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SEVENTH FRAMEWORK PROGRAMME

Network of Excellence

NEWCOM#

Network of Excellence in Wireless Communications#

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D22.3
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Keywords:	EuWIn, Laboratory description, Experimental research, CNIT-BO site, Internet of Things, Smart City, Delay Tolerant Networks, Routing, Localization.

Authors

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Executive Summary

This document describes the activities performed within WP2.2 during the second year of Newcom#.

According to the suggestions received by the project reviewers after year one, the body of the document is quite short, summarizing main achievements, while technical details are given through the annexes.

In the body of this document, the advances and achievements of each active joint research activity (JRA) are summarized. The inter-WP or inter-Track nature of the JRAs is highlighted when present. Technical details about the different JRAs have been included in Annex I, while the plans for the next period are illustrated in Annex III, which gives an overview on the level of integration among the three sites of EuWIn. In Annex II the tests performed for validating the EuWIn platforms are also described and presented.

Within EuWIn a particular effort has been devoted to demonstration activities, meetings with industries, workshops, and to the organization of training schools dedicated to experimental research. Starting from this dissemination campaign, collaboration with an industry (NEC Europe, Germany) willing to exploit the capabilities of the EuWIn platform for experimental research, has been established, as reported in this document. These dissemination activities are described in Annex III.

Annex II and Annex III are attached to this document only, but they are to be intended as common to the three WPs, as they refer to activities carried out in cooperation among the three sites of EuWIn.

Table of Contents

1.Introduction

1.1 Glossary

6LoWPAN	Low-Power Wireless Personal Area Networks
AEF	Aggregation Equivalent Flow
AGGR	Aggregation Layer
AODV	Ad hoc On-Demand Distance Vector
AP	Access point
DIO	Information Object
DIS	Information Solicitation
DODAG	Destination-Oriented Directed Acyclic Graph
FWD	Forwarding Layer
HGI	Home Gateway Initiative
IMU	Inertial measurement unit
IoT	Internet of Things
LWN	Linear Wireless Network
LWSN	Linear Wireless Sensor Network
MAC	Medium Access Control
MTO	Many-To-One
MTO-RR	Route Request
NOS	Network Operating System
PER	Packet error rate
PLR	Packet loss rate
RREP	Route Replay packet
RREQ	Route Request packet
RSS	Received signal strength
RTT	Round-trip-time
SDN	Software Defined Networking
SDWN	Software Defined Wireless Networking
SR	Source Routing
TTL	Time To Live
UWB	Ultrawide bandwidth
WSN	Wireless Sensor Network
ZC	Zigbee Coordinator
ZED	Zigbee end-device

1.2 List of Joint Research Activities (JRAs)

This is the list of JRAs that have been planned at the beginning of the NoE, with the corresponding actual status:

- JRA#1, "Design and experimental validation of algorithms for active and passive indoor positioning": This JRA is active and its results are reported in Sections 2.1 and 4.1.
- *JRA #2 is not active yet.*
- JRA#3, "Experimental activity on data sensing and fusion": This JRA is active and its results are reported in Section 2.2.
- *JRA#4, "Reducing Traffic Congestion in Wireless Mesh Networks"*: This JRA is not active anymore and could be considered as closed.
- *JRA#5, "Socially-aware protocols for wireless mesh networks"*: This JRA started this year and some preliminary results are reported in Section 2.3.
- JRA#6, "Testing IP-based Wireless Sensor Networks for the Internet of Things": This JRA is active and its results are reported in Sections 2.4 and 4.2.

1.3 Description of the Main WP Achievements in the Reporting Period

The main achievements of the WP during the second year of Newcom# can be summarized as follows:

- Finalization of the three platforms available at EuWIn@CNIT-BO and corresponding validation tests (see the validation document included in Annex II). These platforms are FLEXTOP, DATASENS and LOCTEST (Figure 1-1). Their detailed description can be found in Deliverable D22.2.

- Advancement of experimental research within the joint research avtivities (JRAs) carried out using the EuWIn platforms. As will be detailed in the subsequent sections, some JRAs are inter-WP and inter-Track. The former are oriented to increase the integration between the distributed EuWIn laboratories. The latter demonstrates the utility of EuWIn for the experimental validation of theoretical schemes investigated in Track 1. In particular, among the active JRAs, JRA#1 deals with localization issues and mainly uses the LOCTEST platform; JRA#3 is related to efficient and distributed fault detection techniques for wireless sensor networks and it exploits the DATASENS facility. Finally, multi-hop routing protocols and topologies have been studied and tested in JRA#6 using FLEXTOP.

