WiSHFUL

Wireless Software and Hardware platforms for Flexible and Unified radio and network controL

Project Deliverable D6.4

Optimised implementation of testbed on the move

Contractual date of delivery:	31-12-2016
Actual date of delivery:	23-12-2016
Beneficiaries:	TUB, IMEC, NCENTRIC
Lead beneficiary:	TUB
Authors:	Piotr Gawłowicz (TUB), Mikolaj Chwalisz (TUB), Anatolij Zubow (TUB), Vincent Sercu (IMEC), Pieter Becue (IMEC), Peter Ruckebusch (IMEC), Spilios Giannoulis (IMEC), Ingrid Moerman (IMEC), Robin Leblon (NCENTRIC)
Reviewers:	Pierluigi Gallo (CNIT), Luiz Da Silva (TCD)
Work package:	WP6 – Testbed on the move
Estimated person months:	13
Nature:	R
Dissemination level:	PU
Version:	1.0

Abstract:

This public document gives a detailed description of the capabilities and operation of the Portable Testbed in Year 2. This deliverable provides optimised guidelines for packaging, transport, insurance and initial setup of the hardware. This deliverable will also include the improvements and extensions to be implemented in Year 3.

Keywords:

Portable Testbed, Packaging, Transportation, Wireless Network Control, Testbed Management

Executive Summary

This Year 2 deliverable reports on the current status of the Portable Testbed (PT).

In Year 2 the Portable Testbed in version 1 was used to deploy multiple scientific experiments. Those include internal showcases presented in WP2 as well as external ones conducted by **Open-Call** partners. Experimenters provided us with **valuable feedback** regarding the Portable Testbed. Especially, our partners pointed out that equipment is too heavy to be considered as *portable*.

We solved this issue by replacing the server as well as the Ethernet switch with **new hardware** that is smaller and much more handy. However, the new switch is able to power only 6 Device–Under-Test (DUT) nodes at the same time using Power-over-Ethernet technology. For this reason, the remaining nodes must be powered using AC or batteries (also included in PT v2). Furthermore, we developed **new flight-cases** that match the new hardware and is much smaller and lighter as compared to the old one. Moreover, during deployment of OC1 experiments, it turned out that the 3D printed antenna mount is not strong enough and not temperature resistant. To solve this problem we changed manufacturing technology: the new mount is based on polyurethane (PUR), which translates into much higher resilience.

The DUT nodes were equipped with wireless interfaces of different technologies, including: 802.11a/b/g/n, 802.11ac, Zolertia RE-Mote sensor nodes, RM090 sensor nodes, WiSpy USB dongles, and USRP mini.

The hardware platform of the Backbone Node was replaced with a newer version that is more powerful and has smaller dimensions.

Furthermore, the ***capabilities*** of the Portable Testbed were extended in Year 2 by the following ***functionality***:

- *Remote login* to the PT Management Server over a secure connection, if an Internet up-link is available on-site.
- *Spectrum sensing* using WiSpy and mini USRP USB dongles.
- *Visualization of measurement data* using a visualization server.
- *New batteries* allow for simultaneous charging and discharging, which can be helpful during the preparation of an experiment.
- *Automatic DUT to BN mapping discovery* that facilitates the deployment of PT.
- *Improved Wireless BN channel selection mechanism*, which selects the best possible channel for the Wireless Backbone Network.

The following ***improvements and extensions***, to be implemented in the next release by the end of Year 3, have been identified:

- *Time synchronization between BN nodes*: This mechanism will allow the BN to offer time synchronization service to a DUT node connected over an Ethernet interface. This will allow all DUT nodes in the Portable Testbed to share the same global time, which will make timestamping of logging data and debugging easier and more accurate.
- *Integrated battery powered backbone nodes:* This solution will make the BN node able to power up a DUT node over PoE (Power over Ethernet). As a result, the number of required batteries will be reduced and the BN will be able to control the state of a DUT node (e.g., enabling a *remote reboot mechanism*).
- *Software improvements to BN nodes:* In the current version, most reconfigurations of the BN node require a reboot. We will improve our software to allow for *on-line* reconfigurations (i.e. without a reboot).
- *Evaluation of Wireless Backbone performance:* we will analyse and study the performance and limitations of usage of the Portable Testbed with a Wireless Backbone.

- *Strategies for deploying the PT:* we will develop strategies for deploying the PT and possible usage policies.

List of Acronyms and Abbreviations

AC	Alternating current
AMQP	Advanced Message Queuing Protocol
ARP	Address Resolution Protocol
BN	Backbone
BNC	Backbone Network Controller
COTS	Commercial off-the-shelf
CPA	Channel Policy Agreement
CSMA	Carrier Sense Multiple Access
CSMA	Carrier Sense Multiple Access
DCF	Distributed Coordination Function
DGPS	Differential Global Positioning System
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DUT	Device Under Test
EC	Experiment Controller
EGNOS	European Geostationary Navigation Overlay Service
EMF	Experiment Management Framework
EMS	Experiment Management Server
GbE	Gigabit Ethernet
GNSS	Global Navigation Satellite System
GPIO	General Purpose Input/Output
GPS	Global Positioning System
HP	Hewlett-Packard
ISM	Industrial, Scientific and Medical Band
LAN	Local Area Network
MAC	Media Access Control
MIMO	Multiple Input Multiple Output
MSAS	Multi-functional Satellite Augmentation System
NFS	Network File System
NTP	Network Time Protocol
NUC	Next Unit of Computing, a family of Intel Mini-PCs
OC	Open Call
OLSR	Optimized Link State Routing
OMF	A Control and Management Framework for Networking Testbeds

OML	OMF Measurement Library
OS	Operating System
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect
PoE	Power over Ethernet
PPS	Pulse-Per-Second
PT	Portable Testbed
PUR	Polyurethane
PXE	Preboot Execution Environment
QoE	Quality of Experience
QZSS	Quasi-Zenith Satellite System
RAM	Random Access Memory
RC	Resource Control
RMS	Root Mean Square
RTT	Round Trip Time
SBAS	Satellite Based Augmentation System
SFA	Slice-based Federation Architecture
SFP	Small Form-factor Pluggable
SoC	System on Chip
SUT	System Under Test
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TFTP	Trivial File Transfer Protocol
TMF	Testbed Management Framework
TMS	Testbed Management Server
UPI	Unified Programming Interface
USB	Universal Serial Bus
USRP	Universal Software Radio Peripheral
UTC	Universal Time Coordinated
WAAS	Wide Area Augmentation System
Wi-Fi	Wireless Fidelity
WMP	Wireless MAC Processor

Table of contents

1 Introduction

This public document provides a detailed description of the current operational status and capabilities of the Portable Testbed.

The development of the Portable Testbed in Year 2 was driven by improvements and extensions defined in D6.2 as well as valuable feedback collected from its users. In this report, we present new capabilities and extensions implemented in Year 2. We give an overview of new hardware platforms and software tools used in the second release of the Portable Testbed. Moreover, we provide a description of possible connectivity (wired and wireless) and powering options.

This document is structured as follows. In Section 2 we present the second release of the Portable Testbed and its new hardware and software. In Section 3 we provide optimized guidelines for packaging, transporting, insurance and initial setup of the hardware of Portable Testbed. In Section 4 we report on usage of the Portable Testbed for internal showcases (described in WP2) and external ones (i.e. Open Calls). In Section 5, we give a description of the improvements and extensions that will be implemented in Year 3. Section 6 contains a summary and conclusions, while references are listed in Section 7.

2 Second Portable Testbed release

This section provides a description of the second release of the Portable Testbed that was implemented in Year 2. It contains a description of both hardware and software improvements.

2.1 Testbed and Experiment Management

Some changes were made to the server and network configuration of the first version of the portable testbed (cfr. D6.2). Valuable feedback was received from the OC1 experimenters Allbesmart. They pointed out that the server configuration was too big and heavy to be considered "portable". Therefore it was decided to change the server hardware, as well as the Ethernet switch that interconnects the server with the DUTs.

