission and Detection in TV Bands

Transmission and detection experiments for investigation of vertical spectrum sharing / primary-secondary coexistence, as foreseen for CR operation in the TV bands, may be supported in the VESNA-based testbed by transmitting DVB-T signals if a "test and trial" license is obtained for the geographical region of the outdoor testbed deployment. The testbed will mainly support the geo-location database driven experiments. As to CR enabled secondary users the testbed will comprise USRP-based software radios (using GNU radio as well as Iris software-defined radio) integrated with VESNA modules (USRP-VESNA). VESNA modules will provide Cognitive Pilot Channel (CPC) via the sensor network to the spectrum occupancy tables for the secondary user terminal and by hosting a GPS module they will also provide internal geo-location and precise reference timing capability. Moreover, the possibility to execute the algorithms of collaborative spectrum sensing on VESNA modules with relatively high processing capabilities will also be investigated for the USRP-VESNA setup.

The internal use case UC43, summarized in Table 12, remains as originally described in [3], except for the USRP-VESNA additional equipment representing CR enabled secondary users, as indicated in the key features.

Title	Transmission and detection in TV bands
ID	UC43
Goals	To opportunistically detect and avoid a primary user without causing unacceptable interference.
Approach	*1) Transmit a sample DVB-T signal.* *2) Detect the DVB-T transmission.* *3) Reconfigure the centre frequency of the secondary user link, and/or perform spectrum sculpting to coexist with the primary signal without causing unacceptable interference.*
Key Features	Signal generator with TV signal generator (DVB-T) Sensing platform Iris - Software defined radio USRP-based software radios integrated with VESNA modules

Table 12: Internal Use Case 4.3

3. The CREW federation

With the addition of outdoor VESNA-based testbed, the initial CREW federation was extended to five cognitive radio and cognitive networking testbeds. These are:

- The w-iLab.t in IBBT [6], a heterogeneous ISM test environment which incorporates IEEE 802.11a/b/g/n, IEEE 802.15.1, IEEE 802.15.4, and USRP software radios;
- The Iris testbed in TCD [7], a cognitive radio testbed (which can operate in a variety of bands, including TV bands) based on the Iris reconfigurable radio platform and the USRP [8];
- The TWIST wireless sensor network test environment at TU Berlin [9], which incorporates Tmote Sky and eyesIFXv2 sensor nodes, Wi-Spy spectrum analysers, USRP software radios and BEE2 FPGA platforms;
- The LTE+ cellular test environment at TU Dresden [10], incorporating a complete LTE-equivalent base station infrastructure and SDR mobile user terminals;
- The VESNA-based heterogeneous outdoor testbed LOG-a-TEC set up and maintained by JSI in the city of Logatec, using custom-developed low-cost Wireless Sensor Network (WSN) platform VESNA in ISM and TV frequency bands complemented with USRP-based software radios.

These testbeds, constituting the CREW federated platform, also integrate or will also integrate advanced sensing platforms developed by imec (e.g. at IBBT) and TCF, enabling high-sensitivity detection and identification of interference. The main features of the respective five fixed testbeds and their federation are illustrated in Figure 2. The original four testbeds and additional advanced sensing platforms are described in detail in [4], with the most recent evolution provided on the CREW public website[1], while the next subsections provide a brief description of the VESNA-based testbed.