- Establishement of activities developed in collaboration with industries outside the network of excellence NEWCOM#. In particular, a collaboration with NEC Germany started after the dissemination event organized in February 2014 in Heidelberg, at NEC laboratory premises.

- Additional experimental research activities carried out at CNIT-BO (reported in Annex I), not formalized through a JRA. These measurement campaigns have been conducted in the framework of collaborations with other Universities interested in using the experimental platforms, though they did not proceed asking to become Newcom# affiliate partners. Therefore, they are considered relevant dissemination activities, and for this reason they are reported in Annex I of this Deliverable.

- Dissemination activities in the form of papers, workshops, tutorials and other events (described in Annex III).

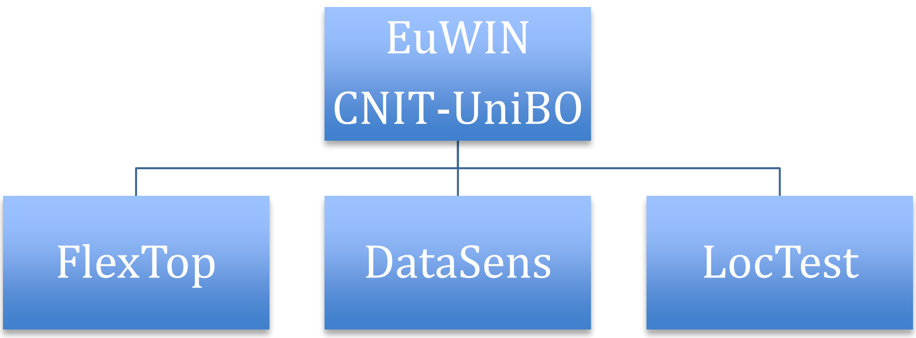


Figure 1-1: The EuWIn@UniBO site platforms

2. Detailed Activity and Achieved Results

In this Section we report the main objectives and results obtained in the second year with reference to the active JRAs, namely JRA#1, JRA#3, JRA#5 and JRA#6. We conclude the section with the description of the industrial activity that EuWIn carried out in the framework of a collaboration with NEC Germany.

2.1 JRA #1 "*Design and experimental validation of algorithms for active and passive indoor positioning*"

Giacomo Calanchi (CNIT-BO)

Pau Closas (CTTC)

Carles Fernandez (CTTC)

Davide Dardari (CNIT-BO)

2.1.1 Description of Activity

The aim of this activity was twofold: on one side, the goal is to create and maintain an open-source, low-cost and easy-to-use platform, featuring several interfaces and sensors, for developing and testing indoor positioning schemes and algorithms (see Figure 2-1); on the other hand, the subject of the work is to test directly on the platform new algorithms, as far as new features are made available on the platform itself.
This JRA is cross WP, WP2.1 and WP2.2, as it involves the EuWIn sites at CTTC and CNIT-BO (LOCTEST and DATASENS platforms). Details can be found in Appendix 4.1.

Figure 2-1: The positioning open platform mounted on a moving robot at CTTC

2.1.2 Relevance with the identified fundamental open issues

Indoor localization remains as a challenging problem, the solution of which could trigger a myriad of new services and applications. The technology mix demanded by indoor location solutions requires a laboratory in which users can access a wide range of interfaces to an heterogeneous set of devices and form factors, and some processing capability to blend those inputs and provide the final output, that is, the device's position. This implies flexibility in the number and type of sources, as well as the possibility to implement low-level algorithms in order to process low data, fast enough to achieve real time. Considering such requirements, we have set an open laboratory with the following main features:

- Hands-on hardware and software oriented activities.
- Addresses the technology mix required for indoor positioning.
- Promotes collaboration and sharing by using low-cost development platforms.
- Promotes reproducible research.
- Open to industry and institutions beyond NEWCOM# members.

The low-cost devices used to build the platform, their availability in the worldwide markets and the common repository used to share and revision the software allowed to replicate the set-up both at EuWIn@CTTC and at EuWIn@UniBO.
This open-source platform will give the possibility to test experimentally localization algorithm developed within the NEWCOM# community and outside under common interfaces and conditions. This will easy the performance assessment and comparison.

