Validation platform implementation description – D5.2

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Abstract

This deliverable describes different test-beds for the validation of the architecture, algorithms and protocols for the operator governed opportunistic networking as defined in the OneFIT Project. Further on, this deliverable provides a description of the implementation of the OneFIT cognitive management systems CSCI and CMON as well as the C4MS protocol. Also, implementation of the blocks supporting the OneFIT system (JRRM, CCM, DSONPM, and DSM) is described. This document also describes the implementation of the OneFIT scenarios for opportunistic coverage extension, opportunistic capacity extension, infrastructure supported ad-hoc networking and device-to-device communication as well as opportunistic resource aggregation in the backhaul network.

Keywords List

OneFIT validation platform, implementation, OneFIT system building blocks, CMON, CSCI, C4MS, JRRM, CCM, DSM, DSONPM, Opportunistic Networks, management phases, OneFIT scenarios, test-bed

Executive Summary

This document describes the implementation of the OneFIT [1] platform components for the management of operator governed opportunistic networks into the OneFIT validation platform which is introduced in D5.1 [2] and further described in this document.

First, test-beds which are brought by OneFIT consortium members are described and mapped onto the overall OneFIT validation platform. A description of every test-bed provides insights into the OneFIT algorithms for operator governed opportunistic networking and protocol variants for the control channels for the cooperation of cognitive management systems (C4MS) which are implemented into the test-bed.

The implementation of the "Cognitive Management system for the Opportunistic Network" (CMON) and the "Cognitive management System for the Coordination of the Infrastructure" (CSCI) as well as the implementation of other building blocks, necessary for OneFIT system realization (including parts of the OneFIT functional architecture – Dynamic Spectrum Management (DSM), Joint Radio Resource Management (JRRM), Configuration Control Module (CCM) and Dynamic and Self-Organizing Network Planning and Management (DSONPM)), in these test-beds is described. Finally, possible and ongoing cooperation between different test-beds are mentioned. Fulfilment of the OneFIT system requirements by the current implementation of the OneFIT platform is presented. Framed in this context, essential requirements related to the establishment and management of the ON and general requirements (e.g. mobility, relaying, communication with infrastructure and between terminals etc.) are taken into account in the current implementation of the OneFIT system. Additionally, user (e.g. hide complexity from the user), algorithmic (e.g. context awareness, decision making mechanisms etc.), protocol (e.g. usage of standardized protocols, unicast communication etc.) and security requirements are sufficiently covered and will be further expanded.

Section 3 describes the implementation of the OneFIT cognitive management system and lists the WP4 algorithms which are implemented into the validation platform. A mapping of the implemented algorithms onto CMON and CSCI tasks as well as ON management phases is described in detail. The implemented versions of OneFIT algorithms provide all necessary functionalities for achieving cognitive management of opportunistic networks (e.g. context, policies, profiles acquisition and management, decision making, solution enforcement, ON creation/maintenance/termination). Different OneFIT algorithms cooperate in order to provide necessary functionalities of the OneFIT cognitive management system. Some of the algorithms address the same challenges, but in different context (RAT, type of the network, different triggers, different nodes involved etc.).

Section 4 of this deliverable presents implementation of supporting blocks, which are presented in functional architecture of the OneFIT system. These building blocks are JRRM, CCM, DSM and DSONPM. The aforementioned building blocks are built on legacy functionalities and expanded in the context of the OneFIT functional architecture in order to include essential features of the ONs.

Implemented variants of the C4MS protocol are described in section 5. First, the 802.21 MIH based C4MS implementation is presented. Next, the implementation of supporting C4MS signalling using IETF OLSR and SNMP is described. Implemented C4MS variants provide required functionalities for enabling context acquisition and signalling support throughout the ON lifecycle phases.

At the end of the deliverable, the realization of the OneFIT scenarios for opportunistic coverage extension, opportunistic capacity extension, infrastructure supported ad-hoc networking and device-to-device communication as well as opportunistic resource aggregation in the backhaul network within the OneFIT validation platform is presented. Each scenario implementation description specifies which test-beds and OneFIT building blocks (ON enabling algorithms, C4MS variants and OneFIT supporting blocks) are utilized.

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Table of Acronyms

Term	Meaning
3G	3rd Generation
3GPP	3rd Generation Partnership Project
ACK	Acknowledgement
ACL	Agent Communication Language
AID	Action Identifier
AP	Access Point
BS	Base Station
BSSID	Basic Service Set Identifier
C4MS	Control Channels for the Cooperation of the Cognitive Management System
CA	Context Awareness
CCM	Configuration Control Module
CMON	Cognitive Management system for the Opportunistic Network
CO	Carbon Oxide
CPU	Central Processing Unit
CR	Cognitive Radio
CRSM	Cognitive Radio System Management
CS	Circuit Switched
CSCI	Cognitive management System for the Coordination of the Infrastructure
D2D	Device to Device
DBMS	Data Base Management System
DHCP	Dynamic Host Configuration Protocol
DM	Decision Making
DRA	Dynamic Resource Allocation
DSM	Dynamic Spectrum Management
DSONPM	Dynamic and Self-Organizing Network Planning and Management
EDGE	Enhanced Data for Global Evolution
ETX	Expected Transmission Count
FA	Functional Architecture
FIPA	Foundation for Intelligent Physical Agents
FTP	File Transfer Protocol
GPRS	General packet radio service

GSM	Global System for Mobile Communications
GUI	Graphical User Interface
GW	Gateway
HNA	Host and Network Association
HSDPA	High-Speed Downlink Packet Access
HTTP	Hyper-Text Transfer Protocol
IETF	Internet Engineering Task Force
INA	Information Answer
INI	Information Indication
INR	Information Request
IP	Internet Protocol
ISM	Industrial Scientific and Medical
JADE	Java Agent DEvelopment Platform
JMF	Java Media Framework
JRRM	Joint Radio Resource Management
KPI	Key Performance Indicator
LAN	Local Area Network
LTE	Long Term Evolution
MAC	Medium Access Control
MAS	Multi Agent System
MID	Multiple Interface Declaration
MIH	Media Independent Handover
MIHF	Media Independent Handover Function
MNO	Mobile Network Operator
MPR	Multi-Point Relay
MRRM	Multi standard Radio Resource Management
MSC	Message Sequence Chart
NAT	Network Address Translator
NIC	Network Interface Controller
OBD	On-Board Diagnostics
OF	Objective Function
ON	Opportunistic Network
ONC	Opportunistic Network Creation
ONE	Opportunistic Network Environment

OneFIT	Opportunistic networks and Cognitive Management Systems for Efficient Application Provision in the Future InterneT
ONM	Opportunistic Network Modification
ONN	Opportunistic Network Negotiation
ONNA	ON-Negotiation-Answer
ONNR	ON-Negotiation-Request
ONRA	ON-Release-Answer
ONRR	ON-Release-Request
ONSN	Opportunistic Network Status Notification
OLSR	Optimised Link State Routing
OPA	Operator Policy Acquisition
PC	Personal Computer
PDU	Protocol Data Unit/ Packet Data Unit
PLMN	Public Land Mobile Network
PM	Profile Management
QoE	Quality of Experience
QoS	Quality of Service
RAT	Radio Access Technology
RB	Router Board
RDQ-A	RAT-Demand-QoS Assignment
RRC	Radio Resource Control
RRM	Radio Resource Management
SA	System Architecture
SAP	Service Access Point
SID	Service Identifier
SIM	Subscriber Identity Module
SINR	Signal to Interference plus Noise Ratio
SIP	Session Initiation Protocol
SNMP	Simple Network Management Protocol
SQL	Structured Query Language
SSID	Service Set IDentifier
STUN	Session Traversal Utilities for NAT
SUMO	Simulation of Urban MObility
TC	Topology Control
TCP	Transmission Control Protocol

TLV	Type Length Value
Tx	Transmission
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USRP	Universal Software Radio Peripheral
UTRAN	Universal Terrestrial Radio Access Network
VoIP	Voice over IP
WARP	Wireless open-Access Research Platform
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network

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1 Introduction

This deliverable provides a description on how the building blocks of the OneFIT functional architecture are implemented in the OneFIT validation platform. Further on, a mapping of the available test-beds (hardware and software elements) onto the ON related challenges, the ON management phases, the building blocks of the OneFIT functional architecture and the OneFIT scenarios is provided. This document also describes how the selected OneFIT scenarios and use cases are implemented in the OneFIT validation platform and which test-beds, algorithms, protocol variants and supporting blocks are utilized in implementation of these scenarios.

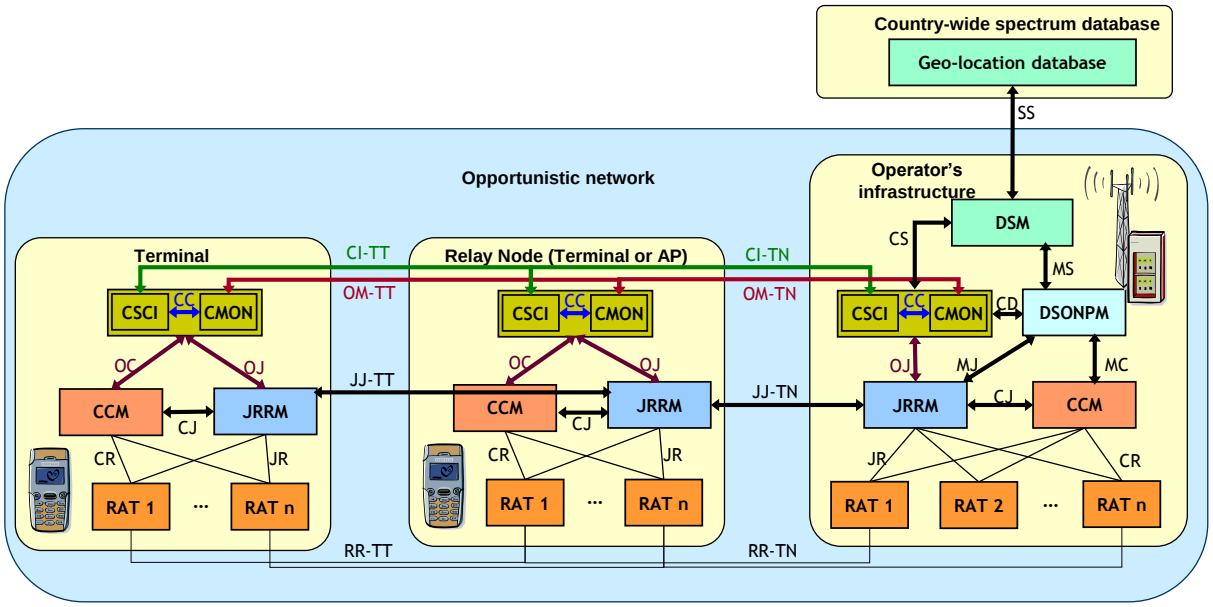


Figure 1: OneFIT functional architecture

Figure 1 shows the OneFIT functional architecture. The key building blocks of this architecture, as presented in D2.2 [4] and as shown in Figure 1 are:

- CSCI: The *Cognitive management System for the Coordination of the Infrastructure* is responsible for the detection of situations where an ON is useful including the ON suitability determination;
- CMON: The *Cognitive Management system for the Opportunistic Network* is responsible for the management of the opportunistic networks, including creation, maintenance and termination of a given ON based on the context and policy information provided by the CSCI;
- C4MS: *Control Channels for the Cooperation of Cognitive Management Systems* are used to communicate between the different nodes and cognitive management systems (CMON and CSCI);
- CCM: The *Configuration Control Module* executes reconfiguration of the devices;
- JRRM: The *Joint Radio Resources Management* performs the joint management of the radio resources across different radio access technologies;
- DSM: The *Dynamic Spectrum Management* provides mid- and long-term management (e.g. in the order of hours and days) of the spectrum for the different radio systems and opportunistic networks.

- DSONPM: The *Dynamic, Self-Organising Network Planning and Management* provides mid- and long-term decisions upon the configuration and reconfiguration of the network or parts of it.

The CMON and the CSCI are parts of the OneFIT cognitive management system, which is responsible for decision making regarding ON lifecycle. The cognitive management system supports all of the ON management stages (phases), from suitability determination, through creation and maintenance, to termination. These building blocks, together with the C4MS protocol, represent key elements of the OneFIT system.

The C4MS protocol [6][7], which is implemented as described in section 5, is used on the interfaces between different nodes (See interfaces CI-TT, CI-TN, OM-TT, OM-TN, JJ-TT, JJ-TN, SS in Figure 1). Definition of all interfaces presented in the Figure 1 can be found in [4].

The CCM, JRRM, DSM and DSONPM are supporting blocks in the OneFIT functional architecture, which enable implementation of the OneFIT system into the existing operator's networks and devices supporting different RATs.

Presented building blocks are implemented into the OneFIT validation platform through their implementation in different test-beds (and combination of test-beds), which comprise the overall validation platform. The WP4 algorithms, which are implemented into the corresponding test-beds, provide different parts of CSCI and CMON systems as well as OneFIT supporting blocks (i.e. DSM). Also, these algorithms address different management phases of opportunistic networks. C4MS protocol variants, which are proposed within [5], are also implemented in test-beds in order to enable the execution of implemented algorithms and to support the ON lifecycle.

Five OneFIT scenarios are defined in D2.1 [3]. The OneFIT architecture is developed in line with requirements set by these scenarios and their use-cases. Also, these scenarios are defined in a way which enables all of the OneFIT advantages and benefits to be showcased. Defined scenarios are (a more detailed description of every scenario and corresponding use-cases can be found in [3]):

- Scenario 1: Opportunistic coverage extension;
- Scenario 2: Opportunistic capacity extension;
- Scenario 3: Infrastructure supported opportunistic device-to-device networking;
- Scenario 4: Opportunistic traffic aggregation in the radio access network;
- Scenario 5: Opportunistic resource aggregation in the backhaul network.

The rest of the document is organized as follows:

- The OneFIT validation platform and test-beds comprising it are described in more detail in section 2;
- Implementation of ON management systems (CMON and CSCI) as well as realization of the ON management phases is described in section 3;
- Section 4 describes implementation of the OneFIT supporting blocks (JRRM, CCM, DSM and DSONPM);
- Section 5 gives description of C4MS implementation;
- Practical realization of the OneFIT scenarios 1, 2, 3 and 5 is described in section 6 of this document.

2 OneFIT validation platform

The OneFIT validation platform was introduced in D5.1 [2]. It comprises of hardware (test-beds and equipment) and software (algorithms and protocols) provided by the OneFIT consortium members. Technical characteristics and capabilities of these test-beds are described in D5.1 [2]. Figure 2 provides a high level insight into the architecture of the overall OneFIT validation platform. The OneFIT validation (proof of concept) platform consists of:

- ON enabled end user devices including smart-phones, tablets and laptops;
- WiFi APs for providing network access to end user devices. ON enabled APs are used for creation of ONs between end user devices and APs as well as ONs between APs.
- Femto APs which are used for mimicking macro APs (BSs) as well as for capacity extension by offloading access traffic from macro APs;
- ON manager system which comprises of cognitive management elements which are implemented in the core side of the operator's infrastructure. These ON management entities are implemented on PCs or properly scaled server stations (including databases of contextual parameters used for knowledge derivation).

The overall OneFIT validation platform doesn't present one physical test-bed, but a collection of different test-beds and OneFIT architecture components provided by different consortium members. These test-beds are utilized in different scenarios, for realization and implementation of different algorithmic approaches and protocol variants.

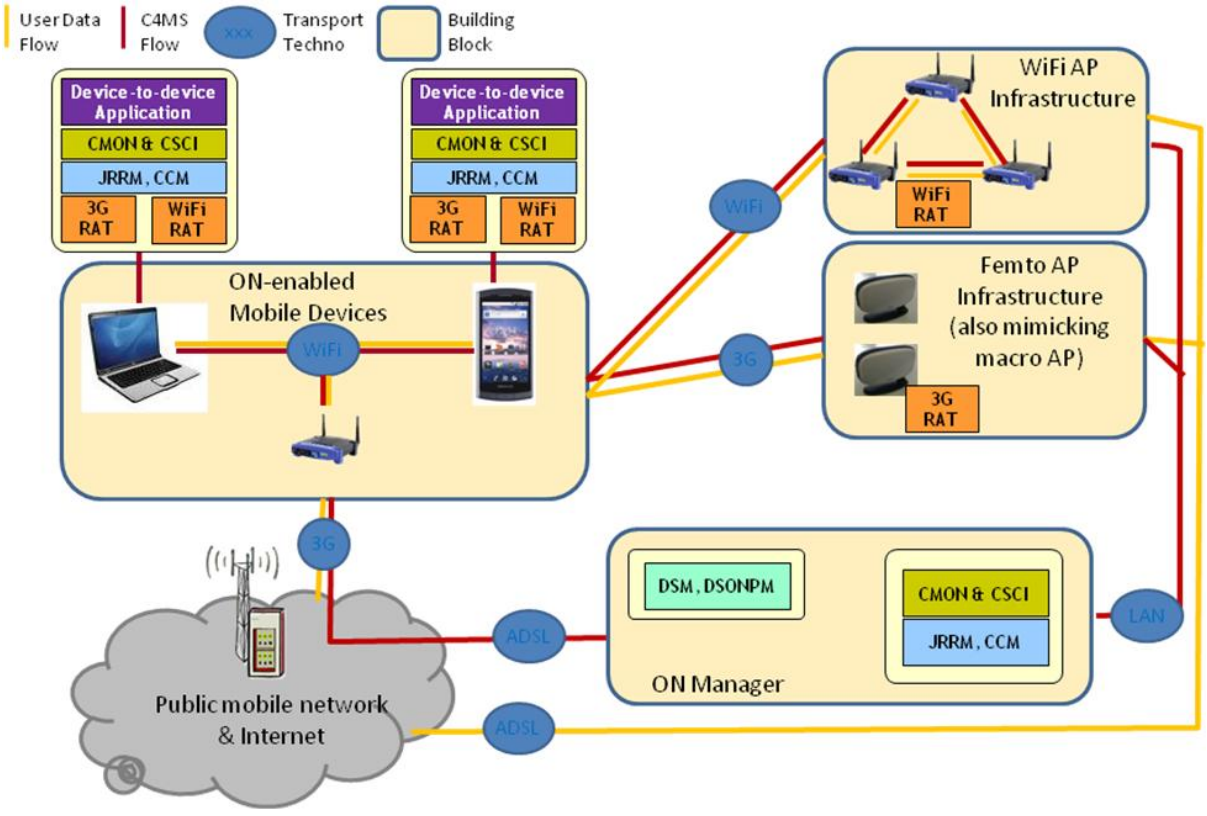


Figure 2: OneFIT validation platform

Different components (hardware and software) of the validation platform are provided by different consortium members. Some of these components are stand-alone test-beds used for implementation and validation of specific algorithmic solutions, scenarios/use cases, protocol variants and supporting building blocks. Other components are test-beds and/or architecture elements (i.e. DSM) which can be used for validation and implementation of different algorithmic and protocol solutions as well as realization of different scenarios. Cooperation between different partners' test-beds already exists in implementation of the OneFIT scenarios (please see section 6 of the deliverable). Also, other possible cooperation opportunities between different test-beds are identified. This cooperation will be further examined in D5.3 (due for December 2012). Detailed description of consortium members' test-beds and their role within the overall OneFIT validation platform is given later in this section.

Test-beds, which are included into the OneFIT validation platform shown in Figure 2, are mapped onto the ON related challenges (spectrum and nodes&routes selection/identification), the OneFIT scenarios and the ON management phases as shown in Figure 3 and Figure 4. These figures show the potentials of partner's test-beds. However, they are currently utilized in implementation and validation of specific scenarios on their own or in cooperation (as described in corresponding test-bed descriptions and section 6 of this deliverable).

OneFIT D2.1 [3] has provided a set of system requirements to be fulfilled by the OneFIT system. The complete list of system requirements, with their classification and codes, is given in Table 1. The requirements are mapped to every test-bed description later in this section since implementations performed within these test-beds address specific set of system requirements.

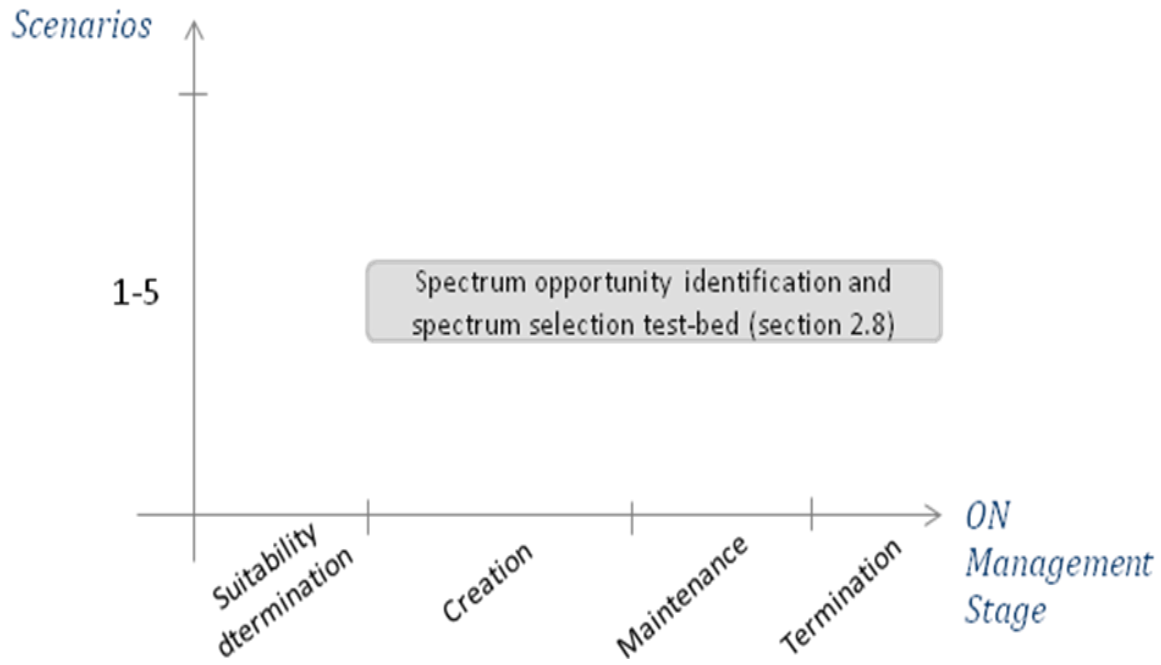


Figure 3: Mapping of the test-beds responsible for spectrum selection/identification challenge onto the OneFIT scenarios and ON management phases

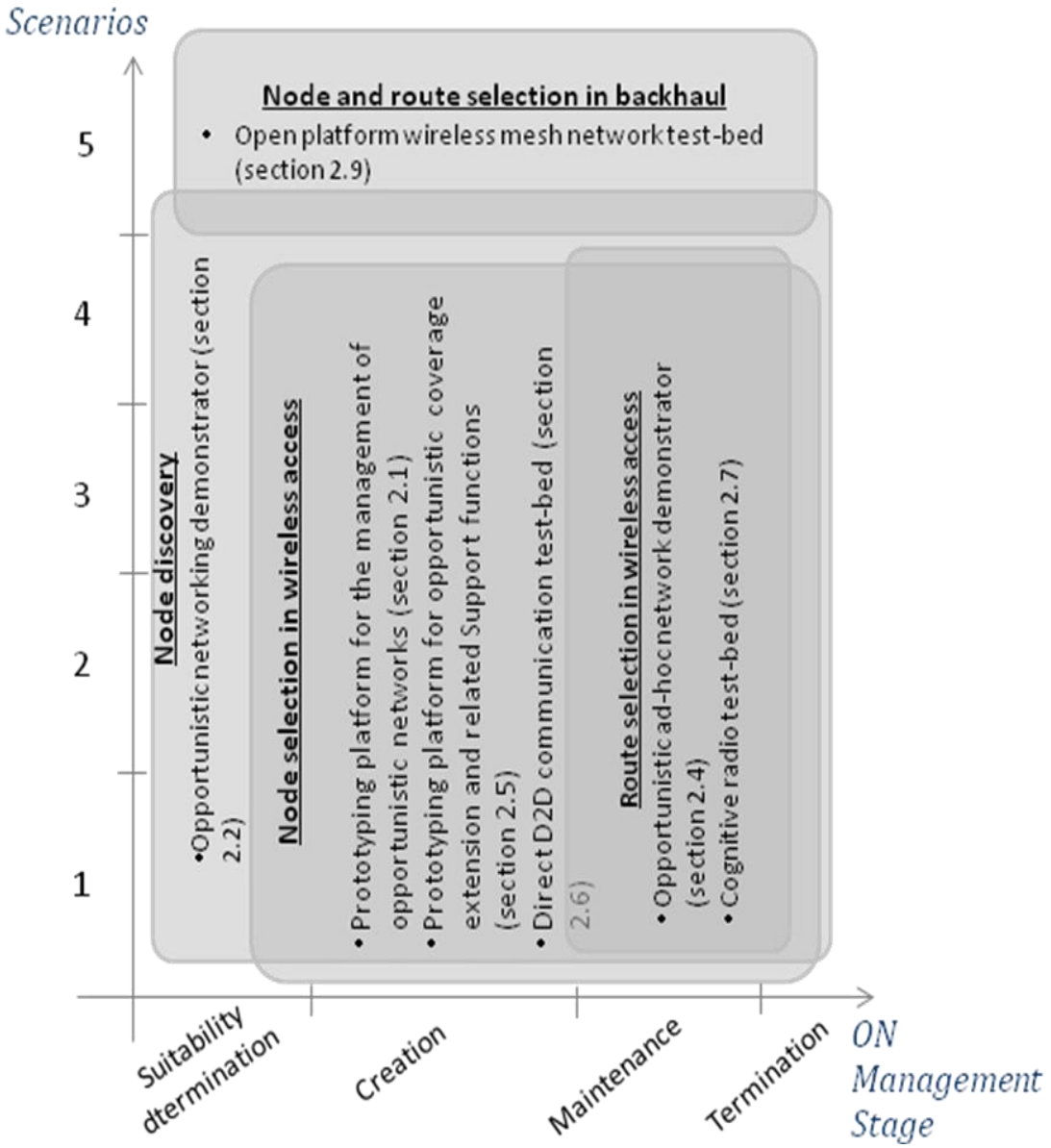


Figure 4: Mapping of the test-beds responsible for nodes and routes selection/identification challenge onto the OneFIT scenarios and ON management phases

Different test-beds and implementation efforts address different subsets of system requirements. Joint together they address all of the system requirements except P3 (partially), P4, S3 and S4. In the current demo implementations, only unsecured communication is used while for a product also secure communication must be supported (Requirement P4) as well as the protection of user identity (S3) and protection of device identity (S4). Available standard solutions for protection of user's and device's identity as well as solutions for secure communication can be incorporated into the OneFIT system enabling it to address these three system requirements. The multicast part of the system requirement P3 is in scope of future evolution (within OneFIT project cycle and post project period) of the C4MS protocol. Several test-beds use broadcast signalling for dissemination of i.e. SSID and ON support. Multicast signalling will provide possibilities for further improvements and optimization of the signalling process behind C4MS protocol.

Table 1: OneFIT system requirements [3][4]

Category	Nbr.	Title of the requirement
General requirements	G1	Communication with the infrastructure
	G2	Communication between terminals
	G3	Versatile spectrum use
	G4	Versatile RAT/RAN use
	G5	Mobility
	G6	Relaying
	G7	Creation of opportunistic networks
	G8	Opportunistic Networks controllable by single operator
	G9	Preservation of legacy RAN operation
	G10	Compatibility with legacy RAN deployments
	G11	Resource efficiency
User and Service related requirements	U1	Hide complexity from the end user
	U2	User's service perception
	U3	Availability of ON-related information to the service layer
Opportunistic network Management related requirements	M1	Identification of the need for an opportunistic network
	M2	Suitability determination
	M3	Creation of opportunistic networks
	M4	Connection set-up
	M5	Maintenance of opportunistic networks
	M6	Release of opportunistic networks
	M7	Coordination of opportunistic networks with the infrastructure
	M8	Opportunistic network identification
	M9	Maximum size of an opportunistic network
	M10	Coexistence of opportunistic networks
	M11	Assignment of bandwidth
Algorithm related requirements	A1	Context awareness
	A2	Decision making
	A3	Routing
	A4	ON Advertisement
Protocol requirements	P1	Protocol usage
	P2	Broadcast/Multicast
	P3	Unicast/Dedicated addressing
	P4	Secure as well as unsecure communication
	P5	Protocol efficiency
Security requirements	S1	Security
	S2	Accountability, charging and billing
	S3	Protection of user identity
	S4	Protection of device identity

2.1 Prototyping platform for the management of opportunistic networks

The prototyping platform for the management of opportunistic networks comprises cognitive management systems and control channels and aims at the efficient application provision through the management of opportunistic networks in coordination with the infrastructure. It has been developed as a Multi Agent System (MAS) based on Java and JADE [16] and it consists of several software and hardware components that can support the execution of a great variety of scenarios and use cases and moreover they are facilitating the integration of new hardware or software

functionalities that are developed in the context of prototyping activities. Also, as part of the platform a modified version of the Opportunistic Network Environment (ONE) simulator [17] is used. It has been modified accordingly, in order to include also communication with infrastructure and to integrate our developed JADE prototype so as to run capacity extension scenarios. The ONE simulator has been chosen for the experiments due to its inherent capabilities in measuring performance of traditional ONs. It is customizable in terms of traffic generation, mobility of terminals, number of nodes and number of interfaces per node. It is also possible to simulate BS or femtocell entities. Furthermore, the prototyping platform due to the utilization of the JADE middleware which provides distributed functionality can be executed in a distributed way, e.g. the BS CSCI/CMON agents can run on different machines and exchange messages according to the C4MS structure, as it was defined in [7]. In general, JADE components exchange messages which are serialized and transmitted over TCP, according to the FIPA Agent Communication Language (ACL) message structure specification [18].

In the aforementioned platform, both use cases of scenario 2 [3] are implemented, i.e. capacity extension through neighbouring terminals and capacity extension through femtocells, in order to be able to make experiments as part of the proof-of-concept. The implementation comprises the suitability determination phase, the ON creation phase and the termination phase.

The functionalities of the capacity extension through neighbouring terminals algorithm are mapped to the CSCI and CMON as follows:

- The context awareness functional block of the CSCI is responsible for acquiring the status of infrastructure elements and the status of terminals;
- The decision making mechanism of the CSCI is responsible for the identification of terminals that are located in a congested area and need access to alternate infrastructure elements through neighbouring terminals;
- The decision making mechanism of the CMON is responsible for the formation of ON paths for each terminal in the congested area that needs to be redirected to alternate BSs and allocates the terminals to alternate BSs;
- The control functional entity of the CMON is responsible for the solution enforcement.

The aforementioned functionalities are depicted in Figure 5.

Furthermore, the functionalities of the selection of nodes algorithms are mapped to the CSCI and CMON as follows:

- The context awareness functional block of the CSCI is responsible for acquiring the status of terminals;
- The decision making mechanism of the CSCI is responsible for the identification of suitable terminals that will potentially participate in the to-be-created ON;
- The decision making mechanism of the CMON is responsible for the selection of terminals that will participate in the ON through the evaluation of terminals' fitness value;
- The control functional entity of the CMON is responsible for the solution enforcement i.e., the selected terminals according to their fitness values will be part of the created ON.

The aforementioned functionalities are depicted in Figure 6.

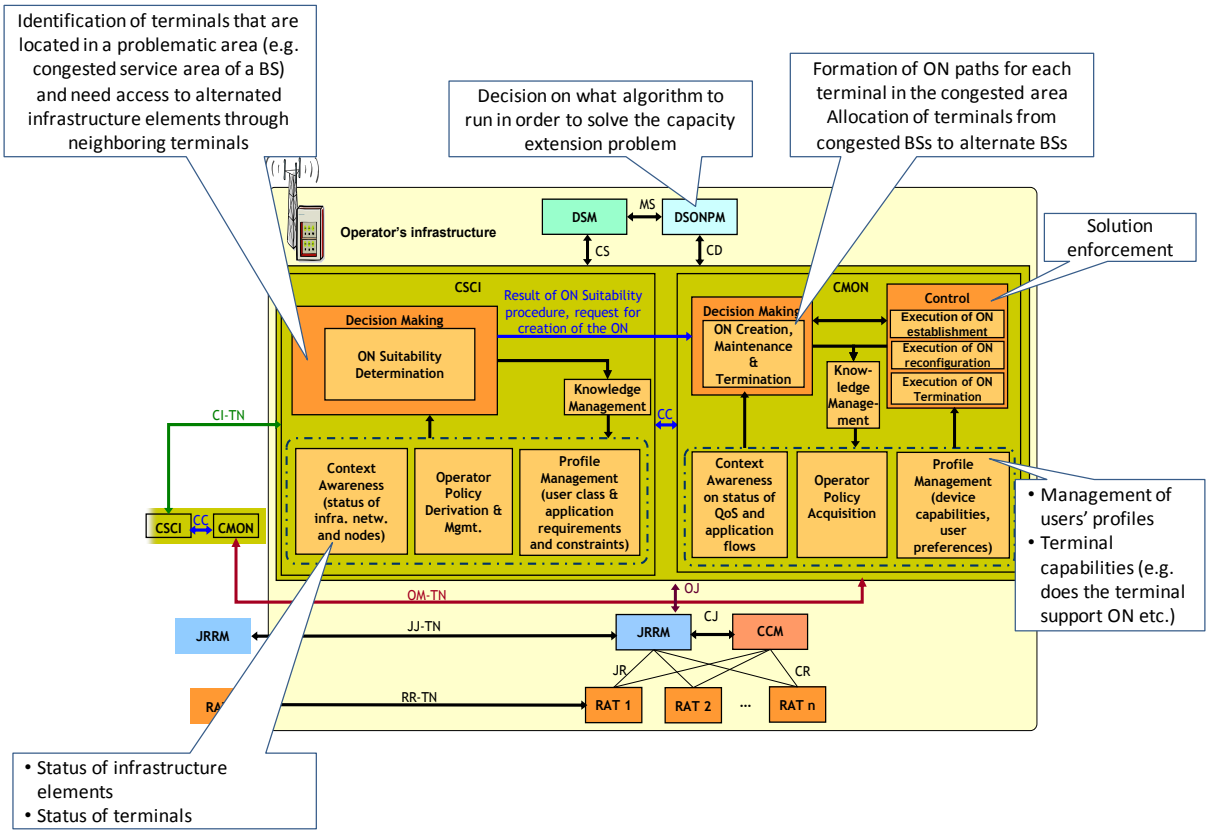


Figure 5 : Mapping of the capacity extension through neighbouring terminals concept to the OneFIT functional architecture

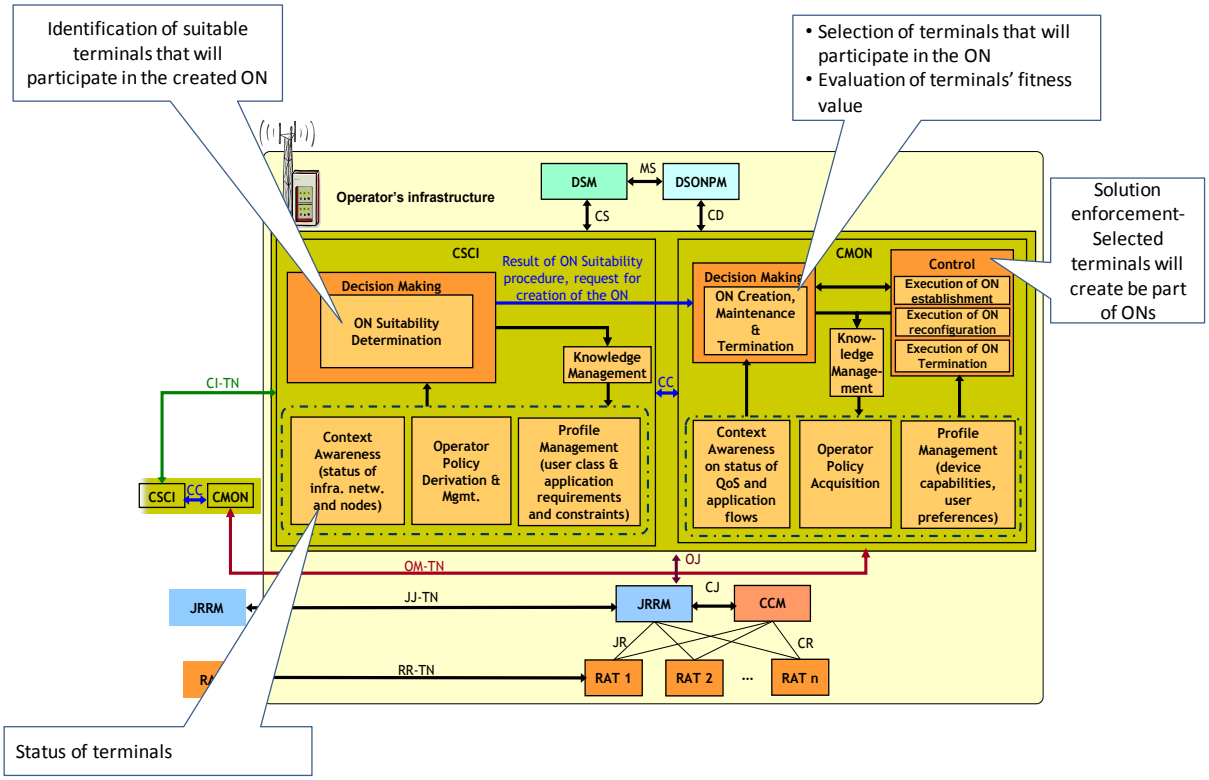


Figure 6 : Mapping of the selection of nodes through a fitness value evaluation concept to the OneFIT functional architecture

Finally, in order to perform capacity extension through femtocells, the algorithm operation is based on the following functional entities:

- The Context Awareness (CA) entity of the CSCI, which is responsible for monitoring the status of the infrastructure network. In addition, it involves information about node capabilities (e.g. their status, location, mobility level, etc.);
- The Decision Making (DM) entity of the CSCI, which identifies the terminals that are suitable to be redirected to the femtocells, e.g. terminals with low mobility level. For that purpose the DM entity interacts with the CA entity.
- The Profile Management (PM) entity of the CMON, which includes terminals capabilities (e.g. possible operating RATs) and user preferences which are required for the decision making;
- The Operator Policy Acquisition (OPA) entity of the CMON which obtains and manages the policies which are being defined by the operator;
- The Decision Making entity of the CMON, which is responsible for assigning the appropriate resources to the femtocells and QoS to terminals. Therefore, the DRA algorithm is executed in this functional entity. The DM entity of the CMON interacts with the PM and OPA entities in order to acquire information required to compute the solution.

The aforementioned functional entities have a direct mapping to the entities of the OneFIT architecture as illustrated at Figure 7.

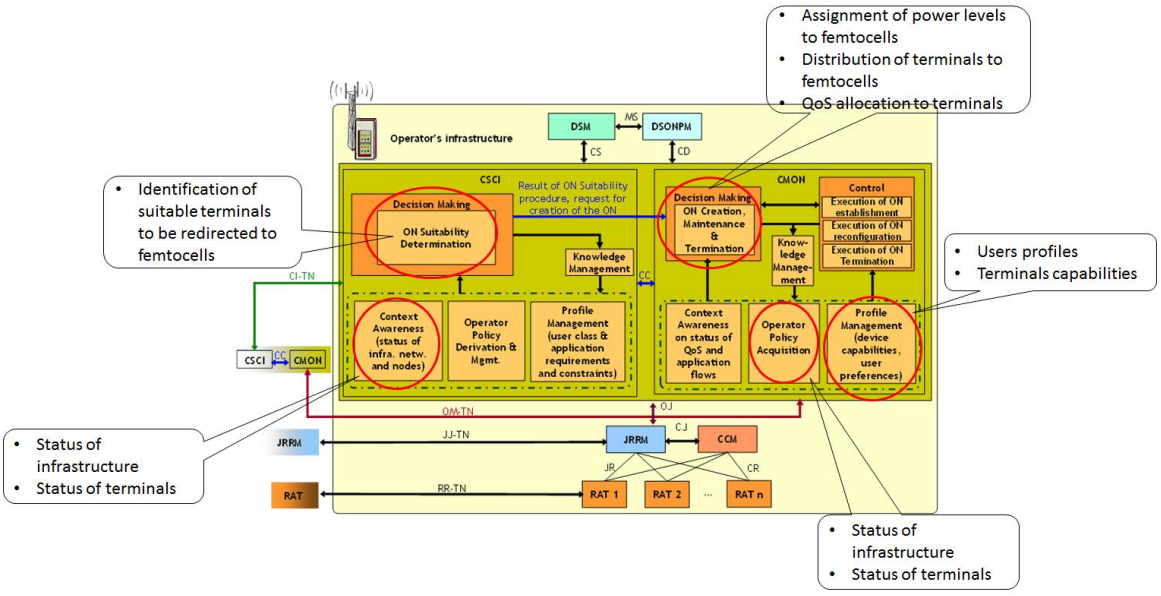


Figure 7 : Mapping of the DRA concept functional entities to the OneFIT functional architecture

2.1.1 Addressed system requirements

The following system requirements are addressed within this test-bed: G1, G2, G4, G6, G7, G11, U1, M1-M7, M10, A1, A2 and A4.

Regarding the general system requirements, the requirements G1, G2, G4, G6, G7 and G11 are addressed in the prototyping platform for the management of opportunistic networks as follows:

- G1- communication with the infrastructure: Communication with the infrastructure is achieved through the exchange of messages between the functional entities of CSCI and

CMON. This is possible through the use of JADE which supports the use of agents which are able to communicate between each other in order to provide the necessary communication with the infrastructure.

- G2- communication between terminals: The same communication mechanisms with G1 are also applicable to this requirement as well, in order to provide the necessary communication between terminals;
- G4- versatile RAT/RAN use: The platform is RAT-agnostic and specifications of various RATs could be simulated (such as coverage range, bandwidth etc.);
- G5- mobility: The platform is based on various mobility models as implemented in the Opportunistic Network Environment (ONE). Indicative mobility models are e.g. Random, Random Waypoint etc.
- G6 –relaying: As soon as the ONs are created intermediate nodes in a topology can act as relay nodes;
- G7- creation of ONs: The platform has the ability to connect terminals between each other, as long as they are in coverage range, in order to form ONs upon request from the operator (e.g. when congestion of an infrastructure element is observed);
- G11- resource efficiency: Through the platform there is the ability to measure the performance of various critical resources such as consumption of energy. It is possible to measure the energy consumption of the infrastructure elements and the various terminals in order to show the gains before and after the solution enforcement.

Regarding the user and service related requirements the U1 is addressed as follows:

- U1- hide complexity from the user: All the operations that take place in the platform are not visible to the user, since messages and decisions for the creation of ONs are made automatically. The user will just connect and served through an ON, once the operator deems such an action necessary.

Regarding the ON management related requirements the M1-M7 and M10 are addressed as follows:

- M1- identification of the need for an ON: It is possible to initiate the ON suitability determination and creation procedures on a triggered-based basis. This means that the need for an ON can be designated by an operator as soon as congestion of an infrastructure element is sensed or some terminals are left without infrastructure coverage.
- M2- suitability determination: Mechanisms of simulating the suitability determination phase are implemented in order to define whether it is possible to create an ON under the current environmental conditions (e.g. are ON-capable terminals in coverage of the problematic ones which are willing to help?);
- M3- creation of ONs: Specific algorithms in the context of WP4 have been implemented to the platform in order to proceed to an effective creation of ONs and provide e.g. coverage or capacity extension;
- M4- connection set up: The connection set-up mechanisms of the ONE are used in order to connect or disconnect terminals upon request by the operator;
- M6 - release of ONs: ONs would be released if the operator designates so, or if the moving terminals move out of coverage between each other, so connection is dropped and the ON is released;

- M7- coordination of ONs with the infrastructure: This requirement is possible in conjunction with the G1 requirement as analyzed previously. To that respect, coordination of terminals (which are part of an ON) with the infrastructure is addressed.
- M10- coexistence of ONs: In the platform there is the possibility to create numerous ONs with a variable size (e.g. comprising 2, 3 terminals etc.);

Regarding the algorithm related requirements the A1, A2 and A4 are addressed as follows:

- A1- context awareness: Context awareness is obtained through the monitoring of specific parameters such as current location, current mobility level/direction etc. These parameters are measured through the implemented ONE mechanisms.
- A2- decision making: Decisions are made according to the implemented algorithms (in the context of WP4) which will designate a solution for the creation of ONs;
- A4- ON advertisement: Through the platform, it is possible to show whether a terminal is connected directly to a BS or is served by an ON. To that respect, nearby terminals will know the connection status of another terminal.