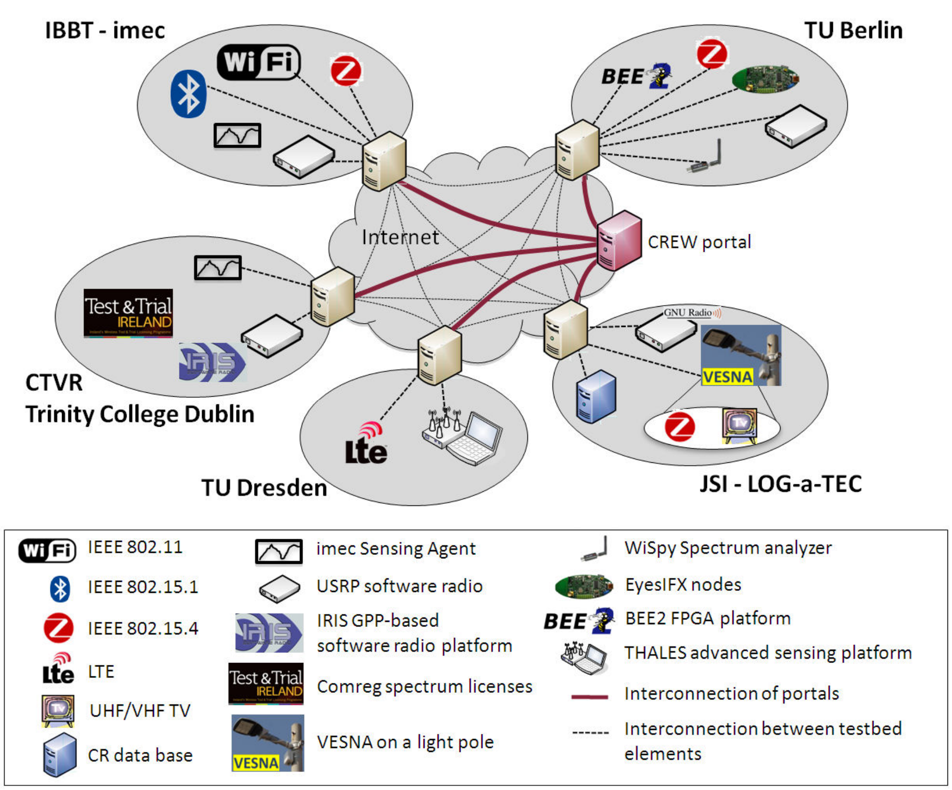

Figure 2: The CREW federated testbeds

[1] http://www.crew-project.eu/

3.1 JSI - The LOG-a-TEC VESNA-based testbed

3.1.1 General description

Following the initial successful outdoor WSN testbed for environmental sensing and light control deployed in 2010 and running for more than 12 months in the Municipality of Miren-Kostanjevica, JSI agreed with the city of Logatec to deploy a LOG-a-TEC WSN testbed for experimental sensor network research on its public lighting infrastructure.

The main component of the WSN testbed was chosen to be the custom-developed WSN platform VESNA that can meet the requirements of diverse applications. Light poles in two distinct parts of the LOG-a-TEC testbed are being equipped with VESNA-based spectrum sensing nodes, in total with approximately 50 nodes with different sensing capabilities in ISM and VHF/UHF bands. The exact layout of nodes in the outdoor environment will depend on the layout of light poles, but the distance between neighbouring nodes will not exceed 200 m. Nodes can be remotely reprogrammed, reconfigured and clustered according to the needs of investigated use case. An example of VESNA-based spectrum sensing node mounting on the light pole and collected measurement values are depicted in Figure 3.