2.1.1 Server configuration

The server now runs on the same hardware as the DUTs: the Intel NUC D54250 (see Figure 1). It features a dual-core Intel i5 1.3GHz processor, 16GB of DDR3 RAM and a 500GB hard drive. The dimensions of the new server are now limited to 11 x 11 x 5 cm^3. Similar to the server configuration described in D6.2, this new server also runs the VMWare ESXi Operating System that hosts all management Virtual Machines. Currently, the following VMs are deployed:

- Emulab BOSS Server: This server provides an SFA GENI v3 interface and takes care of all testbed management services like DHCP, DNS, PXE-booting, disk imaging).
- Emulab OPS Server: This is a file server that provides NFS-mounted storage, that can be shared between experimenters in the same project.
- AMQP server: This server enables the OMF EC to communicate with the OMF RCs that are pre-installed on the DUT nodes. The OMF EC should be installed on one of the DUT nodes.
- OML Database server: This server is used by default by the DUT nodes to store all experiment measurement data.
- OpenVPN gateway server (only in version 2): This gateway allows the experimenters to remotely connect to the portable testbed, if an internet up-link is available on-site.
- Basic spectrum sensing server (only in version 2): This server enables the portable testbed user to include basic spectrum sensing into his experiment by using WiSpy USB dongles (see section 2.2.3d).
- Measurement visualization server (only in version 2): This server allows easy visualization of measurement data. It allows both live and offline visualization. More details can be found in D5.4.

Figure 1: New portable testbed server (11 x 11 x 5 cm)

2.1.2 Network configuration

The large HP Procurve switch (portable testbed v1) is replaced by a much smaller Buffalo BS-GS2016P switch [1]. This 16-port Gigabit Ethernet switch has much smaller dimensions (23 x 33 x 4.3 cm^3). The specifications of this switch are:

- 16 gigabit Ethernet ports;
- 16 x 802.3at PoE+ ports (30W per port);
- 180W maximum PoE budget;
- 2 SFP ports compatible with 1000BASE-SX and 1000BASE-LX transceivers;
- 802.3az Green Ethernet;
- Port trunking and DHCP snooping.

Because the power consumption of one DUT can reach a maximum of 30W and the maximum PoE power budget is limited to 180W, we recommend to power a maximum of 6 DUTs with Power-Over-Ethernet when using this switch. For larger deployments, version 1 of the portable testbed server can be used, or other power sources can be used (battery/AC power). As shown in the table below, several solutions are available to provide power and network connectivity to the DUTs. Depending on the requirements of the experiment, different solutions can be combined.

Figure 2 shows the setup of the new portable testbed server and switch.

Figure 2: New portable testbed switch and server

2.2 DUT nodes

2.2.1 Physical node configuration

The first version of the DUT featured a 3D printed antenna mount as shown in blue in Figure 3. After deployment by Allbesmart (OC1 experiment) in an outdoor swimming pool complex in Portugal during the summer, it became apparent that the 3D printed mount was not strong enough and not resistant to temperatures higher than 30 degrees Celsius. Also, the procedure to 3D print the antenna mount takes about 8 hours.

Figure 3: 3D printed antenna mount (blue colour)

To cope with the aforementioned problems (strength, temperature, time to manufacture), a different solution was developed based on polyurethane (PUR). Using a silicon cast of the 3D printed model, two liquid agents (polypol and isocyanate) can be mixed together and poured in the silicone cast. The agents exothermally harden within 15 minutes, after which the plastic antenna mount can be removed from the cast. The result is a much stronger and more heat resistant antenna mount.

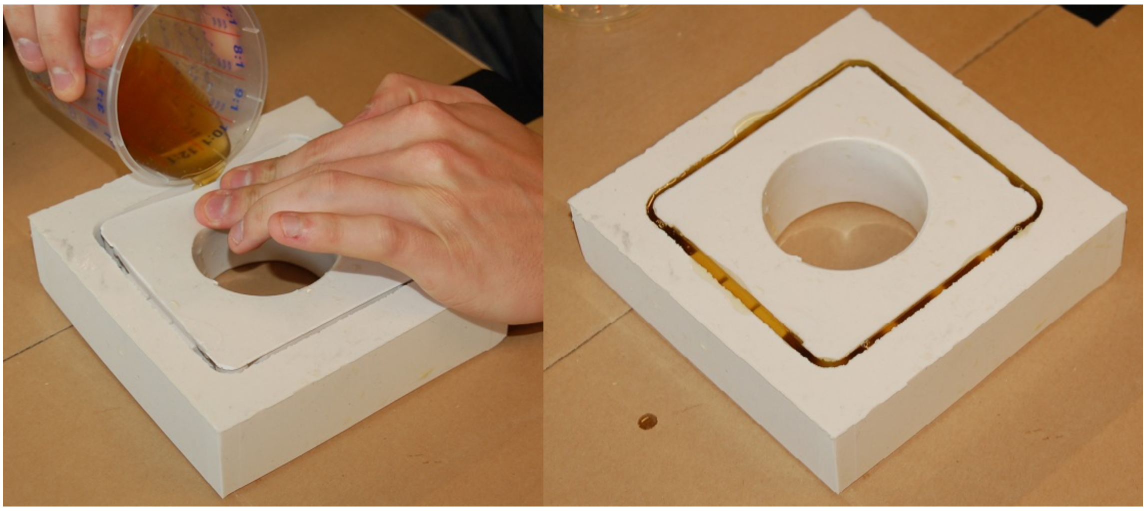

Figure 4: Silicone cast with liquid polyurethane

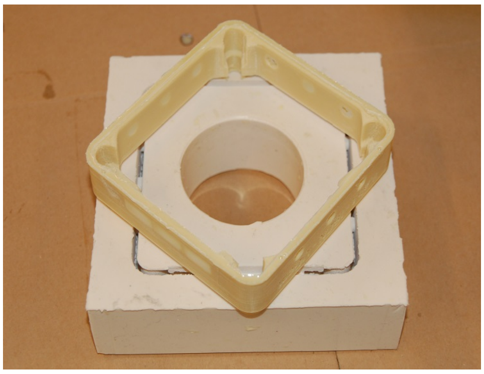

Figure 5: Resulting plastic antenna mount

In addition to the new way of manufacturing, a new component was also added to the antenna mount: a switchable USB hub [2]. This USB hub features 3 USB2.0 ports, of which the power can be cut from the DUT. This way, the experimenter can enable or disable USB devices (like sensor nodes) during his experiment.

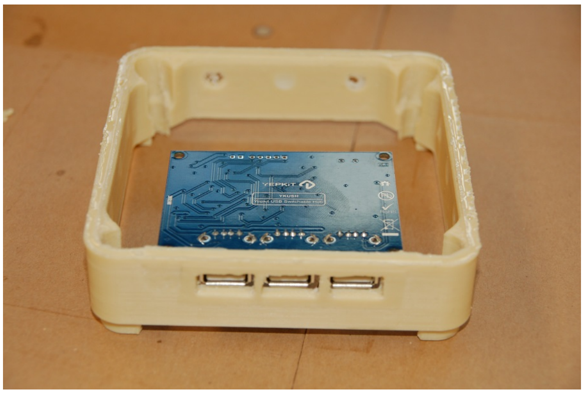

Figure 6: Antenna mount with Yepkit USB hub

2.2.2 Network and power configuration

There are several ways to connect the DUT nodes to the portable testbed server. Different combinations of the solutions proposed in Table 1 can be made. The figures below show some of these combinations.