2.1.3 Main Results Achieved in the Reporting Period

The whole activity carried out so far involved both staffs from CTTC and CNIT-BO, both for the platform deployment task and for the algorithm development. From a hardware/software viewpoint the job has been accomplished, the platform is now ready to be used in the field to take measurements. The common repository created, available in the NEWCOM# Portal at the link http://www.newcom-project.eu/index.php?option=com_remository&Itemid=105&func=select&id=292 allows researchers to further improve the stability of the software and smoothly integrate new features and push the modification remotely in the two locations.

The platform has been tested with a particle filter based algorithms that features data-fusion to process data coming from heterogeneous sensors. In particular inertial measurements were always used and, depending on the location, also IEEE 802.11 received signal strength (RSS) (EuWIn@CTTC) and IEEE 802.15.4 RSS (EuWIn@UniBO).

The algorithm developed to process these data has to be improved to achieve sufficient accuracy in locating the target. In particular an improved measurement model has to be developed.

2.1.4 Publications

In preparation.

2.2 JRA #3 *"Experimental activity on data sensing and fusion"*

Vincenzo Zambianchi (CNIT-BO)

Wenjie Li (CNRS-SUPELEC)

Gianni Pasolini (CNIT-BO)

Francesca Bassi (CNRS-SUPELEC)

Michel Kieffer (CNRS-SUPELEC)

Davide Dardari (CNIT-BO)

2.2.1 Description of Activity

To guarantee its integrity, a wireless sensor network needs to efficiently detect nodes producing erroneous measurements. In WP1.2, Task 1.2.3, fully distributed fault detection algorithms have been proposed and investigated from the theoretical point of view. In fault detection algorithms a node first collects the measurements of its neighborhood, processes them to decide whether they contain outliers, and broadcasts the result. With this strategy each node harvests information about all the tests its measurement has been involved in. Then, it can, in a second stage, autonomously decide about its functioning state.

The experimental activity under implementation will aim at validating in practice the fault detection algorithm conceived in WP 1.2, thus making this JRA an inter-track JRA. To this purpose, the DATASENS platform formed by approximately 70 nodes, either fixed or mobile, is under consideration. The target application chosen is environmental temperature monitoring using wireless sensor nodes with the capability to detect defective nodes using distributed fault detection algorithms proposed in Track. These algorithms aim at detecting the presence of faulty nodes. The detection is collaborative: Defective nodes are not assumed to be malitious but rather do collaborate with non defective nodes to be identified. To assess the performance of such algorithms in real scenarios and accounting for a real communication protocol stack, multiple measurements are required. Moreover some coordination is required: It is necessary that all nodes take measurements in the same time interval, so that they can be considered synchronized at interval level. The algorithm for fault detection might then run either online or offline. The former requires a higher implementation effort as all signal processing has to be done locally at each node. In the second case, it suffices that nodes broadcast/record their measurements without specific local signal processing and the algorithms are performed off-line with the advantage of a lower implementation complexity. However, the offline run requires, instead, that connectivity information is coupled to measurements, saying, for each node, which active communication links it was involved in, at the time when measurements were taken. This requires some extra communications design that is next described, with the help of Figure 2-2. We propose two methods for solving the connectivity recovery issue. We can simply implement a communication protocol such that, whenever a node takes a measurement, it broadcasts a void message, only containing source address information. Assuming that measurements are taken synchronously, this ensures that a local reconstruction of adjacencies is possible. For the scope, it would suffice to store the source addresses of received messages. In Figure 2-2 we can see that node 2 receives messages from nodes 1 and 3. This happens when node 2 is also transmitting its own message, signaling that a measurement was taken. Anyway, this simple communication protocol needs some strong coordination. The synchronicity in the measure process should be quite tightly ensured and possible collisions in medium access might generate ambiguities, if they are solved when new measurements have already been taken. These reasons bring us to consider also a second communication protocol that has higher complexity, but requires less nodes coordination. Again we can see its working principle in Figure 2-2. Here, when node 3 takes a measurement, it broadcasts a message requiring connectivity information. All nodes, receiving it, answer with a dedicated message, independently of their own connectivity requests. This way each node decouples its

connectivity requests from its connectivity answers. This solves the possible ambiguities due to collisions, since, even if an answer is received after a new measurement is taken, it still contains the information denoting it as an answer to a previous round request.
When the measure process and the connectivity recovery have terminated, it is necessary to download the measurements and adjacency information stored into nodes. To this purpose we plan to either program a downloading node, sending direct requests to all the other nodes or a multihop strategy insuring that direct visibility is not required.
Since faults are rare events, the presence of defective nodes will be emulated by an artificial manumission of real world data.