2.2 Opportunistic networking demonstrator

The scope of the opportunistic networking demonstrator is to verify the OneFIT scenarios [3], architecture [4], the algorithms for the suitability determination, creation, maintenance and release of opportunistic networks [8] as well as the C4MS protocol [5][6].

This prototype consists of several devices, one or more access points and at least one PC hosting the cognitive radio system management functionality on infrastructure side as shown in Figure 8.

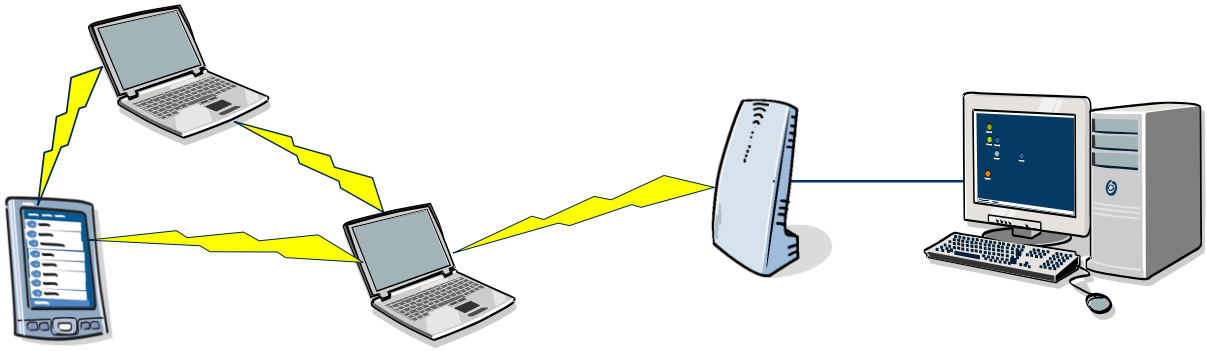


Figure 8: Opportunistic Networking Demonstrator Overview

The most relevant features of this prototype are:

- Use of real terminals;
- Decisions based on real signal measurements. These measurements are mainly managed by the JRRM as described in section 4.1.
- Need for ON occurs due to mobility of users. In the case of the coverage extension scenario, a user moves out of the coverage of the infrastructure.
- Suitability determination: Automatic detection of situations where an ON is needed based on the measurements, e.g. degradation of the radio link and handover to another cell is not possible;
- ON Creation: Decision to create the ON based on suitability determination;

- Spectrum Selection: DSM decides on which spectrum to use for the relay (as well as for the access points). The implementation of the DSM is described in more detail in section 4.2 where the GUI of the DSM is shown in Figure 54.
- Reconfiguration: CSCI/CMON triggered switching on and off of the second radio interface of the relaying device, activation/de-activation of the relaying function;
- Mobility procedures: Handover to relay;
- Routing: Update of routing tables after handover;
- IEEE 802.21 MIH based C4MS implementation.

A more detailed view on the functional building blocks inside the different nodes is given in Figure 9.

On infrastructure side, a "Cognitive Radio System Management" (CRSM) hosts the Dynamic Spectrum Management (DSM), a Cognitive Management system for the Opportunistic Networks (CMON) combined with the Cognitive Management System for the Coordination of the Infrastructure (CSCI) and a Joint Radio Resource Management (JRRM).

Each device (standard terminal or terminal with relaying capabilities) in the prototype contains also a combined CSCI/CMON and a JRRM. Further on, each device has a Configuration Control Module (CCM) which manages reconfigurations like the creation of a relaying access point or deletion of that relaying access point.

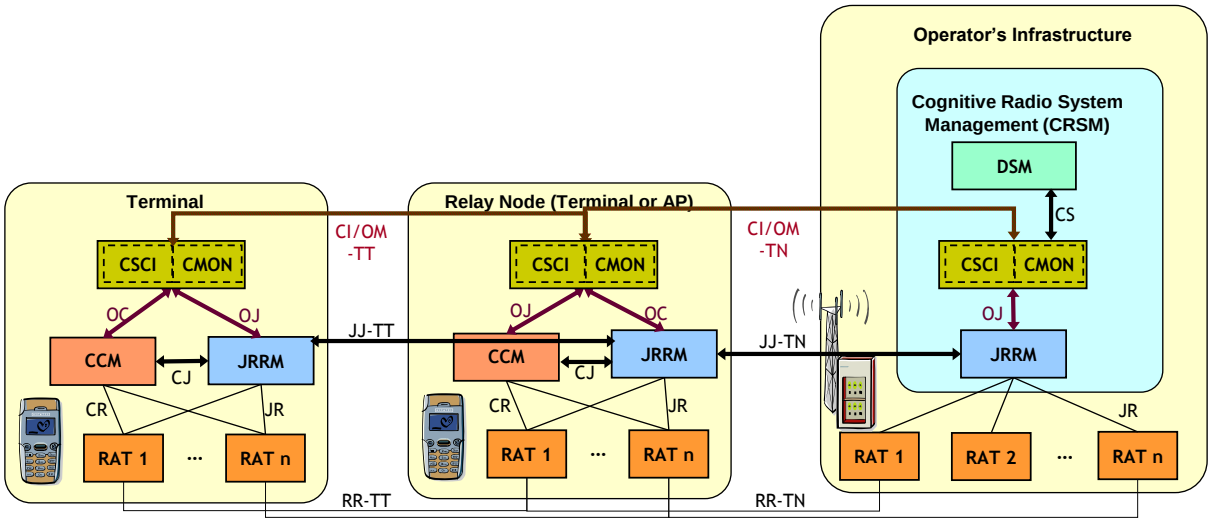


Figure 9: Mapping of the Opportunistic Networking Demonstrator to the OneFIT Architecture [4]

The JRRM on terminal sides sends link events (e.g. link going down, link up) or periodic link measurements to the JRRM on infrastructure side. The JRRM on infrastructure side has an overview on all cells as well as on the terminals attached to each cell. In certain situations, e.g. when a terminal is going out of coverage of a cell and a handover to another cell is not possible, then the JRRM triggers the CSCI/CMON to perform a suitability determination if an ON should be created or not. In the case that a relaying access point shall be created, the CSCI/CMON asks the DSM on which frequency to use for the access point. Then, the CSCI/CMON can send negotiate with the terminal identified as candidate for providing the relaying function and instruct that terminal to create an ON ("ON_Creation.request"). This procedure is shown in the message sequence chart in Figure 69 in section 6.1.

After the creation of the relay, the infrastructure sends an ON_Suitability.indication to the device going out of coverage to indicate that a handover to the opportunistically created access point is

recommended. After performing a handover, the device going out of coverage is then connected via a relaying terminal to the infrastructure and the going out-of-coverage problem is solved by the coverage extension provided by the relay.

2.2.1 Addressed system requirements

The following system requirements, as presented in Table 1, are addressed within this test-bed: G1-G11, U1-U2, M1-M9, M11, A1-A3, P1, P3, P5 and S2.

The prototype used an 802.21 based C4MS (P1, P3, P5 and S2) implementation for the communication between the different nodes in the infrastructure and the devices (G1 and G2) and uses different radio access technologies (G4) like WLAN and Bluetooth. The DSM decides on which spectrum to use (G5) for the relay (G6) when creating the opportunistic network (G6 and G7). Handovers (G5) are executed to connect directly to the infrastructure (G9, G10 and G11) and with the ON. The opportunistic network management (M1-M9, M11 and A1-A3) has been implemented in a distributed way where parts of the functions are located on infrastructure side and others are located inside the devices.

2.3 Opportunistic service provision demonstrator

This demonstrator evaluates the feasibility of building novel end-user services that take advantage of the underlying Opportunistic Network capabilities of both infrastructure and user terminals. The ability to offer such opportunistically-supported services presents a great potential for MNOs to develop new business models to capitalize the investment in the deployment of ON mechanisms.

Therefore, this demonstration does not aim to evaluate the performance of ON procedures and algorithms. Instead, it is assumed that OneFIT mechanisms work, so that an end-user application can be built upon them; after that, service-oriented aspects such as the reliability (the ON is seamlessly handled as the nodes exit and enter in it), the resilience (the service is alive during the lifetime of the ON) or the scalability (the service accepts a growing number of nodes) of the available tools will be assessed.

In particular, according to the use case to be demonstrated (see section 6.3.2 for a detailed description), a high-mobility scenario, where a significant number of nodes enter and exit the ON while it is alive, is depicted. A performance assessment on such scenario could not be performed on the OneFIT validation platform, so a specific test-bed that emulates the behaviour of the wireless network and the OneFIT mechanisms has been developed.

This test-bed is based on a vehicle traffic simulator that uses real cartography with an OneFIT abstraction layer deployed over it. The selected traffic simulator tool is SUMO (*Simulation of Urban Mobility* [13]), an open-source project able to simulate large traffic sets of vehicles and their behaviour over the time in a realistic way. The simulation is therefore split into two different layers: the traffic simulation layer that obtains the position of vehicles and their behaviour over the time and the network simulation layer that evaluates the performance of the ON established over them.

In the test-bed's ONs, mobile nodes are assumed to be the simulated vehicles, which move throughout city streets following certain traffic rules (that depend on the city features, the hour of the day, etc.) Fixed infrastructure nodes are located in defined positions and they mimic the features of real 3G base stations. According to the OneFIT architecture and procedures, an ON is created among one or more mobile nodes and one or more infrastructure nodes. For each ON, the infrastructure selects one of the vehicles as a 'network controller', according to a specified criterion (such as the one with more available resources, the best SINR or any other). This node will act as a gateway between the rest of the mobile nodes in the ON and the infrastructure node. Thus, the

controller will collect all the logs from the surrounding vehicles and send them to the monitoring server. Figure 10 depicts this communication structure.

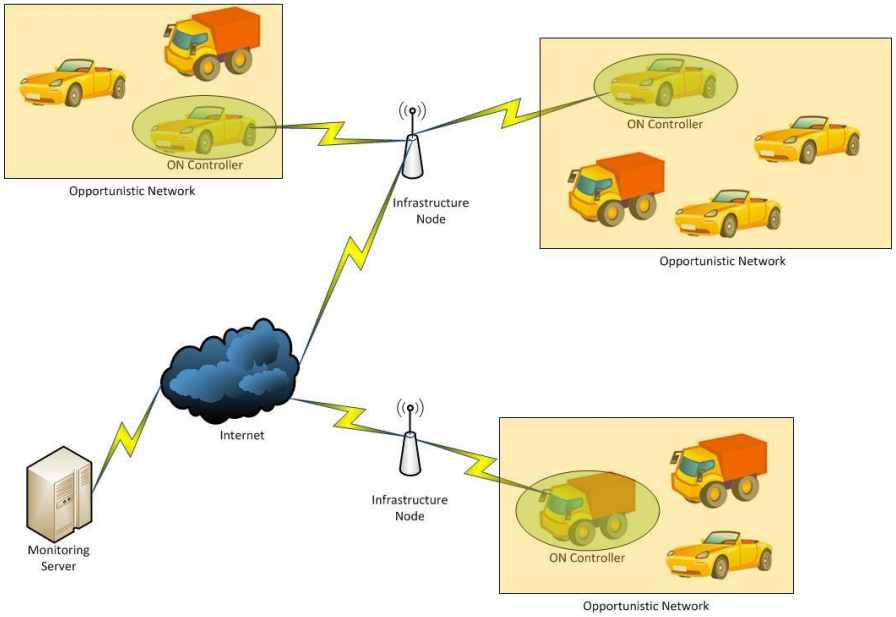


Figure 10: Simulated scenario

The network emulation block is the part of the test-bed that mimics the behaviour of the wireless network and the OneFIT mechanisms. In particular, an abstraction layer that simulates the behaviour of the OneFIT-based vehicle-to-vehicle communications has been developed. It consists of a simplified model of the OneFIT procedures that hides the underlying complexity (C4MS protocol stack and specific algorithms). This abstraction layer thus implements the ON management phases in a simplified way: candidate nodes are selected during Suitability Phase; connections will be established during the Creation Phase using a very basic routing scheme; during the Maintenance Phase, nodes entering and exiting the ON will be controlled; and Termination Phase will consist of dissolving the connections.

The implementation of this abstraction layer needs two kinds of nodes to be defined:

- *OneFitNodes* are generic ON-capable nodes. They implement a set of functions called OneFitNodeRules.
- *OneFitcontrollers* are nodes with the additional functionalities to act as gateway for the rest of nodes in the ON.

Additionally, an entity called *OneFitNet* has been defined to represent the ON created among several *OneFitNodes* and *OneFitcontrollers*. These entities implement a similar set of functions called *OneFitNetRules* to account for the OneFIT mechanisms. Figure 11 shows the relationship between these elements.

There is also a *Network Control Layer* that implements the rules and policies. These rules define the *OneFITNodes* and establish logical links between them. The resulting network structures compose the ONs according to radio conditions. Those logical links will be continuously updated as some *OneFitNodes* leave the ON and new ones join.

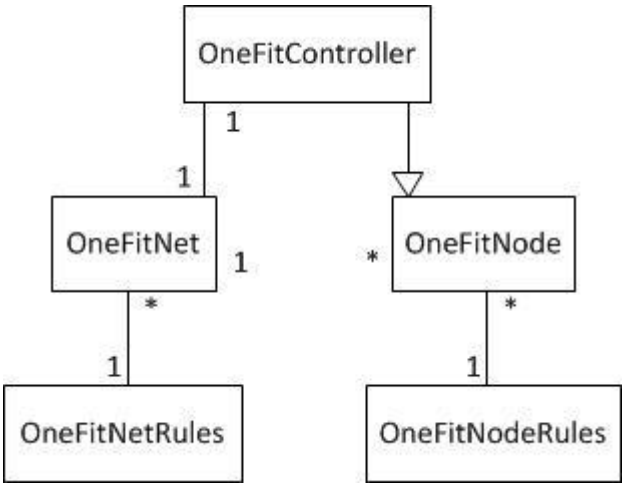


Figure 11: Relationship between simulator entities

Finally, Figure 12 depicts the components of the control system architecture and the data flows among them. The control system is composed by four modules:

- *SUMO-IFACE* is responsible for the translation of the system information to Java format, sending and receiving data to/from SUMO;
- *SIM-ENGINE* controls the rest of modules, monitors system status and invokes the correct functions;
- *CAR-CONTROLLER* monitors the state of all simulated nodes;
- *GUI-ENGINE* is responsible of collecting data and managing user interaction.

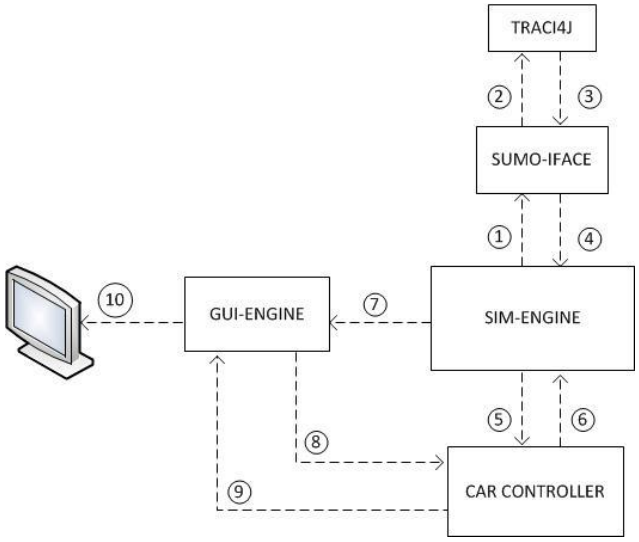


Figure 12: System control structure and data-flow

During the simulation, the data flows between entities proceed in the following way: *SIM-ENGINE* orders *SUMO-IFACE* to request a new iteration (1). *SUMO-IFACE* performs the request (2), receives the answer (3), translates it and redirects it to *SIM-ENGINE* (4). *SIM-ENGINE* notifies the changes to *CAR-CONTROLLER* (5), who updates its data structures and returns the control *SIM-ENGINE* (6). *SIM-ENGINE* orders *GUI-ENGINE* to refresh (7), so *GUI-ENGINE* has to request vehicle information to *CAR-CONTROLLER* (8), *CAR-CONTROLLER* returns the information (9) and finally *GUI-ENGINE* draws in the screen the status of the new iteration (10).

The test-bed includes also a Graphical User Interface (GUI) that manages the process of scenario setup (based on real cartography layouts). It also allows selecting different vehicle densities according to daytime, season of the year or even hazardous situations that may modify traffic flow. The wireless capabilities of simulated vehicles (WiFi, Bluetooth and UMTS) can also be configured. Once the simulation is configured, the GUI launches the SUMO simulator and collects vehicle data. For each simulated vehicle, the application gathers position coordinates current speed and additional data such as fuel consumption, noise generation or polluting gasses emissions (CO, CO2, NOx…). This information can be displayed and is also processed to obtain the KPIs that may trigger the creation of an ON. Figure 13 depicts a view of the graphic interface, where real cartography is used and simulated vehicles (white and grey dots) move through the city cartography according to the established rules. This image illustrates the complexity of the application, where dozens of mobile nodes will be monitored as they become part of one or more ONs.

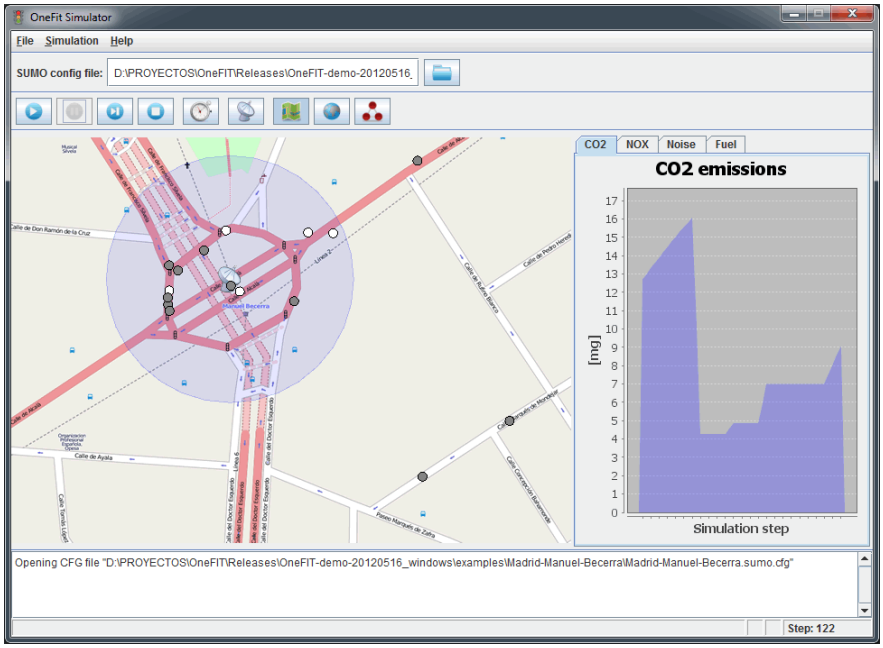


Figure 13: GUI screenshot (1)

Figure 14 shows a different display of the GUI that shows the network topology when an ON has been created among an infrastructure node (Central Square) and five vehicles (circles). Wireless links have been created between pairs of vehicles (white thin lines), but only the controller node (bottom circle) is linked to the infrastructure (green line). The statistical data showed on the left side are retrieved from the highlighted node (the circle under the pointer).

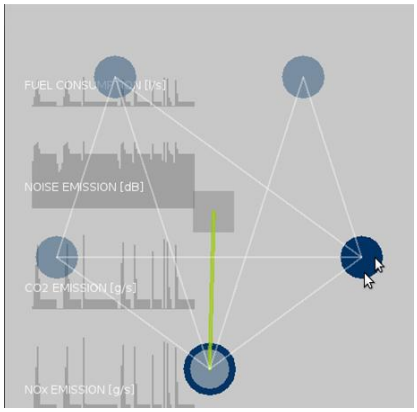


Figure 14: GUI screenshot (2)

2.3.1 Addressed system requirements

The following system requirements are addressed within this test-bed: G1, G2, G4-G7, G9-G10, U1-U3, M1-M7, M10 and A1-A2.

Regarding the general system requirements, the following requirements are addressed:

- G1 – Communication with infrastructure: Some of the terminals are UMTS-enabled, so they are able to communicate with the infrastructure nodes via UMTS RAN;
- G2 – Communication between terminals: Terminals communicate to each other via ad-hoc short-range RATs, such as WiFi and Bluetooth;
- G4 – Versatile RAT/RAN: ONs include terminals capable of using different RATs to communicate (namely, UMTS, WiFi and Bluetooth);
- G5 - Mobility: Terminals are constantly moving around the scenario, following some simple mobility rules defined in the SUMO simulator;
- G6 – Relaying: Report and context data from non-UMTS terminals are relayed towards infrastructure via UMTS-enabled terminals;
- G7 - Creation of opportunistic networks: Infrastructure negotiates with terminals the creation of ONs;
- G9 – Preservation of legacy RAN operation: Infrastructure network behaviour remains unaffected by the presence of ONs;
- G10 – Compatibility with legacy RAN deployments: ON operation does not interfere with current infrastructure RAN deployment.

Regarding the user and service related requirements the following requirements are addressed:

- U1 – Hide complexity from the end user: There is no intervention of final service users in the creation of ONs;
- U2 – User's service perception: The existence of ONs causes no effect on the service perception by end users;
- U3 - Availability of ON-related information to the service layer: The service under test receives information about the existence of ONs and the nodes that are part of them.

Regarding the ON management related requirements the following requirements are addressed:

- M1 - Identification of the need for an opportunistic network: The service under study has a triggering mechanism (based on pollution measures) to detect the need of an ON. When this need is detected, the service asks the infrastructure nodes for the creation of the ON.
- M2 - Suitability determination: Infrastructure selects the most suitable terminal nodes to be part of the ONs, based on context data previously gathered;
- M3 - Creation of opportunistic networks: Infrastructure negotiates with terminals the creation of ONs;
- M4 - Connection set-up: UMTS-enabled terminals are able to establish a connection with the infrastructure nodes;
- M5 - Maintenance of opportunistic networks: Infrastructure is constantly aware of the status of the ONs, allowing the entrance and the exit of terminal nodes as they move, and reconfiguring the relaying routes from non-UMTS terminals to UMTS-enabled terminals;

- M6 - Release of opportunistic networks: The service under study has a triggering mechanism (based on pollution measures) to detect when ONs are no longer needed. When this is detected, the service asks the infrastructure nodes for the termination of the ON.
- M7 - Coordination of opportunistic networks with the infrastructure: The service under study runs on both ON and infrastructure nodes;
- M10 - Coexistence of opportunistic networks: Several ON can be present simultaneously in the scenario, as several instances of the service under study can run independently.

Regarding the algorithm related requirements the following requirements are addressed:

- A1 - Context awareness: The infrastructure nodes are able to retrieve information about terminals (capabilities, status and propagation) that are used to create, reconfigure and terminate ONs;
- A2 - Decision making: The infrastructure is able to make the decision of creating, reconfiguring and terminating an ON based on context data.

2.4 Opportunistic ad-hoc network routing demonstration

The prototyping platform for the realisation of the opportunistic ad-hoc network routing demonstrator is composed of 4 laptops, using Linux as operating system, and communicating between themselves through the WiFi protocol (802.11). The scope is to verify the route pattern selection algorithm as well as the multi-flow route co-determination algorithm. The platform uses a standard WiFi Device driver, which has been modified in order to emulate a multi-hop topology: filtering of the received MAC PDUs has been added in the Wi-Fi Interface adaptation module. On every node a configuration file, containing the list of available neighbours (from WiFi driver point of view) is created.

The environment is configured to get a multi-hop topology and a multi-route possibility to transmit the data.

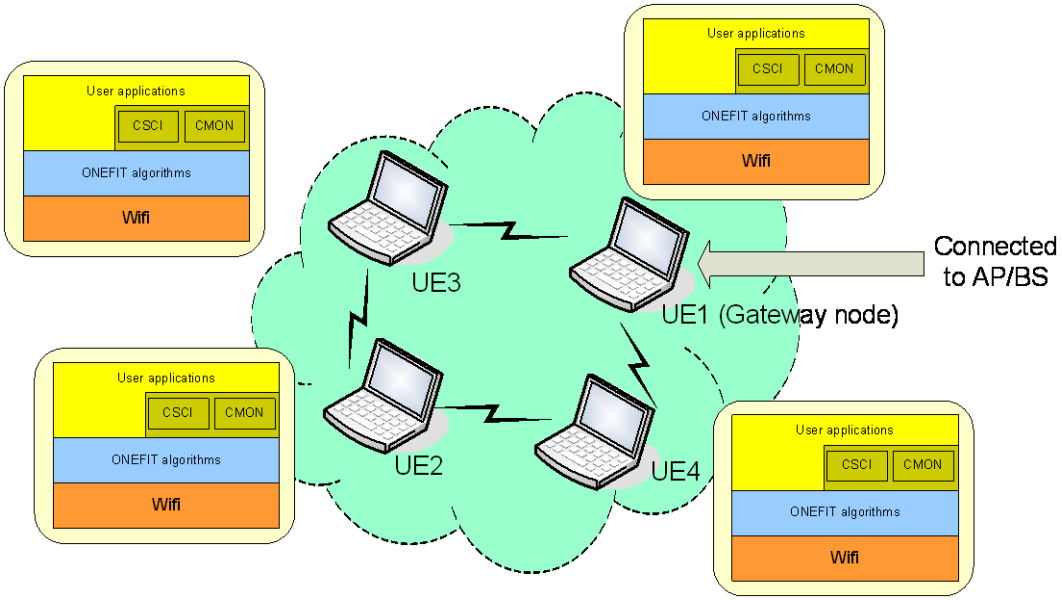


Figure 15: Opportunistic ad-hoc network routing platform

The demonstration is related to the network coverage extension; it is not intended to connect neither an access point nor a base station to simulate the infrastructure. In the ad hoc cloud, the node connected to the infrastructure gets a particular behaviour and acts as a gateway.

The purpose of demonstration is to apply OneFIT routing algorithms by generating different traffic flows between the nodes UE1 and UE2 (Figure 15).

This environment allows using most of existing user applications (for example data streaming (VLC player application), voice over IP (SIP), file downloading (FTP), etc). The implemented software is developed using the concepts of virtual NIC (Network Interface Controller) to allow any standard user's application to be executed.

Figure 16 depicts the detailed architecture implementation of the demonstration.

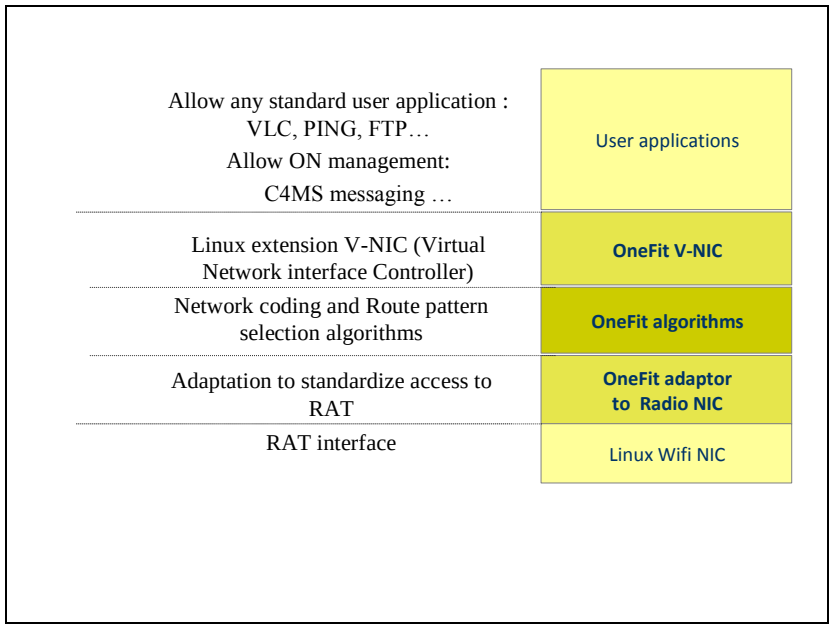


Figure 16: Test-bed software architecture

The "OneFIT V-NIC" module contains one of two OneFIT routing algorithms: Either the route pattern selection algorithm or the multi-flow route co-determination algorithm. Both algorithms are triggered for any IP packet handling. The algorithm controls the transmission of the packet over the air through the Wi-Fi protocol (IEEE 802.11) configured in ad-hoc mode.

2.4.1 Addressed system requirements

The requirements met by the Thales demonstrator are Communication between terminals (G2), Relaying (G6), Resource efficiency (G11), Maintenance of the ad-hoc part of the opportunistic network (M5), Context awareness (A1), Decision making (A2) and Routing (A3).

2.5 Prototyping platform for opportunistic coverage extension and related support functions

The *Prototyping Platform for Opportunistic Coverage Extension and related Support Functions* is addressing the following key features:

- Opportunistic Network Support, i.e. Coverage Extension is achieved by selected Mobile Devices acting as Relay Nodes;
- Best Connection, i.e. in a Coverage Extension context, the most suitable link among a set of available heterogeneous link technologies (WLAN, 3G, etc.) is identified and selected;
- Multi-Homing Support, i.e. a stream is split over two links of distinct Radio Access Technology.

While the first item of the upper list corresponds to the actual implementation of the "Opportunistic Coverage Extension" scenario, items #2 and #3 correspond to support functions which are required for an efficient implementation of the Opportunistic Networking features in a heterogeneous radio environment. The overall prototyping platform architecture is indicated below:

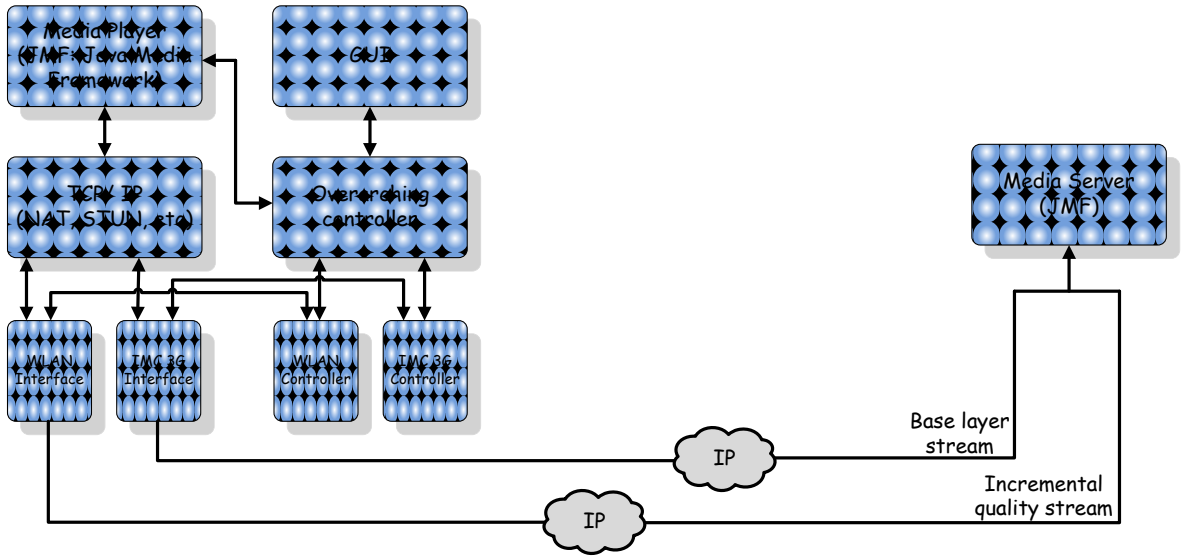


Figure 17: Overall architecture of Prototyping Platform for Opportunistic Coverage Extension and related Support Functions

The employed instantiation with available equipment is further detailed below:

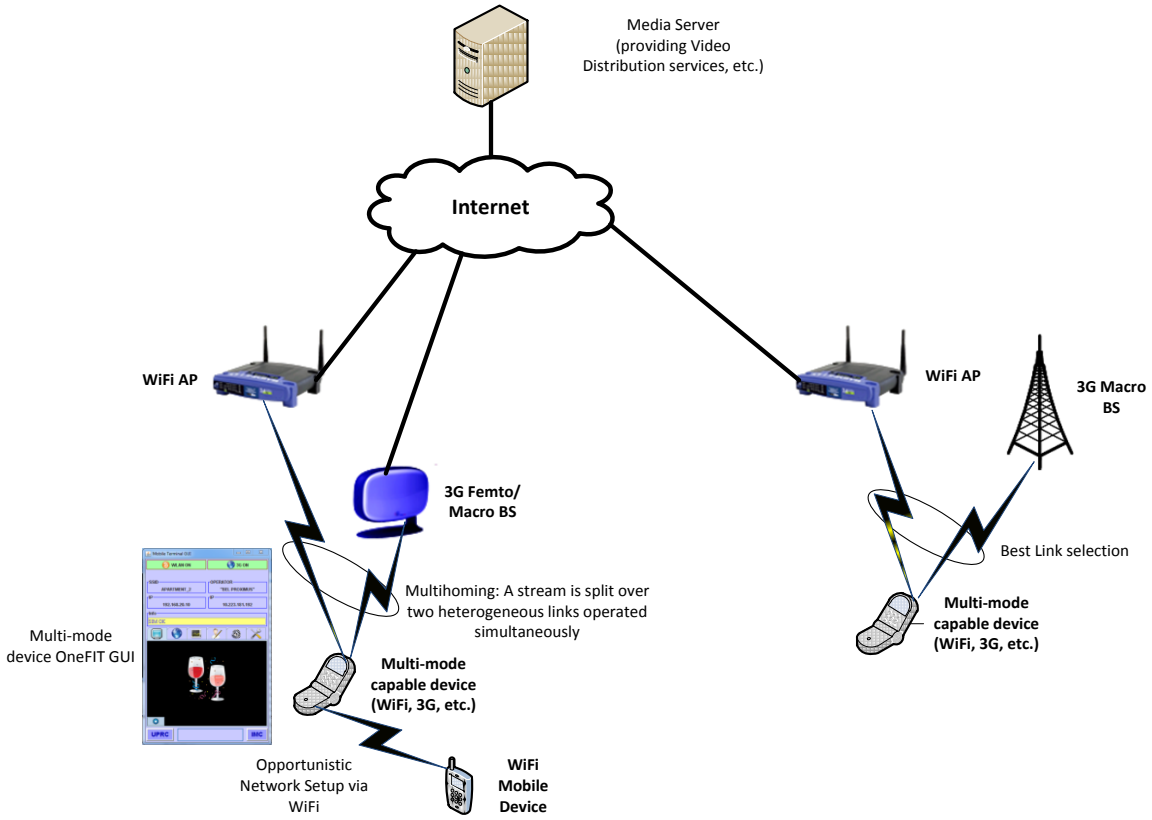


Figure 18: Instantiation of overall architecture of Prototyping Platform for Opportunistic Coverage Extension and related Support Functions

As it will be further detailed in section 6.1, the Prototyping Platform for Opportunistic Coverage Extension and related Support Functions is built such that it can be suitably reconfigured to the following configurations:

- Provision of wireless services in a dense neighbourhood environment building on non interfering Radio Access Technology;
- Provision of wireless services in a dense neighbourhood environment employing an Opportunistic Network for ensuring access for a WiFi-only Terminal Device;
- Provision of wireless services in a dense neighbourhood environment employing automized network reconfiguration and an Opportunistic Network for ensuring access for a WiFi-only Terminal Device;
- Provision of wireless services in a dense neighbourhood environment employing Multi-Homing.

For this test-bed, a Graphical User Interface (GUI) has been developed with the following key features:

i. Illustration of the multitude of wireless links being maintained simultaneously:

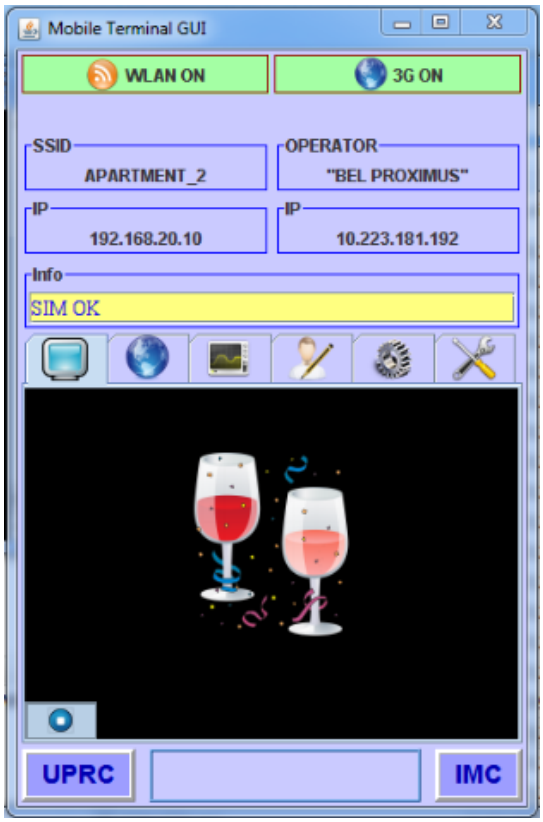


Figure 19: GUI indicating active wireless links and related key parameters

ii. Illustration of test-bed configuration to be operated:

Figure 20: GUI indicating test-bed configuration to be operated

iii. Illustration of Operator policies to be imposed onto Mobile Device centric link selection:

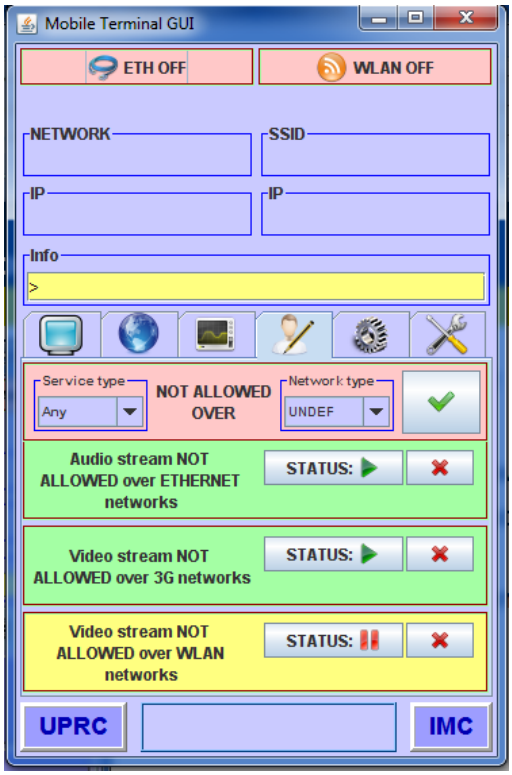


Figure 21: GUI indicating operator policies to be met by mobile device decision making entities

iv. Illustration of GUI showing live video-streaming:

Figure 22: GUI showing live video streaming

2.5.1 Addressed system requirements

The following system requirements are addressed within this test-bed: G1, G4, G6, G7, G9-G11, U1, M1-M7 and A1-A3.

From the group of general system requirements, the requirements G1, G4, G6, G7 and G9-G11 are addressed as follows in the prototyping platform for opportunistic coverage extension and related support functions:

- G1 - Communication with the infrastructure: The platform provides access to cellular Macro/Femto Base Stations, WiFi Access Points, etc;
- G4 - Versatile RAT/RAN use: The choice of Radio Access Technologies is updated depending on the interference/congestion context (e.g., avoid congested Radio Access Technologies). Also, Radio Access Technologies are operated simultaneously;
- G6 – Relaying and G7 - Creation of opportunistic networks: are implemented in the sense that a mobile relay node is initiated for providing access to other devices, which may be out of coverage of the concerned Macro/Femto Base Station, which may not support/prefer 3G at the given point in time, etc;
- G9 - Preservation of legacy RAN operation and G10 - Compatibility with legacy RAN deployments: the whole test-bed builds on the usage of legacy RAN; all new features are transparent to the RAN and therefore full compatibility with legacy RANs is achieved;
- G11 - Resource efficiency: is mainly addressed in the context of best link selection, i.e. resource efficiency is maximized by selecting the most suitable Radio Access Technology.

From the group of user and service related requirements, the requirement U1 is addressed as follows in the prototyping platform for opportunistic coverage extension and related support functions:

- U1 - Hide complexity from the end user: The platform performs RAT selection without any User Interaction.

From the group of opportunistic network management related requirements, the requirements M1-7 are addressed as follows in the prototyping platform for opportunistic coverage extension and related support functions:

- M1-7 (Identification of the need for an opportunistic network, Suitability determination, Creation of opportunistic networks, Connection set-up, Maintenance of opportunistic networks, Release of opportunistic networks, Coordination of opportunistic networks with the infrastructure): The platform performs the management of opportunistic networks going through the main phases (suitability determination, creation, maintenance, termination). Connection set-up is managed on a per-need basis, e.g. an opportunistic network may only be exploited if other links are unsuitable due to congestion events.

From the group of algorithm related requirements, the requirements A1-3 are addressed as follows in the prototyping platform for opportunistic coverage extension and related support functions:

- A1 - Context awareness and A2 Decision making: The platform observes for example congestion events, the availability of multiple heterogeneous RATs to be used simultaneously, etc. and takes corresponding context information for decision making on RAT selection into account;
- A3 - Routing: The platform decides on traffic routing in case that several heterogeneous Radio Access Technologies are operated simultaneously.

2.6 Direct D2D communication test-bed

The objective of the prototype platform is to demonstrate the realization of suitability determination, creation, maintenance and termination of Opportunistic Networks between 2 devices located in proximity by establishing direct device 2 device communications. The prototype is addressing scenario 3 but can be enhanced in future steps to support other scenario (e.g. scenario 2 for coverage extension).

The prototype implements the following CMON functionalities as described in D2.2 [4]:

- Control mutual discovery of nodes (devices);
- obtains context and policy information from the CSCI (QoS requirements);
- Commands for managing the ON operational phases (e.g., ON establishment, maintenance/ reconfiguration and termination procedures);
- Obtain local context information: measurements from devices, geo-location coordinates from device built-in positioning functions;
- Control terminal reconfiguration capabilities (radio link and network layer);
- Control over the establishment/modification/release of bearer services in the infrastructure network to support ON traffic;
- Establish security on ON links.

This demonstrator consists of several devices, which have the capabilities to support several Radio Access Technologies (RAT), and are, on their initial connection, connected to the infrastructure via 3GPP UTRAN radio access.