Table 1: Network and power delivery options for the DUT

Solution	Backbone Network	Power	Pros	Cons
Wired	UTP, 1000Base-T (Gigabit Ethernet)	Power over Ethernet	Low latency and fast connectivity One cable for power and network	Requires (long) cables Limited to cable length Max. 30 watts power
Ethernet over Power	Ethernet over Power devices, ~300Mb/s 	Wall socket	Fast connectivity Power can be delivered from AC grid	Deployment is limited to locations of AC plugs
Battery	Wireless backbone (further explained in §2.2.2)	Power bank or battery pack	Deploy virtually anywhere	Duration of the experiment limited to battery capacity Backbone not designed to provision node images (gigabyte magnitude)

Figure 7: 2 PoE power DUTs

Figure 8: Wireless backbone node connected to switch

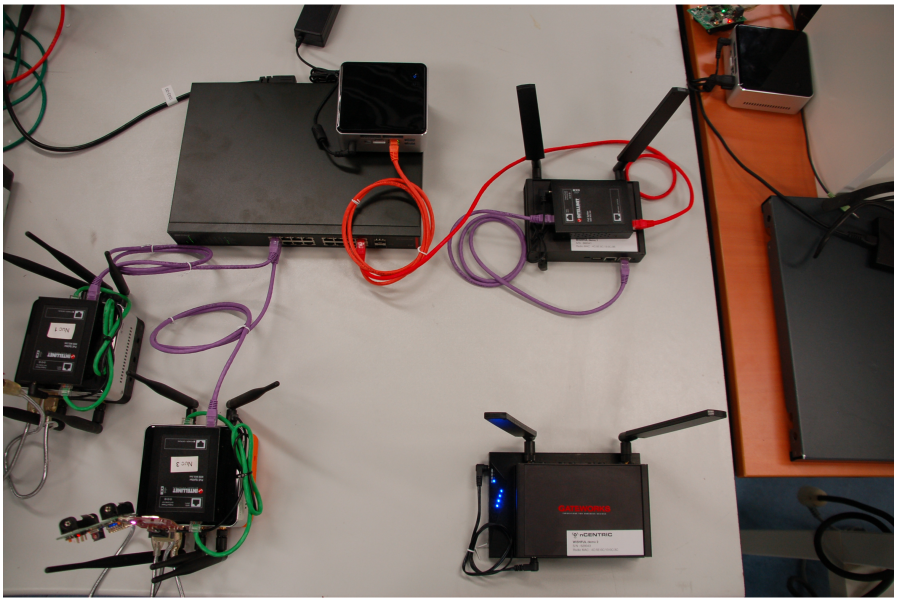

Figure 9: 2 PoE powered DUTs + Battery powered wireless BN

Figure 9 shows a setup of the portable testbed with 2 PoE powered DUTs, one wireless backbone node, which is connected to the switch (gateway for other BNs) and one battery powered wireless backbone node. The latter can be used to wirelessly connect a DUT to the portable testbed backbone network, as shown in Figure 10. We should mention that at the moment, 2 battery packs are still needed: one for the backbone node and one for the DUT. The deployment shown in Figure 10 is described in section 5.2, and will be developed during Y3 of the WiSHFUL project.

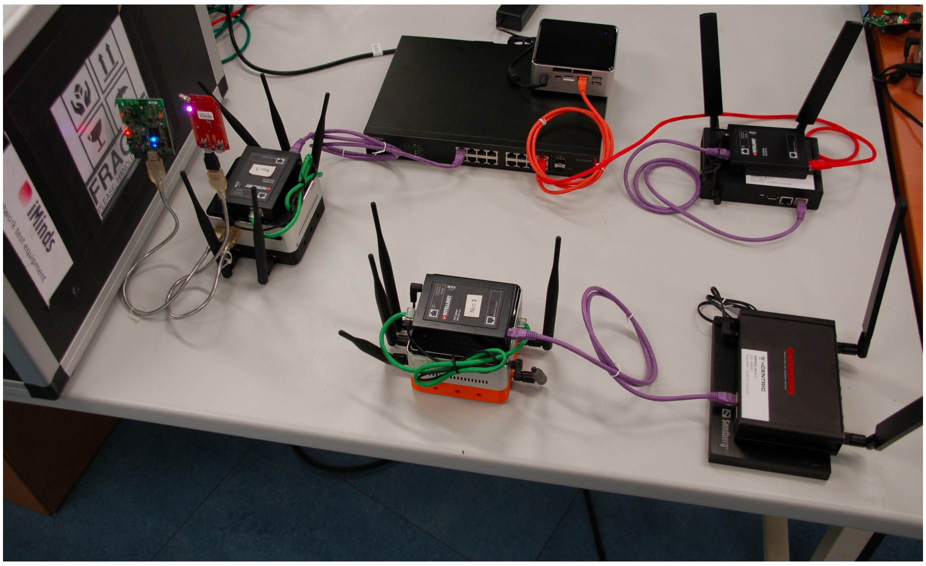

Figure 10: Battery-powered BN and DUT

The battery packs have been replaced by a different brand to support simultaneous charging and discharging of the battery packs. This makes it possible to use the battery-powered nodes (DUT or BN) while the battery packs are being charged. This is specifically useful when experimenters are still configuring their experiment, after which the node can simply be disconnected from the AC power supply and be deployed in the field.

The Sandberg battery pack [3] is shown in Figure 11 and has a capacity of 20.000 mAh. Given an average DUT power consumption of 20W, this battery pack will last for about 12 hours.

Figure 11: Sandberg battery-pack with nCENTRIC BN

2.2.3 Wireless Interfaces

The DUTs of the portable testbed feature several wireless interfaces. The following sections briefly describe the hardware that is used in this version of the portable testbed, as well as the WiSHFUL UPI support for that hardware.

a. 802.11a/b/g/n WiFi

Every DUT has one 802.11a/b/g/n WiFi interface (Sparklan WPEA-251N), which supports 2x2 MIMO. The WiSHFUL UPIs have full support for the ath9k driver that is used to access the features of this wireless card. These WiFi cards also feature a Bluetooth4.0 radio, for which no support is available at this moment in the WiSHFUL UPIs.

b. 802.11ac WiFi

Every DUT has one 802.11ac WiFi interface (Compex WLE900VX), which supports 3x3 MIMO. The WiSHFUL UPIs have no support for this interface, due to the closed wireless driver. However, simple scripts are available to the experimenter to allow easy setup of access points and clients.

Figure 12: 802.11a/b/g/n+BLE (2 antennas) and 802.11ac (3 antennas)

c. Zolertia RE-Mote sensor nodes

Every DUT can be equipped with several USB extensions. The Zolertia RE-Mote sensor node includes a 2.4GHz IEEE802.15.4 radio, bundled with a 868/915MHz RF transceiver. The Zolertia RE-Mote is supported and can be controlled by the WiSHFUL UPIs.

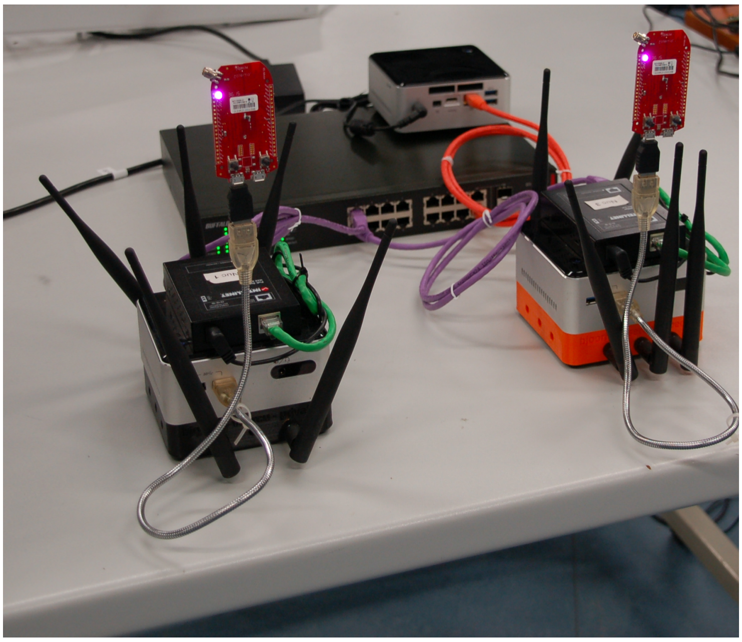

Figure 13: Zolertia RE-Mote sensor nodes in the portable testbed

d. RM090 sensor nodes

The RM090 is another type of IEEE802.15.4 sensor node with 2.4GHz radio that can be connected to the DUTs. The figure below shows a setup with both Zolertia RE-Mote and RM090 connected to a DUT. Using the switchable USB hub, the experimenter can enable/disable one or more USB connected devices during the experiment (e.g. to slowly add more devices to the sensor network).