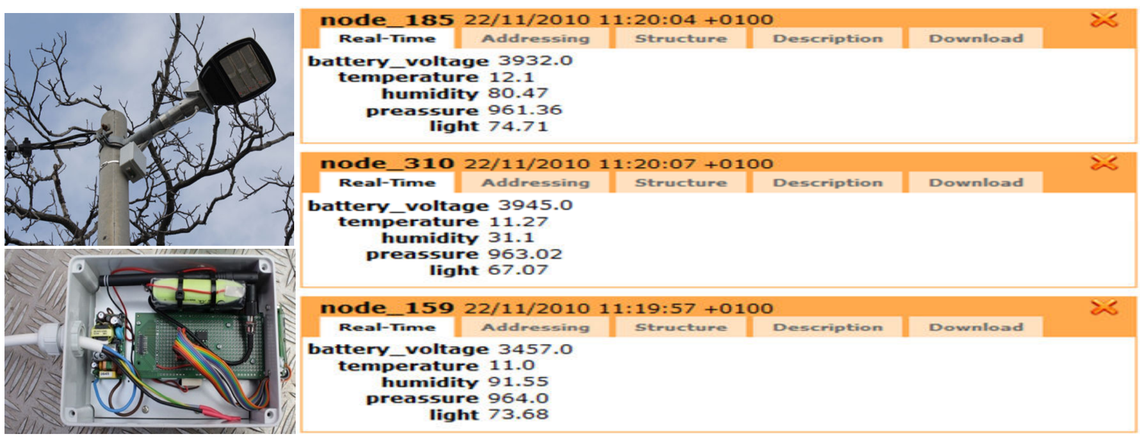

Figure 3: VESNA-based node deployment on a lightpole

VESNA-based spectrum sensing equipment will be complemented with three USRP modules installed on fixed locations, to support advanced spectrum sensing and provide an in-the-field reference. Depending on the investigated use case the testbed will also include portable integrated USRP-VESNA modules, representing secondary user CR enabled terminals.

The outdoor testbed will be complemented also by the indoor VESNA-based cognitive networking testbed at the JSI campus, consisting of approximately 10 VESNA nodes for testing semi-automatic and automatic protocol stack composition based on existing implementations of protocol stacks.

3.1.1.1 VESNA platform

The spectrum sensing capability for the LOG-a-TEC testbed was implemented on a custom-developed fully modular WSN platform VESNA with high processing capability, long-term autonomy and flexible radio. It supports a broad portfolio of sensors and actuators, while its modular approach allows adaptation to diverse application requirements. In this respect the platform, shown in Figure 4, consists of the core module – SNC and a set of special feature modules (radio module – SNR, expansion modules – SNE, power module – SNP) that are used as/if needed. The SNC can be powered by batteries, solar panel or external power supply and together with radio module supports wireless sensor network technologies such as ZigBee, 6LoWPAN and Wireless M-Bus.

Figure 4: VESNA platform: SNC and SNR modules

The SNC is based on a high performance ARM Cortex-M3 microcontroller from ST, which offers a very good trade-off between processing power and energy consumption. It supports clock frequencies up to 72 MHz, has up to 1024 kB of program memory and 96 kB of data memory. For storing large sets of data it also incorporates an SD card interface supporting the SD specification 2.0, which means that up to 32 GB of memory can be addressed. For attaching peripheral devices it offers analog-to-digital converter, a large number of general purpose input-output (GPIO) pins and interfaces like SPI, I2C and UART.

The SNR modules support wireless communication between VESNA nodes in ISM frequency bands and their connection in wireless sensor network. IEEE 802.15.4 compliant communication at 868 MHz is supported by the radio chip AT86RF212 (Atmel), while for the 2.4 GHz frequency band the radio chip AT86RF231 (Atmel) is used. Alternatively, OEM radio modules, comprising the whole ZigBee or Wireless M-BUS protocol stack can be used. In the LOG-a-TEC testbed these could be either ATZB-900-B0 (Atmel) modules with 868 MHz radio interface or ATZB-24-B0 (Atmel) modules with 2.4 GHz radio interface.

For the purpose of spectrum sensing in ISM and TV frequency bands a dedicated SNE module was developed, offering low-cost RSSI-based spectrum sensing using radio chips CC1101 (Texas Instruments) for sub-GHz ISM frequency bands, CC2500 (Texas Instruments) for 2.4 GHz ISM frequency band, and TDA18219HN (NXP) for VHF and UHF TV frequency bands. The module has three antenna interfaces, one for each frequency band, where, depending on the implementation, an omnidirectional antenna or antenna with desired gain and beam pattern can be connected.