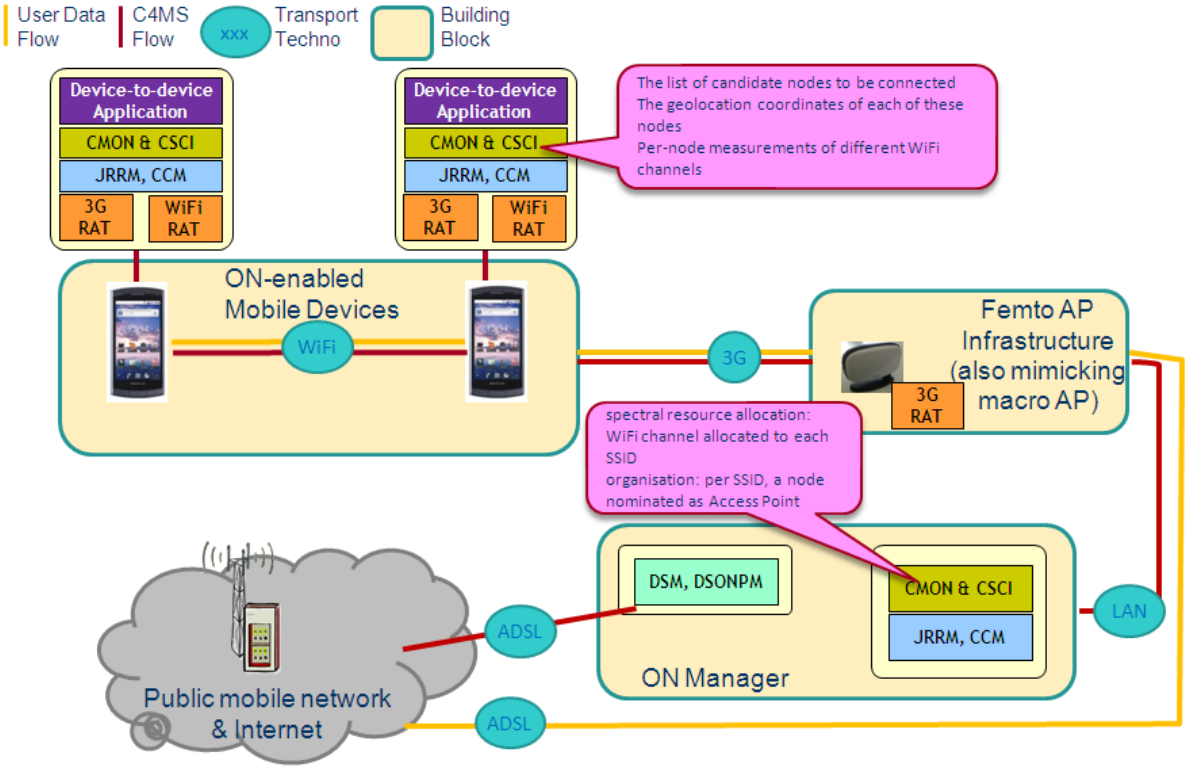


Figure 23: Overall architecture of Prototyping Platform for Direct D2D communication

The prototype implements a basic version of C4MS, using a Multi Agent System (MAS) based on Java and JADE [16]. All communications between the nodes in the prototype are transmitted using TCP/IP protocol. Message structures have not been following C4MS protocol described in current project in order to limit complexity of the development, but could be adapted in future version.

Each UE in the prototype is a Smartphone running Android operating system. The UE and Android middleware have been enhanced to:

- Enable/disable WIFI radio access technology remotely;
- Have the capability to provide RRM WIFI information through C4MS like protocol to remote entity (eg ON manager);
- To provide location GPS based information;
- Offer the capability to be configured as an AP remotely by ON manager using provided information like:
    - SSID;
    - Channel selection;
    - Security algorithm selection;
    - Security key configuration;
- To detect an AP when remotely requested by ON manager;
- To establish secure communication with selected AP using information provided by ON Mgr.

The network infrastructure of the prototype consists of:

- Femtocell providing UTRAN 3GPP access;

- ON mgr consisting of a server on which ON algorithm is executed;
- Asterisk server to provider CS domain service;
- Apache server providing HTTP service in the network, including web browsing service and HTPP video streaming function;
- DHCP server providing IP address to the different network entities (e.g. femtocell);
- PC running Wireshark to perform maintenance and monitor IP traffic between the different nodes of the network infrastructure.

The algorithm running on the ON mgr server allows based on information requested/reported to/by the devices attached within the UTRAN network to determine the opportunity of direct Device to Device communication.

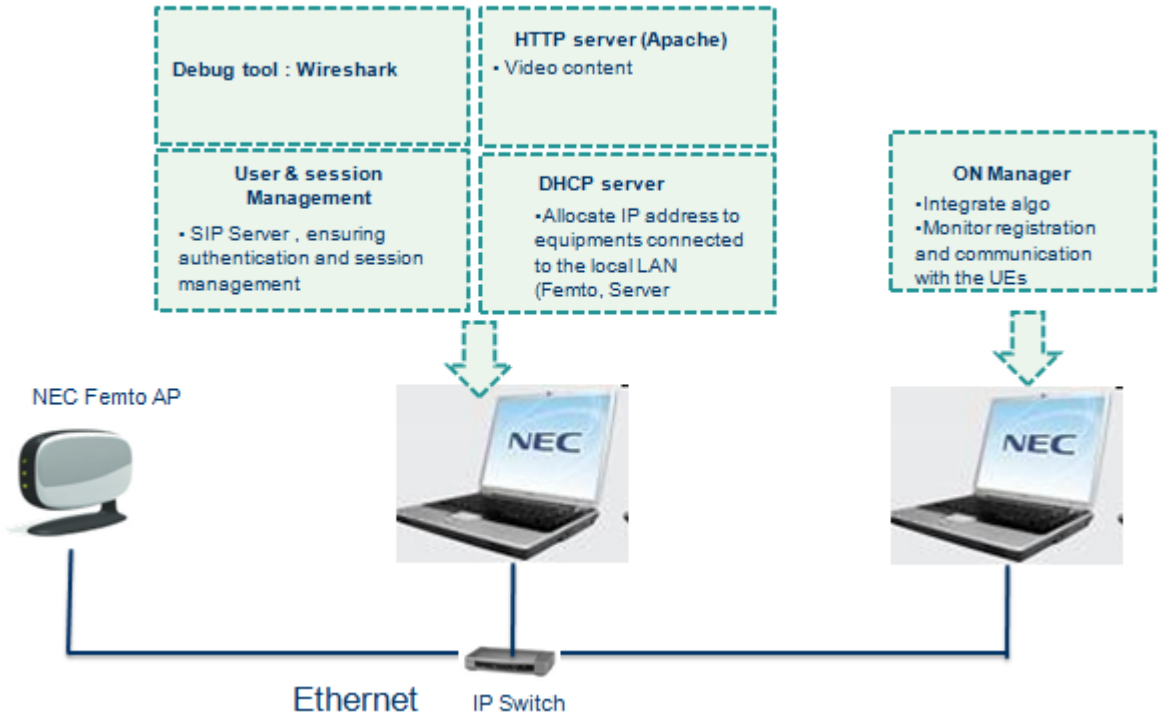


Figure 24: Infrastructure use in the demonstrator

When UE registers in the 3GPP network via UTRAN, they also provide registration information to the ON manager who configures UEs in order to gather adequate information to determine D2D communication opportunity.

In case UE2 is a video streaming server and UE1 wants to play a video available on UE2 (Requesting accessing the video from a server) then ON manager is responsible to determine if UE1, UE2 are close to each other and if the radio condition are met to establish D2D communication. To perform this task, ON Manager checks for the suitability of creating a LAN (i.e. geographical position, 3GPP radio cell and radio measurements). If ON Mgr determines that the initial condition are favourable then ON mgr initiates Wi-Fi discovery algorithm, controlling each UE's procedure and retrieves the discovery results from the UE1, UE2. ON Mgr selects the UE which will act as WiFi-Access Point (Group Owner) in the WLAN to be formed and selects the optimal configuration for the WLAN and informs it to the UE (Role assignment, identities (SSID) and Security information). Then UE1 and UE2

perform necessary WLAN procedure accordingly to establish trusted paths and allow UE2 to start streaming from UE1 content (exchanging user data over the WLAN).

2.6.1 Addressed system requirements

The following system requirements are addressed within this test-bed: G1-G3, G7, G9G10, U1, M1, M3, M4, M8, A1, A2, P1, P3 and S1.

From the group of general requirements the following ones are addressed:

- G1 – Communication with the infrastructure: The test-bed includes a femto Access Point that emulates the behaviour of the infrastructure in charge of controlling the ON. The C4MS messages are transferred between the terminals and the ON Manager (infra CSCI/CMON) through the femto AP.
- G2 – Communication between terminals: The test-bed includes a link between the two or more terminals using a 802.11 WLAN;
- G3 – Versatile spectrum use: The test-bed performs a dynamic spectrum assignment, after having identified the optimal 802.1 channel to be used;
- G7 – Creation of opportunistic networks: The test-bed allows the creation of an ON by setting a WLAN between terminals under the control of the cellular network (ON Manager);
- G9/G10 – Preservation of legacy RAN operation/Compatibility with legacy RAN deployments: The test-bed implements an “over-the-top” solution for C4MS which is compatible with current 3GPP RAN in terms of operation and deployment.

From the group of user and service related requirements, the following ones are addressed by the test-bed:

- U1 – Hide complexity from the end user: the test-bed allows the setup of the ON to be fully transparent to the user. Typically the setup of the relay is completely hidden from the user, being just a part of the video connection establishment.

From the group of opportunistic network management related requirements, the following ones are addressed by the test-bed:

- M1 - Identification of the need for an opportunistic network: The test-bed allows for application-triggered identification of the need;
- M3 – Creation of opportunistic networks: The test-bed implements the ON creation stage;
- M4 – Connection setup: The test-bed provides means for the ON Manager to trigger and control the establishment of WLAN connections between terminals;
- M8 – Opportunistic Network identification: the test-bed re-use the SSID concept and parameter of 802.11 as a means to identify a given ON.

From the group of algorithms related requirements, the test-bed addresses the following ones:

- A1 – Context awareness: The test-bed implements context awareness in the field of 802.11 channel occupation;
- A2 – Decision making: The test-bed implements decision making for the decision to build the ON (application trigger) and optimal setting of the underlying WLAN.

From the group of Protocols related requirements, the test-bed addresses the following ones:

- P1 – Protocol Usage: The test-bed implements a basic subset of C4MS messages, enriched with WLAN specific parameters, over an agent-based application-level protocol;
- P3 - Unicast/Dedicated addressing: The JADE protocol allows allocation of dedicated addresses/identifiers for unicast exchanges.

From the group of Security related requirements, the test-bed addresses the following ones:

- S1 – Security: the test-bed allows the setup of a secure WLAN for the ON, using any legacy WLAN security techniques.

2.7 Cognitive radio test-bed

The demonstration of the QoS and spectrum aware routing algorithm is performed based on a test-bed comprising "Wireless open-Access Research Platform" (WARP) [21] boards. All nodes use wireless 802.11 standards and are loaded with Optimized Link State Routing (OLSR) [22]-based Spectrum-aware routing protocol. Demonstration will address routing/re-routing upon changes in spectrum opportunity availability within OneFIT scenarios 1 & 2. C4MS signalling is not implemented as the focus of demonstration is on performance of modified OLSR (spectrum-awareness). Demonstration platform includes:

- Network of 5 ad-hoc radio nodes (WARP boards), with WiFi connections;
- All boards have multi-radio capability;
- 2 laptops acting as sink/source for streaming application;
- One "control" laptop + router.

It is assumed that the network (operator governed) has completed the neighbour discovery (responsibility of L1) and suitability determination phases. The proposed algorithm covers the routing table setup and maintenance phases (as required during ON creation/re-configuration phases). During creation phase, standard OLSR is used with hop-count as the metric. The primary scenarios of interest relate to ON coverage extension as depicted in Figure 25 and Figure 26 below.

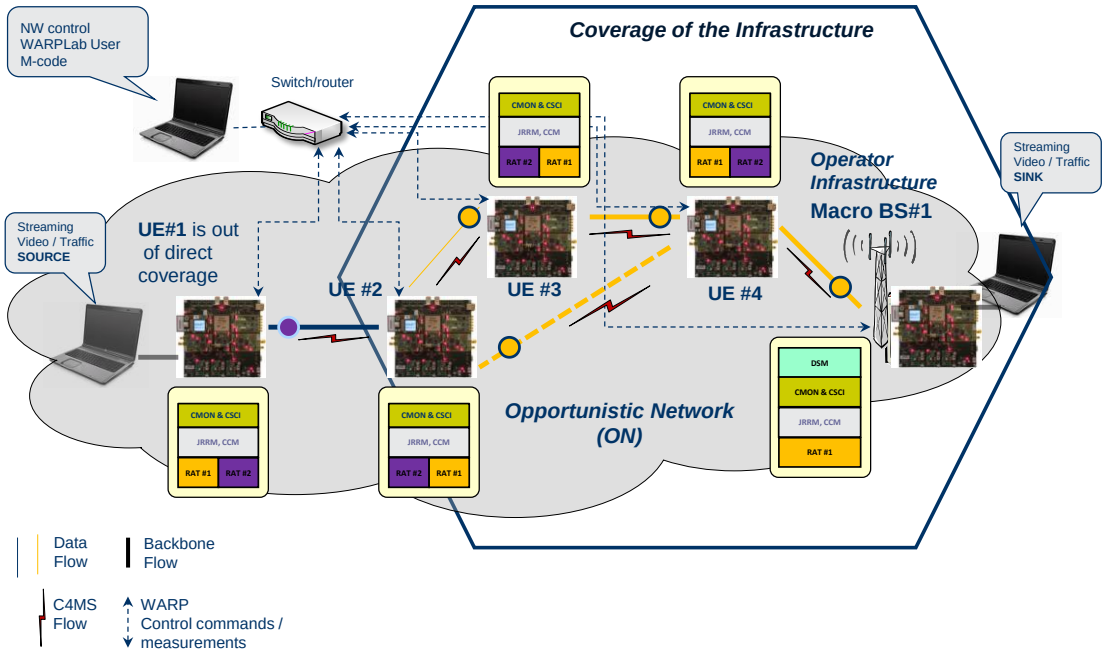


Figure 25: ON "coverage extension" *Scenario 1a* – "Relaying" within infrastructure coverage

Scenario 1a involves the following main steps:

- The terminal (UE #1) is out of coverage of infrastructure i.e. Macro BS #1;
- Following neighbour discovery, candidate node identification and suitability determination phase, the initial path is established between UE #1 and BS #1 via UE #2, #3, #4 (acting as relays), and ON is created;
- UE #3 will be moved (or powered down to emulate loss of connectivity) so it is no longer within BS #1 coverage thus reconfiguration phase is initiated;
- To demo the robustness and adaptability of the prototype implementation under a varying network topology, the ability of MAC and routing protocols to adapt to link breaks caused by topology changes will be shown while the end-user application is running on the laptops connected to SORURCE/SINK WARP boards). The end-user application is video streaming executed over multiple hops. Routing protocol implementation is considered part of CMON module/functionality.
- During Maintenance/Reconfiguration phase, the routing protocol will update the original path (UE#1, #2, #3, #4, BS#1) to the new path (UE#1, #2, #4, BS#1);
- UE #4 will then be moved (or powered down to emulate loss of connectivity) so it is no longer within BS #1 coverage thus reconfiguration phase is triggered once again;
- The routing protocol will update the current path (UE#1, #2, #4, BS#1) to the new path (UE#1, #2, #3, BS#1);
- As reconfiguration takes place it is expected that the routing algorithm will be able to maintain the quality of the application running on the two end laptops.

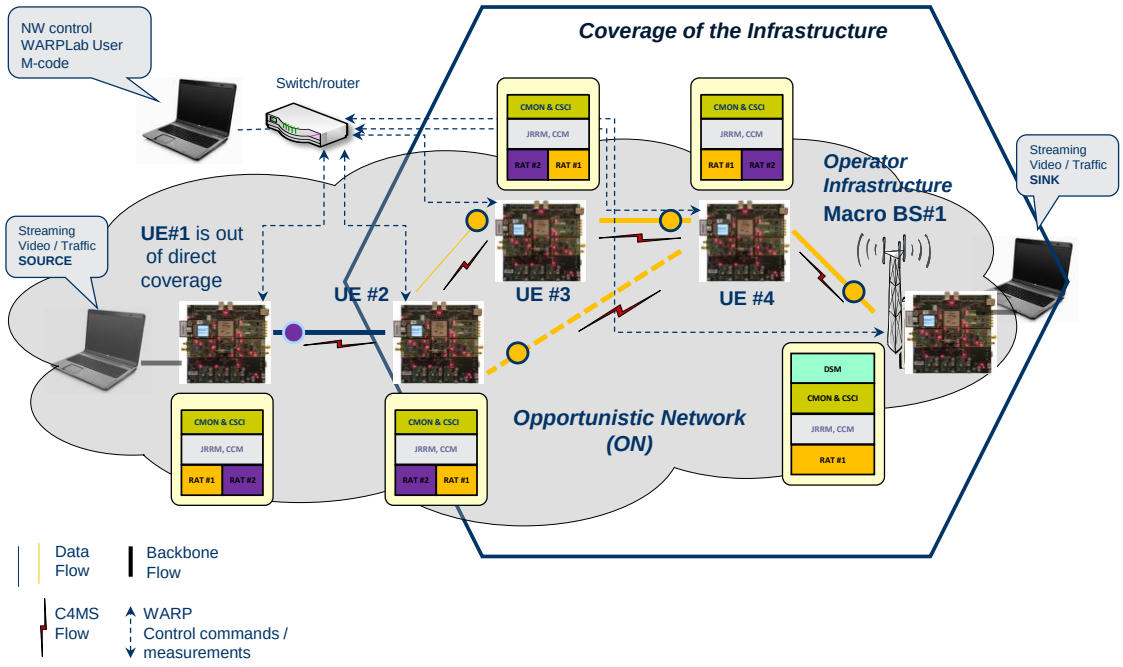


Figure 26: ON "coverage extension" *Scenario 1b* – "Relaying" within ON coverage

Scenario 1b involves the following main steps:

- The terminals (UE #1, 2, 3) are out of coverage of infrastructure i.e. Macro BS #1;

- Following discovery, candidate node identification and suitability determination phases, the initial path is established between UE #1 and BS #1 via relays: UE #2, #3, #4, and ON is created;
- UE #3 will be moved (or powered down to emulate loss of connectivity) so it is no longer within ON coverage thus reconfiguration phase is initiated;
- During Maintenance/Reconfiguration phase, the routing protocol will update the original path (UE#1, #2, #3, #4, BS#1) to the new path (UE#1, #2, #4, BS#1);
- UE #2 will then be moved so it is no longer within ON coverage thus reconfiguration phase is triggered once again;
- The routing protocol will update the existing path (UE#1, #2, #4, BS#1) to the new path (UE#1, #4, BS#1).

Note that whilst in scenario 1a, most of "relaying" takes place by the nodes within Macro cell coverage, in 1b the relaying is managed by the ON. When majority of relays are under control of infrastructure, it is expected that substantially less reconfigurations would be triggered due to mobility etc. as the network can be expected to take more responsibility to manage/maintain connectivity of UEs within its coverage especially if relaying/cooperation is supported and managed by the infrastructure already i.e. RAT already supports relaying. In scenario 1b however, proximity/range and Tx power of UEs plays a more critical role in ON maintenance and more reconfigurations likely to be triggered. So level of stability of ON under two scenarios is different.

The Software/hardware used is:

- Operating system: Linux kernel version 2.6.28;
- OLSRd: version 0.6.1 [23];
- WARP boards (L1/L2/L3 pre-loaded);
- Device-to-Device links based on 802.11 (WiFi ad-hoc mode).

2.7.1 Addressed system requirements

The following system requirements are addressed within this test-bed: G1-G3, G6, G10, M11 and A3.

From the group of general requirements the following are addressed:

- G1 – Communication with the infrastructure: The test-bed includes a WARP node that emulates the behaviour of the infrastructure in charge of controlling the ON. Both terminals communicate with the infrastructure to exchange the control C4MS messages allowing the ON creation and ON maintenance procedures.
- G2 – Communication between terminals: The test-bed supports 802.11 links between the relay nodes for data transmission over multiple hops in the allocated channels. The efficiency in the communication is monitored by the terminals to identify degradations and trigger ON modification.
- G3 – Versatile spectrum use: The test-bed/nodes support spectrum sensing to identify spectrum opportunities that used by the spectrum-aware routing protocol;
- G6 –relaying: Multi-hop relaying is supported i.e. soon as the ONs are created intermediate nodes can act as relay nodes;

- G10 – Compatibility with legacy RAN deployments: The test-bed is prepared to operate in a scenario with existing RAN. In particular, it has been test-bed in the ISM 2.4 band, co-existing with WiFi and Bluetooth devices;

From the group of user and service related requirements, the following are addressed by the test-bed:

- U1 – Hide complexity from end-user: The test-bed implements of spectrum-aware OLSR are entirely hidden from user and no interaction with end-user service/application is required. The video streaming application used in the demonstrations is independent/unaware of the underlying routing protocol used.

From the group of opportunistic network management related requirements, the following are addressed by the test-bed:

- M11 – Assignment of bandwidth: The test-bed supports selection and assignment of channels to the links. This is based on real-time measurements of the current spectrum utilization.

From the group of algorithm related requirements, the test-bed addresses the following ones:

- A3 – Routing: The test-bed demonstrates operation of spectrum-aware OLSR for routing during ON establishment, and re-routing (during maintenance phase) upon detection of degradation in channel quality/link throughput during data transmission.

2.8 Spectrum opportunity identification and spectrum selection test-bed

The objective of this test-bed is to show the behaviour of the spectrum opportunity identification and spectrum selection procedures in an ON. For that purpose, the "Scenario 3: Infrastructure supported opportunistic ad-hoc networking" [4] is considered where two devices need to communicate through an ON controlled by the infrastructure, as graphically illustrated in Figure 27. Both spectrum opportunity identification and spectrum selection functionalities reside in the infrastructure node, namely in the DSM and the CSCI/CMON entities. The result of executing these functions, with the specific frequency band assigned for the ON link between the two terminals is notified using C4MS protocol.

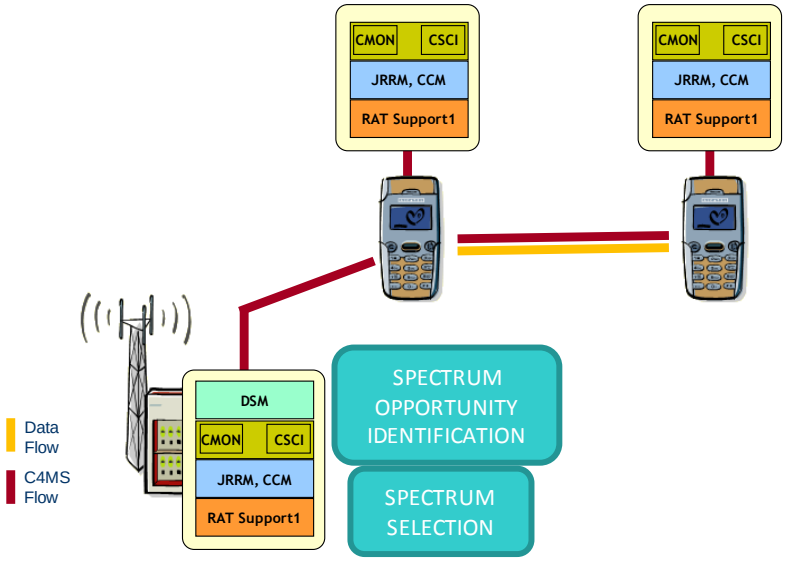


Figure 27: Scenario considered in the demonstration

The infrastructure node and the terminals are implemented by means of Universal Software Radio Peripheral (USRP) transceivers [24], as illustrated in Figure 28. USRP#1 will implement the infrastructure and the associated spectrum identification and selection functionalities, while USRP#2 and USRP#3 are the terminals exchanging data. Moreover, the ISM 2.4 GHz band will be used for the demonstration, detecting the available spectrum opportunities and allocating a portion of this band for the communication between terminals, based on real measurements made in this band.

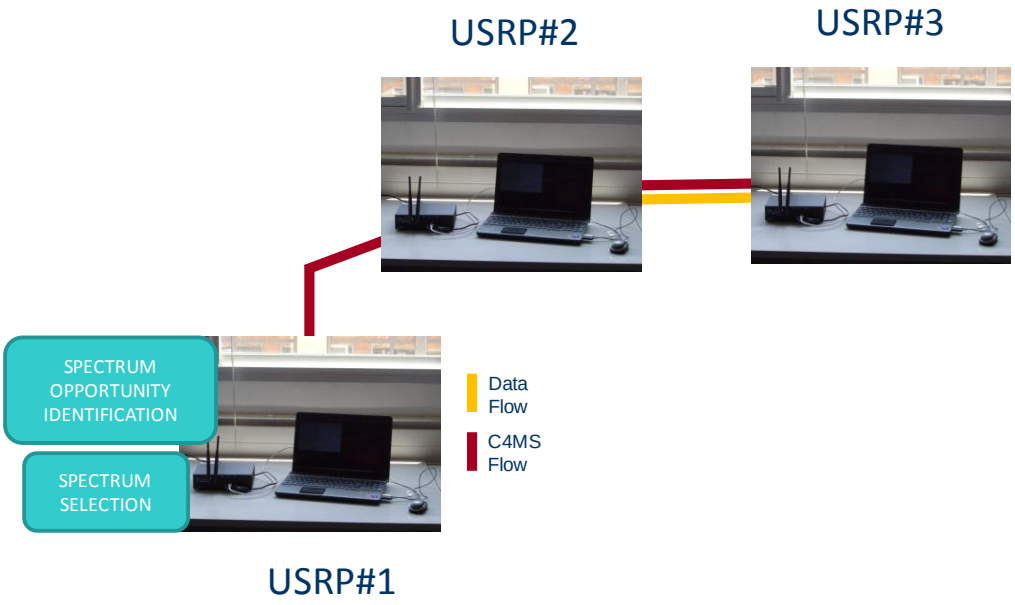


Figure 28: Implementation of the demonstration scenario by means of USRP

Figure 29 presents the mapping of the spectrum opportunity identification and spectrum selection algorithms on the OneFIT architecture. In particular, both are located in the infrastructure, and the spectrum opportunity identification resides in the DSM module while the spectrum selection is carried out in the CMON entity. More specifically, Figure 30 presents the mapping of the spectrum selection in the CMON entity. The algorithm to decide the spectrum assignment will be located in the decision making entity while the knowledge database with statistics of the fittingness factor are included in the knowledge management entity.

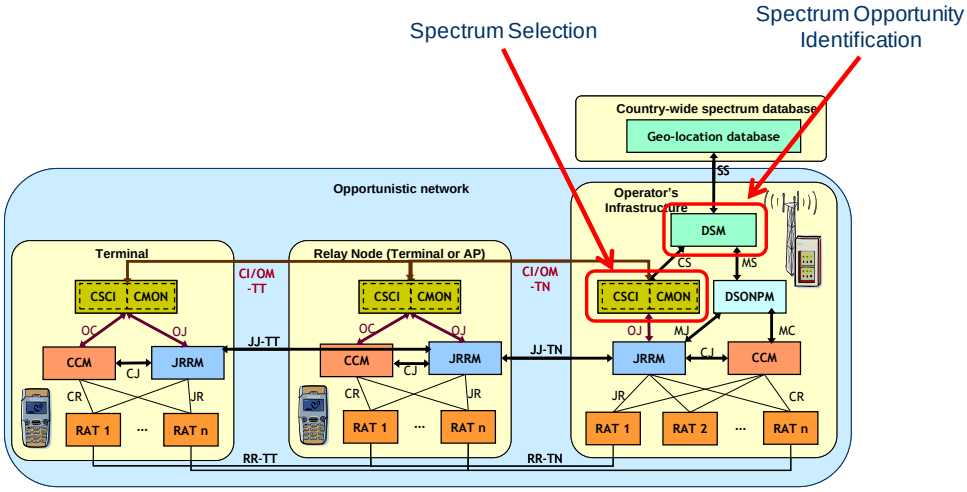


Figure 29: Mapping of the algorithm in the OneFIT architecture

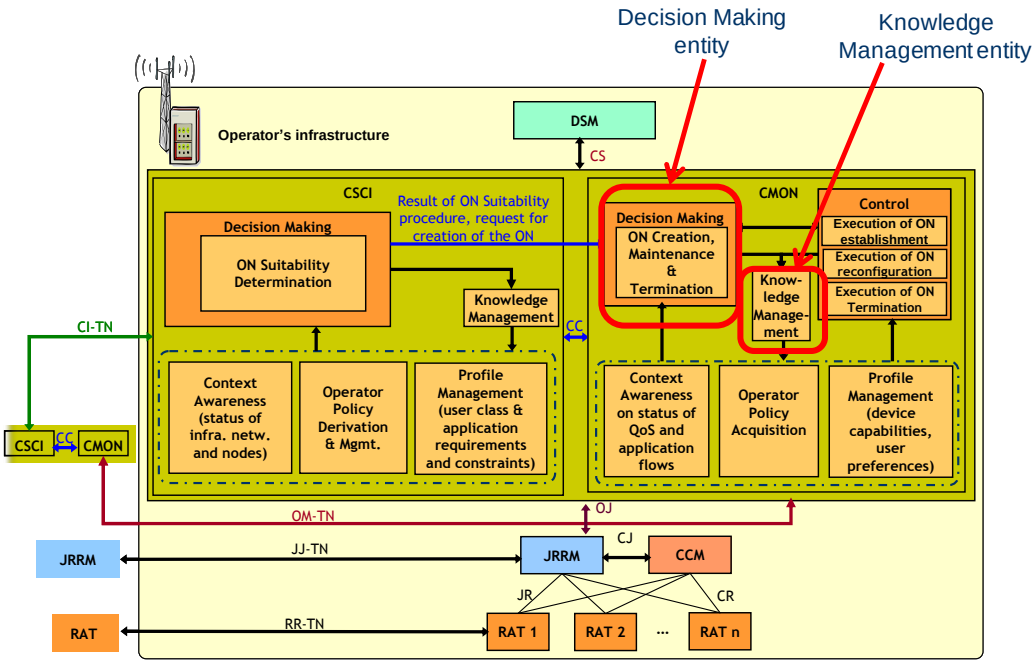


Figure 30: Mapping of the functional entities of the fittingness factor-based spectrum selection onto the CMON

Within the ON lifecycle, the spectrum selection problem considered here is applicable in the following two stages:

- ON creation: In this case the algorithm is executed whenever a new link has to be established in an ON and for that purpose an adequate spectrum pool has to be assigned;
- ON maintenance stage: In this case, the algorithm is executed whenever some changes in the radio environment have been detected such as modifications in the radio and interference conditions of a certain link, or a link release (meaning that we can reallocate the spectrum that was used by the released link to another link). As a result of the spectrum selection during ON maintenance, it is possible that spectrum handover procedures are triggered, whenever the spectrum allocated to any of the active links is modified.

Since the target of the demonstration is the spectrum opportunity identification and spectrum selection, the demonstration implements only the ON creation and ON maintenance stages. It is assumed that the decision to create an ON among the two devices has been previously made in the ON suitability phase. Similarly, a network-centric operation is assumed, in which the infrastructure makes the spectrum selection decisions. Details on the specific procedures for the two stages are given in sections 3.3.2.1 and 3.3.3.1.

The C4MS signalling is realized using the implementation option based on IEEE 802.21 “Media-Independent Handover (MIH) Services” described in chapter 5. Specific details on the considered messages in the test-bed are given in [7].

The spectrum opportunity identification and selection test-bed brings to the OneFIT validation platform the functionalities needed to analyse and decide in real time the current occupation of spectrum blocks in the ISM 2.4 GHz band and to perform the decision making about which of the available spectrum blocks can be more suitable to be allocated to a certain ON radio link with certain associated requirements. In this respect, this test-bed offers possible cooperation opportunities to some other parts of the OneFIT validation platform where the dynamic assignment of a spectrum to ON links is relevant. For example, additional spectrum usage information could be provided to the

DSM in the "Opportunistic networking demonstrator". The decision-making logic for the spectrum allocation could also be exploited. Also, Cognitive radio test-bed for spectrum-aware routing could exploit the results coming from the algorithms for spectrum opportunity identification and the decision making for spectrum selection. These potential ways of cooperation among test-beds will be further considered and elaborated in the framework of the activity on result analysis and validation which runs from July to December 2012.

2.8.1 Addressed system requirements

The following system requirements are addressed within this test-bed: G1-G3, G7, G10, M3, M5, M11, A1 and A2.

From the group of general requirements the following ones are addressed:

- G1 – Communication with the infrastructure: The test-bed includes a USRP node that emulates the behaviour of the infrastructure in charge of controlling the ON formed by the two terminals. Both terminals communicate with the infrastructure to exchange the control C4MS messages allowing the ON creation and ON maintenance procedures.
- G2 – Communication between terminals: The test-bed includes a link between the two USRPs used to transmit data in the allocated spectrum block. The efficiency in the communication is monitored by the terminals to identify degradations and request the ON modification.
- G3 – Versatile spectrum use: The test-bed performs a dynamic spectrum assignment, after having identified based on measurements the available spectrum blocks depending on the current interference conditions in the scenario where it operates;
- G7 – Creation of opportunistic networks: The test-bed allows the creation of an ON link and addresses the problems of spectrum opportunity identification and selection to allocate the appropriate spectrum to the created link. The procedure for ON creation implemented in the test-bed is detailed in section 3.3.2.1.
- G10 – Compatibility with legacy RAN deployments: The test-bed is prepared to operate in a scenario with existing RAN. In particular, it has been test-bed in the ISM 2.4 band, co-existing with WiFi and Bluetooth devices.

From the group of opportunistic network management related requirements, the following ones are addressed by the test-bed:

- M3 – Creation of opportunistic networks: The test-bed implements the ON creation stage, in particular the selection of spectrum for an ON link to be established. The procedure for ON creation implemented in the test-bed is detailed in section 3.3.2.1.
- M5 – Maintenance of opportunistic networks: The test-bed monitors the efficiency in the data transmission between terminals using the allocated spectrum. Whenever the efficiency falls below a specific threshold the ON modification procedure is triggered to request for a different spectrum block. The procedure for ON maintenance implemented in the test-bed is detailed in section 3.3.3.1.
- M11 – Assignment of bandwidth: The test-bed decides the adequate spectrum blocks to be assigned to the link between the two terminals forming the ON. This is based on real-time measurements of the current spectrum utilization.

From the group of algorithm related requirements, the test-bed addresses the following ones:

- A1 – Context awareness: This is addressed in two different ways by the test-bed. On the one hand, whenever the ON link has to be established, the USRP emulating the infrastructure performs the spectrum opportunity identification by measuring the spectrum band (ISM2.4) and identifying which spectrum blocks are available. On the other hand, once the link has been established, the efficiency in the data communication is monitored to identify if a degradation occurs (due to e.g. interference) and then to request for another spectrum block.
- A2 – Decision making: The test-bed carries out the spectrum selection decision making algorithm to decide on the adequate spectrum block to be allocated to the ON link that has to be established, or after degradation has been detected in the assigned block during data transmission.

2.9 Open platform wireless mesh network test-bed

The open platform wireless mesh network (WMN) test-bed is developed in order to test and evaluate scenario 5 specific use cases (in unlicensed spectrum). Also, WP4 algorithms "Application cognitive multipath routing in wireless mesh networks" and "Content conditioning and distributed storage virtualization/aggregation for context driven media delivery" are validated on this platform.

The WMN test-bed includes (see Figure 31):

- Wireless mesh network (WMN) test-bed with open platform access points (APs) based on MikroTik router-boards and OpenWRT system;
- Database of contextual information;
- Traffic generator for emulating traffic flows;
- Simple network management protocol (SNMP) for network monitoring and contextual data gathering;
- Optimized link state routing (OLSR) protocol for route discovery, establishment and maintenance;
- End user's terminals.

Open platform WMN nodes are based on MikroTik router boards RB800 and RB433AH and OpenWRT system. More details about these components can be found in D5.1 [2].

The OneFIT building blocks (CMON and CSCI logic) are implemented in the centralized network management server. The SNMP protocol is used as a variant of the C4MS (see section 5) protocol for contextual data gathering and exchange of control messages. OLSR protocol is used for route discovery and establishment.

The open platform WMN test-bed is included into the OneFIT validation platform as part of the infrastructure side for enabling aggregation of infrastructure's backhaul resources (bandwidth and caching storage).

This test-bed can be used in cooperation with test-beds which are providing resource aggregation in the access side of the WMN in order to demonstrate the overall resource aggregation (in access and backhaul side of the infrastructure).

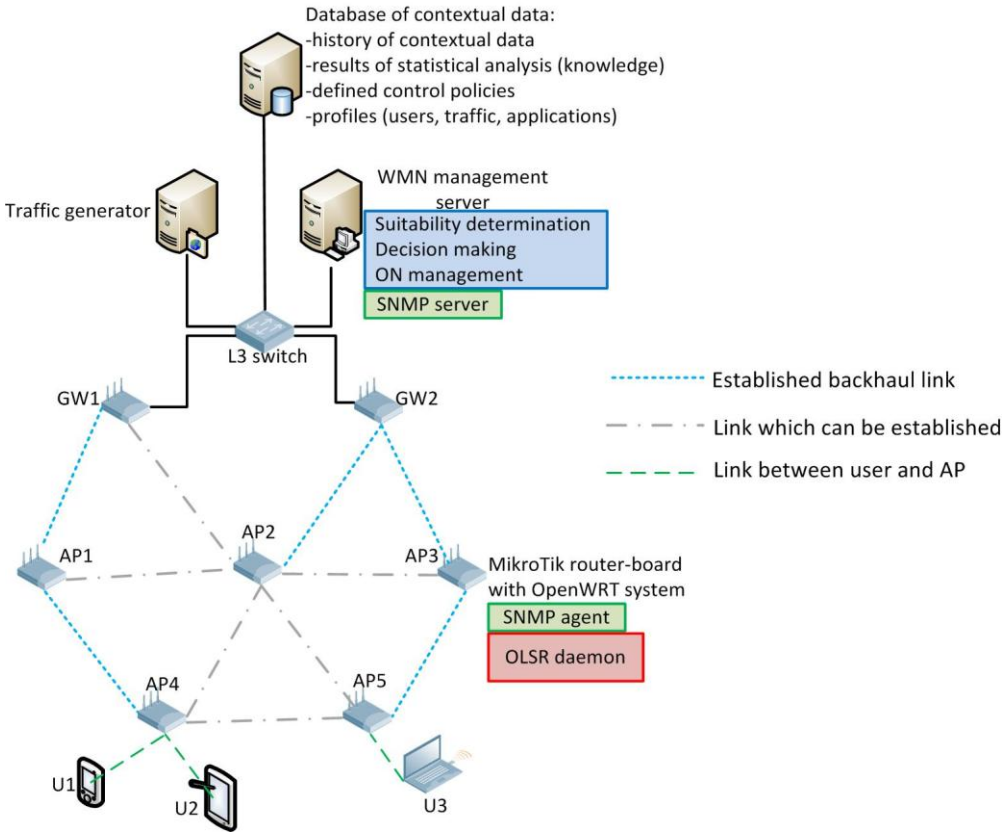


Figure 31: Open platform WMN test-bed

Test-bed demonstrations can be configured and monitored remotely over the custom web interface. This interface provides a sort of the dashboard consisting of several tables and diagrams. The following tables are shown within the dashboard:

- Opportunistic Network table – shows ON management phases that are currently in progress within the test-bed , triggers which started the ON phases, selected ON solution (selected nodes and routes) and current status of the relevant contextual parameters;
- Link table – formed WMN links and their current status (last entry in the contextual database) is shown. Backhaul links formed in order to enable creation of the ON can be seen.
- Interface table – within this table a current status of all WMN interfaces is shown. Interface reconfiguration, which were necessary for ON creation, are shown;
- Routing table – OLSR routing table can be shown, where all paths in the current WMN setting can be seen (including the paths enabled by ON creation).

The dashboard also shows the diagram of the current load of selected interfaces in order to showcase the achieved bandwidth aggregation and/or load balancing. Elements of the dashboard are shown in section 6.4 where implementation of the OneFIT scenario 5 is described.

2.9.1 Addressed system requirements

The following system requirements are addressed within this test-bed: G7, G11, U1, M1-M6 and A1-A3.

From the group of general system requirements, the requirements G7 and G11 are addressed in open platform WMN test-bed:

- G7 - Creation of opportunistic networks: implemented algorithm for opportunistic, application aware multipath routing in backhaul of WMNs provides selection of appropriate set of multiple paths in the backhaul of the WMN over which the requested QoS requirements of end users can be achieved. ON is created among WMN nodes participating in selected multiple paths by creating opportunistic backhaul links between available dormant backhaul interfaces of WMN nodes. Established multiple paths in the WMN backhaul will be terminated (ON termination) when the management system detects that the underlying single path routing can provide required QoS to the end users.
- G11 – Resource efficiency: opportunistic and application aware multipath routing algorithm is implemented in this test-bed in order to provide better load balancing in WMN backhaul and better backhaul bandwidth utilization while, at the same time, QoS requirements of the end users are met.

Regarding the group of system requirements related to users and services, U1 requirement is addressed in this test-bed implementation:

- U1 – Hide complexity from the end user: complexity of the multipath routing in the backhaul of WMNs is hidden form the end users, since all reconfiguration and management are done between WMN stations. Application used by the end user is recognized (this feature is currently performed manually, but it will be automatized by the end of the project) and its load is routed over one of the multiple paths which are made available by ON creation.

From the group of ON management related requirements, M1-M6 requirements are addressed in this test-bed implementation:

- M1 – Identification of the need for an opportunistic network: SNMP based WMN monitoring system collects all relevant contextual parameters every 1 minute. These contextual parameters are stored into the contextual database. Implemented multipath routing algorithm checks the values of selected contextual parameters (number of end users and their QoS requirements and available bandwidth on currently used backhaul paths and ETX values of these paths) as well as trend in which those values are changing. When defined triggering levels are met, the suitability determination phase of the algorithm starts.
- M2 – Suitability determination: implemented multipath routing algorithm performs suitability determination upon trigger detection. A suitability of using multiple paths for solving the problem at hand is checked. For more details please check the section 3.3.1.5.
- M3 – Creation of opportunistic networks: when multipath routing is selected as suitable for solving detected problem, new backhaul paths will be established by turning on dormant backhaul interfaces of selected WMN nodes and assigning appropriate 802.11a channel to them in order to form selected additional backhaul links. After multipath routing is established, application/users' loads are distributed among multiple paths in the application aware manner. More details regarding ON creation can be found in section 3.3.2.7.
- M4 – Connection set-up: new backhaul links are made when multiple path set is selected in suitability determination phase. All WMN stations in this test-bed have two interfaces for backhaul connectivity. Unutilized interfaces are turned on when multipath routing is established.
- M5 – Maintenance of opportunistic networks: SNMP based monitoring system continues gathering relevant contextual parameters from WMN when ONs are established. QoS capabilities of all backhaul paths are constantly checked and, when needed, ONs are reconfigured (different set of multiple paths are selected) in a manner which can address changes in QoS requirements.

- M6 – Release of opportunistic networks: when there is no longer a need for multipath routing (single path routing can provide necessary QoS levels), established ONs will be terminated and selected backhaul paths from ON supported multiple paths sets will be terminated (certain backhaul links will be terminated – corresponding interfaces will be turned off). By returning to single path routing mode of operation, when multipath routing is no longer needed, WMN management system lowers possibilities for interference in WMN backhaul and, at the same time, achieves power savings by turning of unnecessary backhaul interfaces.

Regarding the algorithm related system requirements, the open platform WMN test-bed addresses the following:

- A1 – Context awareness: SNMP based monitoring system collects necessary contextual parameters form WMN environment. Implemented multipath routing algorithm checks the context values and trends in their changes form contextual database in order to detect a need for ON creation and to perform a proper suitability determination.
- A2 – Decision making: implemented multipath routing algorithm makes decisions when to start ON suitability determination based on values of monitored contextual parameters. During the suitability determination phase algorithm decides if the multipath routing is applicable for solving the problem at hand within current contextual boundaries. Creation phase will establish the first multiple paths set which fulfils the QoS requirements. Also, decisions are made regarding when to reconfigure created ONs and when to terminate them.
- A3 – Routing: routing is performed with the OLSR protocol. Implemented multipath routing algorithm selects appropriate set of multiple paths, establishes necessary additional links and makes instructions regarding the routing schedule for access traffic (which load over which path in multiple path sets). These changes are detected by the underling OLSR, which continues with routing in accordance with reconfigured WMN backhaul.