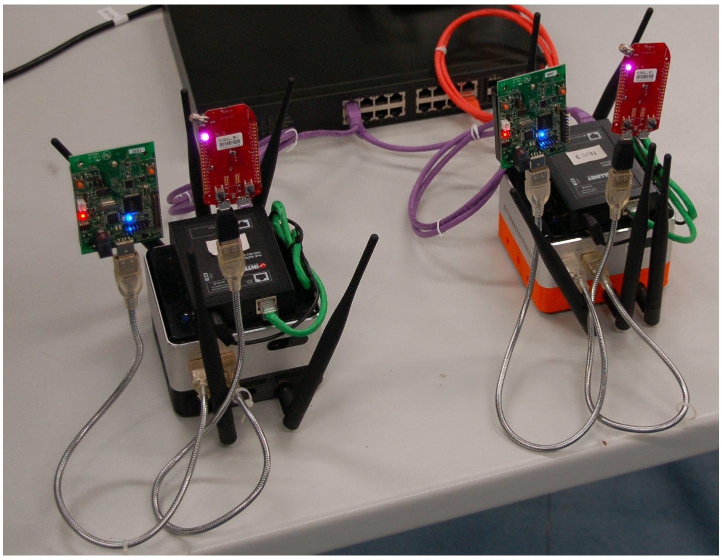

Figure 14: Zolertia RE-Mote and RM090 sensor nodes

e. WiSpy USB dongles

To allow for simple spectrum scanning during portable testbed experiments, a low-cost spectrum sensing device can be connected to the DUTs: the WiSpy. These devices are able to do spectrum scanning on both 2.4GHz and 5GHz. Because it uses a USB interface, it can easily be connected to the DUTs in the portable testbed.

Figure 15: WiSpy USB dongle

The default operating system of the DUTs in the portable testbed includes the necessary software to support these devices. The portable testbed server provides a virtual machine that runs a database server to collect all the spectrum sensing data and visualizes it through a web interface. Figure 16 shows the output of the WiSpy spectrum analyzer, with activity on WiFi channel 1 (on 2.4 GHz). The experimenter can also directly query the database on the portable testbed server.

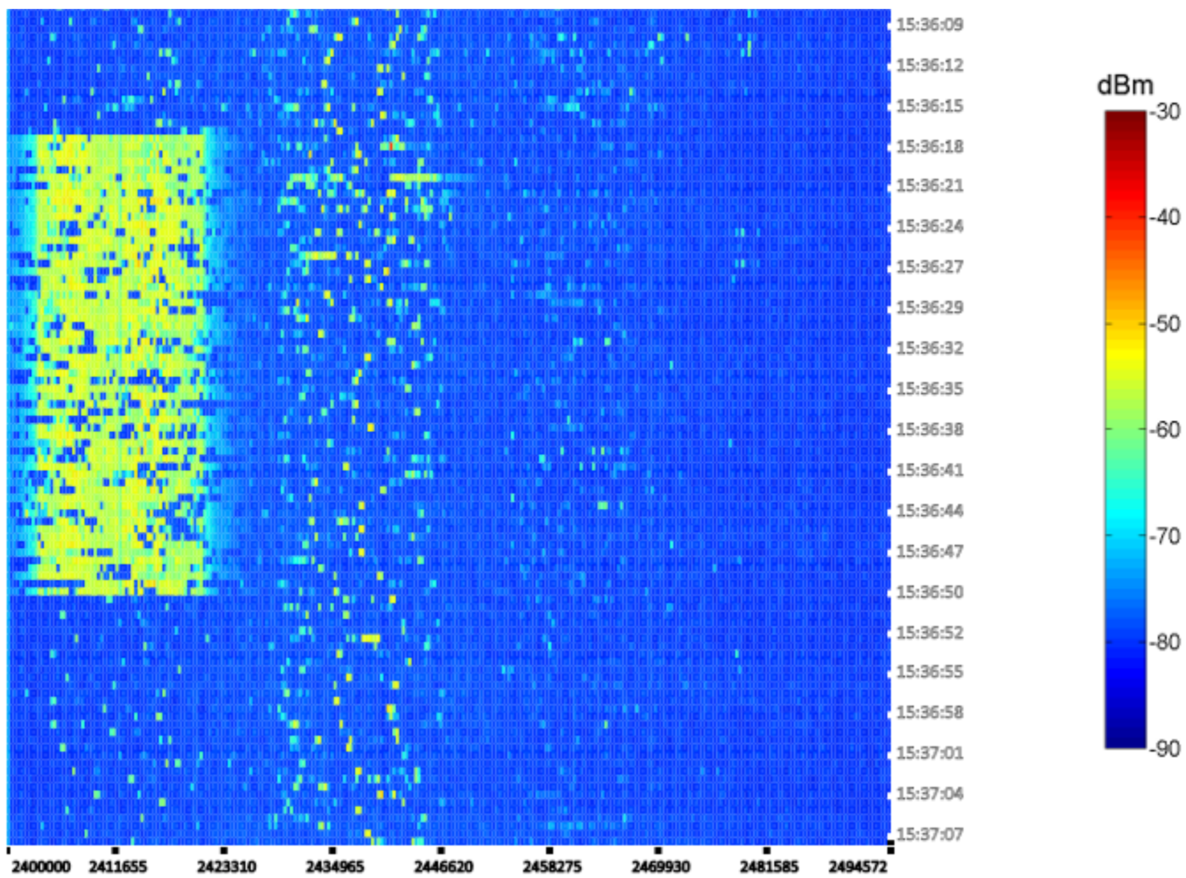

Figure 16: Sample WiSpy output

f. *USRP mini*

The portable testbed also provides three USRP B200mini devices to do more accurate spectrum sensing. The USRP mini can easily be connected to the DUTs with its USB3.0 interface.

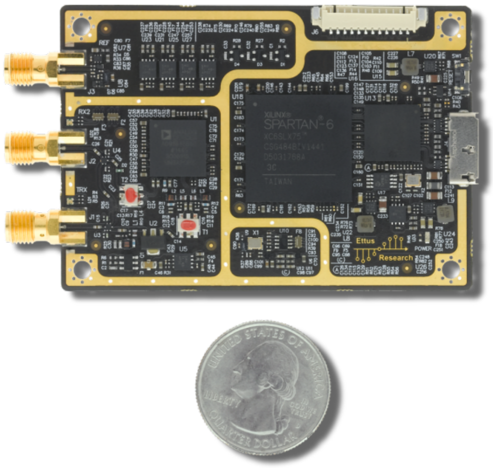

Figure 17: USRP B200-mini

The UHD software in combination with GNUradio allows the experimenter to easily visualize the spectrum from 70MHz to 6GHz, with up to 56MHz bandwidth. Given the form-factor of the device, it is a very good alternative to much larger (and more expensive) spectrum analyzers. A simple screenshot from GNUradio can be seen in Figure 18. It shows simple energy detection on a chosen frequency.

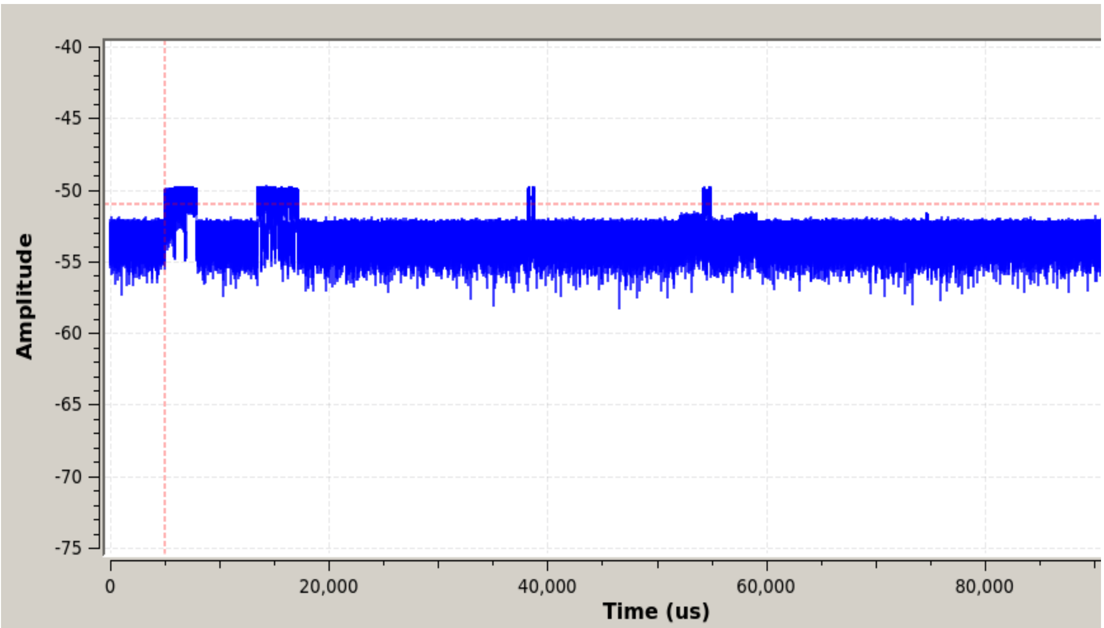

Figure 18: GNUradio energy detection using USRP B200-mini

2.3 Backbone Nodes

2.3.1 Hardware platform

In Year 2, we made transition to the newer Gateworks Ventana platform, with the following features:

- Quad Core ARM Cortex A9 SoC (1GHz)
- 1 GB DDR2 RAM
- Four or two High-Power Mini-PCIe Sockets
- Two GbE Ethernet Ports
- Real Time Clock with Battery Backup
- Voltage and Temperature Monitor
- 8 to 60V DC Input Voltage Range or PoE powered
- -40°C to +85°C Operating Temperature

Comparing to the old platform, the new BN node is much more powerful and has smaller dimensions. The Freescale i.MX6 SoC contains up to four Cortex A9 cores, which leaves opportunity for more advanced functionality on the BN nodes in future developments. Where budget is an issue a dual core version can be selected for cost effectiveness.

Additionally, the selected platform can be expanded with a state-of-the art GPS receiver for localisation, and more importantly, time synchronizing (see section 5.1).

2.3.2 Software improvements

The core daemon of the mesh platform has been thoroughly refactored and many parts rewritten to allow us to expose the full mesh network status from a single BN node. This required a new broadcasting model to facilitate quick network information propagation throughout the mesh network. It guarantees that any change in the network, no matter how many hops away from the node that acts as point of view, is visible within 2 seconds. Most importantly this allows us to provide a reliable network overview to the BN controller that is up to date at all times.

Stability and reaction speed to topology changes has increased greatly as a result of this as well. In our testing we noticed that the specific portable testbed use case generally contains many wireless paths with similar characteristics. This could result into flip-flopping which in worst case conditions could lead to packet loss and severely crippled available bandwidth.

The wireless driver has also been updated and now provides a real-life usable bandwidth estimate, which has proven quite accurate in our testing. This allows us to provide accurate bandwidth estimates to the BN controller.

The improved mesh daemon contains both a TCP server and a unix socket to expose its internal information and to allow configuration. Whereas in Y1 we were scraping console output, the WiSHFUL daemon now communicates over the unix socket.

Moreover, in Year 2 the following functionalities were implemented/improved:

a. Automatic DUT node to BN node mapping discovery

In order to deploy an experiment using the Portable Testbed with a Wireless Backbone Network, an experimenter has to establish a connection between the DUT and the corresponding BN node. Knowledge of the mapping between the DUT and BN nodes is essential for remote reboot functionality (described in detail in section 5.2). As manual maintaining of such mapping would be an error-prone and tedious task, we implemented a mechanism that automatically discovers and reports it to the BN Controller. In this mechanism, a BN node sniffs packets on an Ethernet connection to the DUT node and looks for the MAC source address of its peer. We assume that the MAC address of the Ethernet port of the DUT node allows unique identification of all DUT nodes in the testbed. If multiple DUT nodes are connected to a BN node (e.g. over a switch), the BN node has to discover all of them. Next, the BN node creates a mapping entry for each discovered DUT node, and sends it to the BN controller, which aggregates all entries.

In the presented mechanism, a BN may discover and identify a connected DUT only when it sends at least one packet. We assume that the DUT initiates the sending of a packet on its Ethernet interface on its own. This assumption is reasonable, because usually in testbeds DUT nodes try to perform PXE boot before booting from an internal default image. In order to do this, a DUT usually has to send at least an *ARP Request, DHCP Request, PXE Request and TFTP Request.*

b. Improved Wireless BN Channel Selection

In the first version of the Portable Testbed, an experimenter was able to specify a list of frequencies that she wishes to use in her experiment. Then the list is passed to the BN controller, which translates it to 802.11 channels (because the Wireless Backbone is realized using 802.11 technology) and subtracts this set from the set of all 802.11 channels (in both 2.4GHz and 5GHz bands). If the final set is not empty, the BN Controller selects one of the free channels for the Wireless Backbone Network and instructs all BN nodes to switch to this channel. Otherwise, the proper notification is displayed to the experimenter and she has to manually select the channel for the Wireless BN. Forcing usage of a specific channel in the Wireless Backbone Network is always possible.

In D6.2, we had reported our plans to improve the Channel Policy Agreement in Y2. We wanted to monitor whether the experimenter is using one of the 802.11 channels that she claimed not to use. Finally, we have decided that an experimenter may harm only her own experiment (as we exclude multi-user usage from the Portable Testbed) if she uses not-claimed channels and it is up to her to take care of the proper configuration.

Instead, we have implemented mechanisms for *Improved Wireless BN Channel Selection*, which before the experiment performs scans on all (and not-claimed to be used in the experiment) 802.11 channels and selects the one with lowest interference and highest capacity for the Wireless Backbone Network.

In order to select the best possible channel, we trigger the Wi-Fi adapter to perform measurements on all channels. The adapter returns a channel survey that contains:

- *channel* - the channel this survey record reports,
- noise – channel noise in dBm, i.e. the threshold value used by the energy detection carrier sense mechanism,
- *channel_time* – amount of time in milliseconds the radio spent on the channel,
- *channel_time_busy* – amount of time the primary channel was sensed busy, i.e. sum of times when input power is over the noise threshold and the radio is in TX/RX mode,
- *channel_time_ext_busy* – amount of time the extension channel was sensed as busy (used in case of channel bonding),
- *channel_time_rx* – amount of time the radio spent receiving data,
- *channel_time_tx* – amount of time the radio spent transmitting data.

Using measurements from channel survey we calculate channel duty cycle that equals:

$$channel\_duty\_cycle = channel\_time\_busy / channel\_time$$

For a backbone wireless network, the channel with lowest duty cycle and not used by the System-Under-Test (SUT) is selected.

c. Channel Access Optimisation

This mechanism was primarily planned to be implemented in Year 2. Unfortunately, due to issues with the Backbone Node software (i.e. reconfiguration change requires reboot, see section 5.3), we had to postpone this task until *online* reconfigurations are possible.

d. DUT Power-supply control

This mechanism was planned to be implemented in Year 2. However, it turned out that it will be a better, cleaner and easier solution to implement it on top of *Integrated battery powered Backbone Nodes* (see section 5.2) planned for Year 3. As a result ***DUT Power-supply control*** has been also postponed to Year 3.

2.4 Portable backup power

To allow very flexible installation of the portable testbed, even in locations without AC power available, two portable backup batteries are available [4]. These batteries can also allow the experimenter to move the entire setup (including server) to a new location without powering down the portable testbed. It also protects the portable testbed from sudden power failures.

Figure 19: Portable testbed backup power

As can be seen on Figure 19, the portable backup batteries can provide 220V AC, 12V or 5V (through USB). The batteries have a capacity of 400Wh, which means it could power the portable testbed server and switch for about 8 hours. However, if lots of PoE powered DUTs are connected to the switch, this will significantly reduce the autonomy of the Portable Testbed. This solution is therefore best suited in combination with battery powered DUTs. In that case, experiments up to 8 hours can be supported by only using battery packs.

3 Packaging and transport

The first version of the package had some drawbacks, noticed by IMEC itself or received through feedback of end-users and experimenters (OC1 WiFi-Dense):

- The server-case was very robust, and thus also heavy. It had to be made of plywood, because it needed fixtures for rackmount rails.
- Rackmount rails in the server-case also transfer vibrations and shocks to the equipment inside, which might result in hardware damage in the future.
- The above reasons made the server-case big and heavy (around 23kg).
- The foam in the NUC cases had to be cut, to match changing antenna size and shape.