Finally, since spectrum sensing nodes are being deployed on public lighting infrastructure, they also obtain the power from this infrastructure and take over the control of switching the lights on and off. To this end the nodes also include the power module with back up batteries and battery charger.

The conceptual schematic of the VESNA-based spectrum sensing node is depicted in Figure 5.

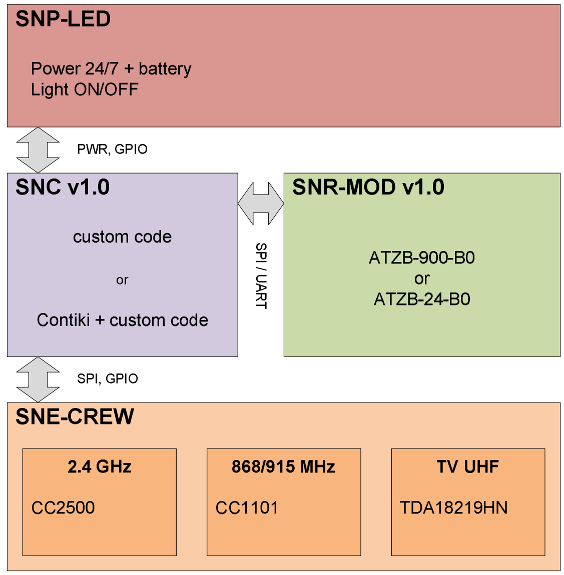

Figure 5: Schematic overview of VESNA-based spectrum sensing node

3.1.1.2 GRASS-RaPlaT

GRASS-RaPlaT[2] is an open-source radio planning tool developed at JSI. GRASS-PlaT is an add-on to the open source Geographical Information Systems (GIS) GRASS, which is one of the projects of the OSGeo foundation. It is one of the most important and widely used open source GIS tools. GRASS operates over raster and vector data and includes methods for image processing and display. It comprises over 350 modules for processing, analysis and visualization of geographical data.

Recently, an open-source radio coverage simulation tool based on GRASS with user extendible set of radio propagation models has been developed, which is especially suitable for research work but at the same time also for professional communication network planning. The GRASS-RaPlaT tool currently includes modules for a number of channel models, a module for sectorisation according to given antenna patterns, a module for calculating and storing the complete radio network coverage data, and a number of supporting modules, e.g. for adapting input data and analyzing simulation results. It is especially designed for radio coverage calculation of GSM/UMTS systems, but can be applied also to other wireless systems in the frequency range 400 MHz - 2.4 GHz. Its structure is modular and characterized by high level of flexibility and adaptability. Its accuracy has been validated with field measurements of GSM, UMTS and TETRA networks, as well as by comparing with results from a professional radio network planning tool.

The GRASS-RaPlaT tool will be applied for data analysis and visualization, but more importantly, for the inverse channel modelling for determination of the interference region of the collaboratively detected hidden nodes.

3.1.2 Use by external participants - access

Both the outdoor and the indoor VESNA-based testbeds will support the access for external participants to conduct experiments on the existing testbed equipment configured according to their needs, or on their equipment brought to the testbed site. When using the existing testbed equipment, external users can also access it remotely by installing their sensor node program images on selected sensor nodes or just reconfiguring them, which will be supported via a web-based interface. Required modifications in sensor nodes will be converted into commands that are sent to the corresponding sensor nodes via sensor network coordinators using the Discovery and Identification Protocol (DIP) [6]. DIP is an application layer protocol, developed for the purpose of managing sensor networks,

[2] http://www-e6.ijs.si/en/software/134

accessing and controlling each individual node as well as for collecting sensor data and storing it. It introduces a sensor network coordinator which on one side communicates with sensor nodes and on the other with the infrastructure, i.e. a remote server for interacting with sensor network which will store the sensor data and metadata and make them accessible through the Web. This data can either be visualised using GRASS-RaPlaT tool or provided for download and subsequent processing or replay in other testbeds as raw spectral measurements. The framework architecture for sending requests and collecting, storing and accessing sensor data is depicted in Figure 6.