3 Implementation of the OneFIT cognitive management system

The OneFIT's infrastructure governed opportunistic networks management is divided into two building blocks, namely the "Cognitive management System for the Coordination of the infrastructure" (CSCI) and the "Cognitive Management system for the Opportunistic Network" (CMON).

The CSCI is mainly responsible for the activities before an ON is created. This includes ON opportunity detection and ON suitability determination. When the CSCI has made a decision that an ON is suitable, the decision is then sent to the CMON.

The CMON is responsible for executing on the ON design, obtained from the CSCI, and then operationally supervising the created ON. This entity is in charge of the creation, maintenance and termination of the opportunistic network. Moreover, the CMON is responsible for the coordination of nodes in the ON. The CMON and the CSCI are located in both the operators' infrastructure and the terminal side.

A detailed view of the CSCI and CMON functional building blocks is shown in Figure 34 and Figure 35. These building blocks are realized by implementation of the following algorithms (tasks) into the corresponding test-beds which comprise the OneFIT validation platform:

- Task 1: Suitability determination for the coverage extension scenario (implemented in the Opportunistic networking demonstrator, which is described in section 2.2);
- Task 2: Fittingness factor-based spectrum selection (implemented in the Spectrum opportunity identification and spectrum selection test-bed, which is described in section 2.8);
- Task 3: Algorithm on knowledge-based suitability determination and selection of nodes and routes (implemented in the prototyping platform for the management of opportunistic networks, which is described in section 2.1);
- Task 4: Route pattern selection in ad-hoc networks (implemented in the Opportunistic ad-hoc network demonstrator, which is described in section 2.4);
- Task 5: Multi-flow routes co-determination (implemented in the Opportunistic ad-hoc network demonstrator, which is described in section 2.4);
- Task 6: QoS and spectrum-aware routing techniques (implemented in the Cognitive radio test-bed, which is described in section 2.7);
- Task 7: Application cognitive multi-path routing in wireless mesh networks (implemented in the Open platform wireless mesh network test-bed, which is described in section 2.9);
- Task 8: UE-to-UE trusted direct path (implemented in the Direct D2D communication test-bed, which is described in section 2.6);
- Task 9: Capacity extension through femtocells (implemented in the prototyping platform for the management of opportunistic networks, which is described in section 2.1).

The listed algorithms are described in more detail in D4.1 [8] and D4.2 [9]. Their implementation into the OneFIT validation platform is described in D4.2 [9]. Their mapping onto the ON related challenges, the ON management phases, CSCI and CMON entities and the OneFIT scenarios is shown in Figure 32.

	Suitability determination for the coverage extension scenario	Fittingness factor-based spectrum selection	Algorithm on knowledge-based suitability determination and selection of nodes and routes	Route pattern selection in ad-hoc networks	Multi-flow routes co-determination	QoS and spectrum-aware routing techniques	Application cognitive multi-path routing in wireless mesh networks	UE-to-UE trusted direct path	Capacity extension through femtocells
Node discovery	x		x						x
Node selection			x						x
Route selection			x	x	x	x	x	x	x
Spectrum identification	x	x							
Spectrum selection		x				x			
Suitability	x		x	x			x		x
Creation		x	x		x	x	x	x	x
Maintenance & Termination	x	x		x	x	x	x	x	x
CMON terminal				x	x				
CSCI terminal	x			x	x			x	
CMON Infrastructure		x	x			x	x	x	x
CSCI Infrastructure	x		x			x	x		x
Scenario 1	x	x	x	x	x	x			
Scenario 2	x	x	x	x	x	x		x	x
Scenario 3	x	x	x	x	x			x	
Scenario 4	x	x	x					x	
Scenario 5		x	x				x		

Figure 32: Mapping of the implemented algorithms onto the ON related challenges, the ON management phases, CMON and CSCI entities and the OneFIT scenarios

Different triggers will require utilization of different algorithmic approaches. Decision making procedures of the OneFIT cognitive management system will select appropriate algorithmic approach (or combination of approaches) for solving the problems at hand, which are identified by detected triggers. Mapping of the algorithms, which are implemented into the OneFIT validation platform, onto the defined triggers is shown in Figure 33.

Decision making of the OneFIT cognitive management system	Suitability determination for the coverage extension scenario	Fittingness factor-based spectrum selection	Algorithm on knowledge-based suitability determination and selection of nodes and routes	Route pattern selection in ad-hoc networks	Multi-flow routes co-determination	QoS and spectrum-aware routing techniques	Application cognitive multi-path routing in wireless mesh networks	UE-to-UE trusted direct path	Capacity extension through femtocells
Device going out of direct infrastructure coverage	x								
Infrastructure not found or only with weak signals	x								
A new link has to be established		x							
An active link is experiencing bad channel quality in the currently used spectrum		x							
A link is released and there are other active links		x							
There is a need for secure direct terminal to terminal communication								x	
A need for ad-hoc network among terminals				x	x				
A need for better load balancing in ad-hoc network				x	x				
Infrastructure element (BS/AP) experiences congestion			x						x
Infrastructure element failure			x						
Nearby femtocells detected									x
Backhaul path of infrastructure node congested							x		
Poor QoS capabilities of the current backhaul path							x		
Poor QoS capabilities of the current path						x			
Increased interference						x			
Re-appearance of primary users & loss of channel in use by secondary users						x			
Degradation in QoS of channel(s) in use						x			

Figure 33: Mapping of the algorithmic solutions onto the triggering events and states

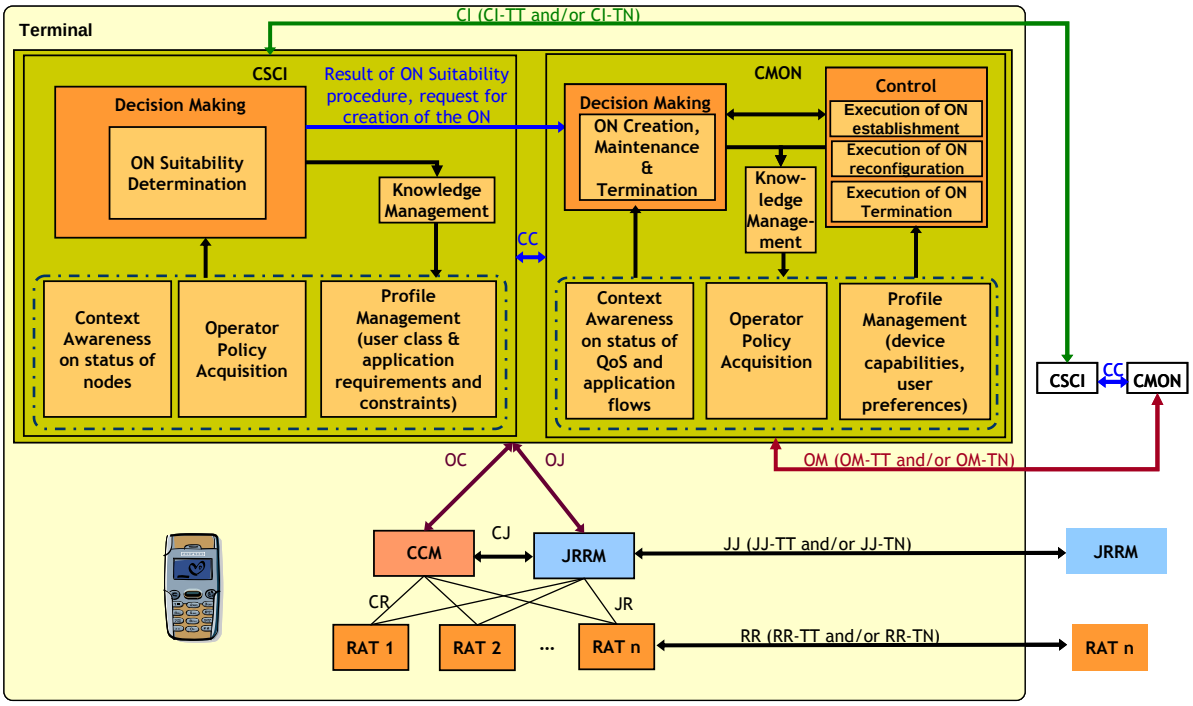


Figure 34: Detailed functional view of the CSCI and CMON in the terminal

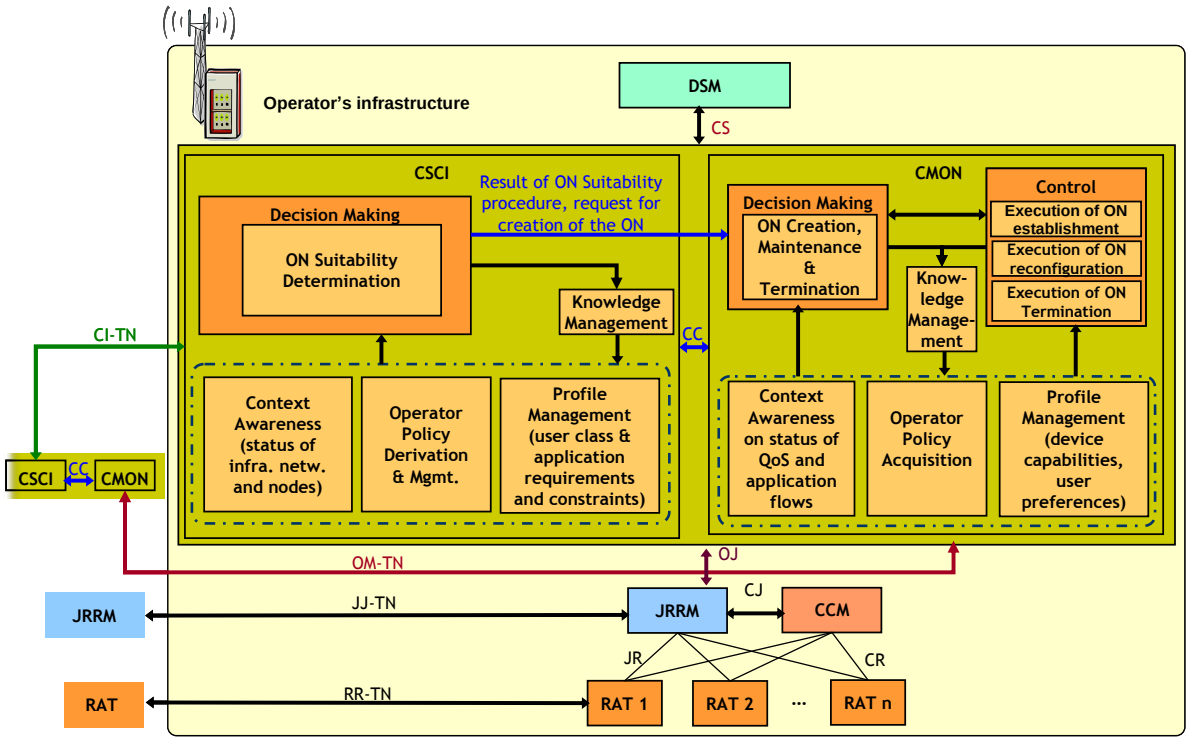


Figure 35: Detailed functional view of the CSCI and CMON in the operator's infrastructure

3.1 Implementation of the CSCI

The CSCI - *Cognitive management System for the Coordination of the infrastructure* is the functional entity in charge of the context acquisition, processing of the same and the determination whether or not right conditions are in place for creating an opportunistic network.

The CSCI is responsible for the detection of situations where an ON may be useful as part of the ON suitability determination phase. The CSCI delegates the actual creation, maintenance and termination of a given ON to the associated CMON functional entity and it is located in both the operators' infrastructure side (then called "CSCI-N") and the terminal side (then called "CSCI-T").

The main tasks of the CSCI are:

- ON opportunity detection and ON trigger recognition;
- ON suitability determination;
- ON blueprint derivation;
- Operator's policy derivation and acquisition;
- Enabling necessary level of context awareness;
- Profiling of users and applications and derivation of their connections;
- Instructing the CMON to create and/or extend the ON;
- Communicating with CSCI entities of other nodes in the network.

The ON opportunity detection requires a set of triggers and scenarios to be defined. These triggers and scenarios are derived from performance evaluation of created ONs and other solutions used for overcoming detected problems. Triggers are set of different threshold levels of certain relevant contextual parameters (link congestion, out of coverage, QoS requirements, resource utilization, and users' requests). Implemented algorithms provide certain trigger detections:

- Insufficient access bandwidth and poor load balancing among BSs are detected by procedures developed within Tasks 3 and 9;
- Link congestion and poor load balancing in backhaul side of the infrastructure are detected by the procedures developed within Task 7 (in the backhaul of the WMNs);
- QoS requirements for applications used by users are detected (through policy acquisition) by procedures of Task 4, task 6 and Task 7;
- Spectrum availability is detected by procedures presented in Task 2 and Task 6;

When these thresholds are reached, the ON suitability determination process can start. The Suitability Determination is a centralized process, with the decision making located typically in the infrastructure but in some cases (e.g. out-of-coverage scenario) located inside a device. The decision making is based on infrastructure-level information provided by functional entities in the network and user/device-level information provided by the CSCI-T entities from a selected set of devices. The Suitability Determination runs before the creation of an ON but also during the lifetime of the ON in order to check that context changes and ON reconfigurations (information from CMON) have not cancelled the benefit/suitability of the ON. The suitability determination requires context awareness in order to come up with a proper suitability conclusion. The implemented algorithms provide the suitability determination:

- Task 1 provides suitability determination with respect to the size of the problematic area, mobility of the involved nodes and number of potentially involved nodes;
- Task 3 and Task 9 provide suitability analysis based on previously gathered knowledge about ONs, nodes and routes;
- Task 4 provides suitability determination with respect to creation of an ON on top of the ad-hoc network formed between end user terminals;

- Task 7 provides analysis of suitability of multi path routing in the backhaul side of the WMN for solving the problems of poor load balancing and insufficient access bandwidth. Also, knowledge about performance evaluation of the selected multiple paths sets is used in the suitability determination process.

When ON is detected as a suitable solution for a problem at hand, the ON blueprint needs to be derived. This blueprint consists of set of detected (identified) nodes (terminals and infrastructure), routes and spectrum. These entities are identified as suitable for creation of ON for solving detected problem. A good practice is to provide a certain level of redundancy in the set of identified candidate nodes, routes and spectrum chunks in order to allow creation process of CMON a certain level of freedom in selecting the appropriate set of mentioned entities. The ON blueprint is also accompanied with a set of necessary operator's policies. The algorithms implemented into the OneFIT validation platform provide the ON blueprint:

- Task 2 provides spectrum analysis and selection;
- Task 3 and Task 9 provide node identification and candidate list derivation among terminals and infrastructure nodes;
- Tasks 3, 4, 5, 6 and 8 provide candidate list of routes among terminals and between terminals and infrastructure nodes;
- Task 7 provides candidate list of routes in the wireless backhaul side of the infrastructure.

All of the implemented algorithms take into account operator's policies for providing proper suitability determination. Spectrum policies, QoS requirements, security requirements and ON related policies (nodes and routes) are defined and provided by operator. These policies can evolve if the gathered knowledge requires it.

Context awareness necessary for proper suitability determination is provided by all of the implemented algorithms:

- Context awareness regarding spectrum is provided by Tasks 2 and 6;
- Awareness regarding link congestions and traffic patterns between terminals is provided by Tasks 3, 4 and 6;
- Context awareness regarding bandwidth utilization and traffic patterns in the backhaul side of the infrastructure network is provided by the Task 7;
- Context awareness regarding capacity of the access side of the infrastructure is provided by the procedures in Task 3 and 9;
- Awareness regarding used RATs is provided by Tasks 1, 3, 6 and 8;
- Awareness regarding distribution of terminals is provided by procedures of the Tasks 1, 3, 4, 8 and 9;
- Awareness regarding distribution and topology of the infrastructure nodes is provided by the Tasks 7 and 9;
- Awareness regarding status of the infrastructure nodes is provided by the Tasks 7, 3 and 9.

Profiles of users and applications are derived by the operator. Users' profiles can be updated by monitoring of the users activities (i.e. willingness to participate in ONs).

Set of candidate nodes, routes and spectrum portions (the ON blueprint) for creating the ON are sent to the corresponding CMON management entities over the C4MS protocol (for details regarding implementation of this protocol please check section 5 of this document).

Communication between CSCI entities belonging to different nodes enables exchange of knowledge and gathered contextual information. Also, CSCI-N sends relevant operators policies and derived profiles to CSCI-T entities. In centralized cognitive management approach (i.e. Tasks 1, 3, 7 and 9) the main CSCI entity is located inside the centralized management server, while CSCI in nodes (infrastructure and terminal) are simple agents responsible for providing interface between centralized management system and reconfiguration engines within nodes.

3.2 Implementation of the CMON

The CMON - *Cognitive Management system for the Opportunistic Network* is responsible for executing on the design obtained from the CSCI and then operationally supervising the created ON. This entity is in charge of the creation, maintenance and termination (according to the policies maintained in the CSCI) of the opportunistic network. Moreover, the CMON is responsible for the coordination of nodes in the ON. The CMON is also located in both the operators' infrastructure (CMON-N) and the terminal side (CMON-T).

Generally, the CMON in the operators' infrastructure involves context awareness, policy acquisition and profile management which provide the input for the decision making mechanism. In the terminal side, the CMON provides functionality for the context awareness, the policy acquisition as defined by the operator and the profile management. The cognition relies on the fact that the knowledge management functional entity interacts with the previously mentioned entities in order to make better decisions in the future, according to the learned results.

The main tasks of the CMON are:

- Context awareness through monitoring of the established ON and its environment;
- Policy acquisition regarding QoS levels and ON related policies (i.e. when to terminate/reconfigure ON);
- Knowledge derivation and management;
- Decision making regarding the most appropriate selection of nodes, routes and spectrum portions from candidate sets provided by the CSCI;
- Execution of ON creation – direct communication with CCM module;
- ON monitoring and maintenance/reconfiguration;
- ON termination.

The CMON will use the system's monitoring capabilities in order to track performance of the established ONs and their environments (i.e. interference levels around ON, battery levels of included mobile terminals, load balancing, stabilization of situations which triggered the creation of the ON). All of the proposed tasks have procedures for monitoring of ONs and their environments or an interface towards operator's monitoring systems and contextual databases.

Derived and defined policies are acquired from corresponding CSCI entity. These policies are used in decision making process when final set of nodes, routes and spectrum is selected from sets of possible candidates. Profiles of applications (defining QoS requirements) are used in Tasks 4, 6 and 7 for route selection process.

By monitoring of the ON and its environment, CMON gathers necessary contextual data regarding performance of the established ON and impact that it has on its environment. These contextual data are used for knowledge derivation which can be used in suitability determination and decision making processes. The implemented algorithms provide knowledge derivation:

- Penalization process, based on reinforced learning, for multiple paths sets is implemented in the Task 7;
- Machine learning techniques are used for derivation of fittingness factor used for selection of spectrum (Task 2) and nodes/routes (Task 3).

Decision making is part of the creation, reconfiguration and termination phase. All of these ON management phases require proper decision before execution. The decision process needs to detect triggers for reconfiguration/termination and to derive set of nodes, routes and spectrum used for creation or reconfiguration of an ON. Figure 32 shows which of the ON management phases are addressed by which of the implemented algorithms (more detailed analysis of implementation of the ON management phases is given in subsection 3.3).

3.3 Implementation of ON management phases

This section presents how the different ON management phases have been implemented in the different components of the OneFIT validation platform presented in section 2, in accordance to the mapping between algorithm and ON management phases that was reflected in Figure 32. For that purpose, this section is subdivided into three parts, devoted to the ON suitability determination, ON creation and ON maintenance & termination stages. In each one the implemented algorithms covering each phase are presented. It is worth mentioning that in some cases, the three stages are integrated within the same algorithm. In these cases, the algorithm is presented in one of the sections and references are given in the other ones.

3.3.1 ON suitability determination

Different algorithms for ON suitability determination are implemented in the components of the OneFIT validation platform. In particular, this section details first the implementation of the suitability determination for the coverage extension scenario using the Opportunistic Network demonstrator. Then, the capacity extension and node selection algorithms implemented during the ON suitability determination phase in the prototyping platform for the management of opportunistic networks are presented. After this, the route selection algorithm implemented in the opportunistic ad-hoc network platform is described. It is presented in this section although it is general for the different ON stages. Finally the section describes the ON suitability determination for the application cognitive multi-path routing implemented in the wireless mesh network test-bed.

3.3.1.1 Suitability determination for the coverage extension scenario

For the suitability determination, the infrastructure must have knowledge about the nodes in the network, the capabilities of these nodes, the quality of the radio links and about neighbourhood relationships. Such information is typically already collected via Radio Resource Management (RRM) procedures or Joint Radio Resource Management (JRRM) procedures.

Measurements of the radio link can be reported from the terminal to the network using e.g. IEEE 802.21 MIH_Link_Parameters_Report.indiation, MIH_Link_Up.indication, MIH_Link_Going_Down .indication or MIH_Link_Detected.indication messages. Such messages are included for example in the message sequence chart in Figure 62 on page 92.

The suitability determination procedure is shown in Figure 36. When the RRM/JRRM receives an indication that a device is going out of the coverage of the current serving cell, the RRM/JRRM first searches for another cell to which a handover can be done. Only in the case that a handover to another cell is not possible, the CSCI/CMON is triggered to execute the suitability determination for the creation of an ON as shown in Figure 36. The CSCI/CMON then searches for another terminal in

the geographical proximity. If such a terminal is found and if policies allow, then that second terminal can act as relay between the user going out of coverage and the infrastructure network.

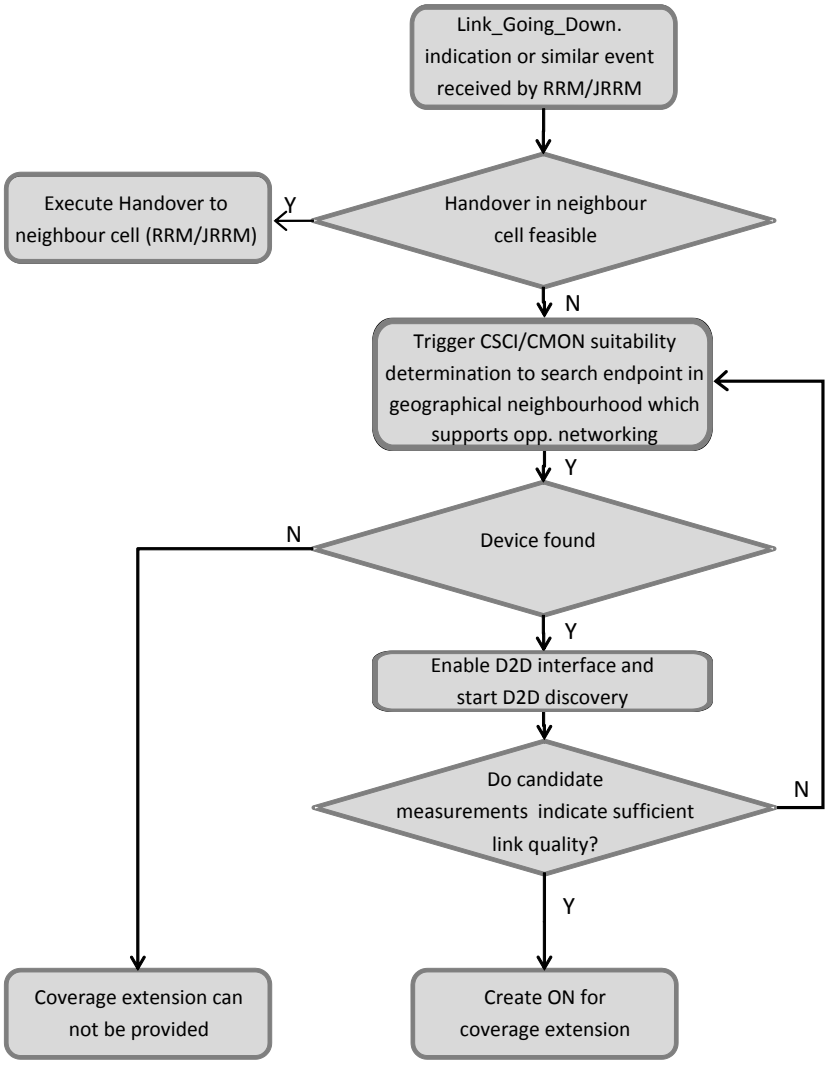


Figure 36: Suitability Determination for the coverage extension scenario

3.3.1.2 Capacity extension of the infrastructure through neighbouring terminals

The solution mechanism is triggered whenever a congestion situation occurs in the infrastructure and makes decisions on the establishment of routes which will redirect traffic from the congested service area into non-congested ones. The proposed solution is based on the Ford-Fulkerson maximum flow algorithm and it is assumed that each terminal in the congested service area creates one application flow which can be redirected through neighbouring terminals (e.g., which are in range of a typical 802.11b/g connection) to alternate, non-congested BSs. A flowchart of the proposed algorithm is provided through Figure 37.

In the OneFIT platform, the input of the algorithm consists of the following:

- Sets of congested and non-congested BSs;
- Set of terminals in the congested area that have ON capabilities and can be redirected to alternative BSs;

- Paths from source to destination. Each path originates from a 'virtual' source where terminals with ON capabilities in the congested area are connected and ends to a 'virtual' destination where BSs are connected.

To this respect, the following procedure is followed:

- As soon as the BS detects the problematic situation, the CSCI sends a notification to the DSONPM which triggers the suitability determination mechanism;
- The DSONPM constructs the set of the congested BSs and sends a request to the CSCI entities of the neighbouring BSs in order to determine the ones that can acquire a proportion of the traffic of the congested BS and construct the set of the non-congested BSs. The information is then sent to the congested BS that will execute the solution algorithm.
- The selected BS sends a message (an Information.Request according to C4MS) to the other congested BSs in order to acquire the list of terminals with ON capabilities that can be redirected to alternative BSs. The information then is forwarded to the CMON.
- The procedure then advances to the ON creation phase which is described at the respective section 3.3.2.2.

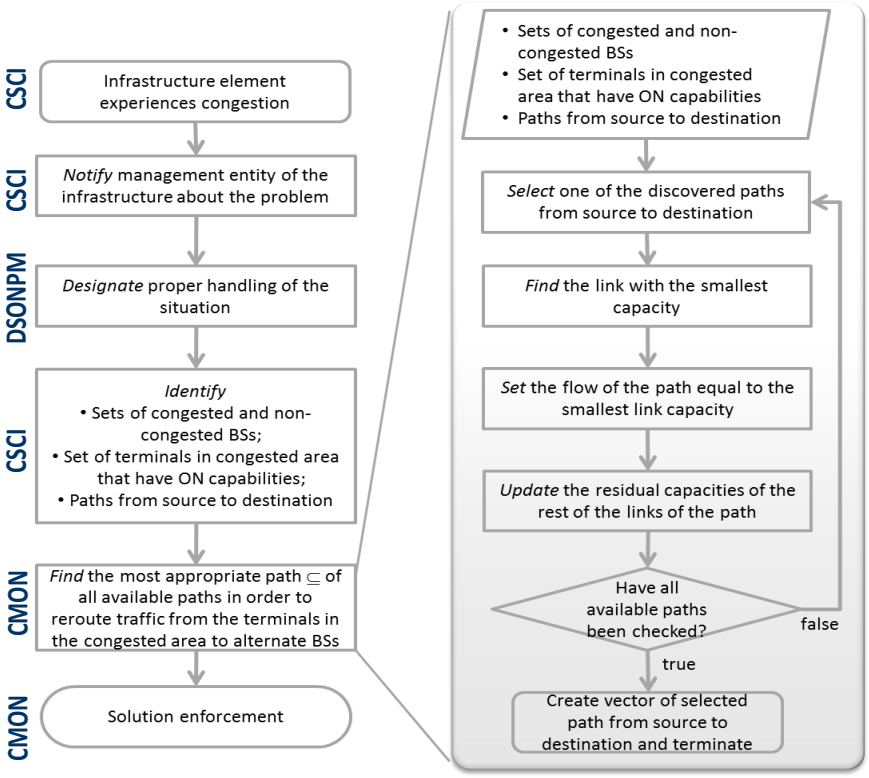


Figure 37: Algorithm on capacity extension of the infrastructure through neighbouring terminals

3.3.1.3 Selection of nodes through a fitness value evaluation

According to the OneFIT concept, ONs are created in an infrastructure-less manner under the supervision of the operator and include numerous network-enabled elements. To ensure application provisioning in an acceptable QoS level, the selection of the proper nodes, among all discovered nodes in the vicinity is rather essential. As a result, this approach proposes a mechanism for selecting nodes that will participate to the ON. The selection mechanism is based on a fitness function which is a weighted, linear formula which takes into consideration the following:

- Candidate node's energy level;
- Candidate's node availability level which shall take into account:
  - Capabilities (e.g. available interfaces/supported RATs, support of ON);
  - Status of each node in terms of communication resources (e.g. status of the active links), storage (e.g. available buffer/cache), computing resources;
  - Node's location;
  - The ability of a node to support a requested application;
- Candidate node's delivery probability (i.e., ratio of successfully transmitted packets to messages received by a node).

For example, if a neighbouring node does not have available buffer/cache because it is loaded with data packets waiting to be delivered, then the node is considered as unavailable, despite the fact that in terms of other parameters (e.g. energy) that node may perform in an acceptable level.

In the OneFIT platform, the input of the algorithm consists of the set of candidate nodes which are located in a specific service area that have ON capabilities (i.e., they have the ability to participate in an ON) and they are legitimate to participate in an ON according to the operator policies, in order to stress on the operator-governance during the ON formation. The output of the algorithm consists of the selected nodes that will form the ON. Then, the ON creation procedure is triggered in order to allow the nodes/terminals to negotiate between each other and establish links. A flowchart of proposed algorithm is provided through Figure 38.

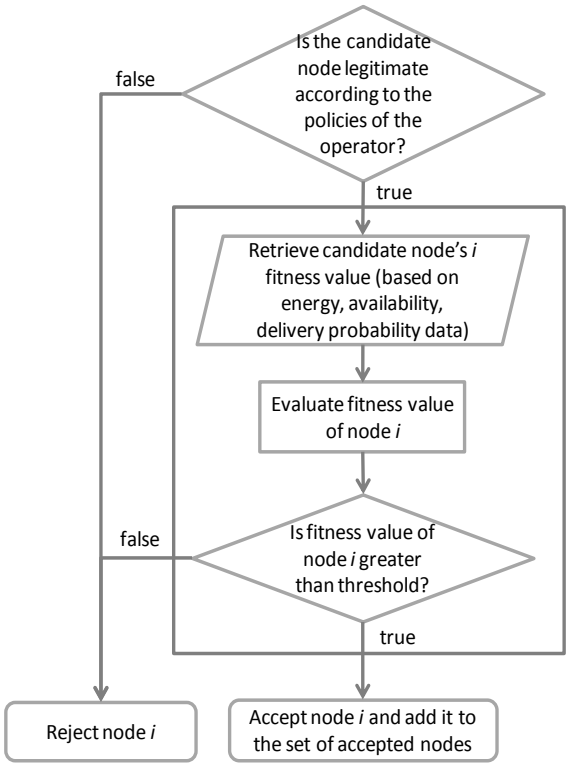


Figure 38: Algorithm on selection of nodes through a fitness value evaluation

The algorithm is implemented in the OneFIT prototyping platform described in section 2.1. The target of the demonstration is to depict the selection of nodes according to their fitness values as dictated by the algorithm in order to form an ON. The technical challenge of the algorithm is relevant to the Scenarios 1 and 2 related to "Opportunistic coverage extension" and "Opportunistic capacity extension" respectively which was identified in [3].

Figure 39 provides an illustration of the implementation of the selection of nodes through a fitness value evaluation concept in the OneFIT platform.

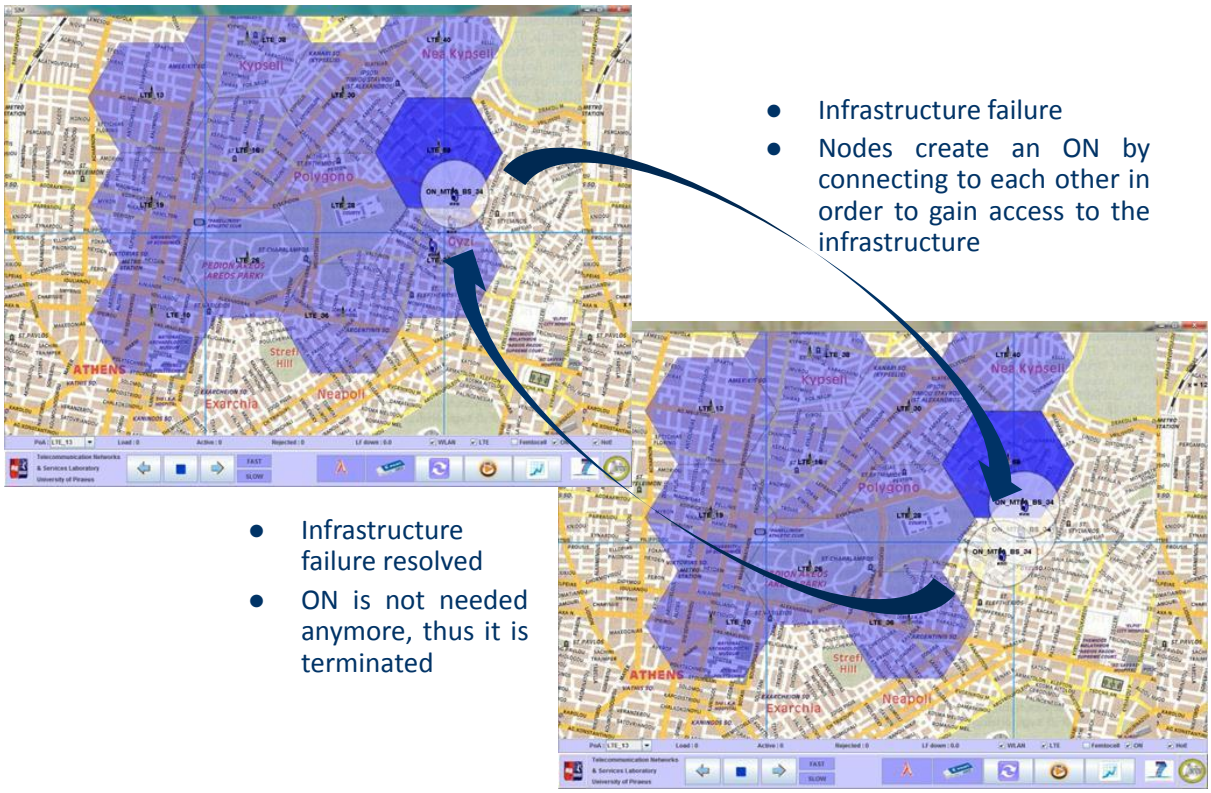


Figure 39: Implementation of the selection of nodes through a fitness value evaluation concept in the OneFIT platform

3.3.1.4 Route pattern selection in ad-hoc networks

The route pattern selection algorithm is executed on the terminals, which are working in an ad-hoc environment, in the test-bed presented in section 2.4.

The algorithm is not particularly dedicated to one phase of the opportunistic network's lifecycle; it applies as an intermediate layer for enabling of C4MS services. The algorithm fulfils the C4MS discovery service and the message forwarding and routing in the multi ad-hoc environment. For every packet (user data or signalling message), which is to be transmitted over the air through the opportunistic network, the algorithm is triggered to determine and establish the most appropriate route to reach the infrastructure.

The purpose of the algorithm is to establish and select the most appropriate route, in order to fulfil the QoS (or QoE) requested by the user applications. The algorithm also takes into account the handling of the signalling information exchanges by the application protocols.

For every message (user data or signalling messages), which is to be transmitted through the opportunistic network, the algorithm determines and selects the best route for transmitting the data to the destination.

The algorithm takes as an input the information provided by the lower layers and information provided by other nodes of the opportunistic network through the C4MS protocol. The information and metrics necessary to process the algorithm are contained in the knowledge database described in D3.3 [7].

The C4MS discovery service is fulfilled by an active mechanism by exchanging routing messages between nodes involved in the opportunistic network. The C4MS forwarding/routing feature is fulfilled by the algorithm, which selects the routing pattern according to the QoS requested by user's application and depending on the constraint related to the data transmission to be performed.

3.3.1.5 Application cognitive multi-path routing in wireless mesh networks

This algorithm falls into group of route selection and management algorithms. Its main function is selection and establishment of appropriate set of multiple paths in the wireless backhaul side of the wireless mesh networks (WMNs) in order to opportunistically achieve aggregation of the backhaul bandwidth. In this way, higher levels of backhaul bandwidth utilization and load balancing can be achieved. Algorithm addresses OneFIT scenario 5. More precisely a use case "Opportunistic backhaul bandwidth aggregation in unlicensed spectrum" is addressed. More detailed description of the algorithmic solution can be found in D4.2 [9].

The algorithm makes decision whether or not to create opportunistic network for providing multi-path routing as a solution for the detected problem. Besides having responsibility to decide when to kick in with the multipath routing, the algorithm also selects the multiple paths set which is able to provide required level of bandwidth aggregation and satisfy necessary QoS requirements of the used application. The net effect of opportunistic backhaul bandwidth aggregation is to match the access bandwidth of modern wireless technology with the adequate transport bandwidth in the backhaul/core network. The proposed solution makes use of OLSR as underlying routing protocol in the WMN. Necessary contextual data is gathered from WMN nodes with simple network monitoring protocol (SNMP). Decision making algorithm resides on the centralized management server, which monitors network status/state with SNMP protocol and stores gathered contextual data into database. The suitability determination phase of the algorithm is shown in Figure 40.

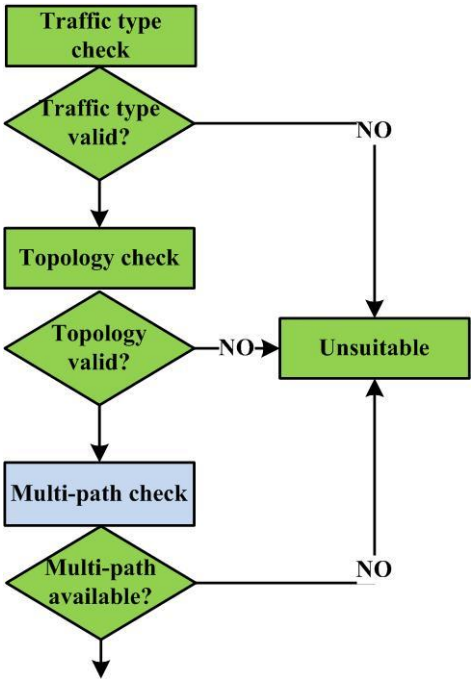


Figure 40: Suitability determination phase of the multipath routing algorithm

Three access traffic types are identified for the suitability determination phase:

- *Type 1* represents the case where all of the access traffic belongs to one user who is using one application which is sensitive to packet reordering and jitter (i.e. VoIP, live video streaming);
- *Type 2* represents the use case where all of the access traffic belongs to one user who is using one application which is not sensitive to problems which may arise from transferring packets over multiple paths (i.e. download);
- *Type 3* is the case where access traffic is generated by one user who is using several independent applications;
- *Type 4* is the case in which access traffic is generated by a number of users.

When trigger is detected, or predicted, the ON suitability determination phase starts. This phase is composed of three tasks performed in sequence. The task #1 is traffic examination with aim to determine which of the four types of access traffic, mentioned above, is responsible for the backhaul congestion at AP_i. Should the access traffic examination classify the problem in hands to be of *type 1,* then multi-path routing is considered as inappropriate solution and ON suitability determination results in the negative outcome. For all other *types* the control algorithm proceeds to the task #2, which is topology check (see Figure 40). The goal is to determine whether or not the given WMN topology allows for multiple paths to be formed in order to relieve the congestion at the node AP_i. It is important to note that should the AP_i happen to be a leaf node with only one neighbour it cannot be provided with more bandwidth if the link connecting it to its only neighbour is a bottleneck link on the current path. Finally, task #3 of the suitability determination (see Figure 40) is performing a check on whether or not an appropriate path can be found, which will, in addition to the current path, provide aggregation of the available backhaul bandwidth on the access side of AP_i.

Task #3 has two main parts. In the first one, paths, which are link disjoint (with regard to the detected bottleneck link) with the current path, are determined. Next, candidate paths are examined with respect to QoS constraints and aggregated backhaul bandwidth, which they can achieve in cooperation with the current path for AP_i. Paths, which are selected as solutions for the previous bandwidth aggregation problems for AP_i, are evaluated by the measured performance of the selected solution. Those paths which don't result in satisfying performance (they are unstable, interference is increased, necessary aggregation is not achieved) are penalized. On the other hand the penalty for a selected path is decreased (until 0 is reached) when a provided solution results as expected. When a certain threshold in a penalty is reached, the path will not be taken into account as a solution for a problem. High penalty value (equal to threshold) has a cool-down period (certain number of executions of the algorithm) after which it is decreased in order to give the problematic path a new chance to prove its value. Described process of penalization is in line with the reinforced learning paradigm. The first path satisfying all of the constraints and requirements is selected as a solution in order to provide faster decision making. To achieve fairness in path selection, a set of all available paths for AP_i is randomly shuffled before algorithm is executed. In this way, all appropriate paths will be tested as a solution and, in time, a penalization process will sort them out.

The suitability determination tasks execution sequence depicted in Figure 40 facilitates the fastest possible decision making. This is achieved by starting the suitability determination with task #1 which is the least demanding in terms of execution time. Determinations associated with task #2 are somewhat more demanding. Nevertheless the most demanding determination is left for the task #3 which is performed only if the previous two tasks return positive outcome and warrant further engagement of computational resources.

The ON suitability determination can return three possible outcomes: (1) the multi-path is not suitable for the identified problem, ON will not be created among WMN nodes which continue with single path routing, (2) the combination of the current path with any other candidate path cannot

provide solution (try suitability determination with different combinations of paths, which don't include the current one – subject of future research), (3) additional path to the current one is successfully selected. This additional path will trigger the ON creation.

3.3.2 ON creation

This section addresses the implementation of the ON creation stage in the different components of the OneFIT demonstration platform. First, the section starts with the implementation in the case of the spectrum opportunity identification and selection test-bed. Then, the implementations in the prototyping platform for the management of opportunistic networks are presented, for the cases of the capacity extension scenario. After this, the multi-flow routes co-determination algorithm used by the opportunistic ad-hoc network demonstrator is presented, followed by the QoS and spectrum-aware routing techniques. The section concludes with the ON creation stage of the application cognitive multi-path routing for the wireless mesh networks test-bed, and the UE-to-UE trusted direct path.

3.3.2.1 Spectrum Opportunity Identification and Selection

The focus of the test-bed presented in section 2.8 is on the procedures related with spectrum opportunity identification and selection, while it is assumed that the decision to create an ON among two devices has been previously made in the ON suitability phase. Then, the focus is on the ON creation and ON maintenance stages. Similarly, a network-centric operation is assumed, in which the infrastructure makes the spectrum selection decisions.

The implemented procedure for the ON creation is shown in Figure 41. The steps of the procedure are explained below. It is assumed that, as a result of the ON suitability determination phase, UE#1 has determined that the direct link establishment can be assisted by the infrastructure.

1. A MIH_C4MS_ONN.request message is sent from UE#1 to the infrastructure to start the ON-Negotiation procedure intended to obtain a valid configuration of the radio link. The message indicates the terminals involved and the QoS requirements that the link is expected to support, in terms of required bit rate. It is assumed that the information in terms of supported bands by the terminals is already known by the network (e.g. obtained during the suitability stage).
2. The infrastructure sends a MIH_C4MS_ONN.request to UE#2 in order to inform the terminal about the intention to establish a direct radio link with UE#1 and allow it to join the negotiation process for the derivation of the radio link configuration;
3. UE#2 replies with a MIH_C4MS_ONN.response message to BS by means of which it notifies its acceptance for the establishment of the link;
4. At this point, CSCI/CMON entities in the BS send an inquiry to the Dynamic Spectrum Management (DSM) entity to determine spectrum availability for the link. As a result of this inquiry, the spectrum opportunity identification algorithm is executed to determine the available spectrum blocks.
5. DSM reply provides the CSCI/CMON entities in the BS with the available spectrum blocks. This is used by the Spectrum Selection algorithm to decide on the spectrum to be allocated to the link.
6. The proposed ON configuration with the selected spectrum is transferred to UE#1 by issuing a MIH_C4MS_ONN.response message. This message also includes the ON identifier to be used in future communications.