The new version of the flight-cases will incorporate a smaller server and switch (see 2.1.1). The server and switch won't be attached to the case with DIN rails anymore, but will be packed just as the DUT nodes, in lightweight plastic with aluminium cases (see Figure 20). The switch and server have to be removed from the case before powering them, to avoid over-heating.

However, using a smaller, less powerful switch will have the limitation of only powering 6 DUT nodes at the same time over PoE. This smaller solution thus targets smaller deployments, using AC or battery power to power up the DUTs.

Figure 20: New portable server case (concept)

4 Showcases deployed on Portable Testbed

In this section, we provide a short overview of showcases deployed on the Portable Testbed. We divide them into two categories: Internal and External. The former contains showcases implemented by WiSHFUL project partners, while the latter contains showcases implemented by Open-Calls participants.

4.1 Internal showcases

4.1.1 Load and topology aware MAC adaptions.

This showcase was demonstrated during the Y1 review meeting using the portable testbed. In this showcase, it was demonstrated that the same Control Program can be executed on multiple platforms and technologies. More details can be found in D2.3. Only the sensor node part of this showcase was evaluated using the portable testbed. Figure 21 illustrates the results obtained while executing this showcase experiment.

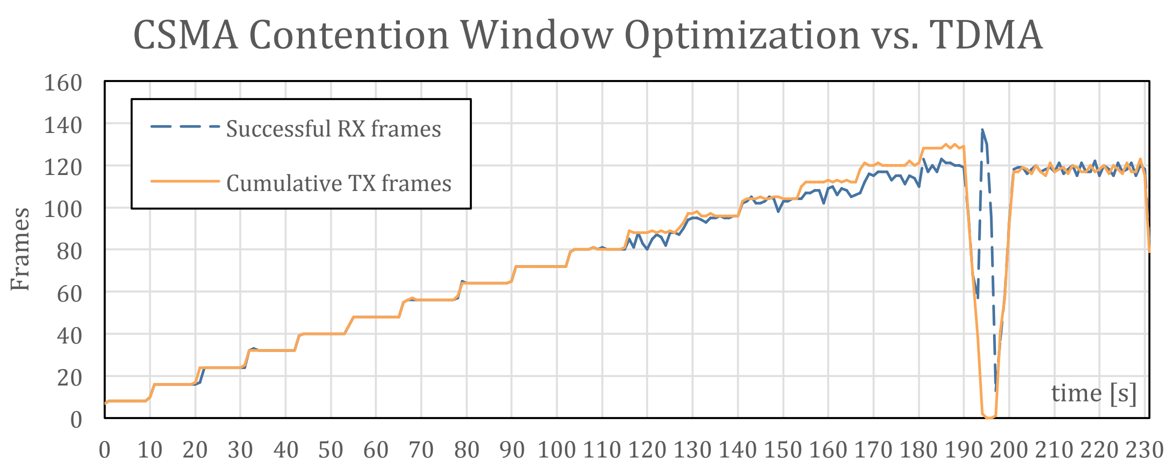

Figure 21 Results obtained on the Portable Testbed while executing showcase *Load and topology aware MAC adaptions* on 32 RM090 sensor nodes.

4.1.2 Co-existence of heterogeneous technologies:

a. Blacklisting interfered IEEE-802.15.4e channels

This showcase was also demonstrated during the Y1 review meeting using the portable testbed and discussed in detail in D2.3. This showcase was also used as a demo on multiple international conferences. Figure 22 illustrates the results of this showcase obtained during one of these conferences.

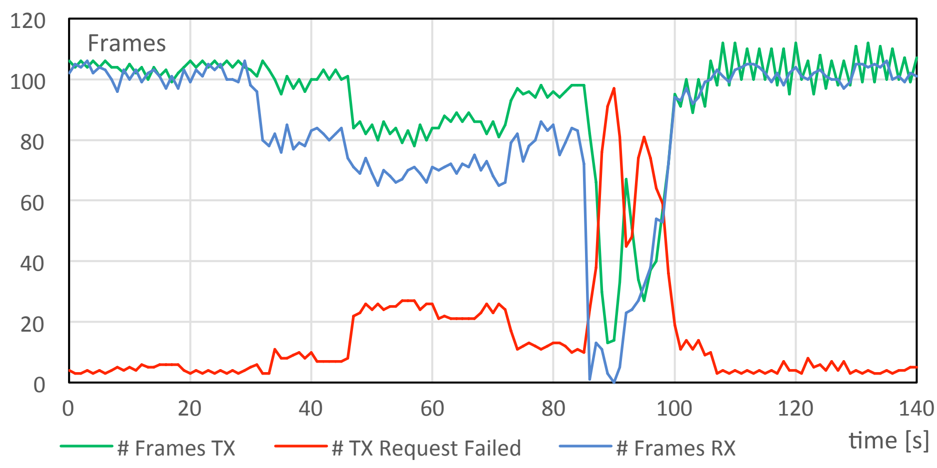

Figure 22 Results obtained on the portable testbed while executing showcase 2(a) on 32 sensor nodes and 8 Linux NUCs Wi-Fi nodes.

b. Shared TDMA scheme zigbee/wifi (beacon detection using RM090, ALIX and WMP)

This showcase was also demonstrated during the Y1 review meeting using the portable testbed and discussed in detail in D2.3. This showcase was also used as a demo on multiple international conferences. Figure 23 illustrates the results of this showcase obtained during one of these conferences.

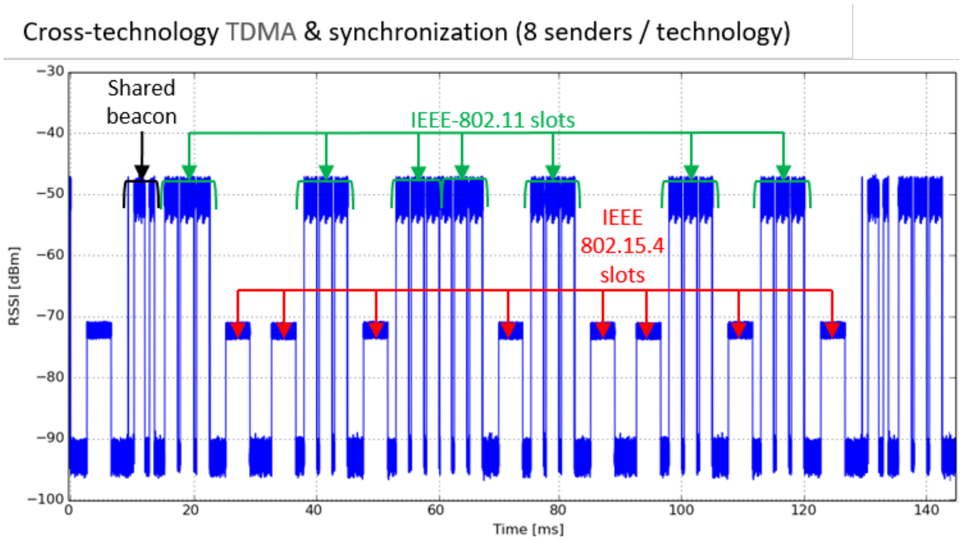

Figure 23 Results obtained on the portable testbed while executing showcase 2(b) on 8 RM090 sensor nodes and 8 Alix Wi-Fi nodes.

4.1.3 Infrastructure-initiated handover in WiFi networks

This showcase was demonstrated during the Y1 review meeting using the Portable Testbed with a Wireless Backbone Network. The main goal of this demo was to show how easy it is to replace a wired backbone network with a wireless one. Such replacement did not require any reconfiguration of SUT nodes and had no negative effect on showcase operation or its results (i.e. this particular showcase did not depend on low RTT nor high throughput).