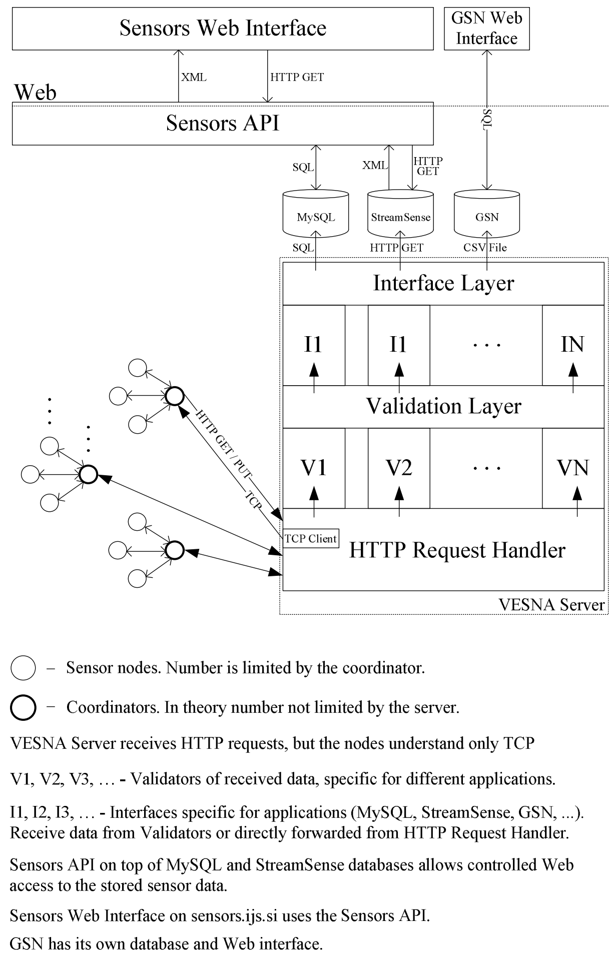

Figure 6: Data management framework architecture for the VESNA-based testbed

For providing fair sharing of the access to the testbeds a scheduling and quota system will be implemented, if needed.

3.1.3 Use by external participants - example experiment

On the CREW portal, a step-by-step guide will explain how a remote user can set-up a very basic experiment. A simple experiment setup could assume a user logging in to the web interface, browse through the remote configuration possibilities and visualise previously collected and stored spectrum sensing measurements.

Another example experiment showcasing basic functionality of the VESNA-based testbed could assume remotely selecting subset of sensor nodes to be reprogrammed by user generated or previously provided sensor node program images and subsequently used to detect RF signal transmitted by another sensor node(s) and construct a geo-location spectrum occupancy database. This database can then be visualised and raw data can be downloaded for further processing.

3.1.4 Expected achievements by the end of year 2

The outdoor VESNA-based testbed will be set up and the use cases UC11 and UC12 will be supported and carried out by the end of year 2. Access to the testbed via the web-interface as described in the example above will be available to experimenters before the second open call. Measurement traces from UC12 will be recorded to be reused in the Iris testbed at TCD. Also some basic experiments in usage scenarios US3 and US4 will be supported.

3.1.5 Why do we need the federation in order to perform these experiments?

The federation is essential to compare and benchmark low-complexity spectrum sensing devices based on the VESNA platform against other low-cost off-the-shelf devices as well as devices with advanced spectrum sensing capabilities. Furthermore, for advanced CR functionalities we will consider relocation of some Iris or imec nodes and potential integration of both mentioned nodes with the VESNA platform. Moreover, VESNA platforms will be made available for relocation to other testbeds, where they can be used as spectrum sensing agents (UC11, UC12, UC41) or for testing semi-automatic and automatic protocol stack composition based on existing implementations of modular abstractions of protocol stacks (UC31, UC32, UC33). Finally, the benchmarking framework will make comparison of solutions in different testbeds, or comparison of different solutions available in the consortium side-by-side.