7. To create the ON, the UE#1 sends a MIH_C4MS_ONC.request to the BS with the final ON configuration;
8. BS sends another MIH_C4MS_ONC.request towards UE#2 with the final ON configuration;
9. UE#2 replies with a MIH_C4MS_ONC.response message where a successful result-code is reported to indicate that the terminal is ready to establish the link;
10. BS concludes the ON creation procedure by sending a MIH_C4MS_ONC.response message to UE#1;
11. The link establishment takes place at this point;
12. Finally, the creation of the ON is notified to the infrastructure from UE#1 by sending a MIH_C4MS_ONSN.indication message.

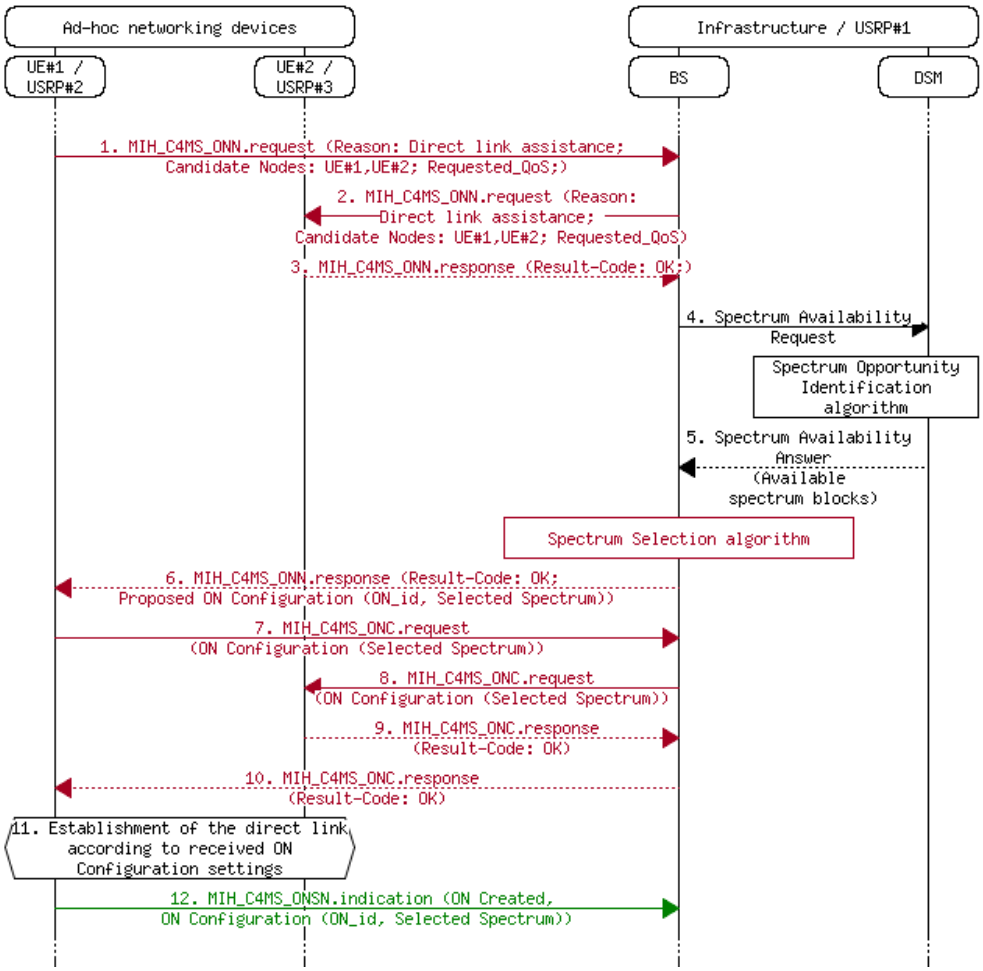


Figure 41: Implemented message exchange for the ON creation.

From an algorithmic perspective, the problem considered in the test-bed is the selection of the spectrum to be assigned to a set of radio links between a pair of terminals and/or infrastructure nodes. The purpose of each radio link is to support a certain CR application with certain bit rate requirements. The algorithm uses as input the set of available spectrum pools resulting from the spectrum opportunity identification, together with the characteristics of each pool in terms of available bit rate based on radio considerations.

The algorithm makes use of the fittingness factor concept as a metric to capture how suitable a specific spectrum pool is for a specific radio link [9]. Different statistics regarding the observed fittingness factor based on the accumulated experience are stored and used to make decisions. The spectrum selection is done either when a new application needs to be established or as a result of changes in the radio conditions or in the current active links.

The following two algorithms are implemented in the test-bed, and executed at the infrastructure as reflected in the message sequence chart of the ON creation in Figure 41.

3.3.2.1.1 Spectrum Opportunity Identification algorithm

The spectrum opportunity identification is at the DSM entity of the infrastructure. The algorithm executes two different procedures: the measurement procedure and the spectrum block formation.

In the measurement procedure, the total band (i.e. in the platform the ISM 2.4 band) is subdivided in N smaller portions of equal band Δf. The measurement algorithm consists in performing an energy detection sensing (during a period of time Δt) for each Δf portion until measuring the total band, starting from frequency F_min_band. This measurement is repeated Num_Meas times. Then, based on the multiple measurements carried out, the opportunity index is obtained for each portion, defined as the fraction of measurements in which this portion has been detected as available.

In the spectrum block formation procedure, the consecutive spectrum blocks with opportunity index above a certain threshold are grouped in blocks. Each block is formed by a maximum of P_{max} portions (i.e. in case there are more than P_{max} consecutive portions, they are splitted in different blocks).

For each block, the algorithm returns the 2-tuple $SB_k = (f_k, BW_k)$ composed of the following parameters:

- f_k central frequency of the block;
- BW_k is the bandwidth of the block.

The reader is referred to [9] for the detailed pseudo-code of this algorithm.

3.3.2.1.2 Spectrum Selection algorithm

During the ON creation stage, the spectrum selection algorithm is executed at the infrastructure node whenever a new link has to be established

The algorithm is based on estimating the fittingness factor for each link and available spectrum block based on a knowledge database that is maintained with different fittingness factor statistics. Details on the algorithm, including its functional architecture and the statistics stored in the knowledge database are given in [15] and [9].

The algorithm takes as inputs the list of available spectrum blocks provided by the DSM after execution of the spectrum opportunity identification algorithm, the bit rate requirements of the link to be assigned, the list of current assignments, and a database with different statistics capturing the historical evolution of the fittingness factor that is obtained based on measurements of link context information when the different links utilise the available blocks.

The algorithm output is the list of spectrum assignments to each of the existing links.

The reader is referred to [9] for the detailed pseudo-code of this algorithm included in the demonstration platform.

3.3.2.2 Capacity extension of the infrastructure through neighbouring terminals

In this phase, the CMON of the selected BS, i.e. the congested BS that will execute the Ford-Fulkerson algorithm, needs to collect the possible paths from the terminals of the congested BSs to non-congested areas. Therefore, the following procedure takes place:

- The CMON of the selected BS sends a message (an ON_Negotiation.Request according to C4MS) to the CMONs of the other congested BSs in order to request the aforementioned paths;
- The CMONs of the congested BSs forward the message to the CMONs of the terminals with ON capabilities and a discovery process starts. As soon as the paths are discovered, an answer is sent back to the CMONs of the congested BSs and to the CMON of the selected BS.
- The CMON of the selected BS has acquired the necessary information and the Ford-Fulkerson algorithm is executed.

The output of the algorithm consists of the selected paths for each terminal with ON capabilities for which the flow is maximized, as described in [9]. A path includes a starting point (e.g. a terminal in the congested region), an ending point (e.g. a BS), and the links that create the full path from the starting to the ending point (each link is identified by a starting point and ending point each of which is an intermediate node).

The algorithm is implemented in the OneFIT prototyping platform described in section 2.1. The target of the demonstration is to depict the formation of paths as dictated by the algorithm in order to redirect traffic from congested to non-congested BSs. The technical challenge of the algorithm is relevant to the Scenario 2: “Opportunistic capacity extension” which was identified in [3].

The algorithm is executed to the CMON agent of the BS and ONs are created that redirect a number of macro-terminals to alternative BSs, as can be seen at the figure below.

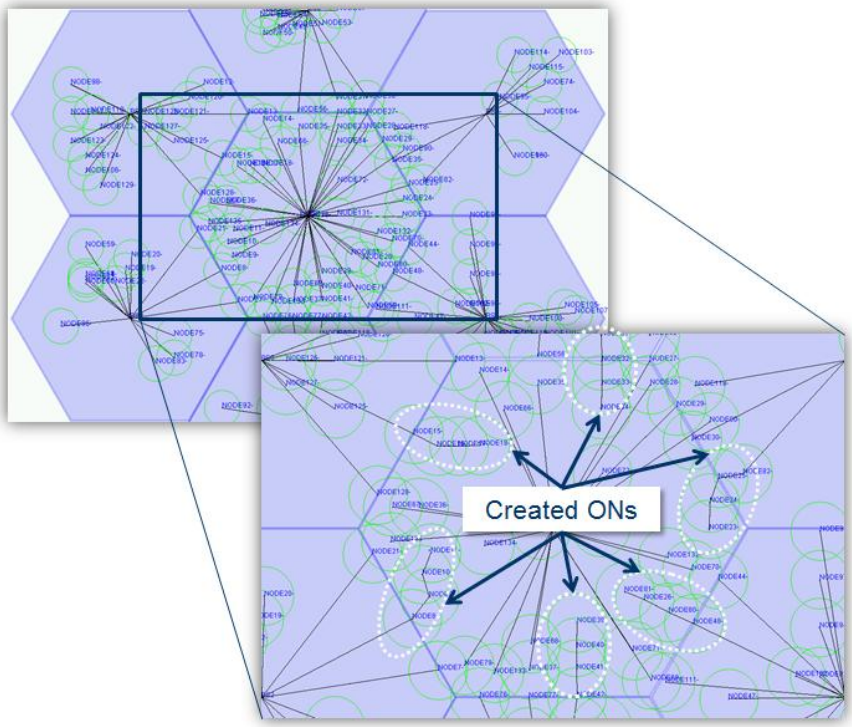


Figure 42: Resolution of hotspot situation by redirecting traffic to alternate BSs

3.3.2.3 Selection of nodes through a fitness value evaluation

The algorithm presented in section 3.3.1.3 was used in the ON suitability identification stage to select the nodes that will form the ON. With the selected nodes, the ON creation stage is triggered (for more details about the algorithm please refer to D4.2 [9]).

3.3.2.4 Capacity Extension through femtocells

The problem considered in this section is the capacity extension of congested infrastructure through the exploitation of deployed femtocells. More specifically, an area is considered which contains a macro BS, terminals served by the BS and femtocells within the area of the BS. At some point, the macro BS faces congestion issues due to the traffic by the macro-terminals. The solution provided in this section is to offload the traffic of a proportion of the macro-terminals to the femtocells, through the creation of an ON among the terminals and the femtocells. The main objective of the algorithm, namely Dynamic Resource Allocation (DRA) that will provide the solution is not only to reroute macro-terminals to the femtocells, but also allocate the minimum possible power level to femtocells, that is required to cover the most users possible. In addition, the algorithm exploits the RAT-Demand-QoS Assignment (RDQ-A) algorithm [19] in order to assign terminals to femtocells and QoS (in terms of bit-rate) to terminals. Furthermore, the algorithm utilizes an objective function (OF) to evaluate the quality of each solution.

The functionality of the algorithm can be described in steps as follows. At *Step 1* the algorithm starts by configuring all femtocells to operate at their minimum power-level. At *Step 2*, for this minimum power allocation, which corresponds to a minimum coverage, the terminals are assigned to femtocells using a variation of the RDQ-A algorithm [19]. *Step 3* inspects whether all terminals are assigned to femtocells or if all femtocells have reached their maximum transmission power the algorithm ends. If not, the launch of *m* sub-problems is triggered at *Step 4*, where *m* is the number of femtocells that have not reached the maximum transmission power. At each sub-problem, the power-level of a different femtocell is increased to the next power-level resulting to different power-allocations $(A_{PF})_1,\ldots,(A_{PF})_m$. Each sub-problem is processed simultaneously at *Step 5*. More specifically, for each sub-problem the RDQ-A algorithm is executed and the assignment A_{UF} of terminals to femtocells and the assignment A_{QU} of QoS to terminals are computed. The selection of the best triplet takes place at *Step 6*, in terms of minimization of the *OF*. Finally, the algorithm performs a transition to *Step 3*.

After the termination of the above steps, the femtocells are configured to the power level at which they lastly acquired at least one terminal. The reason is that otherwise all femtocells could be configured to operate to their maximum transmission power. Figure 43 illustrates flow-chart of the DRA algorithm.

Specifically, the following procedure is followed in order to collect the input needed by the algorithm:

- As soon as the problematic situation is identified, the CSCI of the congested BS notifies the DSONPM;
- The DSONPM acquires the status of the deployed femtocells in order to construct the set of femtocells that will help the congested BS and the information is sent to the CSCI of the congested BS;
- The CSCI forwards the information to the CMON that also acquires profile information for each user;
- The DRA algorithm is executed and the decision is sent to the CMONs of the terminals and the femtocells.

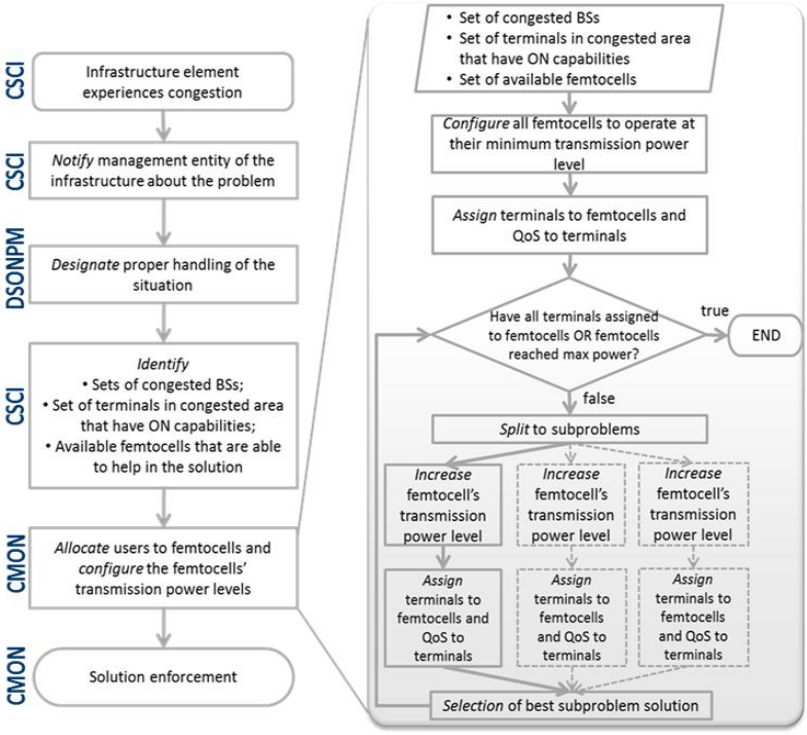


Figure 43: Flow-chart of the DRA algorithm.

The algorithm is implemented at the OneFIT prototyping platform described in section 2.1. The target of the demonstration is to depict the allocation of power levels to femtocells through which the femtocells are able to serve more terminals. The technical challenge of the DRA mechanism is relevant to the Scenario 2 [3], and specifically for Use case 2: "Macro-cell/femtocell management", where resources are allocated to femtocells which are integrated then to ONs. The algorithm is executed to the CMON agent of the BS and an ON is created that redirects a number of macro-terminals to the femtocells and power levels are allocated to the femtocells. Figure 44 illustrates a screenshot from the prototyping platform. The dark blue hexagon corresponds to the coverage of a macro BS, while the circles within the hexagon depict the coverage of the femtocells. The inner circles present the minimum coverage of the femtocells, while the outer circles depict the coverage of the femtocells after the execution of the DRA algorithm.

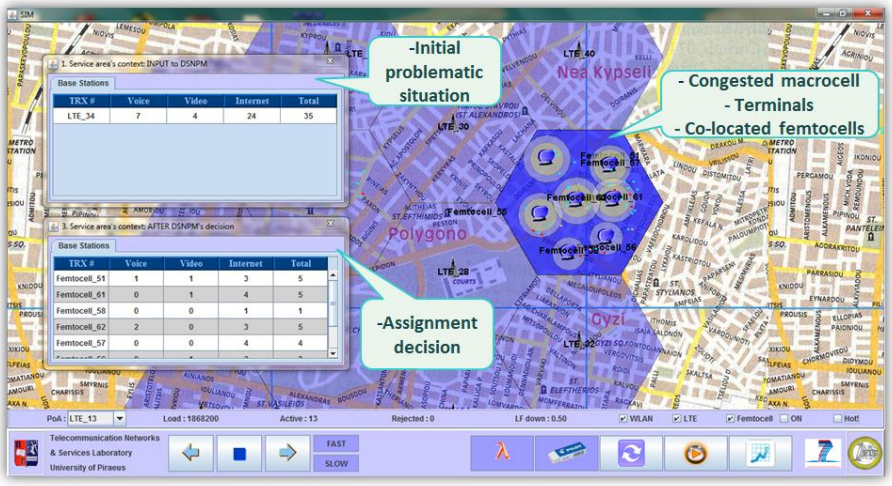


Figure 44: A screenshot of the prototyping platform, regarding the capacity extension through femtocells scenario

Figure 45 illustrates a screenshot from the statistics that are collected by the DSONPM, e.g. the allocation of power levels to femtocells and the assignment of terminals to femtocells.

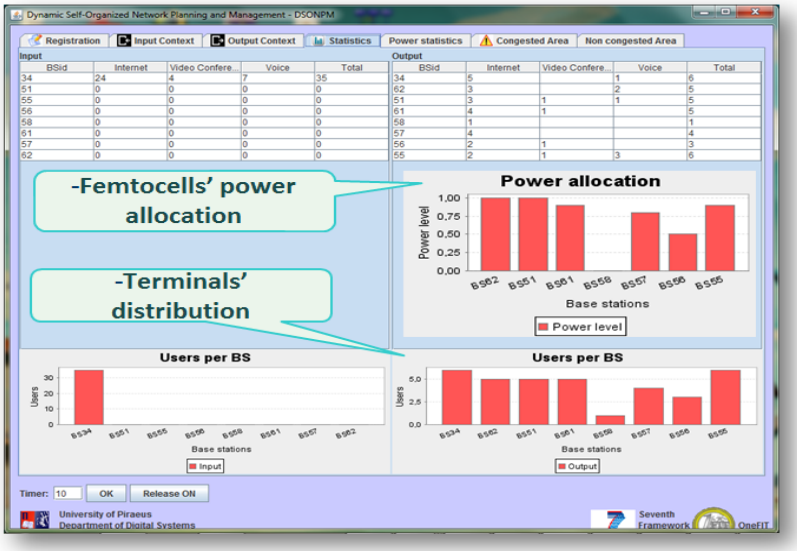


Figure 45: A screenshot from the DSONPM

3.3.2.5 Multi-flow routes co-determination

The multi flow routes co-determination algorithm, which is fully described in D4.1 [8], is executed on the terminals, which are working in an ad-hoc environment. It adapts routing algorithms, enriching the flooding (called MTopo messages) and path detection messages (called MEstab messages), to define topology patterns which different flows may use to combine the packets sent to improve the bandwidth of the traffic flows. Implementation of the algorithm in the OneFIT validation platform is described in [9].

This phase of the algorithm is applied to each traffic flow. It consists of the memorization, for each node in the neighbourhood of a traffic path coming from the ingress node, of the distance in a number of nodes to the traffic ingress, and of the precedent nodes identifier to access to this originator ingress node.

The selection of short paths to the ingress node traffic can be considered as a restriction, to restrict the flooding to n-hops distance, potentially dependant on quality of service requirements such as latency. The application of our example is shown in Figure 46 on a 3 hop bounded flooding exploration.

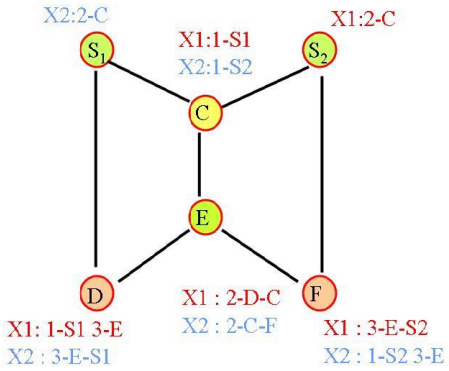


Figure 46: Step 1 of the algorithm

Detection of potential "pivot" nodes candidates from egress nodes

This step of the algorithm consists, periodically from candidate egress nodes by sending specific messages, to send information on these flows. These messages, called Mtopo messages contain the following fields:

- **Lf** flows list;
- **Lp** list of optimisable flows with network coding;
- **Firstcod** list of the first node identifiers to which the network coding may be applied, and the distance **Ldp** of the path to which the network coding will be applied;
- **Nd** list of egress nodes;
- **Ln** list encoding the tree of the paths explored;
- **Lft** list indicates, for each path of the **Ln** tree, the flow id of path including the ingress node of the flow.

In the following figures, the symbol  represents Mtopo messages.

As illustrated in Figure 47, a node (in the example the node E) receiving such message from different egress node has the sufficient information to determine if it can be such a potential "pivot" node. The egress nodes that can send such messages are egress nodes of several flows.

Messages relayed from potential "pivot nodes"

The pivot node identification is "pushed" to the nodes that potentially transfer the flows (in the example 2 flows).

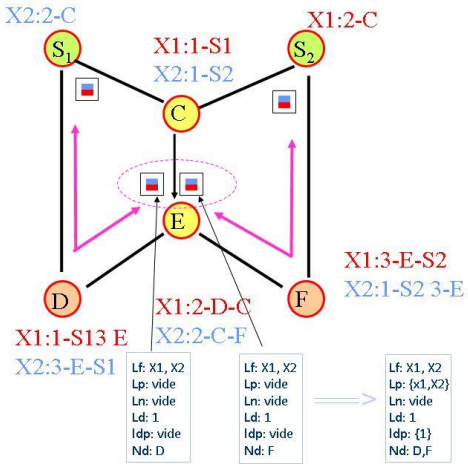


Figure 47: Step 2 of the algorithm

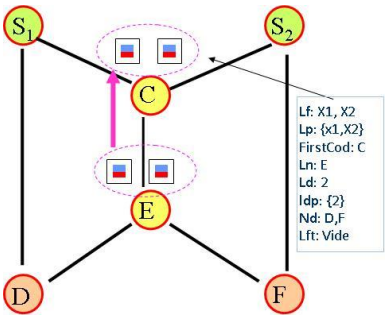


Figure 48: Step 3 of the algorithm

Decision function on ingress nodes

The messages are finally sent to the ingress nodes. From the information received from the different paths of this information, network coding is applicable only if one path is common with another flow (i.e. with a message coming from a node identified as a potential network coding pivot node) and one another. The network coding decision will be applied taking care of the different constraints required for the traffic flow (latency, resource allocation capabilities, link stability). In case of network coding application decision, the flow is reinitiated with the information of network coding application sent to the respect nodes. The network coding is actually applied on a "pivot" candidate node if the node receives information from the two originator nodes. Protocol between the ingress nodes and the pivot node may be defined to know if the ingress nodes decide or not to apply network coding.

The Mtopo messages transmitted to the ingress nodes provide the sufficient information to detect the topology information to decide if a network coding is applicable.

In the example, the ingress node S1 (resp. S1) has the knowledge:

- Of a path S1-D (S2-F) over which the traffic flow X1 (resp.X2) may be transmitted;
- Of a tree S1-C-E-D;F over which the flows X1 and X2 may be transmitted, with 2 nodes encoding of the two flows from the node C;
- Of a path transmitting the X2 (resp.X1) flow from the ingress node to the egress node F (resp.D).

The S1 and S2 nodes have the sufficient information to (re)establish the optimal traffic routes as depicted in Figure 49 and labelled "Routing based Network Coding".

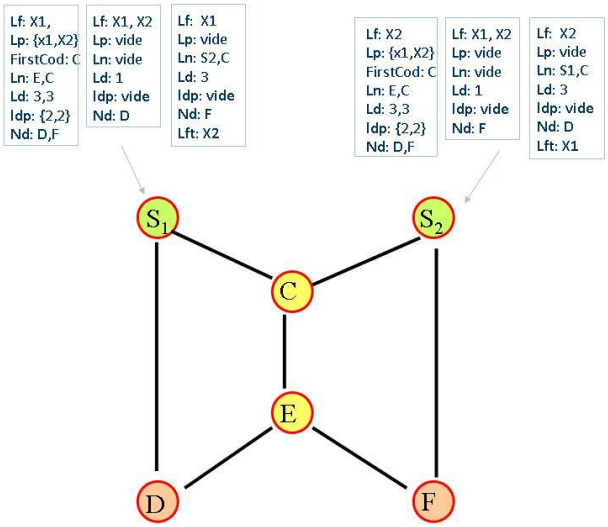


Figure 49: Step 4 of the algorithm

Traffic paths re-establishment

The fifth step is the network coding application on common path and decoding on the egress nodes. The ingress nodes assign the route establishment in transmitting to the next hop nodes of the traffic path defined, MEstab messages including:

- The flow identifier, and any other parameter needed to initiate the traffic;
- Flows coding authorization, with the flows identifiers;
- The first node identifier to which the coding will be applied;
- The nodes tree to access to the egress nodes.

Each node receives the MEstab message:

- Allocate the resources needed to initiate the traffic;
- Suppresses its id in the nodes tree;
- Transfers the message to the neighbouring nodes of the tree.

If the first node identifier in which the coding will be applied is the current node, the node memorizes the information and will proceed with the coding of the flows at the receipt of packets of the flows.

3.3.2.6 QoS and spectrum – aware routing techniques

This algorithm belongs to the group of route selection and management algorithms. Its main function is establishment and maintenance of spectrum-aware paths in the wireless access of the ONs. The proposed routing protocol makes use of the available channels opportunities for the purpose routing/forwarding data. The algorithm uses as input the set of available spectrum pools resulting from the spectrum opportunity identification procedure, together with the characteristics of each pool in terms of available bit rate based on radio considerations. The spectrum selection is done either whenever a new path needs to be established or paths reconfigured as a result of changes in the radio conditions or channel availability.

Details on the implementation of the algorithm on the WARP-based platform have been presented in [9]. In the following, a summary of the involved procedures is presented.

A central entity in the BS is assumed to receive updates on route and channel availabilities from the ON nodes and continuously calculates the shortest paths between all pair of nodes considering their channel availabilities.

The spectrum aware route calculation algorithm uses the ETX metric [20] which makes use of the predicted number of data transmissions required to send a packet over a link. ETX metric combined with Dijkstra shortest-path algorithm have been integrated into the base OLSR protocol to form the spectrum aware routing algorithm. Basically the modified version of OLSR routing protocol provides the information for the spectrum aware algorithm to start running and finding the path with highest throughput. The algorithm runs continuously - locally at ON nodes and centrally i.e. at Base Station. Since ON nodes running OLSR routing algorithm only have local information (regarding global network graphs), they cannot provide optimal solution in certain situations e.g. when topology changes rapidly, so the algorithm needs to also be running at the access point/central level to increase the responsiveness of the network to topology changes.

The proposed algorithm is not scenario/use-case specific. The pseudo-code of proposed algorithm is provided in [9].

The target of the demonstration is to show route selection and reconfiguration based on available spectrum opportunities in ONs. The routing protocol follows two phases of route setup and maintenance. At setup phase all the routing tables are created and the network nodes become connected. Route maintenance phase is when entities of the routing table are periodically updated to maintain the best and most stable routes whilst avoiding interference with both secondary users and primaries.

3.3.2.7 Application cognitive multi-path routing in wireless mesh networks

The application cognitive multipath routing algorithm for WMNs provides creation of the ON for supporting establishment of multiple paths in the backhaul side of the network. Suitability

determination phase provides a set of paths which, when combined with the current paths, provide the required level of QoS and bandwidth aggregation.

The algorithm sends configuration messages over TCP protocol. Within these messages are commands for the OpenWRT system operating at open platform WMN APs. First, links which need to be established in order to enable creation of necessary paths are identified. The command sequence is as follows:

- Set wireless channel of the interface (802.11a channel selected in way which minimizes the possibility of interference with the existing wireless links in the backhaul – spatial channel distribution);
- Enable the dormant wireless interface;
- OpenWRT takes into account the up status of the interface;
- Set the new interface into the mesh mode (logically and physically);
- Restart the OLSR daemon running on a WMN AP in order to update the routing tables and let the OLSR know about the new available path over the backhaul link which is brought up.

The same sequence is performed on every pair of nodes comprising the wireless backhaul links which need to be established. The opportunistic multiple paths from one WMN AP to one or more WMN GWs are created and the underlying routing protocol (OLSR) recognizes them.

3.3.2.8 UE-to-UE trusted direct path

The main objective of the demonstrated algorithm is the optimal creation of one or more WLANs to interconnect a set of candidate nodes (twin-mode Cellular + WiFi terminals) to form an ON.

Note that 2 options were considered in WP4 for the WLAN setup: normal infrastructure-based (one UE playing the role of an AP) WiFi mode and WiFi Direct mode which is an enhancement of WiFi ad-hoc mode. In WP5, the normal mode option has been implemented. The implementation of the WiFi Direct option was not judged necessary, given that the outcome of the algorithm is identical in both options, only associated protocol procedures are different.

The algorithm considers the following criterion:

- To ensure the foreseen QoS requirements of the ON members;
- To minimize the use of spectral resources;
- To minimize the use of the nodes' power.

Inputs to the algorithm:

- The list of candidate nodes to be connected;
- The geo-location coordinates of each of these nodes;
- A forecast of per-link (node to node) QoS requirements;
- Per-node measurements of different WiFi channels.

Outcome of the algorithm is a WLAN configuration made of:

- Structure: one or more (interconnected) SSIDs;
- Spectral resource allocation: a WiFi channel allocated to each SSID;
- Organisation: per SSID, a node nominated as Access Point.

To ensure that the foreseen QoS/traffic for the ON can be supported, the chosen method makes use of global link capacity computations, per WiFi channel in the ON area, for comparison to a pre-determined Target QoS which is assumed available from previous phase (Suitability Determination). The algorithm is used in Creation and Maintenance phases of the ON Life Cycle and therefore pertains to the CMON entity. It is running on the infrastructure side as it requires links to the candidate UE's prior to the establishment of any inter-UE link, so the cellular links are used for the necessary C4MS exchanges. The algorithm is applicable to any scenario which ensures that all candidate nodes have operational cellular links allowing C4MS exchanges. Therefore the out-of-coverage scenario is excluded.

The target of the demonstration is to demonstrate allocation of resource channels necessary for direct to direct communication between UEs based on the implemented algorithm. The algorithm is implemented at the OneFIT prototyping platform described in [2]. An overview of the demonstrator environment is given in Figure 50.

The validation platform comprises a femtocell providing 3GPP cellular network, Android UEs embedding Gingerbread Android version 2.3 and supporting cellular network and WiFi access.

UE is registered on the 3GPP cellular network through femtocell and integrates local CMON agent to communicate with the CMON agent of the BS. UE is reporting necessary information using C4MS exchanges. The relevant information is an input to the algorithm (e.g.: geo-location, WiFi channel measurements reports...) allowing taking decision to setup an ON. Operating system of the UE was modified to allow setting WiFi channel selection for direct to direct communication establishment according to the received information.

Based on the algorithm an ON can be created to establish suitable device to device connections between Android terminals using the most suitable WiFi channel as determined by the algorithm.

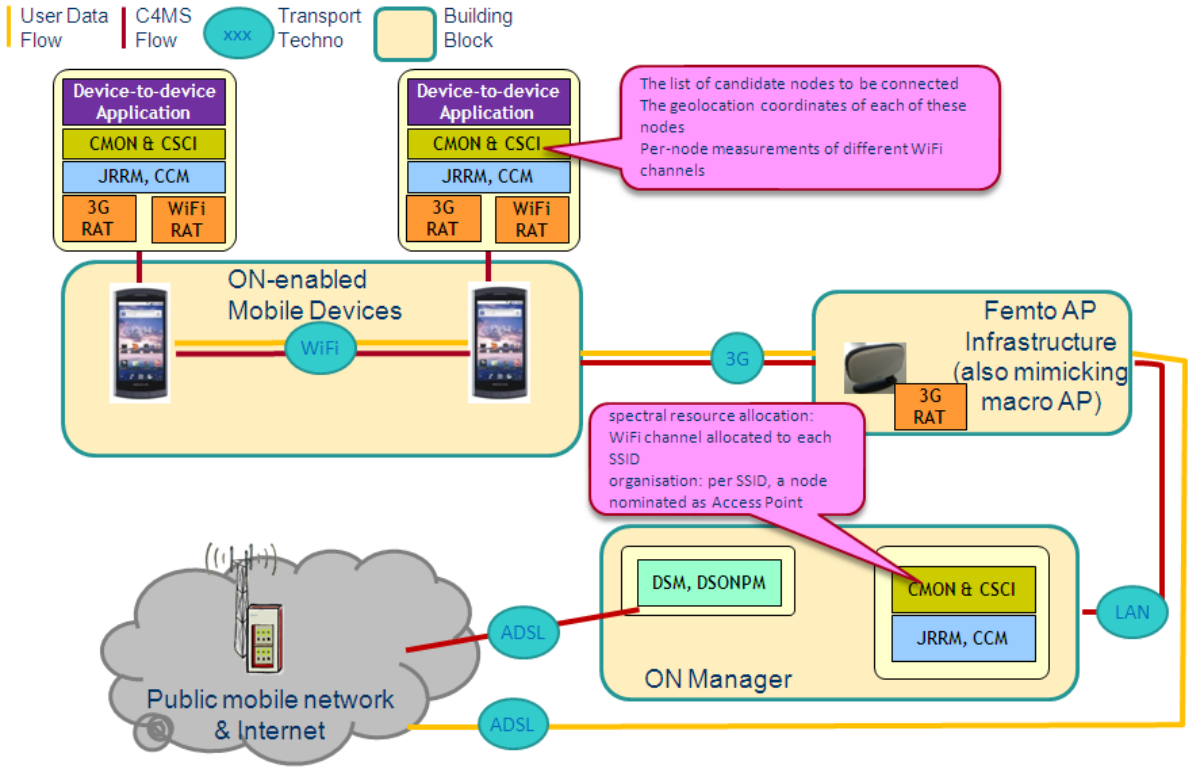


Figure 50: Demonstrator environment overview

3.3.3 ON maintenance and termination

This section presents the implementation of the ON maintenance and termination stages in the different elements of the demonstration platform. In some of the cases, the implementation is the same as in the ON suitability determination or the ON creation stages. In such cases, just a reference to the previous section has been given. Specific implementations are given for the spectrum opportunity identification and selection test-bed and for the application cognitive multi-path routing in wireless mesh networks.

3.3.3.1 Spectrum Opportunity Identification and Selection

During the lifetime of the established radio link between both devices, context changes might occur that makes the ON to be reconfigured in order to keep fulfilling its objective. Figure 51 describes the MSC of an ON reconfiguration process that could take place during the ON maintenance phase as will be shown in the demonstration in the context of the Spectrum Opportunity Identification and Selection test-bed presented in section 2.8. The description of the different steps is as follows:

1. UE#1 detects that the radio link is not performing as expected. In the demonstration, this will be due to interference generated in the spectrum currently in use in the radio link connecting UE#1 and UE#2;
2. As in the creation phase, it's considered that ON operational policies dictate that the direct link establishment can be assisted by the infrastructure so that a MIH_C4MS_ONN.request is sent from UE#1 to the infrastructure. This message will indicate the reason (low link quality level), the ON identifier and the required QoS in terms of bit rate.
3. Also as in the creation phase, CSCI/CMON entities in the BS may need to refresh spectrum availability information and determine to send an inquiry to the Dynamic Spectrum Management (DSM) entity, triggering the spectrum opportunity identification;
4. DSM reply provides the CSCI/CMON entities in the BS with the available spectrum blocks at this time. Based on this information, the selection of new spectrum blocks to carry out the transmission will be performed.
5. The new proposed ON configuration in terms of selected spectrum is transferred to UE#1 by issuing a MIH_C4MS_ONN.response message;
6. UE#1 sends a MIH_C4MS_ONM.request message (ON-Modification) towards UE#2 with the new ON configuration;
7. UE#2 replies with a MIH_C4MS_ONM.response message where a successful result-code is reported to indicate that the terminal is ready to reconfigure the link with the proposed settings;
8. The link is reconfigured at this step;
9. Finally, the modification of the ON is notified to the infrastructure from UE#1 by sending a MIH MIH_C4MS_ONSN.indication message.

From an algorithmic perspective, the spectrum opportunity identification algorithm used in the ON maintenance stage is the same that was described in section 3.3.2.1. Similarly, the spectrum selection algorithm is also described in section 3.3.2.1, but, as a difference from the ON creation stage, in the ON maintenance case the trigger of the algorithm occurs whenever some changes are identified in the environment such as bad channel quality experienced by an active link or a link release while there are other active links. In these two cases, the algorithm makes decisions on spectrum mobility to modify the current spectrum block allocated to an active link. Like during the

ON creation, the spectrum selection algorithm takes as input the list of available spectrum blocks provided by the spectrum opportunity identification, the bit rate requirements of the link to be assigned, the list of current assignments and a database with different statistics capturing the historical evolution of the fittingness factor based on measurements. The algorithm output is the list of spectrum assignments to each of the existing links.

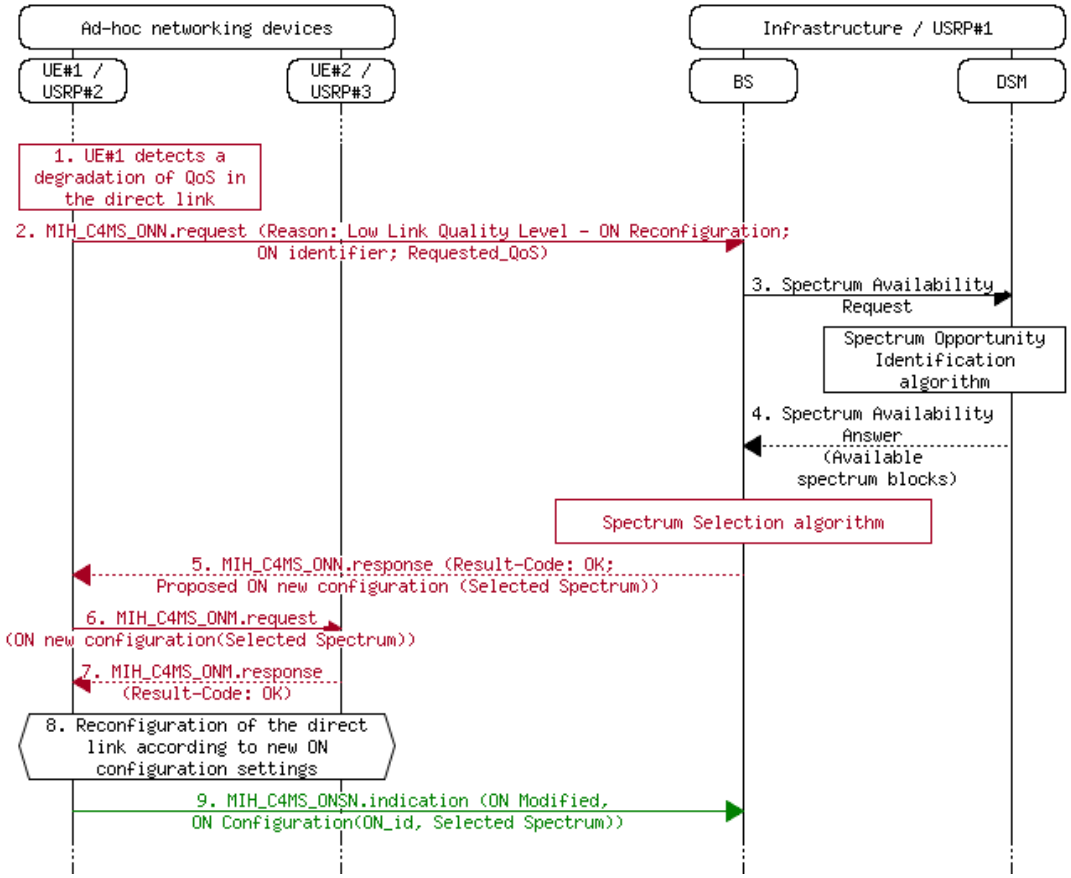


Figure 51: Implemented message exchange for the ON modification.

3.3.3.2 Route pattern selection in ad-hoc networks

The algorithm presented in section 3.3.1.4 in the framework of ON suitability determination stage is also applicable during the ON maintenance (for more details about the algorithm please refer to D4.2 [9]).

3.3.3.3 Multi-flow routes co-determination

The algorithm presented in section 3.3.2.5 in the framework of ON creation stage is also applicable during the ON maintenance (for more details about the algorithm please refer to D4.2 [9]).

3.3.3.4 QoS and spectrum – aware routing techniques

The algorithm presented in section 3.3.2.6 in the framework of ON creation stage is also applicable during the ON maintenance (for more details about the algorithm please refer to D4.2 [9]).

3.3.3.5 Application cognitive multi-path routing in wireless mesh networks

The application cognitive multi path routing algorithm for WMNs also performs the ON maintenance phase of the ON management cycle. The monitoring system continues to fill the contextual database which is constantly inspected by the algorithm. When QoS capabilities of the formed multiple paths drop below the QoS requirements dictated by the used applications, then the suitability determination starts once again in order to try and find the new, appropriate set of multiple paths which will satisfy the QoS requirements. If the need for reconfiguration of the existing ON is detected, after the successful suitability determination phase the creation of new set of multiple paths will be performed in the same way as described in 3.3.2.7. Some of the backhaul wireless links will be terminated in order to establish the new ones for enabling the new, updated set of multiple paths. The same process takes place when the need for termination of the ON is detected. The termination process will start when the ON (all possibilities for multiple paths) cannot provide the required level of QoS. This is done in order to remove the burden from the management system, decrease the interference between backhaul paths and avoid problems of packet reordering. The ON is also terminated when there is no longer a need for backhaul bandwidth aggregation or when the QoS requirements are relaxed. Before the termination process, the paths in the multiple paths set are inspected in order to determine which one is the most suitable to work on its own (transports the most of the current load, has the best QoS capabilities and imposes the least interference to the rest of the backhaul mesh network). The algorithm performs the termination process by sending the following commands in a form of TCP messages:

- Disable the radio interface (logically by informing the OpenWRT system and physically by turning down it power);
- Logically turn off the mesh mode of the interface;
- Restart the OLSR daemon on the WMN AP in order to update the routing tables (remove entries).

This reconfiguration needs to be performed on all of the interfaces forming the links which are selected for termination.

After the termination process the OLSR single path routing is running normally.

3.3.3.6 UE-to-UE trusted direct path

The algorithm presented in section 3.3.3.6 in the framework of ON creation stage is also applicable during the ON maintenance (for more details about the algorithm please refer to D4.2 [9]).

4 Implementation of supporting OneFIT building blocks

4.1 Implementation of the JRRM

The *Joint Radio Resources Management* (JRRM) performs the joint management of the radio resources across different radio access technologies. It selects the best radio access (Access-Selection & Handover Decisions) for a given user based on the session's requested Quality of Service (QoS), radio conditions, network conditions like cell load, user preferences and network policies.