4.2 External showcases

4.2.1 OC1 experiment WiFi-Dense (Allbesmart)

The WiFi-dense OC1 experiment by Allbesmart performed an experimental assessment of WiFi coordination strategies in dense wireless scenarios. By using the portable testbed, the experiment was run in two different locations:

- The portable testbed DUTs were spread over two floors of the School of Technology of the Polytechnic Institute of Castelo Branco (Portugal). This setup tested a dense indoor scenario in a building with thick concrete walls and floors.
- The second location was the outdoor swimming pool complex of Castelo Branco (Portugal). This setup tested a dense outdoor scenario, by co-existing with the free WiFi provided for the visitors of the swimming pool complex.

4.2.2 Visual and aural evaluation of MAC switching in a multi-tenant network

In this experiment two applications are executed, each in a different sensor network. The first application consists of a sensor node grid in which each node measures the light intensity and reports this value back to a central processing node, outside the grid. A character is projected on the sensing grid and reproduced on a screen by the central processing node based on the reported measurements. In case of packet loss, the character is reproduced incorrectly. In the second application, an audio stream is transmitted from a capturing device to a playback device. In case of packet loss, the played back audio is of bad quality.

Both applications are evaluated subjectively using QoE (Quality of Experience) metrics, i.e. a visual QoE for the first application (e.g. can the character be reproduced) and an aural QoE in the second application (e.g. is the audio stream of sufficient quality). The results clearly show that both applications work well separately, regardless of the MAC protocol in use. When both applications are active, however, they can only obtain a sufficient QoE when

- Using a TDMA MAC protocol;
- Sharing a TDMA schedule in both networks (using the WiSHFUL UPIs).

The setup is illustrated in Figure 24. It consists of 4 NUCs and 38 RM090 sensor nodes. There are two logical networks: a) a 35 node light intensity sensing grid (7 by 5), attached to a single NUC and a single sensor node for retrieving the sensed data, attached to a separate NUC; b) Two sensor nodes each attached to a separate NUC. It was used in national conferences and for educational purposes.

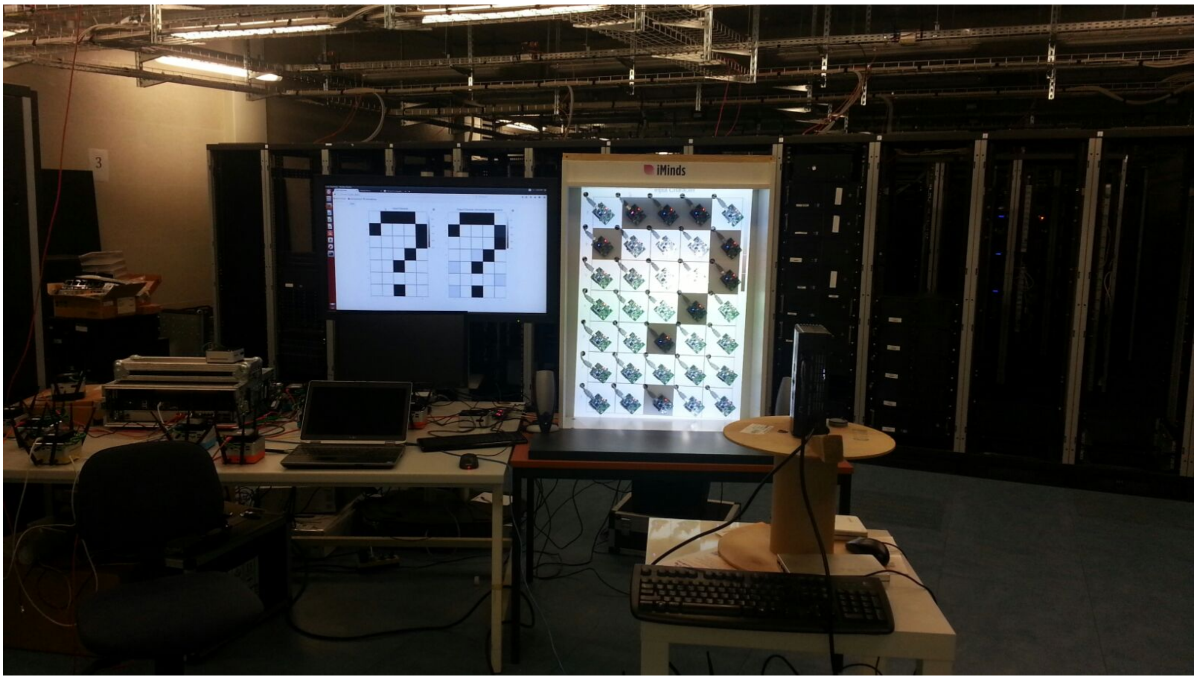

Figure 24 Picture of the portable testbed while running a MAC switching control program in a multi-tenant environment. Two applications are executed in different networks: a 36 node sensing network (low throughput) and a 2 node audio capturing and forwarding network. The solution is tested with two MAC protocols: 1) CSMA and 2) TDMA. In the latter a slotframe is shared amongst the two networks using the WiSHFUL UPIs. The results clearly show that in this case TDMA outperforms CSMA.

5 Future improvements and extensions

In this section we present improvements and extensions that are planned to be implemented in Year 3.

5.1 Time synchronization between BN nodes

In this section, we describe GPS-augmented time synchronization on the BN nodes. This work will be implemented during Y3 of the project.

The new hardware platform for the BN nodes supports adding in a high-performance GPS receiver with Pulse-Per-Second (PPS) capabilities, without sacrificing a pci-e mini slot. The following highlights are of interest:

- 72-channel concurrent position receiver engine supporting multiple concurrent Global Navigation Satellite System's (GNSS):
- GPS: L1C/A (1575.42MHz)
- GLONASS: L1OF (1602MHz)
- QZSS: L1C/A (1575.42MHz)
- SBAS: WAAS/EGNOS/MSAS: L1C/A (1575.42MHz)
- Differential GPS (DGPS): RTCM 10402.3:
- Navigation Update Rate: 10Hz (GPS&GLONASS) or 18Hz (GPS)
- Sensitivity for tracking & navigation: -164dBm (GPS&GLONASS) -163dBm (GPS)
- PPS:
    - Accuracy of 30ns RMS, 99% 60ns
    - configurable rate: 0.25Hz to 10Mhz
    - configurable polarity
    - configurable pulse-width: 2^{32} micro-seconds or duty-cycle

The PPS signal can be used to get a high-precision time reference that an application can use to adjust the system clock time. A common use is to configure the Network Time Protocol Daemon (NTPD) with a PPS source to obtain a time with sub-millisecond synchronization to UTC. Any drift in the system clock or hardware clock will be immediately corrected by use of the PPS signal.

Additionally, we can use this to synchronize the BN nodes with each other using the precision time protocol (PTP) to achieve sub-microsecond accuracy between the nodes.

5.2 Integrated battery powered backbone nodes

In this section, we describe a modification to the approach proposed in D6.2. This work will be implemented during Y3 of the project.

Instead of providing two battery packs per node (one for the BN and one for the DUT), it was decided to only provide the BN node with a battery pack (Figure 26). The BN node then relays the power, through PoE, to the DUT. This approach has several advantages:

- No changes are required to the DUT design. The same DUTs can be used for both portable testbed versions: in combination with Power-Over-Ethernet switch or fully battery powered.
- The DUT can easily be replaced by other types of hardware, as long as it is PoE-compatible.

- The BN has full control over the power supply of the node. This is especially useful when the configuration of a DUT node is broken, or the DUT violates the channel usage policies in the portable testbed. In both cases, the BN can easily power down (or reboot) the DUT.
- The only connection between BN and DUT is one Ethernet cable. This allows for even more flexible installation opportunities as the BN can be installed close to – or further away – from the DUT.
- Only one device has to be recharged. Obviously this also has the drawback of having less available power, since the battery pack is shared between BN and DUT. Depending on the intensity of the experiment, the battery pack is expected to last 4-5 hours. This proves to be enough for most experiments, if one excludes the setup time, which can be done when connected to an AC power supply.

The solution is described in Figure 25, where the red wires indicate those that have to be disconnected when the node is in the field. An Ethernet cable connects the BN+DUT box to the central server (useful for imaging the nodes and setting up the initial experiment) and the power cable charging the batterypack.

The BN node will act as a router: when connected wired it will not route the traffic over the wireless backbone. When the UTP cable is disconnected, it will change its routing and send traffic over the backbone network.