4. Basic functionality of the federation

4.1 Modes of operation of the CREW federation

As described in [5], the CREW federation of testbeds can be used in three main modes:

- Single usage of a given testbed
- Heterogeneous usage where parts of one testbed are physically relocated to another testbed
- Sequential usage based on recorded wireless traces in one test environment and subsequently replayed in the same or other test environments

Given that the VESNA-based testbed is to be fully integrated in the CREW federation it will support all three federation modes, which are also conceptually depicted in Figure 7.

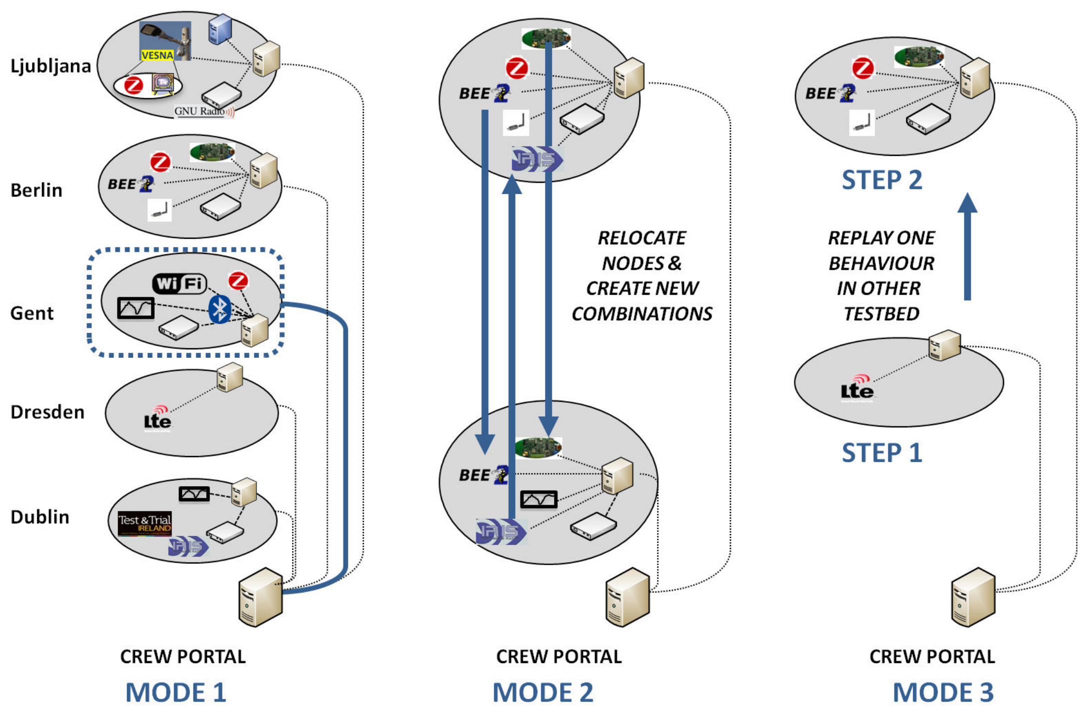

Figure 7: Federation modes of usage

4.2 Common CREW Portal

The CREW portal is the primary way of getting information on the CREW federation, and serves as a gateway through which external experimenters get all necessary details to get to know and access the facilities. The portal is implemented as a website[3]. To date, the portal already includes basic information about the JSI as a new partner in the CREW project, whereas further data about the testbed and its components will be added and updated as it gets available, i.e. as the outdoor deployment of the VESNA-based testbed concludes, and the latest before the second open call for external experimenters is issued.

To this end we do not foresee any need for changing the existing organisation of the portal.