The main JRRM tasks in the OneFIT Prototype, as shown also in Figure 52, are:

- Link performance monitoring: Configuration and retrieval of link performance measurements in each device (e.g. signal strength of current active link);
- Neighbourhood Information Collection and Provisioning: Configuration and retrieval of information about candidate links in the neighbourhood (e.g. which WLAN SSID`s are detected in the neighbourhood?);
- Resource monitoring: Configuration and retrieval of load information in the base stations, access points and relays in the network;
- Access Selection in Idle State as well as Access Selection in Connected State: The Access Selection is based on link performance, neighbourhood information and resource status. The Access Selection also triggers standard handover procedures.
- Triggering of CSCI/CMON: Evaluation of link performance, neighbourhood information and resource status to trigger CSCI/CMON to execute a suitability determination for a potential creation or reconfiguration of an ON (e.g. for coverage extension or capacity extension).

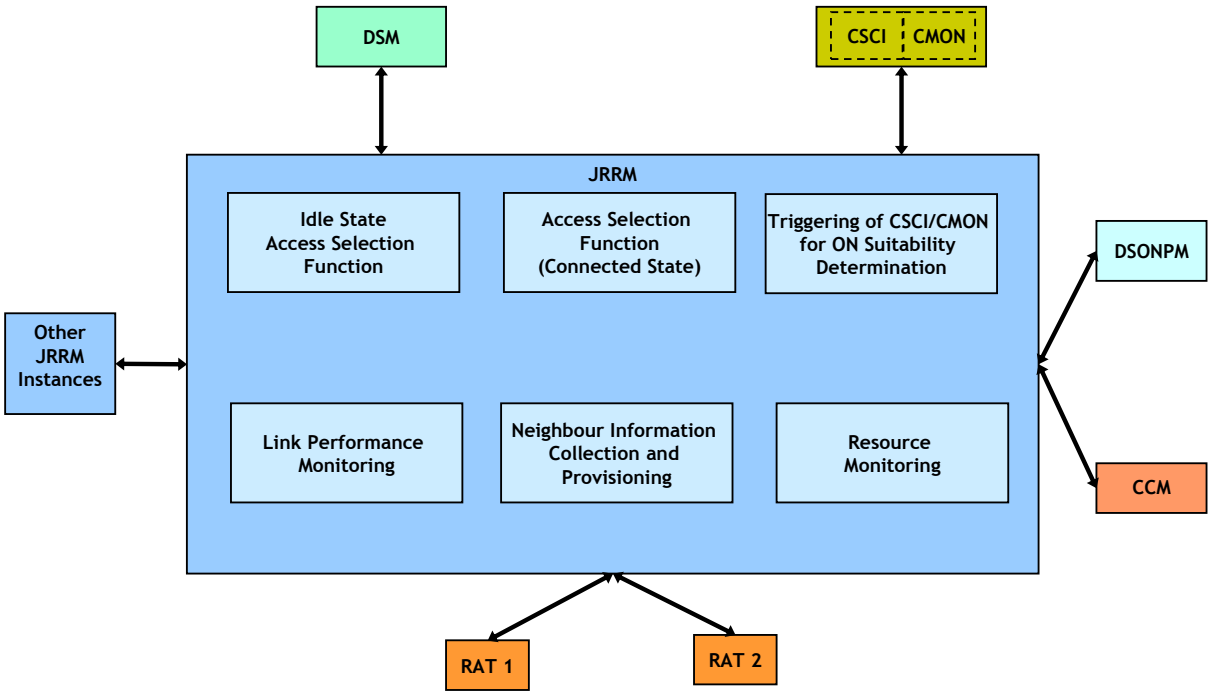


Figure 52: Main building blocks of the JRRM

A key component is related to link selection and the corresponding decision making processes subject to Operator Policies. The corresponding engine available in the test-bed environment is illustrated in the sequel.

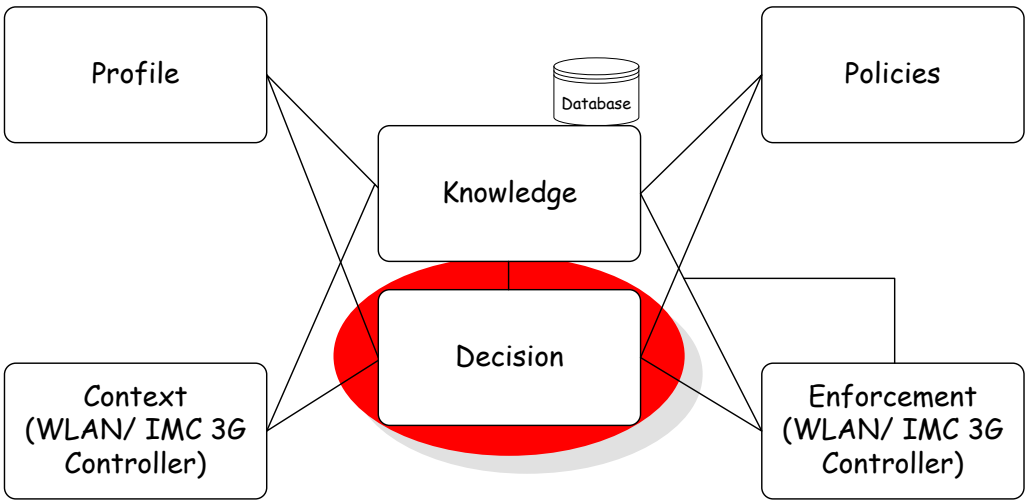


Figure 53: Link Selection Engine.

4.2 Implementation of the DSM

The main task of the Dynamic Spectrum Management is to decide on which spectrum to use in the different cells in the radio access networks including dynamic opportunistic cells.

Therefore, the DSM has knowledge on granted licenses, policies and on the current spectrum usage in the network.

Figure 54 shows an example of the GUI where at a selected geographical position three access points are using the ISM-band around 2.4 GHz.

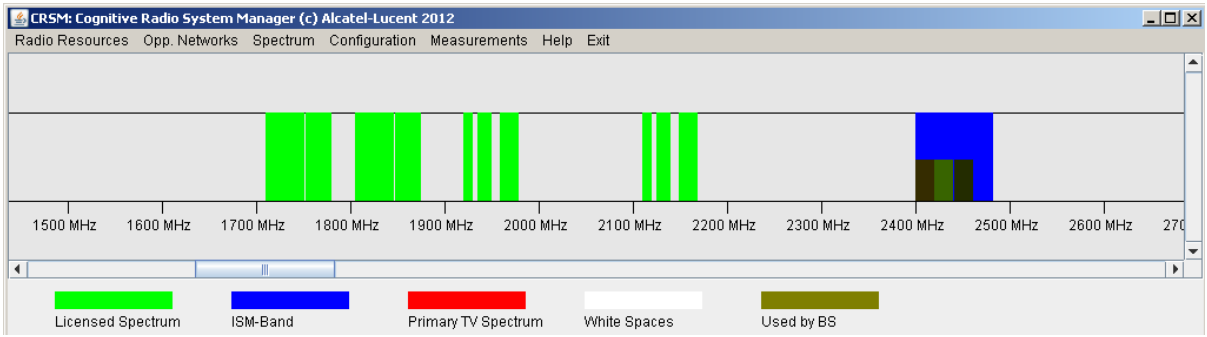


Figure 54: GUI of the Dynamic Spectrum Management

Figure 55 shows the DSM with its external interfaces and its internal building blocks.

Users of the DSM like CSCI, CMON, JRRM and DSONPM provide information to the DSM on the current configuration of the network. Further on, these building blocks shall ask the DSM for the creation of new cells on which spectrum to use for these cells. The DSM then provides then one or more options on which spectrum to use for these cells. After creation of such a cell, the DSM is then informed about the actual spectrum usage of these cells. The DSM is also informed in the case that a cell is switched off, e.g. to save energy or because an ON is released.

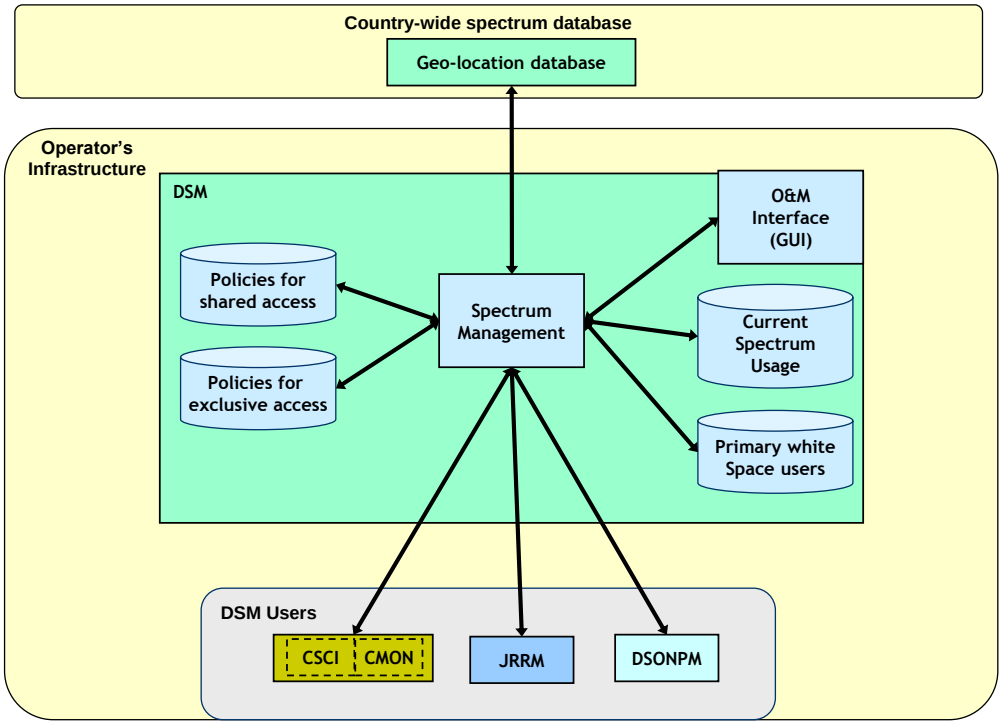


Figure 55: External interfaces and internal structure of the DSM.

4.3 Implementation of the CCM

The Configuration Control Module (CCM) is responsible for executing the reconfiguration of a terminal or a base station, following the directives provided by the JRRM or the DSONPM. According to the OneFIT Functional Architecture (FA) the CCM is located in the operator's infrastructure side and the terminal side and interacts directly with JRRM and DSONPM through specific interfaces namely, CJ (used by the JRRM to instruct the CCM on reconfigurations) and MC (used by the DSONPM to instruct the CCM on reconfigurations) respectively.

In the terminal side, the CCM interacts with the JRRM through the OJ interface and with the CSCI/CMON through the OC interface as Figure 56 suggests. The OC interface may be used to obtain additional information about the current device configuration which cannot be provided by the JRRM. However, it is assumed that for the normal ON management procedures, the CCM is not involved because the CMON uses the OJ-interface to trigger link setup or release procedures. Moreover, through the CR interface there is a possibility of interconnection between the CCM and the underlying RAT to control the reconfiguration of the radio access in a terminal or base station by the CCM.

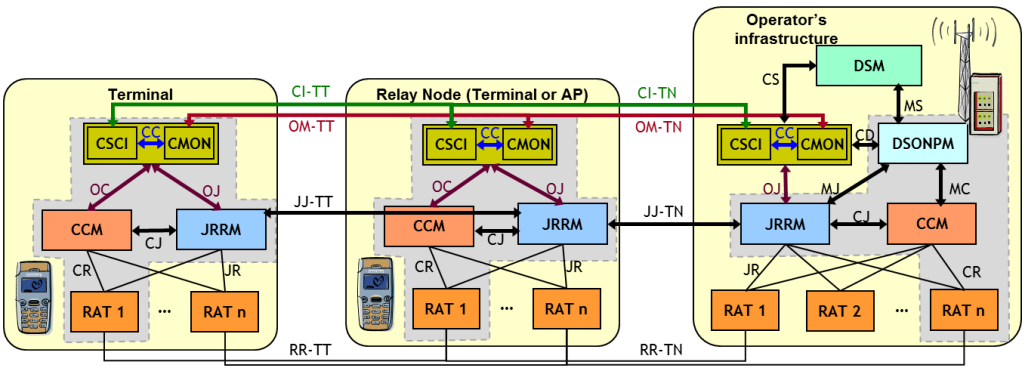


Figure 56: CCM interactions in the OneFIT FA.

4.4 Implementation of the DSONPM

The main aim of the Dynamic Self-Organizing Network Planning and Management (DSONPM) is to provide to the ON the necessary management functionalities of the infrastructure entities in order to proceed to necessary decision making on which solution is most appropriate to be enforced.

Specifically, as soon as an infrastructure element (e.g. a macro BS) experiences a problematic situation (e.g. congestion due to heavy load), the DSONPM is the functional entity of the FA, which will be notified and will be responsible for the designation of the solution which will be followed.

In order to achieve this goal, a specific procedure has been defined in OneFIT, according to which some necessary steps are identified. As Figure 58 suggests, a specific sequence of messages takes place in order to reach the "Decision for solving the situation". In the initialization phase of the validation platform each infrastructure element registers to the DSONPM as Figure 57 illustrates.

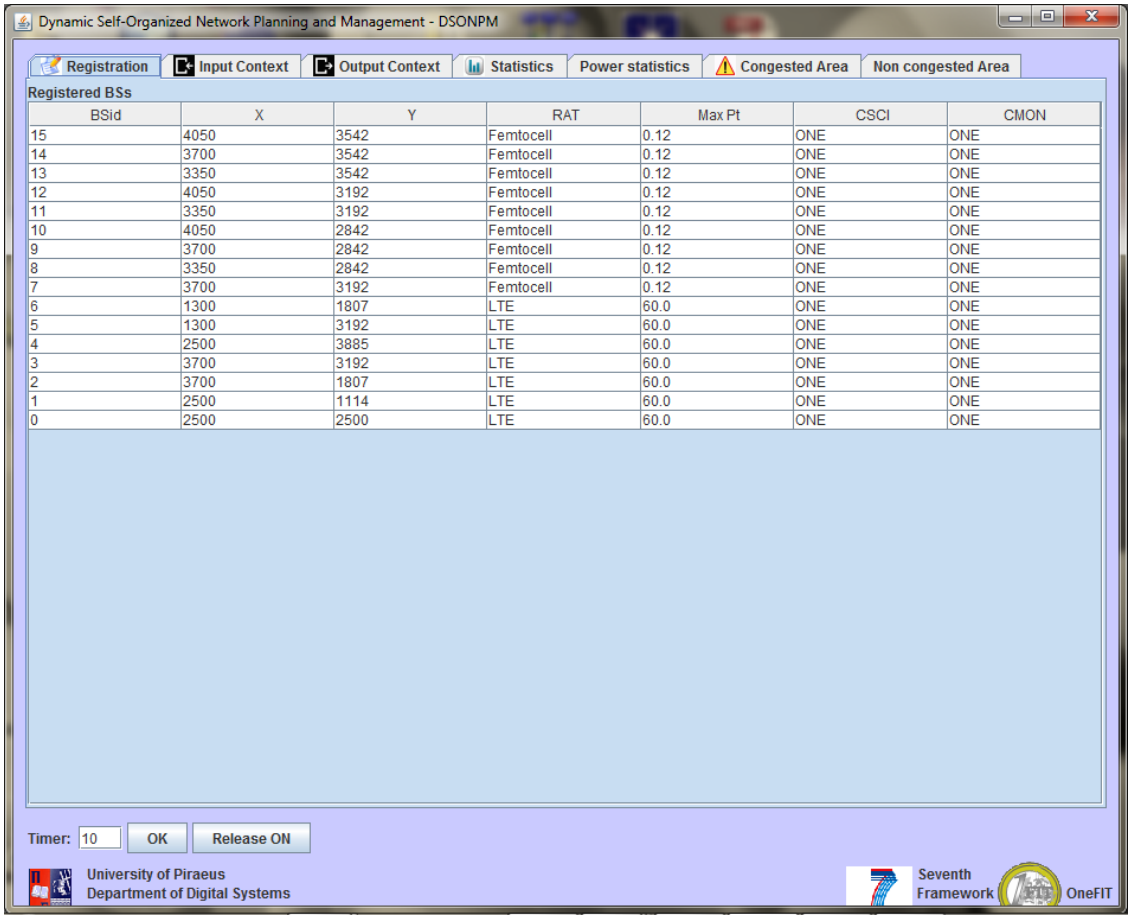


Figure 57: Registered infrastructure elements at DSONPM.

Initially the congestion situation is identified by a BS (e.g. BS1) and a message is sent to the DSONPM entity. This message informs the DSONPM about the congestion of BS1 and sends the current context (including load) of the BS1 to the DSONPM. The DSONPM sends a message to neighbouring, available BS(s) (e.g. BS2 or more), in order to request their current context. BS2 responds with its context (including its current load), in order to provide the necessary input to the DSONPM for the decision making. As soon as the DSONPM has acquired necessary information from available infrastructure elements, it is ready for the decision making process. When the decision is reached, the DSONPM shall send a message back to the congested BS (BS1) with the acquired context of the available BSs in order to start the problem resolution according to the designated decision.

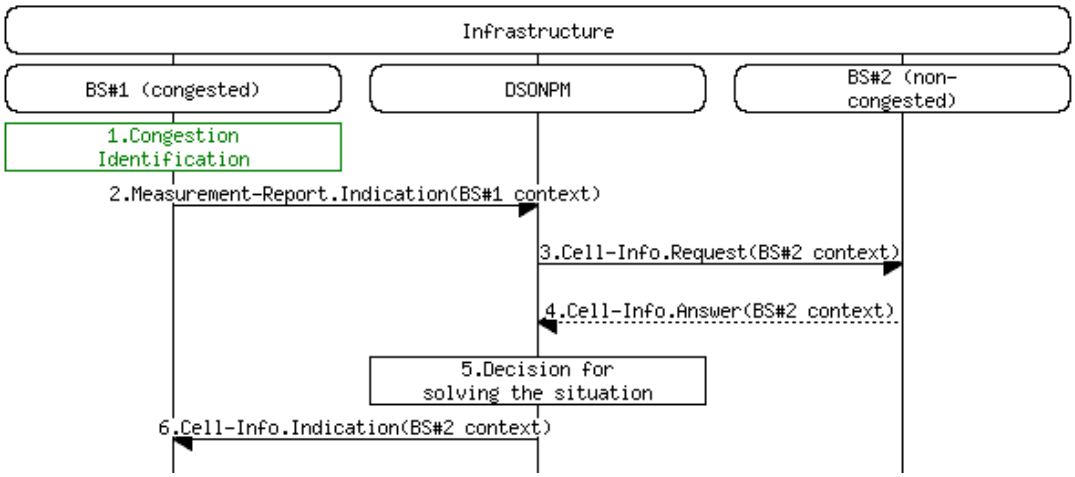


Figure 58: Sequence of messages interacting with DSONPM.

5 Implementation of the C4MS protocol

The Control Channels for the Cooperation of Cognitive Management Systems (C4MS) are used to transport the protocol information needed for the management of opportunistic networks (ONs). The information exchanged over C4MS is used for the realization of suitability determination, creation, maintenance and termination of Opportunistic Networks.

Control Information for the Management of Cognitive Radio Systems needs to be distributed in different phases of the connectivity (i.e. before a connection is established, after a connection has been established), using different distribution mechanisms (Unicast, multicast, broadcast) and the data must be exchanged between different types of nodes (between terminals/Device-to-Device communication, between terminals and the radio access network, inside a radio access network e.g. between Base Station and a Central Control Point or a database).

As a single C4MS implementation solution does not support all these different aspects [10], the C4MS implementation is based on a combination of different radio independent and radio dependent solutions.

The following subsections describe the different implementation options used in the OneFIT prototyping and validation activities and the purpose they are used for.

5.1 IEEE 802.21 for device-to-device and terminal-network communication

IEEE 802.21 is a standard on “Media-Independent Handover (MIH) Services” [14] which defines a protocol and mechanisms to enable handover and interoperability between heterogeneous network types including both 802 and non 802 networks.

As this protocol can be used on top of different radio access technologies and because it is easily extensible, IEEE 802.21 has been selected as one of the base protocols to be extended with functionalities for the management of opportunistic networks.

An example C4MS message as used in the opportunistic networking demonstrator (see section 2.2) is shown in Figure 59.

This prototype described in section 2.2 is also used for the C4MS protocol signalling evaluation. Therefore, the number of transferred C4MS messages and bytes are measured as shown in Figure 60. The results of the signalling evaluation are described in detail in D3.3 [7]. One result, the number of C4MS per second for a basic ON (one device going out of coverage, one device providing the relaying service, one infrastructure network) is also shown in Figure 61. A large part of the ON related signalling is caused by the exchange of link measurements during the lifetime of an ON. The messages for ON negotiation, creation and release have the average number of C4MS per second mainly for ONs with small duration, e.g. less than 2 minutes.

```
** Transmitted: 127 Bytes over TCP/IP
10 00 34 72    *C4MS Header, MIH Message ID: C4MS_ON_Creation_REQ
00 0b 00 77    *C4MS Header, Payload Length: 119
01 06          *TLV Source_MIHF_Id NODE87
4e 4f 44 45
38 37
02 06          *TLV Dest_MIHF_Id   NODE46
4e 4f 44 45
34 36
c0 01          *TLV ON_Id          7
07
c1 0b          *TLV ON_Name        AL_OppNet_1
41 4c 5f 4f
70 70 4e 65
74 5f 31
af 01          *TLV Reconfig.Type  2: Create Access Point (Relay)
02
f1 52          *TLV Type 241: Cell-Descriptor (Grouped), Length 82
a0 0b          *TLV Access-Network-Id: AL_OppNet_1
41 4c 5f 4f
70 70 4e 65
74 5f 31
a1 08          *TLV Cell-Id
ff ff ff ff
ff ff ff ff
04 01          *TLV Link-Type
13
ad 01          *TLV Cell-Radius
64
b0 08          *TLV Freq-Used
80 24 f1 08
00 25 3f 28
b2 04          *TLV Configuration-Status
00 00 00 02
d0 23          *TLV Tech-Spec-Cell-Info
02 02 03 04
00 ff fe fd
fc 0c 22 4e
7f 20 40 b4
9e 0c 10 20
2c 41 6c 63
61 74 65 6c
2d 4c 75 63
65 6e 74
```

Figure 59: Example of an IEEE 802.21 based C4MS message (C4MS ON Creation Request)

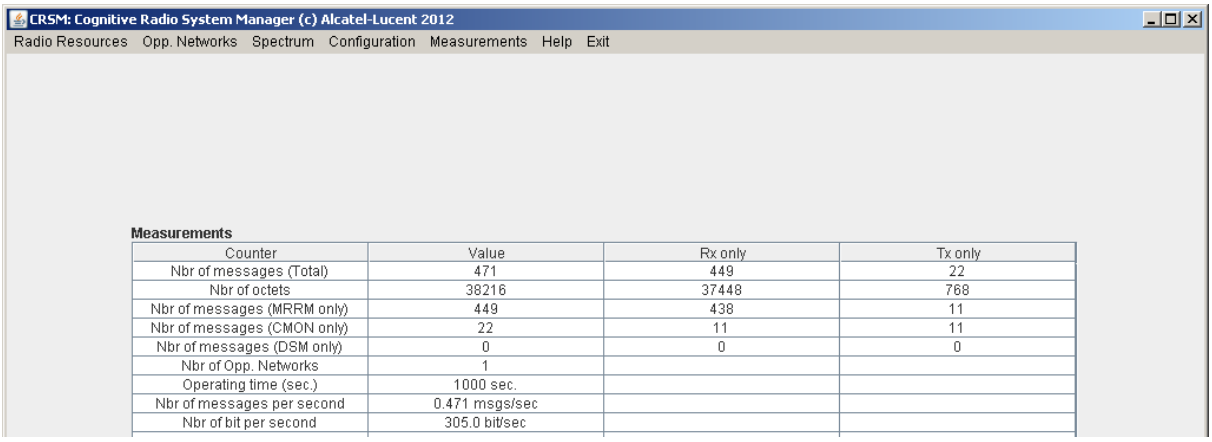


Figure 60: Measurements of the C4MS signalling load in the Cognitive Radio System Manager

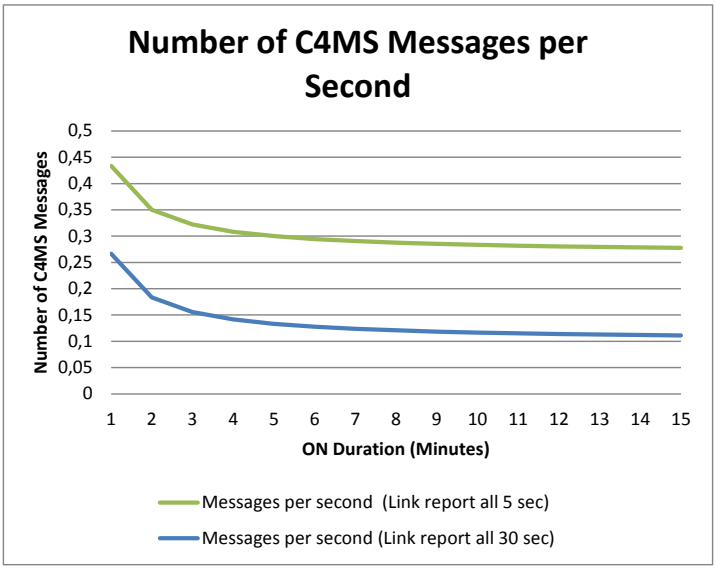


Figure 61: Number of C4MS messages for an ON dependent on the ON duration

5.1.1 IEEE 802.21 based C4MS protocol overview

In the prototype, the 802.21 based C4MS messages are transported via TCP/IP and as default the TCP port 4551 is used. The alternatively allowed use of UDP is not supported in the prototype.

In general, an 802.21 based C4MS message consists of

- A protocol header with 8 byte length;
- A source identifier (802.21 Source MIHF identifier);
- A destination identifier (802.21 Destination MIHF identifier);
- Zero, one or more parameters.

5.1.2 IEEE 802.21 protocol header format

A summary of the MIH Protocol Header format [14] is shown below:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|A|S|U|M| FragmentNbr |r|   MIH Message ID              |
|       | | | | |             | | SID   | Op|    AID            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|r r r r| Transaction ID        |    Variable Payload Length    |
|       |                       |                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Version: The protocol version is set to 1;

A: This field requests an acknowledgement of the message;

S: This field is used for responding to the request for an ACK of the message;

U: Unauthenticated information request (flag not used in the prototype);

M: More fragment flag (flag not used in the prototype);

FragmentNbr: The fragment number is always set to 0 in the prototype;

SID: The Service Identifier of the Message Id, e.g. 10 for Event Service;

Op: The Opcode of the Message Id,
Values: 01=Request, 10=Response, 11=Indication;

AID: Action Identifier, e.g. for Link Down or ON Creation;

MIH Message ID: Combines SID, Op and AID, for example
value 0x2C02 = MIH Link Up Indication
value 0x3472 = ON Creation.Request
value 0x3872 = ON Creation.Response;

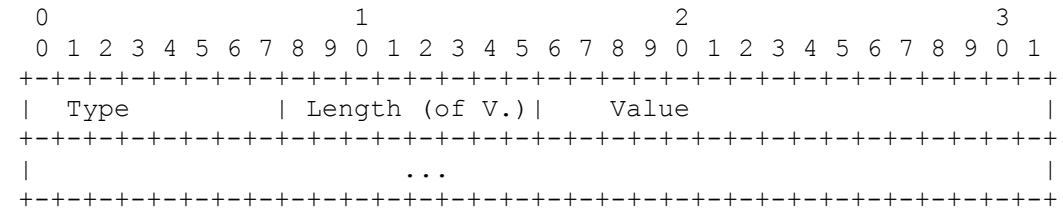
r: Reserved;

Transaction Id: This field is used for matching Requests and Responses;

Variable Payload Length: Indicates the length of the variable payload (Message length without header).

5.1.3 IEEE 802.21 parameter format

The parameters are encoded in the Type-Length-Value (TLV) format as shown below:



Type: The type of the parameter, e.g.
01 = Source MIHF Id,
02 = Destination MIHF Id,
03 = Status,
04 = Link type;

Length: This field requests an acknowledgement of the message;

Value: This field is used for responding to the request for an ACK of the message.

5.1.4 Procedures and messages

5.1.4.1 Link events

Different types of link events are reported from a terminal to the base station / access point or to the next relay. Relays also send link events to the base station / access point or towards the next relay. The following link events are reported:

- Link_Detected: A link to another access point is detected;
- Link_Up: A L2 connection is established;
- Link_Going_Down: The link conditions are degrading and connection loss is imminent;
- Link_Down: A L2 connection is broken;
- Link_Parameters_Report: A link parameter has crossed a pre-specified threshold.

The MIH_Link_Up.indication for example uses the following message format:

```
<MIH_Link_Up.Indiation> ::
```

```
= < Message Type: 0x2C02>
  { Source MIHF ID}
  { Destination MIHF ID}
  { Terminal-Capabilities}
* { LinkIdAndParam}
```

Please note that this format has some differences to the MIH_Link_Up Indication as specified by IEEE 802.21 section 8.6.2.2:

- The Terminal Capabilities parameter is not specified in 802.21. This parameter is needed in certain scenarios for the support of the ON_Negotiation procedure, see section 5.1.4.2 below.
- The LinkIdAndParam (Link parameter report list TLV) is according 802.21 used in the MIH_Link_Parameters_Report.indication but not in the MIH_Link_Up.indication while in the prototype, this parameter is also used in the MIH_Link_Up.indication.

5.1.4.2 Intrinsic ON Negotiation support

In the 802.21 based C4MS implementation, no dedicated ON Negotiation messages have been implemented because the information needed for the negotiation can already be transported intrinsic within other messages which are already exchanged by standard procedures.

The information needed for the negotiation process consists of terminal capabilities, user preferences and desired QoS. This information is either exchanged via existing session setup procedures or this information is included as a protocol extension in other messages.

In the 802.21 based C4MS implementation, the terminal capabilities are transported in the MIH_Link_Up.indication (see section 5.1.4.1 above).

The Terminal-Capabilities Parameter has been implemented as a bitmap where each bit can indication certain capabilities.

Several bits are used to indicate which radio access technologies are supported, e.g. GSM, GPRS, EDGE, Fixed/Ethernet, IEEE 802.11 WLAN, UMTS and LTE.

Further bits are used to indicate relaying capabilities:

- Indicator if the device supports RELAYING of IEEE 802.11 WLAN;
- Indicator if the device supports RELAYING of UMTS;
- Indicator if the device supports RELAYING of LTE;
- Indicator if the device supports RELAYING between different technologies.

5.1.4.3 ON Creation by Device Reconfiguration

In several Opportunistic Networking scenarios a device must be reconfigured in order that an ON can be created. For example, a new Access Point must be created and a Relaying Function must be activated or a Femto-Cell must be reconfigured to support other users or user groups. In other cases, a Base Station may have to be waked from a power-save mode or the cell reconfiguration may have to be changed.

For such an ON-Creation by Device Reconfiguration, a procedure as shown in the example below can be used:

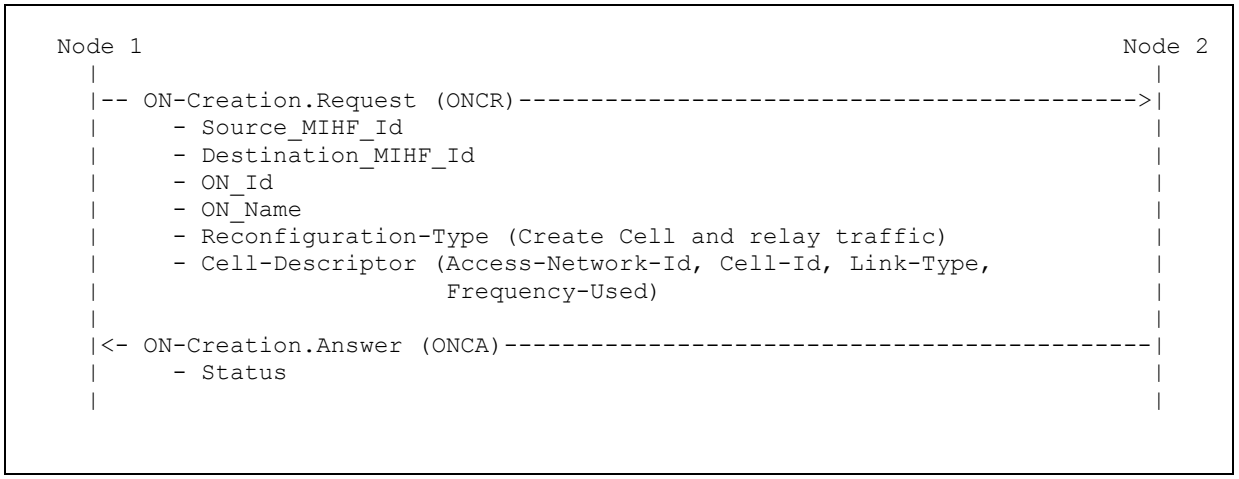


Figure 62: ON-Creation by Reconfiguration procedure

The ON-Creation.Request contains an indicator for the type of the reconfiguration (e.g. indication that a new cell/access point shall be created and that the traffic shall be relayed) and further on a description of the new configuration. In the prototype, this descriptor consists of the so called “Cell-Descriptor” which describes the Access-Network-Id (e.g. the WLAN SSID or the UMTS/LTE PLMN Identity), the Cell-Id (e.g. the WLAN BSSID or the UMTS/LTE Cell identity), the Link-Type describing the Radio Access Technology (e.g. WLAN or LTE) and the Frequency or Frequencies to be used.

The ON-Creation.Answer either indicates the success or the failure of the operation. In the failure case, a description of the failure is added. Based on such a failure description, it can be decided to abandon the reconfiguration or to try to reconfigure the device with a different set of parameters.

5.1.4.4 ON Suitability indication

The ON Suitability procedure is used to determine the suitability of an ON at a specific time and place based on the observed radio environment and some established criteria.

To support this ON Suitability procedure, an ON-Suitability.indication message can be sent from one node to another to initiate a suitability determination procedure in that node.

As an example, after the setup of a new access point in the network, a first node (Node 1 in Figure 63) informs a second a node that it may now be suitable to use a new cell/access point as described in the cell descriptor.

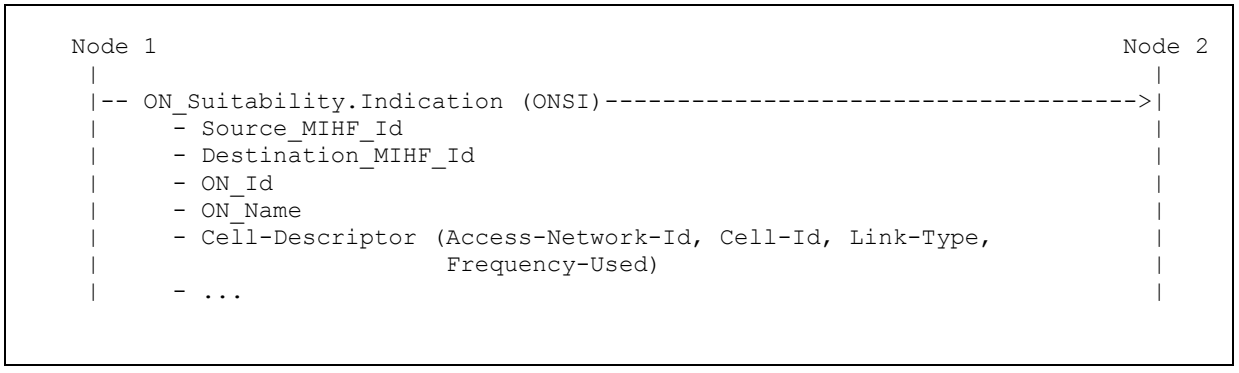


Figure 63: ON Suitability indication

Based on this information, the second node can then start a discovery procedure for the described access or cell. Based on the result of the suitability and discovery procedure, this may then lead to a handover to the new access or cell.

5.1.4.5 ON Release

When an ON is no longer needed, the links between the nodes in the ON can then be released, e.g. via normal release procedures. This is usually combined with a handover e.g. back to the infrastructure.

Further on, Access points which have been created for the support of the ON but which are no longer needed can then be disabled with a reconfiguration procedure as shown in Figure 64. Any relaying function for the traffic of that cell will then also be disabled.

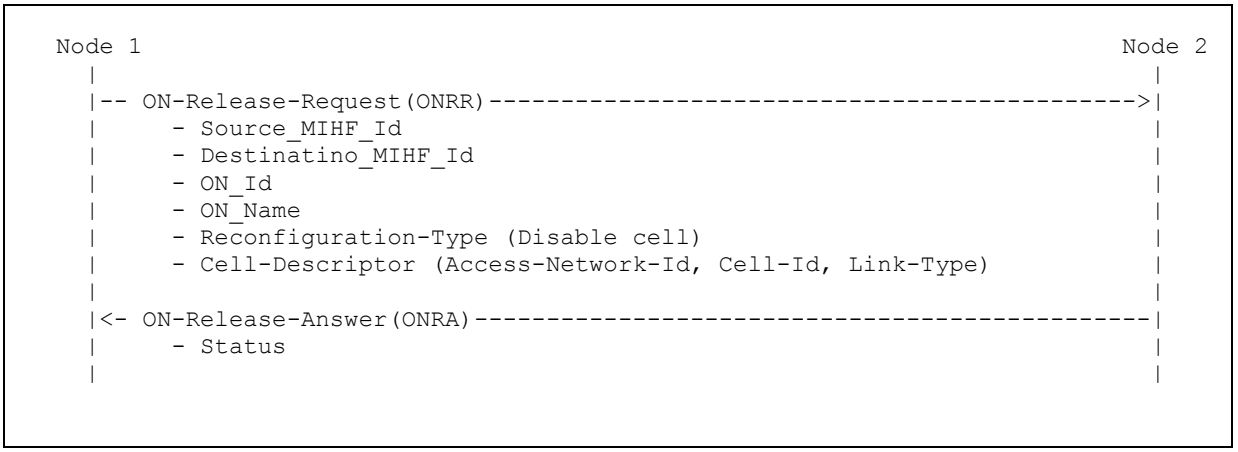


Figure 64: ON-Release by Reconfiguration of a device to shut down a cell and the corresponding relaying function

5.2 IETF OLSR for route discovery and management

Optimized Link State Routing Protocol (OLSR) is an IP routing protocol optimized for mobile ad-hoc networks, which can also be used on other wireless ad-hoc networks. OLSR is one of the main internet standards for mesh networks and it is widely used and well tested. It was shown that OLSR has high scalability; it uses very little CPU time and due to its high portability OLSR is used for routing in One Fit's wireless mesh network test-bed. The IEEE802.11a protocol is used for node discovery, channel selection and link establishment in this test-bed. OLSR signal flows between nodes in this test-bed are presented in Figure 65.

The OLSR protocol is used to exchange information for the route discovery and management between the different open wireless mesh network routers. OLSR does not send data packets; it only sends its own messages such as TC, HELLO, HNA etc. These are sent, received and processed in order to find valid routes between network nodes. Once routes to all nodes in the network are discovered for a particular node, OLSR will simply set the corresponding kernel routing table entry. OLSR uses the UDP protocol for message exchange and runs on Layer 3.

Since there is not much dynamicity in the topology of WMNs, the OLSR signalling overhead can be significantly reduced when compared to the OLSR signalling in mobile ad-hoc networks with dynamic topology.

Nodes participating in an OLSR routing domain can be multi-homed. That means that they can run OLSR on multiple communication interfaces using multiple identifiers.

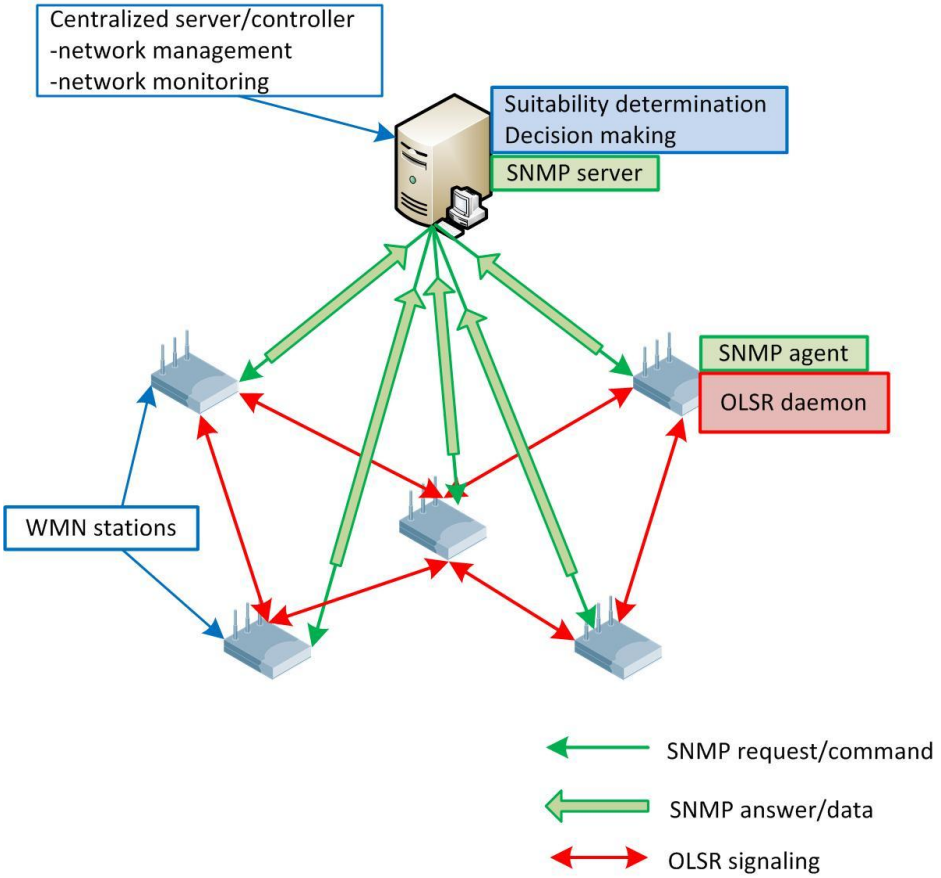


Figure 65: Example of SNMP and OLSR signalling between WMN nodes and centralized management server

In a classic link-state algorithm, link-state information is flooded throughout the network (see Figure 66). OLSR uses this approach as well, but since the protocol runs in wireless multi-hop scenarios the message flooding in OLSR is optimized to preserve bandwidth (see Figure 67). The optimization is based on a technique called Multi Point Relaying.

OLSR defines three basic types of control messages:

HELLO - *HELLO* messages are transmitted to all neighbours. These messages are used for neighbour sensing and selection of Multi Point Relays (MPRs).

TC - *Topology Control* messages are the link state signalling done by OLSR. This messaging is optimized in several ways using MPRs.

MID - *Multiple Interface Declaration* messages are transmitted by nodes running OLSR on more than one interface. These messages list all IP addresses used by a node.

The concept of multipoint relaying is to reduce the number of duplicate retransmissions while forwarding a broadcast packet. This technique restricts the set of nodes retransmitting a packet from all nodes, to a subset of all nodes. The size of this subset depends on the topology of the network.

Reducing the control overhead of the routing protocol is achieved by selecting neighbours as multi point relays. Every node calculates its own set of MPRs as a subset of its symmetric neighbour nodes chosen so that all 2 hop neighbours can be reached through a MPR. This means that for every node *n* in the network that can be reached from the local node by at minimum two symmetric hops, there must exist a MPR *m* so that *n* has a symmetric link to *m* and *m* is a symmetric neighbour of the local node.