In order to control the powerflow to the DUT, a piece of hardware will be needed to control the PoE power. In Y3 a PCB board will be designed to toggle the DUT power on and off. A simplified design without this PCB is depicted in Figure 27.

This remote reboot mechanism works as follows:

1. Using the TMS-BNC interface, an experimenter requests reboot of a particular DUT node by passing the MAC address of its Ethernet interface.
2. Upon reception of such request, the BN Controller gets the identifier of the BN node from the DUT-BN mapping table (described in section 2.3.2a) and sends a *RebootRequest* to it.
3. Finally, the BN node reboots the DUT node.

The remote reboot mechanism is also used to release resources after the end of the experiment. As we allow experimenters to upload their own OS image with their own configuration to any DUT node in our testbed, we need a way to regain control over our resources. Our solution allows us to reboot the DUT node and make it boot with default OS image with known configuration.

Another future extension would consist of a powerline adapter and a docking solution (described in D2.2, section 4.1.3).

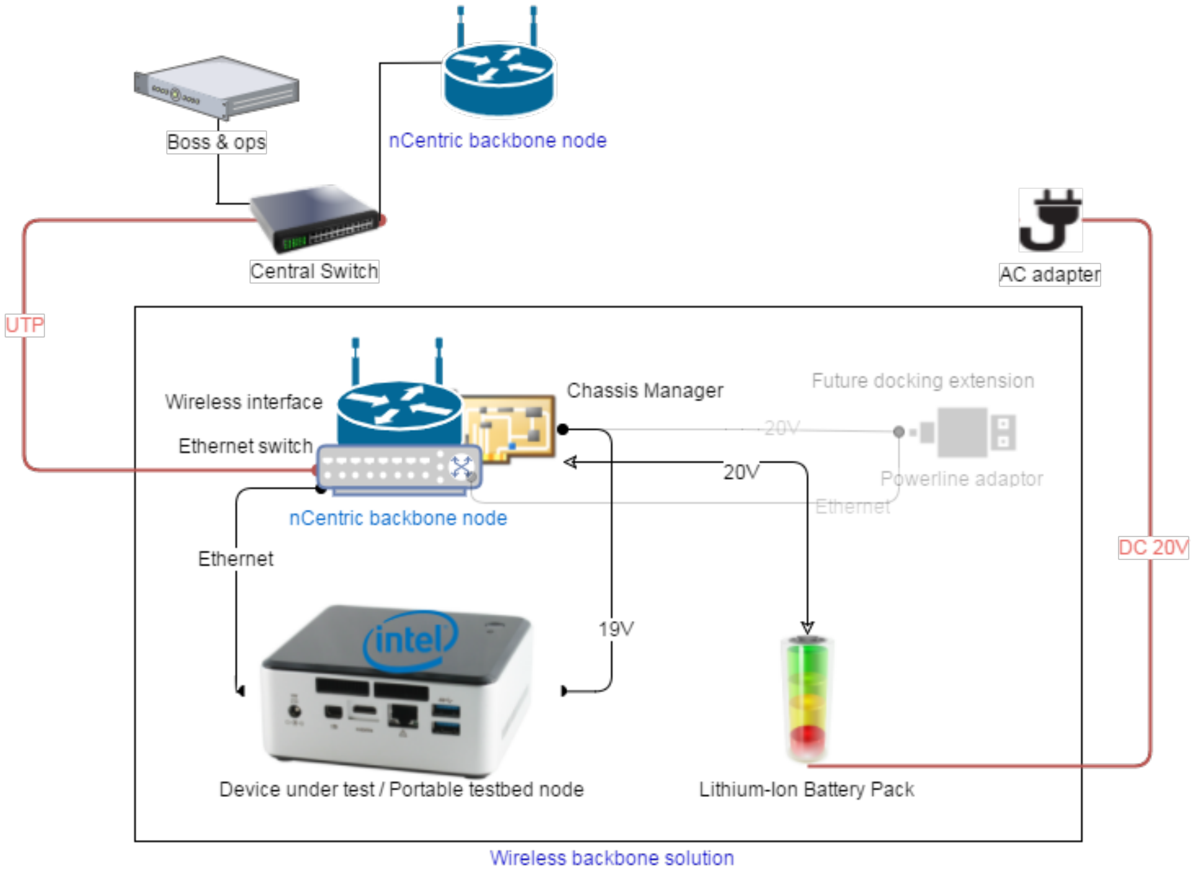

Figure 25: Proposed battery powered wireless backbone solution

Figure 26: Battery powered BN node

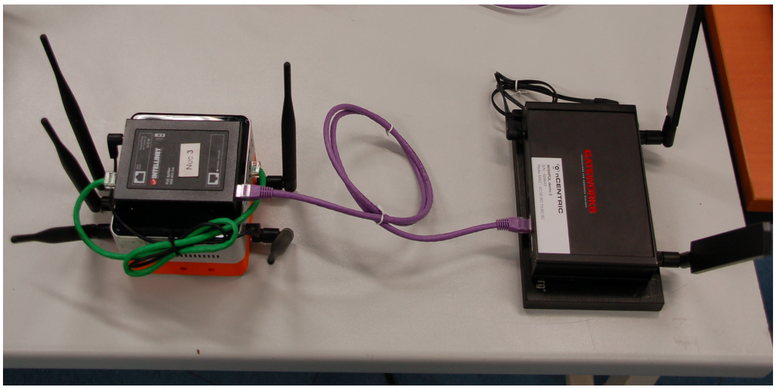

Figure 27: Proposed battery powered solution

5.3 Software improvements to BN nodes

In this section, we describe the planned software improvements for the BN nodes. This work will be implemented during Y3 of the project.

Although the core mesh daemon and the WiSHFUL agent now communicate properly over a unix socket, configuration is still done through manipulation of text files and often requires a reboot. This is error prone, as validation of the configuration files is only done once at start time of the core mesh daemon. Additionally, changes are not detected, and a reboot is required to actually apply the changes.

Therefore, we wish to implement parameter changes over the UNIX socket as well. These changes would then be immediately validated and, if correct, immediately applied. We will strive to make every parameter change applied live, eliminating the need for a reboot.

As interference is a known issue with ISM channels, we also will implement an interference avoidance scheme. The idea is to notify the controller if any interference has been detected, and then initiate a network-wide, coordinated channel change for all BN nodes.

6 Conclusion

Within Year 2 of the WiSHFUL project, we have implemented the second release of the Portable Testbed.

In order address **feedback from users** regarding the Portable Testbed version 1, we have decided to change hardware platforms of the Testbed and Experiment Management Server and switch. The new hardware is much smaller and lighter, which makes the Portable Testbed more portable. Also BN nodes were moved to newer hardware platforms that are smaller, lighter and more powerful. Regarding DUT hardware, it turned out that the 3D printed antenna mount is not resistant to high temperatures (above 30^{O}C). We replaced it with a new one developed based on polyurethane. Moreover, **new wireless adapters** were added to DUT nodes. The set includes also two types of spectrum sensing devices: low cost WiSpy USB and more accurate USRP-mini.

We developed a couple of options for **connecting and powering DUT** nodes. Their description (including advantages and drawbacks) is presented in this document.

For the ***packaging and transportation*** of the hardware, we designed and developed new cases, which fit new hardware and provide better protection against vibrations.

The first version of the Portable Testbed was used in several experiments, where it has shown its advantages over fixed testbeds (e.g. experiments in a swimming pool complex in Portugal). Those experiments confirmed the usability of Portable Testbed as well as its proper design.

Improvements and extensions, to be implemented in the next release by the end of Year 3, have been identified. The main goal is to further facilitate the deployment of experiments using the Portable Testbed, reducing the configuration and maintenance overhead, and improving the performance of the backbone network and wireless control channel.

7 References

[1] New portable testbed switch, http://www.buffalotech.com/products/gigabit-green-ethernet-high-power-poe-smart-switches

[2] Yepkit USB switchable hub, https://www.yepkit.com/products/ykush

[3] Sanberg battery pack, https://sandberg.it/en-gb/product/Powerbank-20000-for-Laptop

[4] Backup power for portable testbed server and switch, http://www.goalzero.com/p/165/Goal-Zero-Yeti-400-Solar-Generator