[3] http://www.crew-project.eu/portal

4.3 Testbeds hardware platform interface

The VESNA-based testbed includes, in addition to VESNA spectrum sensing modules, also fixed and portable USRPs. This platform has been selected in CREW [5] for the design and implementation of the Transceiver Facility Specification defined within the Wireless Innovation Forum (WInnF). Once the reference implementation of the current version of the API is provided, it will also be used on USRPs in VESNA-based testbed to better support the federation and enable new functionalities.

As part of federation building it will also be investigated, if this specification could be used as the interface to combine the CR elements from VESNA-based testbed with those from other testbeds, and what modifications or extensions would be needed to the Specification to achieve this.

4.4 Common Data Collection/Storage Methodology Design

Given that CREW federates five testbeds and that these testbeds will be used in experimental research for a number of different usage scenarios and use cases, it is necessary to define a common methodology, format and structures for collecting and storing input and output data.

JSI already contributed to the task T3.3 of creating a common data storage methodology design [6], which defines data of interest, common structures for storing data and creates a federation database for storage of any input / output data relevant for CREW. As the baseline for the common data format the IEEE 1900.6 standard was adopted and JSON as a suggested file format. By describing the outdoor spectrum sensing with VESNA platform JSI already provided an example of the JSON representation [6].

4.5 Benchmarking framework

An important aspect of the CREW project is also creating a benchmarking framework for cognitive radio and wireless systems in general, considering the specific limitations and requirements of wireless experimentation. The framework will enable running experiments under controlled and reproducible test conditions, with the extension of offering automated procedures for experiments and performance evaluation. The benchmarking framework will allow a fair comparison between different cognitive radio and cognitive networking concepts or between subsequent developments on a System Under Test (SUT) [5]. As such, the CREW benchmarking framework will be deployed also on VESNA-based testbed.

5. Conclusion

This document reports on a thorough review of deliverables D2.1 [3], D2.2 [4] and D2.3 [5] from the perspective of the VESNA-based testbed. In particular, it investigates the applicability of CREW usage scenarios and use cases, it defines general requirements for the integration of the VESNA-based testbed in the CREW federation, and describes the basic functionality of the federation.

Among the five usage scenarios with focus on different areas of cognitive radio and cognitive networking defined in CREW three have been identified as suitable for implementation on the VESNA-based testbed, i.e. context awareness for cognitive networking (US1), horizontal resource sharing in ISM bands (US3) and cooperation in heterogeneous networks in licensed bands (US4). For each of these scenarios the existing use cases have been reviewed from the perspective of the VESNA-based testbed and amended where needed. Moreover, a new use case has been defined for US3 concerned with horizontal resource sharing in outdoor environment (UC34).

Next, this document provides a description of the basic functionality of the VESNA-based testbed in the same way as this was done in [4] for the other four testbeds constituting the CREW federation. It is also described how this new testbed can be accessed by external users. Two example experiments are outlined, which could help external researchers to become familiar with the basic functionalities of the VESNA-based testbed. Given that this testbed only becomes available for full integration in the CREW federation by the middle of year 2, the deliverable also determines, which use cases are expected to be completed by the end of year 2, and clarifies the role of the federation in experiments planned on the VESNA-based testbed.

The CREW federation is based on three modes of operation, i.e. individual usage of a given testbed, heterogeneous usage assuming mixing and matching of cognitive elements from different testbeds, and sequential usage based on recording of radio environment during an experiment in one testbed and replaying it during other experiments in the same or another testbed. All three modes of operation will be supported also in the VESNA-based testbed. In the light of this, the present deliverable briefly reviews the common CREW portal, which was built for providing the information on the federation and individual testbeds as well as the access for individual usage of each testbed; it discusses the interfacing of different pieces of hardware within the testbeds, particularly important for the heterogeneous usage of the federation; and it outlines the necessity for a common data collection and storage methodology design, and for creating a benchmarking framework, both especially relevant to the sequential usage of the federation.

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