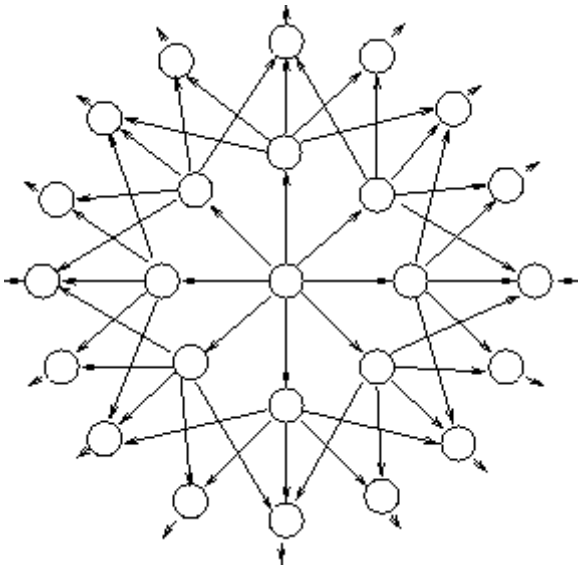


Figure 66: Flooding a packet in a wireless multi hop network. The arrows show the way information is passed, not all transmissions.

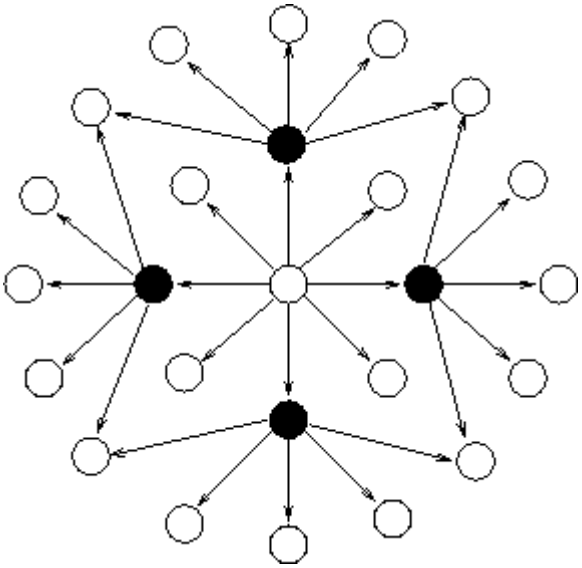


Figure 67: Flooding a packet in a wireless multi hop network from the center node using MPRs (black). The arrows show the way information is passed, not all transmissions.

In Table 2 it is presented how different C4MS messages can be mapped onto the protocol specific messages of SNMP, OLSR protocol and IEEE802.11a. These protocols are used in OneFIT's WMN test-bed (for validation of Scenario 5 specific use-cases) for gathering of contextual information and system monitoring (SNMP), route/topology discovery, establishment and maintenance (OLSR) and for providing MAC specific mechanisms (channel selection, node discovery, link establishment) (IEEE802.11a).

The OLSR routing protocol is used as the underlying single path routing protocol in the open platform WMN test-bed used for implementation and validation of the algorithms addressing the OneFIT scenario 5 use cases.

Table 2: Mapping of C4MS messages on messages of protocols used in WMN management

C4MS messages	**SNMP messages**	**OLSR messages**	**802.11a**
Information-Request (INR)	Get-request		
Information-Answer (INA)	Get-response		
Information-Indication (INI)	Trap		
Node discovery			Beacons/probe response
Node identification and selection		MID messages	802.11a
Spectrum opportunity identification and selection			802.11a
Route identification and selection		Hello messages, TC messages	
ON-Suitability-Indication (ONSI)	Suitability determination and indication is done by a centralized controller		
	Trap		
ON-Negotiation-Request (ONNR)	Negotiation request/answer messages are exchanged between node and centralized controller		
	Get-request/get-response		
ON-Negotiation-Answer (ONNA)	Get-request/get-response		
ON-Creation-Request (ONCR)	Messages/commands over ssh (secure shell) from centralized controller to node		
	Set-request		
ON-Creation-Answer (ONCA)	Get-request/get-response		
ON-Modification-Request (ONMR)	Messages/commands over ssh from centralized controller to node		
	Set-request		
ON-Modification-Answer (ONMA)	Get-request/get-response		

ON-Release-Request (ONRR)	Messages/commands over ssh from centralized controller to node		
	Set-request		
ON-Release-Answer (ONRA)	Get-request/get-response		
ON-Status-Notification (ONSN)	Get-request/get-response		

5.3 IETF SNMP for network management of infrastructure elements

The Simple Network Management Protocol (SNMP) is a simple request/response protocol in which SNMP manager communicates with SNMP agents using SNMP messages in which PDU (Packet Data Unit) are encapsulated (see Figure 68). A SNMP message consists of a sequence that contains a SNMP version, community string and the SNMP PDU which forms the body of message.

The SNMP protocol is used for WMN monitoring (contextual data gathering) in the open platform WMN test-bed which is used for implementation and validation of the algorithms addressing the OneFIT scenario 5 use cases.

The following messages are supported by the SNMPv2 protocol:

Get-request - Accesses and retrieves the value of one or more instances of management information.

Get-next-request - Accesses and retrieves the value of the next instance of management information in lexicographical order.

Get-bulk – Accesses multiple values at one time.

Get-response – Reply to a Get-request, Get-next-request and Set-request operations.

Set-request – Stores and sets a value in variable.

Trap – An unsolicited message that is sent by an SNMP agent to an SNMP manager and indicates that some event has occurred.

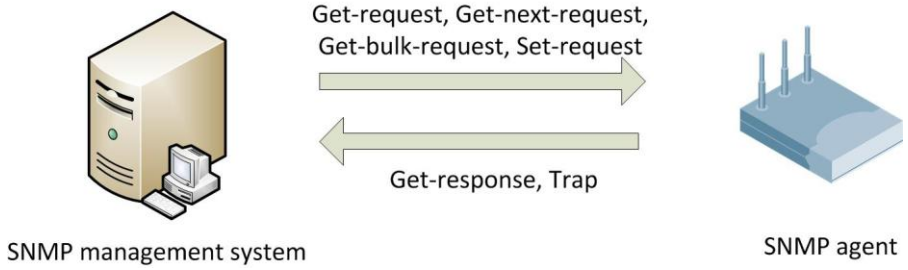


Figure 68: Exchange of messages between SNMP management system and SNMP agent

As an example of infrastructure elements, we will consider wireless mesh network (WMN) nodes. Relevant contextual information is gathered from these nodes by using the SNMPv2.

Contextual data include standard info which is obtainable with this protocol:

- Interface related information: SINR, channel used, inbound/outbound packet count, packet drop count, MAC address of the interface with which the link is established;

- Node related information: power consumption, CPU load, routing table, cache storage status (size, free space).

Information regarding which WMN node supports ONs is considered as known, because only infrastructure nodes are forming these ONs (we consider that operators know ON capabilities of their equipment).

A centralized decision making process is responsible for associating nodes with existing ONs and creation of new ONs. Whether or not a particular WMN node participates in any of the existing ONs can be obtained over the SNMPv2 protocol, but it can also be considered as known.

These contextual data are sent from WMN nodes to centralized decision making and monitoring controller/server (see Figure 65).

The mapping of C4MS messages onto the SNMP specific messages is presented in Table 2.

6 Implementation of the OneFIT scenarios

Five OneFIT scenarios are defined in the D2.1 [3]. These scenarios are:

- Scenario 1: Opportunistic coverage extension;
- Scenario 2: Opportunistic capacity extension;
- Scenario 3: Infrastructure supported opportunistic device-to-device networking;
- Scenario 4: Opportunistic traffic aggregation in the radio access network;
- Scenario 5: Opportunistic resource aggregation in the backhaul network.

Different use cases of scenarios 1, 2, 3 and 5 are implemented and validated in the OneFIT validation platform. The test-beds, which are described in section 2, are utilized in implementation of different scenarios.

Implementation of the scenario 1 utilizes the following test-beds:

- Prototyping platform for the management of opportunistic networks (section 2.1);
- Opportunistic Networking Demonstrator (section 2.2);
- Opportunistic ad-hoc network demonstrator (section 2.4);
- Prototyping Platform for Opportunistic Coverage Extension and related Support Functions (section 2.5);
- Cognitive radio test-bed (section 2.7).

Implementation of the scenario 2 utilizes the following test-beds:

- Prototyping platform for the management of opportunistic networks (section 2.1);
- Opportunistic networking demonstrator (section 2.2);
- Opportunistic ad-hoc network demonstrator (section 2.4).

Implementation of the scenario 3 utilizes the following test-beds:

- Direct D2D communication test-bed (section 2.6);
- Opportunistic service provision demonstrator (section 2.3);
- Opportunistic ad-hoc network demonstrator (section 2.4);
- Spectrum opportunity identification and spectrum selection test-bed (section 2.8).

Implementation of the scenario 5 use case utilizes the following test-bed:

- Open platform wireless mesh network test-bed (section 2.9).

Some of these scenario implementations are still in progress and will be presented in D5.3 due for December 2012. Those scenario implementations which are already validated and successfully demonstrated are described in the following.

The implemented WP4 algorithms provide the building blocks for ON management systems. Mapping of these algorithms onto the OneFIT scenarios is given in Figure 32.

6.1 Implementation of the OneFIT scenario 1 "Opportunistic coverage extension"

The scenario 1 is about opportunistic coverage extension and the main goal of the scenario is to create ONs in areas where coverage of the infrastructure is insufficient or terminals cannot connect to the infrastructure due to a RAT mismatch. The operator-governed ONs will enable the non-connected terminals to gain access to the infrastructure through intermediate nodes.

For more information regarding definition of the scenario and description of use cases please refer to D2.1 [3].

6.1.1 Sub-scenario: Device going out of coverage

A first implemented coverage extension scenario is the case where a device is first directly connected with infrastructure, but due to mobility of the user, the user is moving out of coverage of the infrastructure. The solution is to create an ON for coverage extension as shown in the message sequence chart in Figure 69. This scenario is implemented in the opportunistic networking demonstrator described in section 2.2 on page 25.

6.1.2 Sub-scenario: Device cannot connect to infrastructure

In this scenario, a device is switched on and cannot find an access point or a base station of the infrastructure or the device has already moved out of the infrastructure coverage. To solve this situation, the device being out of coverage starts a discovery procedure to detect other devices in its neighbourhood. If such a device is found – as shown in the message sequence chart (MSC) in Figure 70 – the suitability determination, negotiation and ON creation tasks are then performed. When the ON is created, the device being out of direct infrastructure coverage is then served via another device proving a relaying service.

This scenario can also be applied to the case where a macro BS experiences failure. As a result, mobile devices are left without coverage. ON is started forming up by collaboration of CSCIs and CMONs in order to serve the out of infrastructure terminals. Mobile devices are connected to each other in order to gain access to the infrastructure.

When the previously failed macro BS goes back online, ON is not needed anymore and it is terminated.

Further descriptions on the MSCs are also documented in [3]. Moreover, C4MS messages are exchanged by using the FIPA Agent Communication Language (ACL) messages. So, through the JADE platform which is agent-based, messages are transferred between various functional entities (e.g., CSCI, CMON, and DSONPM) according to the predefined MSCs.

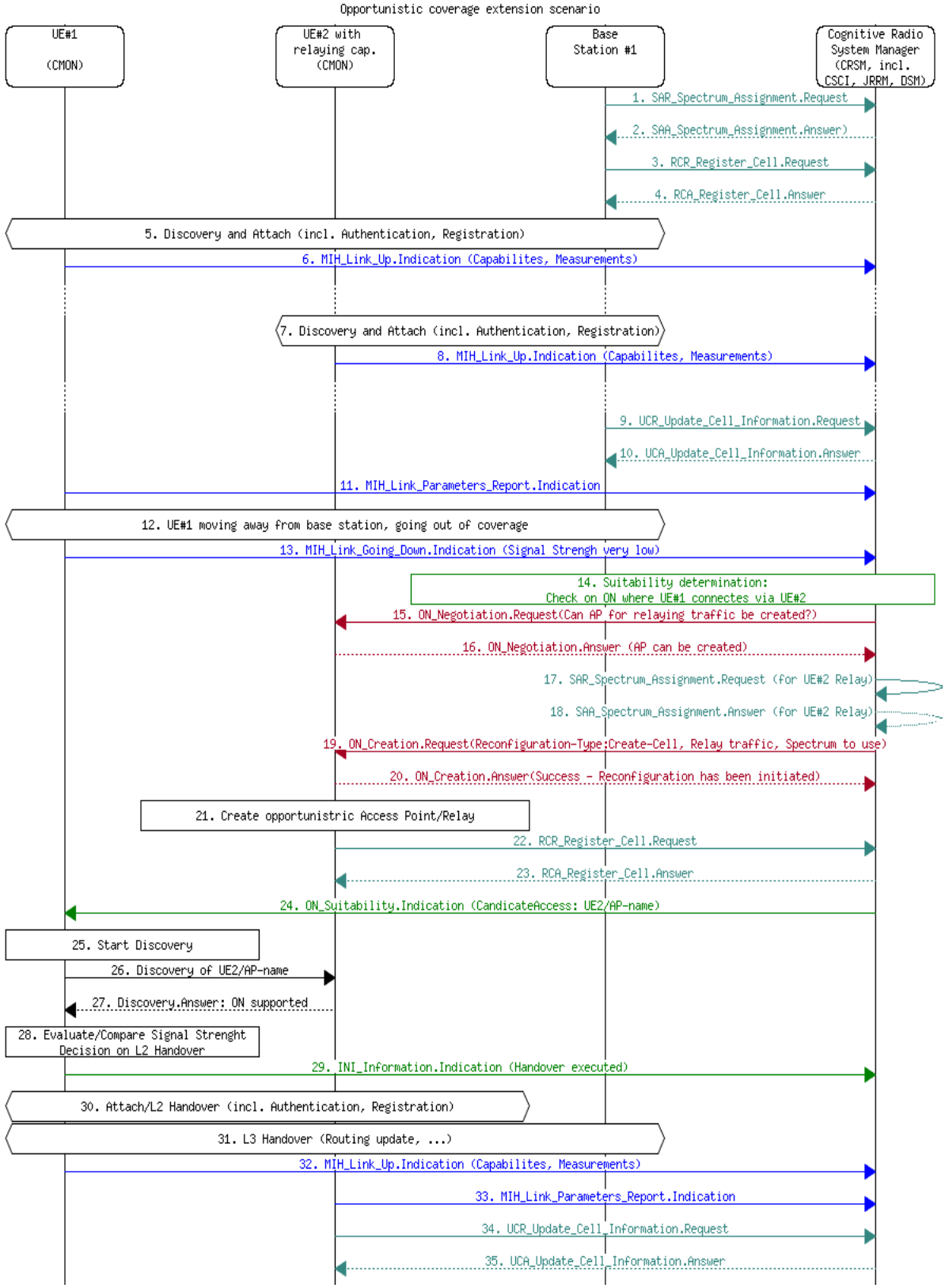


Figure 69: MSC for solving a going out-of-coverage situation using extended 802.21 messages

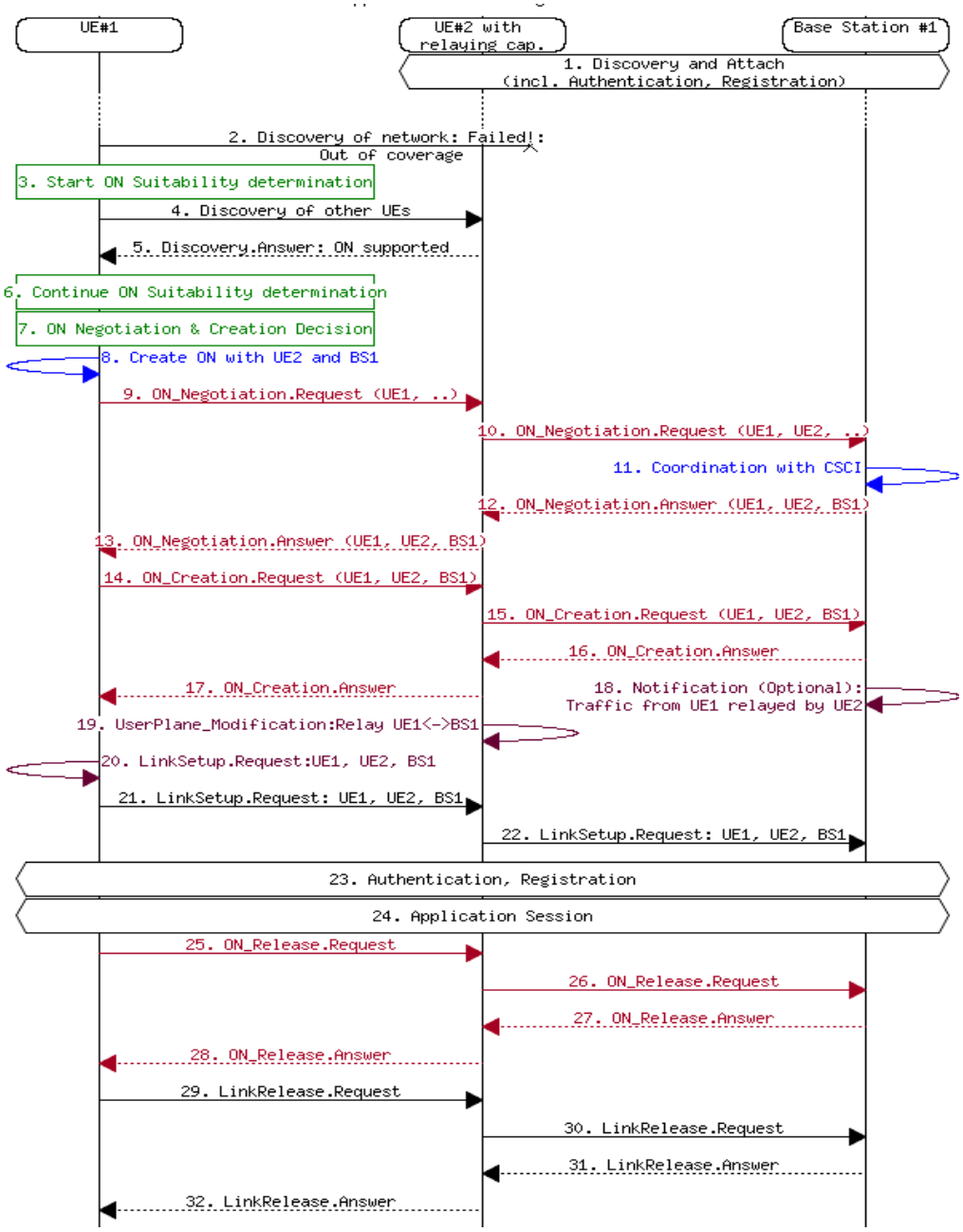


Figure 70: Coverage extension procedure

For showcasing key-features from a Mobile Device / Terminal perspective, the Prototyping Platform for Opportunistic Coverage Extension and related Support Functions as introduced in section 2.5 is built such that it can be suitably reconfigured to the following configurations:

i. Provision of wireless services in a dense neighbourhood environment building on non-interfering Radio Access Technology.

This configuration represents the performance reference case with no interference, congestion, etc. occurring. In particular, mobile devices are communicating directly with a Femto/Macro BS and a WiFi AP respectively.

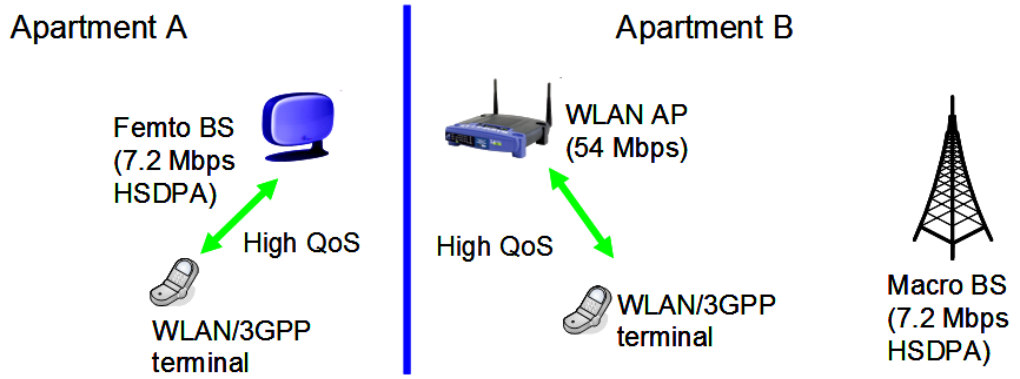


Figure 71: Basic Reference architecture of Prototyping Platform for Opportunistic Coverage Extension and related Support Functions

ii. Provision of wireless services in a dense neighbourhood environment employing an Opportunistic Network for ensuring access for a WiFi-only Terminal Device.

In one part of the dense neighbourhood environment, an Opportunistic Network is set-up in order to ensure internet access for a WiFi-only Terminal Device. Without the corresponding Opportunistic Network feature, the concerned Terminal would not be able to access internet, since both illustrated domains ("Apartment A" and "Apartment B") are considered to be closed.

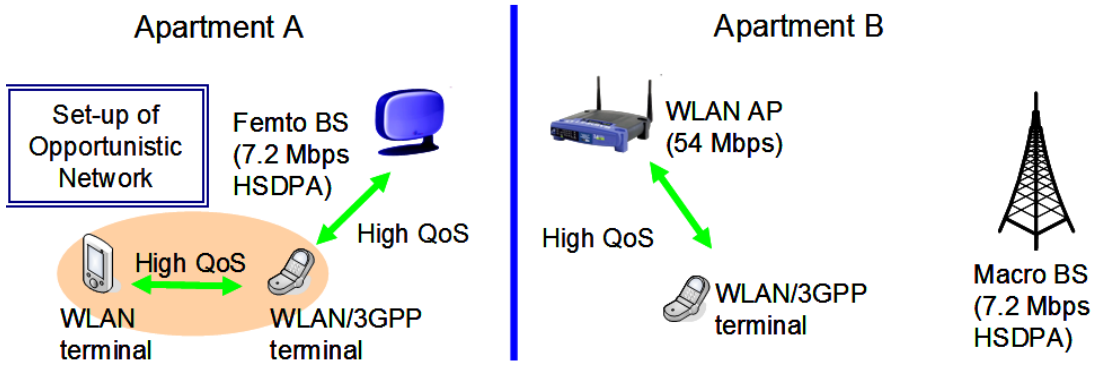


Figure 72: Architecture of Prototyping Platform for Opportunistic Coverage Extension and related Support Functions including an Opportunistic Network Configuration

iii. Provision of wireless services in a dense neighbourhood environment employing automized network reconfiguration and an Opportunistic Network for ensuring access for a WiFi-only Terminal Device.

A complex wireless networking environment is considered in a dense neighbourhood. It is expected that non-expert users will constantly add wireless devices in their respective domains. Improperly configured devices may indeed lead to congestion/interference events and thus to poor QoS for concerned users. In this configuration of the test-bed, such congestion case is shown and the network is correspondingly reconfigured employing suitable Opportunistic Network configurations. Finally, QoS is maintained within the concerned environment.

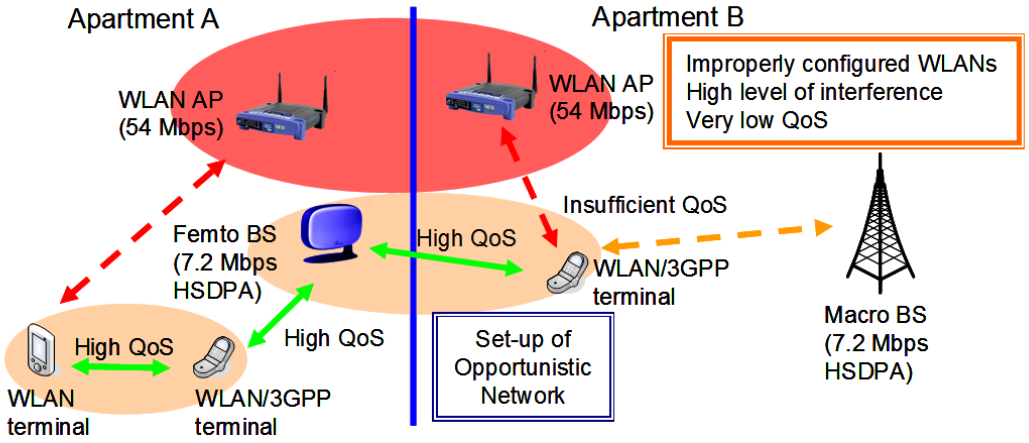


Figure 73: Architecture of Prototyping Platform for Opportunistic Coverage Extension and related Support Functions including multiple Opportunistic Network Configurations and automized reconfiguration for preventing service degradation by congestion in the WiFi APs

iv. Provision of wireless services in a dense neighbourhood environment employing Multi-Homing.

A further improvement of QoS for wireless Mobile Devices is achieved through Multi-Homing support. It is demonstrated how a split of a data stream over two distinct radio links can improve the overall QoS. In particular, it is shown that i) bandwidth can be aggregated across multiple wireless systems and ii) a break-down of a single given link can be partly compensated by the second link still operating.

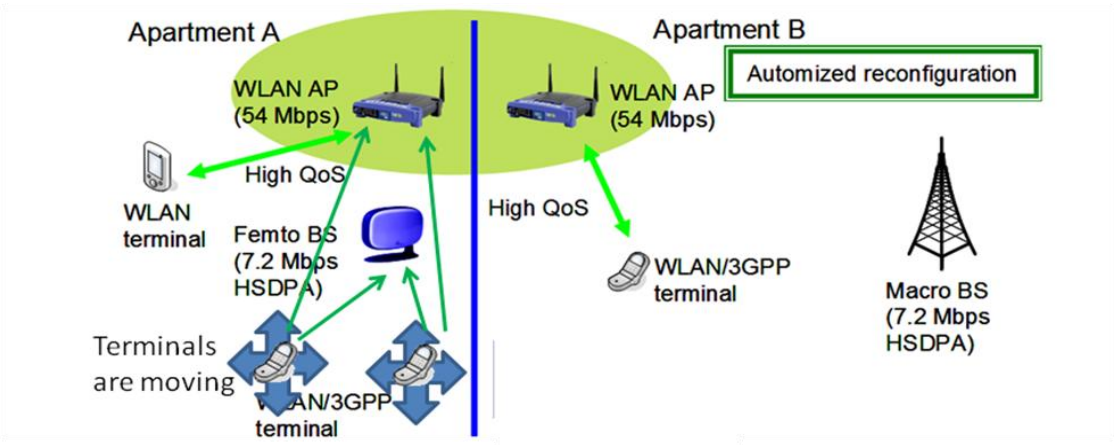


Figure 74: Architecture of Prototyping Platform for Opportunistic Coverage Extension and related Support Functions including a Multi-Homing Feature

6.2 *Implementation of the OneFIT scenario 2 "Opportunistic capacity extension"*

Scenario 2 "Opportunistic capacity extension" depicts a situation in which a device cannot access the operator's infrastructure due to the congestion of the available resources at the serving access node. The proposed solution proposes the redirection of the access route through an opportunistic network that avoids the congested network segment.

For more information regarding definition of the scenario and description of use cases please refer to D2.1 [3].

Two use cases of scenario 2 are considered, the opportunistic capacity extension through neighbouring terminals and the opportunistic capacity extension through femtocells.

Aligned with these ideas the following tasks are performed:

- Infrastructure elements experience congestion problems and traffic hotspots are identified.
- The DSONPM, CSCI and CMON collaborate in order to solve congestion by redirecting terminals with ON capabilities to alternate BSs.
- Terminals of the congested area with ON capabilities find paths to other, available BSs through other terminals with ON capabilities in non-congested and congested area.

A detailed message sequence chart is provided in the figures that follow. Further descriptions in the respective procedure are also documented in [6]. As previously mentioned, C4MS messages are exchanged by using the FIPA ACL messages. So, through agents, messages are transferred between various functional entities (e.g., CSCI, CMON and DSONPM).

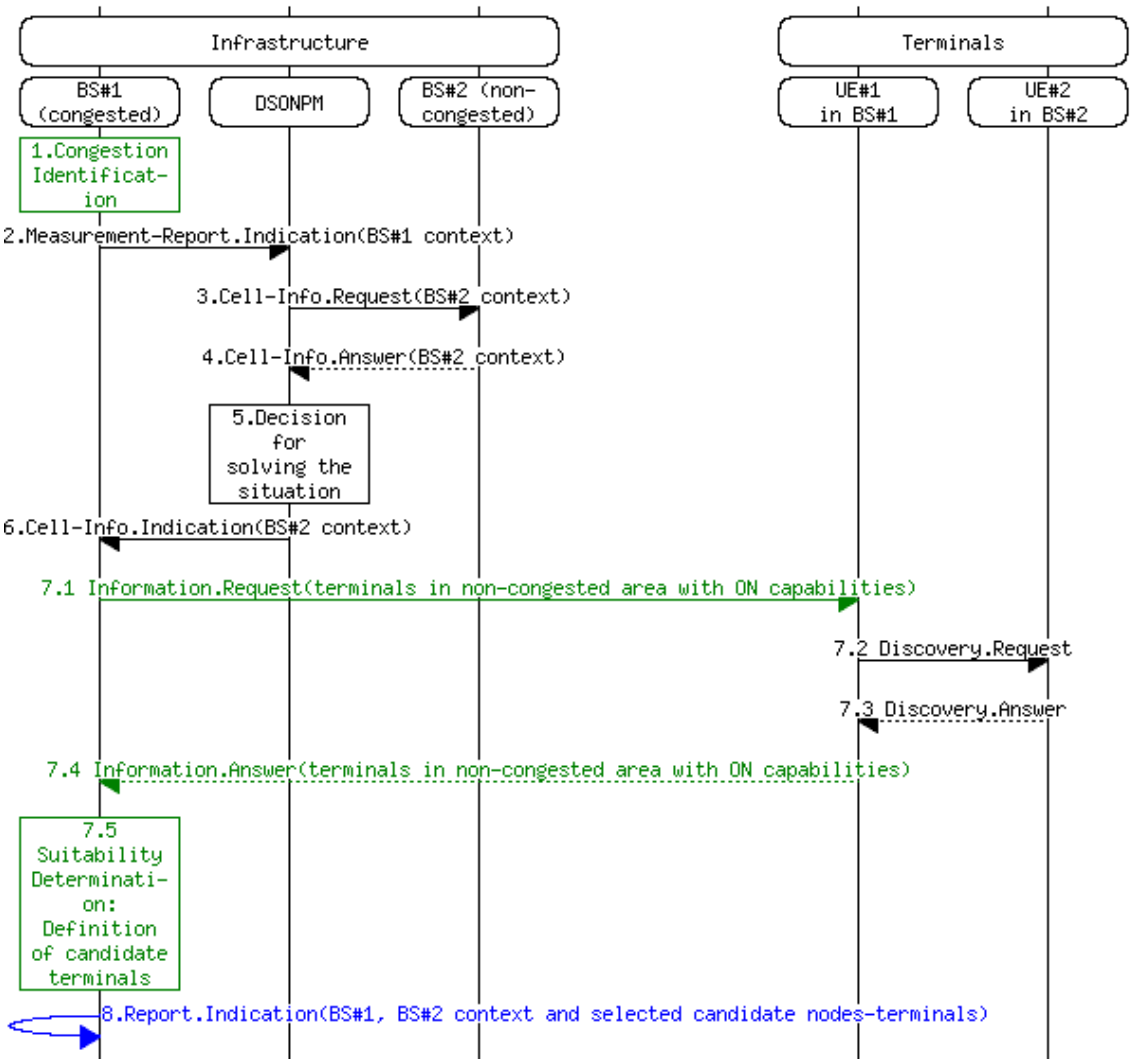


Figure 75: Capacity extension through neighbouring terminals procedure –suitability extension.

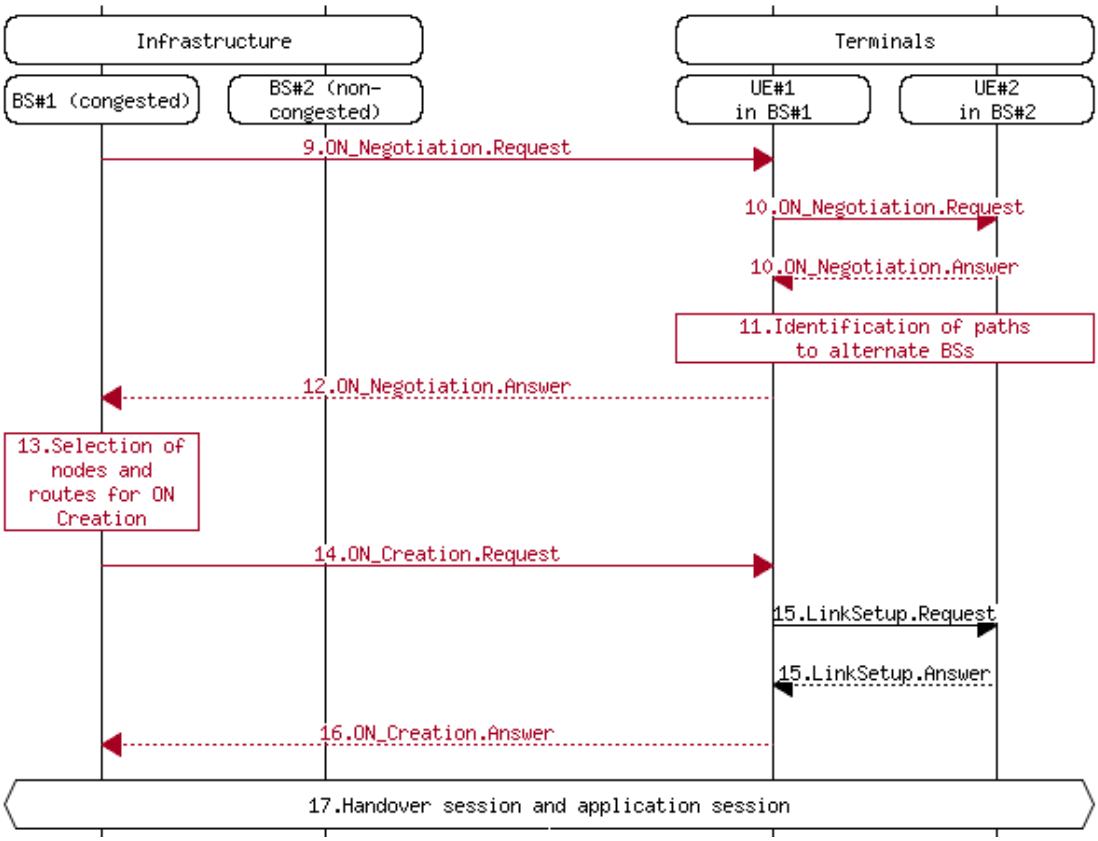


Figure 76: Capacity extension through neighbouring terminals procedure – creation.

Also, the implementation of the capacity extension through femtocells is available, which follows the provided procedure:

- A macro BS starts experiencing traffic congestion issues. Femtocells are also available in the area;
- As soon as the macro BS gets congested, the DSONPM is notified and CSCIs, CMONs collaborate in order to redistribute traffic to uncongested cells in the area;
- As a result, traffic is re-assigned to available femtocells and the congestion situation is resolved.

6.3 Implementation of the OneFIT scenario 3 "Infrastructure supported opportunistic ad-hoc networking"

Scenario 3 "Infrastructure supported opportunistic ad-hoc networking" shows the creation of an infrastructure less opportunistic network between two or more devices for the local exchange of information (e.g. peer-to-peer communications, home networking, location-based service providing, etc.). The infrastructure governs the ON creation and benefits from the local traffic offloading, as well as on new opportunities for service providing.

For more information regarding definition of the scenario and description of use cases please refer to D2.1 [3].

OneFIT scenario 3 will be validated using two different approaches. The first one will make use of the validation platform to implement a "local video sharing" use case. The second one will use a specific network emulator where a massive-multi-user service on a high-mobility environment will be deployed.

6.3.1 Local video sharing implementation

In this use case, 2 or more terminals (smart-phones or laptops) are connected through an ON in order to share a video file via HTTP streaming. One of the terminals is acting as the HTTP server and the other(s) is using the embedded browser to display the video.

The required C4MS is implemented in order to allow the remote establishment of an 802.11 WLAN between the 2 terminals: message exchange is performed using the JADE framework and a limited set of C4MS messages.

This scenario is implemented in the Direct D2D communication test-bed described in section 2.6. The algorithm defined in section 3.3.3.6 UE-to-UE trusted direct path is used to establish the D2D link between the devices. The MSC of the implemented use case including the used C4MS messages is shown in Figure 77.

6.3.2 Opportunistic Service Provision Demonstrator

This demonstration (carried out over the platform described in section 2.3) fits into the scope of OneFIT Scenario 3, especially under use case 3 ("ONs as platforms for location-specific services"), in which the infrastructure manages the creation of ad-hoc opportunistic networks able to support a geographically- and temporally-limited application.

Therefore, to test the usefulness of having an underlying ON-enabled infrastructure network, an example service has been developed. For demonstration purposes, the suggested service is related to the environmental management of 'Smart Cities'. The 'Smart City' concept was developed in [9], and describes economically and environmentally sustainable towns fuelled by modern telecommunications infrastructures. Therefore, power and spectrally efficient wireless network deployments, such as the OneFIT solution, are expected to boost the competitiveness of Smart Cities. Moreover, applications that are opportunistic in nature (e.g. traffic-lights pre-emptive control for emergency/safety vehicles; ad-hoc real-time route retracing for refuse collection; or personalized assistance for tourists) will probably be the common practice when offering services to citizens.

The Smart City-oriented service that has been developed for the demonstration is a tool for the environmental department of a city council to monitor the air pollution emissions of motor vehicles. Such tool might, ultimately, allow them to develop mid-term solutions and policies to enlarge the green footprint of the city. This service takes advantage of the versatility of the OneFIT mechanisms to enable vehicle-to-vehicle and vehicle-to-infrastructure communication links, and to allocate spectrum and other radio resources. The test-bed assumes that most of the vehicles in the monitored city have pollution sensors that collect data about their own emissions (for example, using the OBD-II standard [12], mandatory in all European motor vehicles since more than a decade ago). Vehicles are also assumed to be able to establish wireless connections using any of the available mobile technologies. On the other hand, some infrastructure nodes are deployed at strategic locations where traffic jams usually occur.

The simulated scenario is the following: at certain times of the day, or when vehicle density grows over a threshold, an opportunistic network is created among one of the infrastructure nodes and the surrounding vehicles. The creation of the ON relies on the awareness of the radio context and the cognitive mechanisms to allocate resources in both infrastructure nodes and terminals. Once the ON is established, all the vehicles begin downloading their emissions logs, relaying through other vehicles when needed and using the infrastructure node as a gateway to reach the city council monitoring server. The server collects all these logs and stores them for further analysis. During the process, vehicles keep exiting and entering the monitored area, but the ON will be kept alive through different users. After the traffic jam situation ends or the rush hour expires, the ON is dissolved.

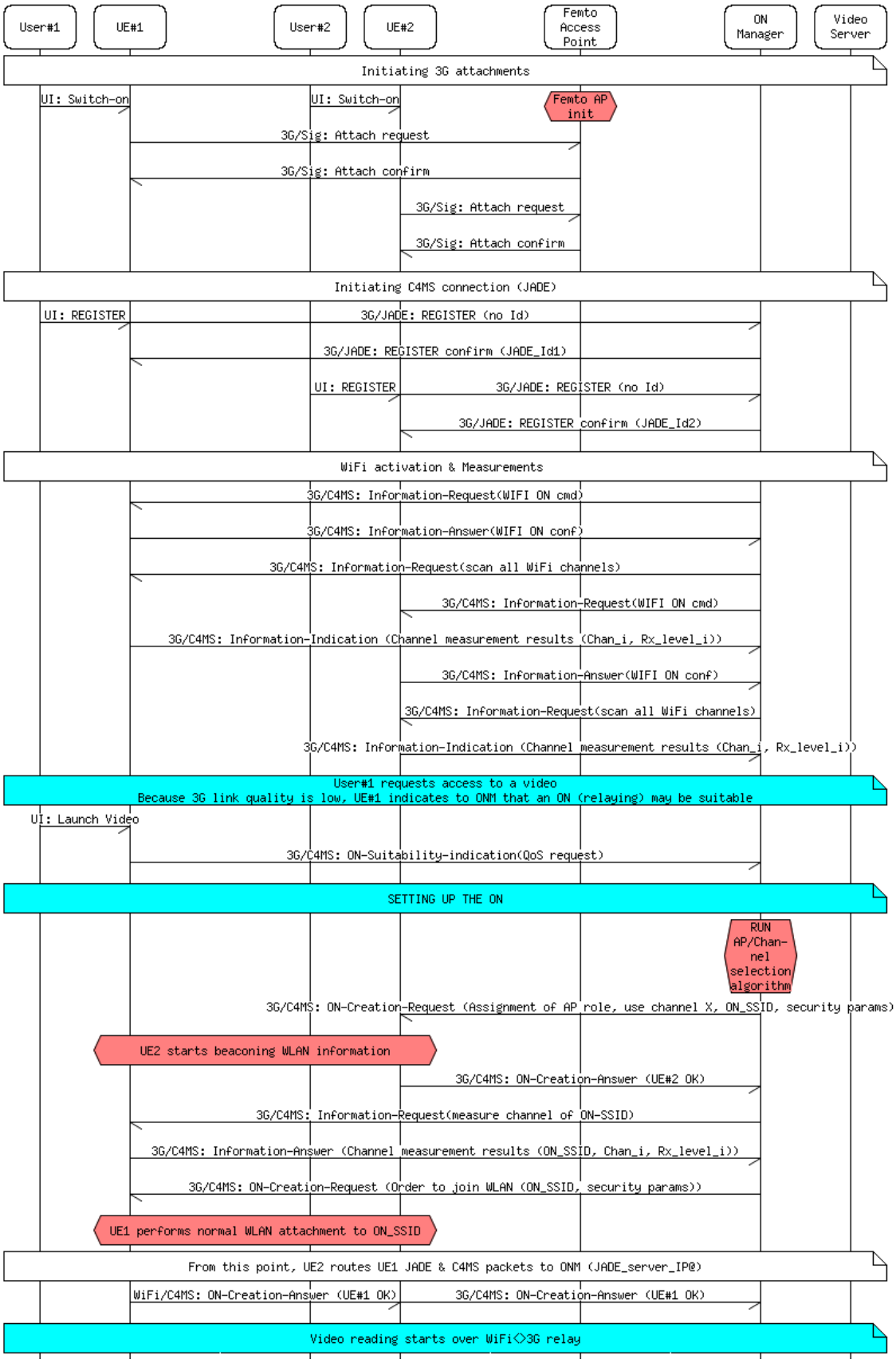


Figure 77 : UE-to-UE trusted path - creation

6.4 Implementation of the OneFIT scenario 5 "Opportunistic resource aggregation in the backhaul network"

Scenario 5 "Opportunistic resource aggregation in the backhaul network" depicts how opportunistic networks can be used to aggregate both backhaul bandwidth and processing/storage resources on infrastructure access nodes. In this case, the ON is created over infrastructure nodes (i.e. APs, BSs etc.) rather than user terminals, thus offering a new focus on system performance improvement.

For more information regarding definition of the scenario and description of use cases please refer to D2.1 [3].

The OneFIT scenario 5 "Opportunistic resource aggregation in the backhaul network" is implemented and validated in the OneFIT validation platform through realization of the use case "Opportunistic backhaul bandwidth aggregation in unlicensed spectrum". The open platform WMN test-bed (see subsection 2.9 and Figure 78) is used for realization of this use case. The bandwidth aggregation is achieved with "Application cognitive multipath routing in wireless mesh networks" algorithm. The nodes shown in Figure 78 are named after Serbian rivers. The web interface used for algorithm testing and demonstration can be accessed from the Internet while the shown test-bed is located in the LCI's premises.

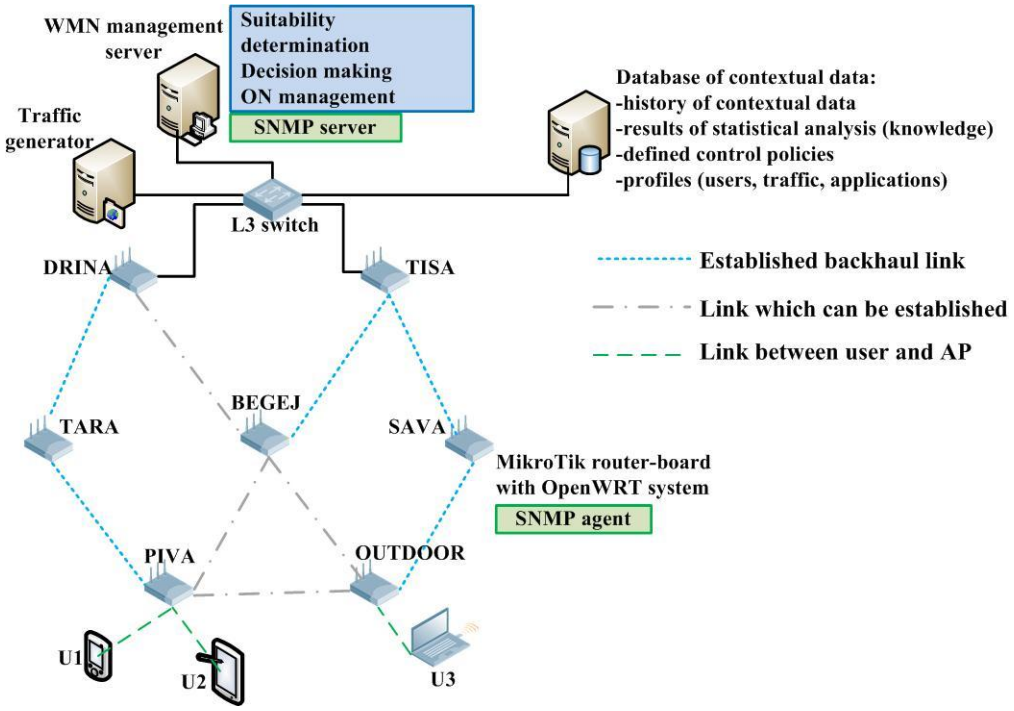


Figure 78: The test-bed used for realization of the scenario 5 use case

Next, different tables of the web interface illustration the ON management process will be presented. Opportunistic networks table displays results of the ON management phases performed by the backhaul bandwidth aggregation algorithm and provides interface for setting the profile of the application (see Figure 79) which is used by the newly connected user (next phase of the algorithm development is implementation of the application identification engine).

Figure 79: Opportunistic networks table – settings phase

In the initial state of the demonstration there are no clients connected to the APs which are considered as candidates (OUTDOOR and PIVA) for ON creation in order to enable multipath routing between them and the existing GWs. Figure 80 shows what happens when a new user connects to the OUTDOOR AP and requests the VoIP service. Opportunistic networks table will display algorithms query for suitable opportunistic network (multiple paths set). It includes name of the node for which the multipath needs to be enabled, time of the query, required bandwidth and ETX (expected transmission count) of the detected application profile, available bandwidth and ETX on the current paths connecting the OUTDOOR AP with the TISA GW. We can see which of the two QoS requirements triggered the algorithm, insufficient bandwidth or, in this case, higher ETX.

Figure 80: Opportunistic networks table - start of the suitability phase

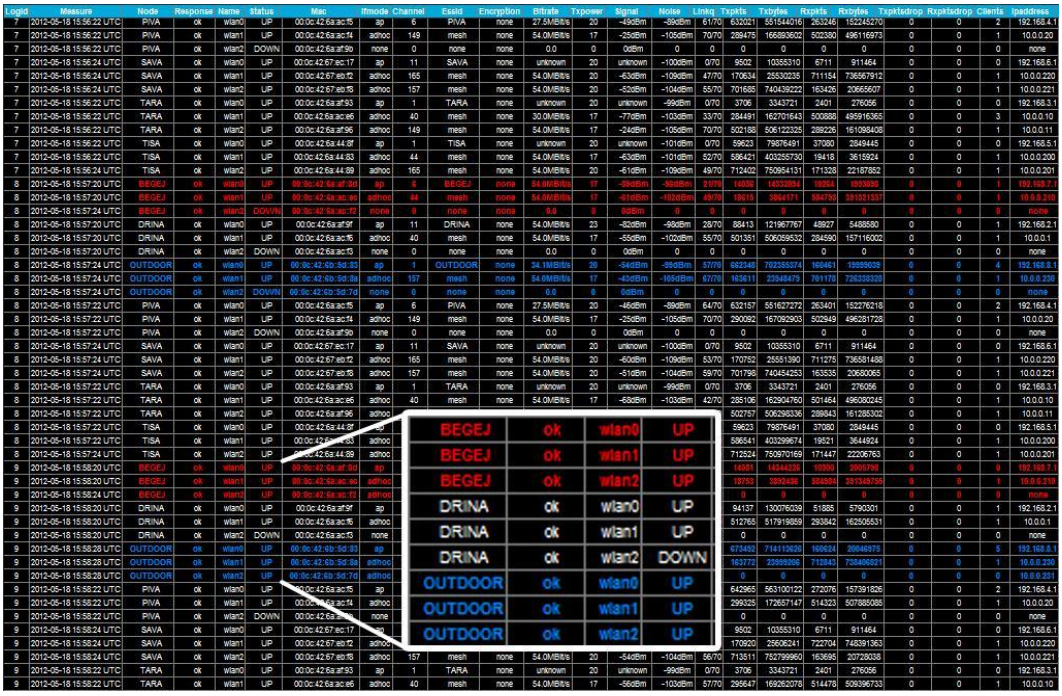
Once the algorithm finds suitable path it starts the ON Creation phase (see Figure 81). In the Opportunistic table the selected additional path (BEGEJ - TISA) and its available bandwidth and ETX as well as total available bandwidth, provided by combination of selected path with the current one, are displayed. In this phase, algorithm will send configuration commands to nodes in order to create additional path for the OUTDOOR AP.

Figure 81: Opportunistic networks table – creation phase

After reconfiguration of the underlying WMN, the algorithm waits for confirmation of the process. If the ON is successfully created, confirmation can be found in the contextual database which is updated by the monitoring system. The corresponding 802.11a interfaces of the OUTDOOR AP are now active which is detected by their UP status in the Interfaces table stored in the contextual database and which is also presented in the web interface (see Figure 82).

OLSR Links table will also display that there is a link between OUTDOOR and BEGEJ and the new path from the OUTDOOR to the TISA GW (see Figure 83).

After verifying that necessary connection was made (ON created), algorithm will enter the ON Maintaining phase (see Figure 84) and it will continuously check if the ON is still required.



Logid	Measure	Node	Response	Name	Status	Mac	Iftmode	Channel	Essid	Encryption	Bitrate	Txpower	Signal	Noise	Link%	Txpkts	Txbytes	Rxpkts	Rxbytes	Txpktsdrop	Rxpktsdrop	Clients	Ipaddress
7	2012-05-18 15:56:22 UTC	PIVA	ok	wlan0	UP	00:0c:42:6a:ac:f5	ap	6	PIVA	none	27.5MBit/s	20	-49dBm	-89dBm	51/70	632021	551544216	263246	152345270	0	0	2	192.168.4.1
7	2012-05-18 15:56:22 UTC	PIVA	ok	wlan1	UP	00:0c:42:6a:ac:f4	adhoc	149	mesh	none	54.0MBit/s	17	-25dBm	-105dBm	70/70	289475	166893602	502380	496116973	0	0	1	10.0.0.20
7	2012-05-18 15:56:22 UTC	PIVA	ok	wlan2	DOWN	00:0c:42:6a:af:90	none	0	none	none	0.0	0	0dBm	0	0	0	0	0	0	0	0	0	none
7	2012-05-18 15:56:24 UTC	SAVA	ok	wlan0	UP	00:0c:42:67:ac:17	ap	11	SAVA	none	unknown	20	unknown	-100dBm	0/70	9502	10355310	6711	911464	0	0	0	192.168.6.1
7	2012-05-18 15:56:24 UTC	SAVA	ok	wlan1	UP	00:0c:42:67:eb:f2	adhoc	165	mesh	none	54.0MBit/s	20	-63dBm	-109dBm	47/70	170634	25530235	711154	736567912	0	0	1	10.0.0.220
7	2012-05-18 15:56:24 UTC	SAVA	ok	wlan2	UP	00:0c:42:67:eb:f3	adhoc	157	mesh	none	54.0MBit/s	20	-52dBm	-104dBm	55/70	701685	740439222	163426	20655607	0	0	1	10.0.0.221
7	2012-05-18 15:56:22 UTC	TARA	ok	wlan1	UP	00:0c:42:6a:af:93	ap	1	TARA	none	unknown	20	unknown	-99dBm	0/70	3706	3343721	2401	276056	0	0	0	192.168.3.1
7	2012-05-18 15:56:22 UTC	TARA	ok	wlan1	UP	00:0c:42:6a:ac:e6	adhoc	40	mesh	none	30.0MBit/s	17	-77dBm	-103dBm	33/70	284491	162701643	500888	495916365	0	0	3	10.0.0.10
7	2012-05-18 15:56:22 UTC	TARA	ok	wlan2	UP	00:0c:42:6a:af:96	adhoc	149	mesh	none	54.0MBit/s	17	-24dBm	-105dBm	70/70	502188	506122325	289226	161089408	0	0	1	10.0.0.11
7	2012-05-18 15:56:22 UTC	TISA	ok	wlan0	UP	00:0c:42:6a:44:8f	ap	1	TISA	none	unknown	20	unknown	-101dBm	0/70	59623	79876491	37080	2849445	0	0	0	192.168.5.1
7	2012-05-18 15:56:22 UTC	TISA	ok	wlan1	UP	00:0c:42:6a:44:83	adhoc	44	mesh	none	54.0MBit/s	17	-63dBm	-101dBm	52/70	586421	403256730	19418	3615924	0	0	1	10.0.0.200
7	2012-05-18 15:56:24 UTC	TISA	ok	wlan2	UP	00:0c:42:6a:44:89	adhoc	165	mesh	none	54.0MBit/s	20	-61dBm	-109dBm	49/70	712402	750954131	171328	22187852	0	0	1	10.0.0.201
8	2012-05-18 15:57:20 UTC	BEGEJ	ok	wlan0	UP	00:0c:42:6a:af:90	ap	6	BEGEJ	none	54.0MBit/s	17	-59dBm	-96dBm	21/70	14858	14332894	10264	1893899	0	0	1	192.168.7.1
8	2012-05-18 15:57:20 UTC	BEGEJ	ok	wlan1	UP	00:0c:42:6a:ac:ac	adhoc	44	mesh	none	54.0MBit/s	17	-61dBm	-102dBm	49/70	18615	3864171	684750	391021337	0	0	1	10.0.0.210
8	2012-05-18 15:57:24 UTC	BEGEJ	ok	wlan2	DOWN	00:0c:42:6a:ac:f2	none	0	none	none	0.0	0	0dBm	0	0	0	0	0	0	0	0	0	none
8	2012-05-18 15:57:20 UTC	DRINA	ok	wlan0	UP	00:0c:42:6a:af:9f	ap	11	DRINA	none	54.0MBit/s	23	-82dBm	-98dBm	28/70	88413	121967767	48927	5488580	0	0	1	192.168.2.1
8	2012-05-18 15:57:20 UTC	DRINA	ok	wlan1	UP	00:0c:42:6a:ac:f5	adhoc	40	mesh	none	54.0MBit/s	17	-55dBm	-102dBm	55/70	501351	506059532	284590	157116002	0	0	1	10.0.0.1
8	2012-05-18 15:57:20 UTC	DRINA	ok	wlan2	DOWN	00:0c:42:6a:ac:f3	none	0	none	none	0.0	0	0dBm	0	0	0	0	0	0	0	0	0	none
8	2012-05-18 15:57:24 UTC	OUTDOOR	ok	wlan0	UP	00:0c:42:6b:5d:83	ap	1	OUTDOOR	none	54.1MBit/s	20	-54dBm	-89dBm	57/70	662348	702355374	169461	19989039	0	0	4	192.168.8.1
8	2012-05-18 15:57:24 UTC	OUTDOOR	ok	wlan1	UP	00:0c:42:6b:5d:8a	adhoc	157	mesh	none	54.0MBit/s	17	-43dBm	-105dBm	67/70	163411	23548479	701175	726338328	0	0	1	10.0.0.230
8	2012-05-18 15:57:24 UTC	OUTDOOR	ok	wlan2	DOWN	00:0c:42:6b:5d:7d	none	0	none	none	0.0	0	0dBm	0	0	0	0	0	0	0	0	0	none
8	2012-05-18 15:57:22 UTC	PIVA	ok	wlan0	UP	00:0c:42:6a:ac:f5	ap	6	PIVA	none	27.5MBit/s	20	-46dBm	-89dBm	64/70	632157	551627272	263401	152276218	0	0	2	192.168.4.1
8	2012-05-18 15:57:22 UTC	PIVA	ok	wlan1	UP	00:0c:42:6a:ac:f4	adhoc	149	mesh	none	54.0MBit/s	17	-25dBm	-105dBm	70/70	290092	167092903	502949	496281728	0	0	1	10.0.0.20
8	2012-05-18 15:57:22 UTC	PIVA	ok	wlan2	DOWN	00:0c:42:6a:af:90	none	0	none	none	0.0	0	0dBm	0	0	0	0	0	0	0	0	0	none
8	2012-05-18 15:57:24 UTC	SAVA	ok	wlan0	UP	00:0c:42:67:ac:17	ap	11	SAVA	none	unknown	20	unknown	-100dBm	0/70	9502	10355310	6711	911464	0	0	0	192.168.6.1
8	2012-05-18 15:57:24 UTC	SAVA	ok	wlan1	UP	00:0c:42:67:eb:f2	adhoc	165	mesh	none	54.0MBit/s	20	-60dBm	-109dBm	53/70	170752	25551390	711275	736581488	0	0	1	10.0.0.220
8	2012-05-18 15:57:24 UTC	SAVA	ok	wlan2	UP	00:0c:42:67:eb:f3	adhoc	157	mesh	none	54.0MBit/s	20	-51dBm	-104dBm	59/70	701798	740454253	163535	20680065	0	0	1	10.0.0.221
8	2012-05-18 15:57:22 UTC	TARA	ok	wlan1	UP	00:0c:42:6a:af:93	ap	1	TARA	none	unknown	20	unknown	-99dBm	0/70	3706	3343721	2401	276056	0	0	0	192.168.3.1
8	2012-05-18 15:57:22 UTC	TARA	ok	wlan1	UP	00:0c:42:6a:ac:e6	adhoc	40	mesh	none	54.0MBit/s	17	-68dBm	-103dBm	42/70	285106	162904750	501464	496380245	0	0	1	10.0.0.10
8	2012-05-18 15:57:22 UTC	TARA	ok	wlan2	UP	00:0c:42:6a:af:96	adhoc									502757	506298336	289043	161089302	0	0	1	10.0.0.11
8	2012-05-18 15:57:22 UTC	TISA	ok	wlan0	UP	00:0c:42:6a:44:8f	ap									59623	79876491	37080	2849445	0	0	0	192.168.5.1
8	2012-05-18 15:57:22 UTC	TISA	ok	wlan1	UP	00:0c:42:6a:44:83	adhoc									586541	403299674	19521	3644924	0	0	1	10.0.0.200
8	2012-05-18 15:57:24 UTC	TISA	ok	wlan2	UP	00:0c:42:6a:44:89	adhoc									712524	750970169	171447	22206763	0	0	1	10.0.0.201
9	2012-05-18 15:58:20 UTC	BEGEJ	ok	wlan1	UP	00:0c:42:6a:af:9d	ap									14091	14344235	10309	2005798	0	0	0	192.168.7.1
9	2012-05-18 15:58:20 UTC	BEGEJ	ok	wlan1	UP	00:0c:42:6a:ac:ae	adhoc									18793	3892436	684884	391349755	0	0	1	10.0.0.210
9	2012-05-18 15:58:24 UTC	BEGEJ	ok	wlan2	UP	00:0c:42:6a:ac:f2	adhoc									0	0	0	0	0	0	0	none
9	2012-05-18 15:58:20 UTC	DRINA	ok	wlan0	UP	00:0c:42:6a:af:9f	ap									94137	130076039	51885	5790301	0	0	1	192.168.2.1
9	2012-05-18 15:58:20 UTC	DRINA	ok	wlan1	UP	00:0c:42:6a:ac:f5	adhoc									512765	517919859	293842	162505531	0	0	1	10.0.0.1
9	2012-05-18 15:58:20 UTC	DRINA	ok	wlan2	DOWN	00:0c:42:6a:ac:f3	none									0	0	0	0	0	0	0	none
9	2012-05-18 15:58:28 UTC	OUTDOOR	ok	wlan0	UP	00:0c:42:6b:5d:83	ap									673492	714113620	169624	20046975	0	0	5	192.168.8.1
9	2012-05-18 15:58:28 UTC	OUTDOOR	ok	wlan1	UP	00:0c:42:6b:5d:8a	adhoc									163772	23999006	712843	738406921	0	0	1	10.0.0.230
9	2012-05-18 15:58:28 UTC	OUTDOOR	ok	wlan2	UP	00:0c:42:6b:5d:7d	adhoc									0	0	0	0	0	0	0	10.0.0.231
9	2012-05-18 15:58:22 UTC	PIVA	ok	wlan0	UP	00:0c:42:6a:ac:f5	ap									642965	563100122	272076	157391826	0	0	2	192.168.4.1
9	2012-05-18 15:58:22 UTC	PIVA	ok	wlan1	UP	00:0c:42:6a:ac:f4	adhoc									299325	172657147	514323	507885088	0	0	1	10.0.0.20
9	2012-05-18 15:58:22 UTC	PIVA	ok	wlan2	DOWN	00:0c:42:6a:ac:f2	none									0	0	0	0	0	0	0	none
9	2012-05-18 15:58:24 UTC	SAVA	ok	wlan0	UP	00:0c:42:67:ac:17	ap									9502	10355310	6711	911464	0	0	0	192.168.6.1
9	2012-05-18 15:58:24 UTC	SAVA	ok	wlan1	UP	00:0c:42:67:eb:f2	adhoc									170920	25606241	722704	745391363	0	0	1	10.0.0.220
9	2012-05-18 15:58:24 UTC	SAVA	ok	wlan2	UP	00:0c:42:67:eb:f3	adhoc	157	mesh	none	54.0MBit/s	20	-54dBm	-104dBm	56/70	713511	752799960	163695	20728038	0	0	1	10.0.0.221
9	2012-05-18 15:58:22 UTC	TARA	ok	wlan0	UP	00:0c:42:6a:af:93	ap	1	TARA	none	unknown	20	unknown	-99dBm	0/70	3706	3343721	2401	276056	0	0	0	192.168.3.1
9	2012-05-18 15:58:22 UTC	TARA	ok	wlan1	UP	00:0c:42:6a:ac:e6	adhoc	40	mesh	none	54.0MBit/s	17	-56dBm	-103dBm	57/70	296647	169262078	514478	509396733	0	0	1	10.0.0.10

BEGEJ	ok	wlan0	UP
BEGEJ	ok	wlan1	UP
BEGEJ	ok	wlan2	UP
DRINA	ok	wlan0	UP
DRINA	ok	wlan1	UP
DRINA	ok	wlan2	DOWN
OUTDOOR	ok	wlan0	UP
OUTDOOR	ok	wlan1	UP
OUTDOOR	ok	wlan2	UP

Figure 82: Interface table – showing that corresponding 802.11a interfaces of the OUTDOOR are UP

Logid	Measure	Node	Response	Entry	Localip	Remoteip	Hyst	Lq	Nlq	Cost
7	2012-05-18 15:56:24 UTC	OUTDOOR	ok	1	10.0.0.230	10.0.0.221	0.0	1.0	1.0	1.0
7	2012-05-18 15:56:22 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	0.462	1.0	2.16
7	2012-05-18 15:56:24 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	1.0	1.0	1.0
7	2012-05-18 15:56:24 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	1.0	1.0	1.0
7	2012-05-18 15:56:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	1.0	0.854	1.169
7	2012-05-18 15:56:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	0.944	0.886	1.193
7	2012-05-18 15:56:22 UTC	TARA	ok	3	10.0.0.10	10.0.0.211	0.0	0.223	0.0	0.0
7	2012-05-18 15:56:24 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	1.0	1.0	1.0
7	2012-05-18 15:56:24 UTC	TISA	ok	2	10.0.0.200	10.0.0.210	0.0	1.0	0.0	0.0
8	2012-05-18 15:57:20 UTC	BEGEJ	ok	1	10.0.0.210	10.0.0.200	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:20 UTC	DRINA	ok	1	10.0.0.1	10.0.0.10	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:24 UTC	OUTDOOR	ok	1	10.0.0.230	10.0.0.221	0.0	0.894	1.0	1.118
8	2012-05-18 15:57:22 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:24 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:24 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:24 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	1.0	1.0	1.0
8	2012-05-18 15:57:24 UTC	TISA	ok	2	10.0.0.200	10.0.0.210	0.0	1.0	1.0	1.0
9	2012-05-18 15:58:20 UTC	BEGEJ	ok	1	10.0.0.210	10.0.0.200	0.0	0.888	1.0	1.128
9	2012-05-18 15:58:20 UTC	DRINA	ok	1	10.0.0.1	10.0.0.10	0.0	0.886	0.701	1.606
9	2012-05-18 15:58:28 UTC	OUTDOOR	ok	1	10.0.0.230	10.0.0.221	0.0	0.94	0.894	1.188
9	2012-05-18 15:58:22 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	1.0	1.0	1.0
9	2012-05-18 15:58:24 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	1.0	1.0	1.0
9	2012-05-18 15:58:24 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	0.886	0.94	1.198
9	2012-05-18 15:58:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	1.0	1.0	1.0
9	2012-05-18 15:58:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	0.627	0.886	1.798
9	2012-05-18 15:58:24 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	1.0	1.0	1.0
9	2012-05-18 15:58:24 UTC	TISA	ok	2	10.0.0.200	10.0.0.210	0.0	0.937	1.0	1.066
10	2012-05-18 15:59:20 UTC	BEGEJ	ok	1	10.0.0.210	10.0.0.200	0.0	0.533	0.948	1.976
10	2012-05-18 15:59:20 UTC	BEGEJ	ok	2	10.0.0.211	10.0.0.231	0.0	0.38	0.396	6.637
10	2012-05-18 15:59:20 UTC	DRINA	ok	1	10.0.0.1	10.0.0.10	0.0	0.886	0.662	1.702
10	2012-05-18 15:59:24 UTC	OUTDOOR	ok	1	10.0.0.230	10.0.0.221	0.0	0.831	0.94	1.277
10	2012-05-18 15:59:24 UTC	OUTDOOR	ok	2	10.0.0.231	10.0.0.211	0.0	1.0	1.0	1.0
10	2012-05-18 15:59:24 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	1.0	1.0	1.0
10	2012-05-18 15:59:24 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	1.0	1.0	1.0
10	2012-05-18 15:59:24 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	0.94	0.839	1.266
10	2012-05-18 15:59:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	1.0	1.0	1.0
10	2012-05-18 15:59:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	0.662	0.886	1.702
10	2012-05-18 15:59:24 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	1.0	1.0	1.0
10	2012-05-18 15:59:24 UTC	TISA	ok	2	10.0.0.200	10.0.0.210	0.0	0.94	1.0	1.063

Figure 83: OLSR table – a new entry for the new path between OUTDOOR and TISA GW over the BEGEJ AP

Opportunistic networks

Node	Time	Required_bandwidth	Required_ETX	Available_bandwidth	Current_ETX	ON_phase	Selected_path	SP_available_bandwidth	Total_available_bandwidth	SP_ETX	FLAG
OUTDOOR	2012-05-18 15:57:46 UTC	0.1	1.0	2.118	2.0	Suitability determination			3.696		false
OUTDOOR	2012-05-18 15:57:57 UTC	0.1	1.0	3.696	2.118	Creating	BEGEJ-TISA	3.691	7.386	1.0	false
OUTDOOR	2012-05-18 15:59:42 UTC	0.1	1.0	1.66	3.253	Maintaining	BEGEJ-TISA	3.614	5.274	1.976	false

Set requirements for candidate nodes:

Node	Application	
OUTDOOR	VoIP	Submit
PIVA	No Client	Submit

Figure 84: Opportunistic networks table – maintenance phase started

Next, the client is disconnected from the OUTDOOR AP. This means that there is no need for opportunistic network that was created and the algorithm will terminate it. Terminating phase is created and configuration commands are sent. Note that flag is set to "false" (see Figure 85). Once the termination is confirmed, flag will be set to "true".

Opportunistic networks

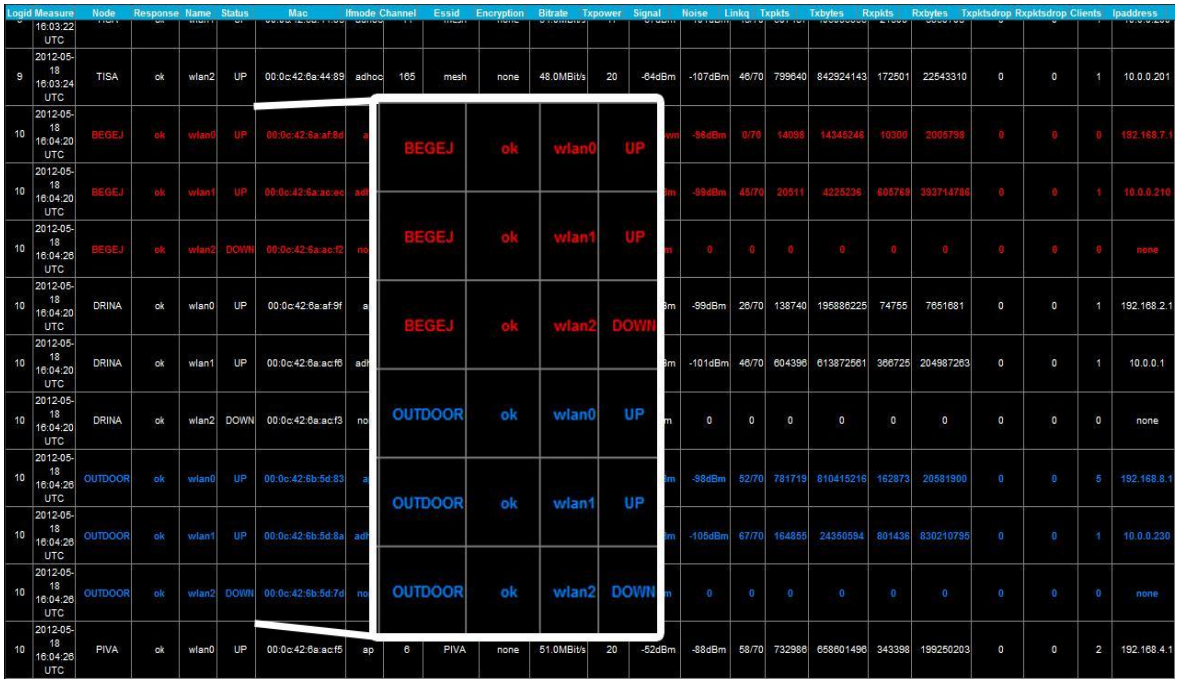
Node	Time	Required_bandwidth	Required_ETX	Available_bandwidth	Current_ETX	ON_phase	Selected_path	SP_available_bandwidth	Total_available_bandwidth	SP_ETX	FLAG
OUTDOOR	2012-05-18 15:57:46 UTC	0.1	1.0	2.118	2.0	Suitability determination			3.696		true
OUTDOOR	2012-05-18 15:57:57 UTC	0.1	1.0	3.696	2.118	Creating	BEGEJ-TISA	3.691	7.386	1.0	true
OUTDOOR	2012-05-18 16:01:48 UTC	0.0	99.0	1.667	2.617	Maintaining	BEGEJ-TISA	3.599	5.267	1.261	true
OUTDOOR	2012-05-18 16:01:55 UTC	0.0	99.0	1.667	2.617	Terminating	BEGEJ-TISA	3.599	5.267	1.261	false

Set requirements for candidate nodes:

Node	Application	
OUTDOOR	No Client	Submit
PIVA	No Client	Submit

Figure 85: Opportunistic networks table – termination phase

Algorithm will again search for confirmation that a link is terminated. Log 10 in the Interfaces table (see Figure 86) is showing that both BEGEJ and OUTDOOR have their interface wlan2 set to DOWN.



Logid	Measure	Node	Response	Name	Status	Mac	Ifmode	Channel	Essid	Encryption	Bitrate	Txpower	Signal	Noise	Linkq	Txpkts	Txbytes	Rxpkts	Rxbytes	Txpktsdrop	Rxpktsdrop	Clients	Ipaddress
	16:03:22 UTC																						
9	2012-05-18 16:03:24 UTC	TISA	ok	wlan2	UP	00:0c:42:6a:44:89	adhoc	165	mesh	none	48.0MBit/s	20	-64dBm	-107dBm	46/70	799640	842924143	172501	22543310	0	0	1	10.0.0.201
10	2012-05-18 16:04:20 UTC	BEGEJ	ok	wlan0	UP	00:0c:42:6a:af:8d	a							-96dBm	0/70	14098	14345248	10309	2005798	0	0	0	192.168.7.1
10	2012-05-18 16:04:20 UTC	BEGEJ	ok	wlan1	UP	00:0c:42:6a:ac:ec	adh							-99dBm	45/70	20511	4225236	605768	393714786	0	0	1	10.0.0.210
10	2012-05-18 16:04:26 UTC	BEGEJ	ok	wlan2	DOWN	00:0c:42:6a:ac:f2	no							0	0	0	0	0	0	0	0	0	none
10	2012-05-18 16:04:20 UTC	DRINA	ok	wlan0	UP	00:0c:42:6a:af:9f	a							-99dBm	26/70	138740	195886225	74755	7651681	0	0	1	192.168.2.1
10	2012-05-18 16:04:20 UTC	DRINA	ok	wlan1	UP	00:0c:42:6a:acf6	adh							-101dBm	46/70	604396	613872561	366725	204987263	0	0	1	10.0.0.1
10	2012-05-18 16:04:20 UTC	DRINA	ok	wlan2	DOWN	00:0c:42:6a:acf3	no							0	0	0	0	0	0	0	0	0	none
10	2012-05-18 16:04:26 UTC	OUTDOOR	ok	wlan0	UP	00:0c:42:6b:5d:83	a							-98dBm	52/70	781719	810415216	162873	20581909	0	0	5	192.168.8.1
10	2012-05-18 16:04:26 UTC	OUTDOOR	ok	wlan1	UP	00:0c:42:6b:5d:8a	adh							-105dBm	67/70	164855	24350584	801436	830210795	0	0	1	10.0.0.230
10	2012-05-18 16:04:26 UTC	OUTDOOR	ok	wlan2	DOWN	00:0c:42:6b:5d:7d	no							0	0	0	0	0	0	0	0	0	none
10	2012-05-18 16:04:26 UTC	PIVA	ok	wlan0	UP	00:0c:42:6a:acf5	ap	6	PIVA	none	51.0MBit/s	20	-52dBm	-88dBm	58/70	732986	658601496	343398	199250203	0	0	2	192.168.4.1

Figure 86: Interface table – Link between OUTDOOR and BEGEJ APs is terminated

Also the OLSR table shows that there is no longer a path between the OUTDOOR AP and the TISA GW over the BEGEJ AP (see Figure 87).

Logid	Measure	Node	Response	Entry	Localip	Remoteip	Hyst	Lq	Nlq	Cost
7	2012-05-18 16:01:20 UTC	DRINA	ok	1	10.0.0.1	10.0.0.10	0.0	0.761	0.831	1.58
7	2012-05-18 16:01:24 UTC	OUTDOOR	ok	1	10.0.0.230	10.0.0.221	0.0	0.831	0.886	1.356
7	2012-05-18 16:01:24 UTC	OUTDOOR	ok	2	10.0.0.231	10.0.0.211	0.0	1.0	0.886	1.128
7	2012-05-18 16:01:22 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	0.886	1.0	1.128
7	2012-05-18 16:01:24 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	0.839	0.94	1.266
7	2012-05-18 16:01:24 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	0.886	0.831	1.356
7	2012-05-18 16:01:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	1.0	0.886	1.128
7	2012-05-18 16:01:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	0.808	0.761	1.627
7	2012-05-18 16:01:24 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	0.94	0.839	1.266
7	2012-05-18 16:01:24 UTC	TISA	ok	2	10.0.0.200	10.0.0.210	0.0	1.0	1.0	1.0
8	2012-05-18 16:02:22 UTC	BEGEJ	ok	1	10.0.0.210	10.0.0.200	0.0	1.0	1.0	1.0
8	2012-05-18 16:02:22 UTC	BEGEJ	ok	2	10.0.0.211	10.0.0.231	0.0	1.0	1.0	1.0
8	2012-05-18 16:02:20 UTC	DRINA	ok	1	10.0.0.1	10.0.0.10	0.0	0.776	0.831	1.549
8	2012-05-18 16:02:30 UTC	OUTDOOR	no	1	no	no	0.0	0.0	0.0	0.0
8	2012-05-18 16:02:22 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	1.0	1.0	1.0
8	2012-05-18 16:02:24 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	1.0	0.94	1.063
8	2012-05-18 16:02:24 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	0.94	0.776	1.368
8	2012-05-18 16:02:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	1.0	1.0	1.0
8	2012-05-18 16:02:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	0.831	0.776	1.549
8	2012-05-18 16:02:24 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	0.886	1.0	1.128
8	2012-05-18 16:02:24 UTC	TISA	ok	2	10.0.0.200	10.0.0.210	0.0	0.886	1.0	1.128
9	2012-05-18 16:03:20 UTC	BEGEJ	ok	1	10.0.0.210	10.0.0.200	0.0	0.419	0.952	2.5
9	2012-05-18 16:03:20 UTC	DRINA	ok	1	10.0.0.1	10.0.0.10	0.0	0.796	0.839	1.496
9	2012-05-18 16:03:30 UTC	OUTDOOR	no	1	no	no	0.0	0.0	0.0	0.0
9	2012-05-18 16:03:24 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	0.94	0.886	1.198
9	2012-05-18 16:03:24 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	0.937	0.94	1.133
9	2012-05-18 16:03:24 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	0.94	1.0	1.063
9	2012-05-18 16:03:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	0.886	0.94	1.198
9	2012-05-18 16:03:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	0.732	0.886	1.538
9	2012-05-18 16:03:24 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	0.94	1.0	1.063
9	2012-05-18 16:03:24 UTC	TISA	ok	2	10.0.0.200	10.0.0.210	0.0	0.944	1.0	1.058
10	2012-05-18 16:04:20 UTC	BEGEJ	ok	1	10.0.0.210	10.0.0.200	0.0	0.894	0.94	1.188
10	2012-05-18 16:04:20 UTC	DRINA	ok	1	10.0.0.1	10.0.0.10	0.0	0.886	0.831	1.356
10	2012-05-18 16:04:26 UTC	OUTDOOR	ok	1	10.0.0.230	10.0.0.221	0.0	0.886	1.0	1.128
10	2012-05-18 16:04:26 UTC	PIVA	ok	1	10.0.0.20	10.0.0.11	0.0	1.0	1.0	1.0
10	2012-05-18 16:04:26 UTC	SAVA	ok	1	10.0.0.220	10.0.0.201	0.0	0.537	0.944	1.969
10	2012-05-18 16:04:26 UTC	SAVA	ok	2	10.0.0.221	10.0.0.230	0.0	1.0	0.886	1.128
10	2012-05-18 16:04:22 UTC	TARA	ok	1	10.0.0.11	10.0.0.20	0.0	1.0	1.0	1.0
10	2012-05-18 16:04:22 UTC	TARA	ok	2	10.0.0.10	10.0.0.1	0.0	0.831	0.886	1.356
10	2012-05-18 16:04:26 UTC	TISA	ok	1	10.0.0.201	10.0.0.220	0.0	1.0	0.537	1.86

Figure 87: OLSR table – Link OUTDOOR – BEGEJ is removed

When the termination is found to be a success, algorithm will set the flag to "true" (see Figure 88) which concludes the lifecycle of the ON.

Opportunistic networks

Node	Time	Required_bandwidth	Required_ETX	Available_bandwidth	Current_ETX	ON_phase	Selected_path	SP_available_bandwidth	Total_available_bandwidth	SP_ETX	FLAG
OUTDOOR	2012-05-18 15:57:46 UTC	0.1	1.0	2.118	2.0	Suitability determination			3.696		true
OUTDOOR	2012-05-18 15:57:57 UTC	0.1	1.0	3.696	2.118	Creating	BEGEJ-TISA	3.691	7.386	1.0	true
OUTDOOR	2012-05-18 16:01:48 UTC	0.0	99.0	1.667	2.617	Maintaining	BEGEJ-TISA	3.599	5.267	1.261	true
OUTDOOR	2012-05-18 16:01:55 UTC	0.0	99.0	1.667	2.617	Terminating	BEGEJ-TISA	3.599	5.267	1.261	true

Set requirements for candidate nodes:

Node	Application	
OUTDOOR	No Client	Submit
PIVA	No Client	Submit

Figure 88: Opportunistic networks table – the ON is terminated

The MSC of the implemented use case is shown in Figure 89.

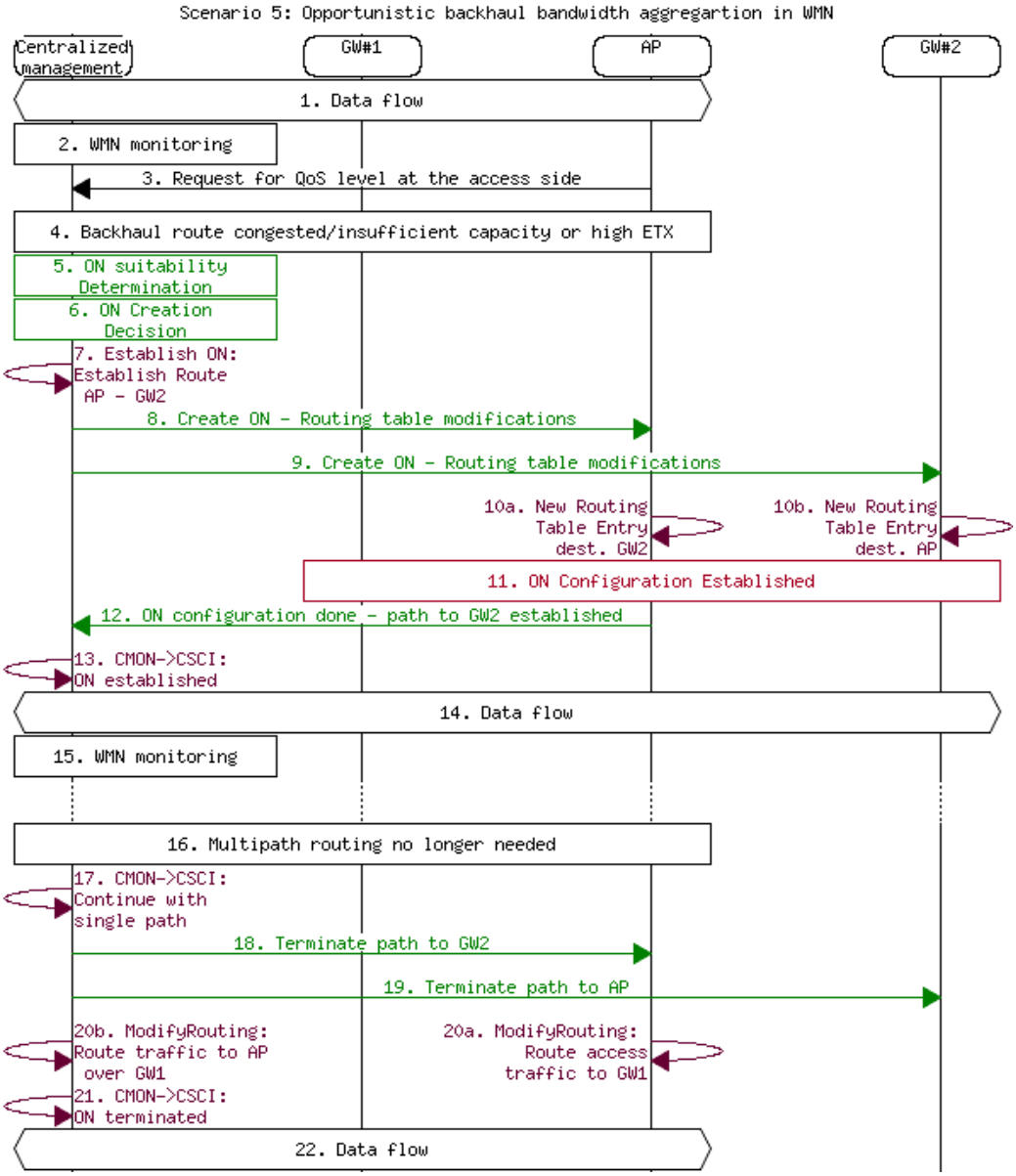


Figure 89: MSC of the backhaul bandwidth aggregation in WMN

7 Conclusion

For the verification of the OneFIT scenarios, architecture, algorithms and protocols, several test-beds have been developed for the OneFIT validation platform. Detailed description of these test-beds and their role in the OneFIT validation platform is provided in this document. These test-beds are used to verify the main OneFIT scenarios, which provide:

- Opportunistic coverage extension;
- Opportunistic capacity extension;
- Infrastructure supported ad-hoc networking and device-to-device communication;
- Opportunistic resource aggregation in the backhaul network.

All of the involved partners' test-beds are described and clearly mapped onto the ON related challenges, ON management phases, OneFIT algorithms, scenarios and onto the overall OneFIT validation platform. Joint capabilities of these test-beds are sufficient and are successfully addressed by the majority of the OneFIT system requirements (defined in D2.1 [3] and D2.2 [4]). However, limited requirements related mostly to security aspects (such as protection of user/device identity, or secured protocol communication) remain out of the main focus of the OneFIT project and are not fully addressed so far. For fulfilment of these requirements, available standard solutions can be used. The main requirements, with respect to OneFIT project tasks, are successfully addressed within implementation of partners' test-beds.

The implementation of the OneFIT building blocks is described in three sections. All of the OneFIT building blocks are successfully implemented into the OneFIT validation platform and corresponding partners' test-beds. First, the implementation of the ON cognitive management systems (CMON and CSCI) is described together with the description of the realization of the ON management phases. Next, a description of the implementation of the OneFIT supporting blocks (JRRM, CCM, DSM and DSONPM) is given. Finally, a description of how the C4MS protocol is implemented into the OneFIT validation platform is provided. With the implementation of the C4MS protocol, measurements have been made on how much signalling is needed for the management of opportunistic networks. These results have been incorporated into the C4MS signalling evaluation and performance assessment described in D3.3 [7]. Implemented variants of the C4MS protocol (802.21MIH and SNMP/OLSR) and the OneFIT supporting building blocks provide solid basis for implementation of the OneFIT algorithms for enabling ONs. A list of the OneFIT algorithms (enabling cognitive management systems and OneFIT supporting blocks) and C4MS variants which are implemented into the OneFIT validation platform is provided. Implemented algorithmic solutions provide all of the functionalities required for CMON and CSCI cognitive management systems realization. Although there are different algorithmic solutions providing the same functionality (i.e. routing), these solutions address different situations and are applicable in different contextual environments/scenarios (i.e. Application cognitive multipath routing is applicable between infrastructure nodes while Multi flow routes co-determination algorithm is applicable in ad-hoc networks between mobile terminals).

The last section of the document provides a description of the implementation of different OneFIT scenarios into the validation platform (test-beds comprising it). Implemented scenarios include enough aspects of the OneFIT system solution for enabling its successful validation.

Next steps in WP5 are related to the further exploitation of the available test-bed platforms: Following the project planning, at the time that this document is finalized, the development cycle has ended and the phase of results analysis and validation has started. The forthcoming WP5 deliverable D5.3 will therefore contain corresponding results on operational characteristics and performance measurements indicating the benefits of the proposed solutions and implementation approaches.

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