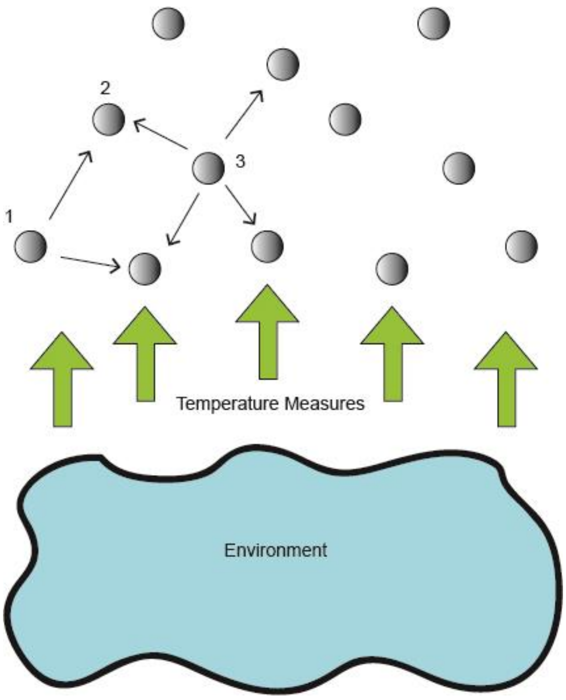


Figure 2-2: Example of experimental wireless sensor network for fault detection

2.2.2 Relevance with the identified fundamental open issues

The design and implementation activities that constitute the core of this JRA actions are related to the distributed detection of defective nodes, that is the addressed open issue. The activities aim at validating in practice the performances theoretically predicted in Task 1.2.3. The distributed detection of defective nodes is a higly innovative concept. In fact the developed algorithm exploits the diversity given by a distributed environment.

2.2.3 Main Results Achieved in the Reporting Period

This JRA founds its activities on the main results achieved on the theoretical side (see activities in Task 1.2.3. The main contributions for the reporting period can be summoned as follows:

- Design of the wireless communication protocol necessary for the correct information sharing across the network of collaborative sensor nodes.
- Design of the computational phase of the distributed fault detection algorithm
- Initial programming of sensor nodes.

2.2.4 Publications

Two conference papers and two journal papers are about to be submitted.

2.3 JRA#5 "Socially-Aware Protocols for Wireless Mesh Networks"

Laura Galluccio (CNIT-CT)

Giacomo Morabito (CNIT-CT)

Sergio Palazzo (CNIT-CT)

Angelos C. Anadiotis (CNIT-CT)

Salvatire D'Oro (CNIT-CT)

Chiara Buratti (CNIT-BO)

Andrea Stajkic (CNIT-BO)

Stefan Mijovic (CNIT-BO)

Colian Giannini (CNIT-BO)

Roberto Verdone (CNIT-BO)

2.3.1 Description of Activity

This is a JRA between CNIT-BO and CNIT-CT aiming at designing delay tolerant networking (DTN) protocols for crowded indoor environment, where people moving around are used as mules, to carry data from a given transmitter to the intended receiver. The designed protocol is based on the concept of sink-aware centrality, which refers to the capability of a given mule to carry the data toward the intender receiver, that is the sink.

The designed protocols will be tested over a network simulator, based on ONE, taking as input some data measured on the field.

The measurements are aimed at characterizing the social mobility of people in a crowded environment and at deriving the inter contact time among people. The EuWIn facility used for such measurements was DATASENS.

2.3.2 Main Results Achieved in the Reporting Period

In order to characterize the inter contact time and the social mobility of people in an indoor environment we performed some measurements during the Conference EuCNC 2014, which took place in June 2014 in Bologna, Italy. DATASENS was used in the experiments.

At the Conference venue we deployed 20 fixed devices in the different rooms (black dots in the map below) and we provided from 40 to 50 conference attendees the mobile devices, to be carried for the full day during the Conference. People carried devices in their pocket/bag from 9.00 in the morning until the after lunchtime, which was scheduled for 14.00.

Devices, both fixed and mobile, were periodically (every one minute) transmitting beacon packets in broadcast with a transmit power of 20 dBm for fixed devices and 0 dBm for mobile devices.

Mobile nodes, upon receiving a beacon from another node were recording the following data:

- ID of a transmitting node
- Timestamp (resolution in minutes, so the minute in which the beacon was received starting from the moment when the device was switched on)
- RSSI (the power with which the beacon was received)

As a result we were able to derive the inter contact time statistics; an example of result is shown in Figure 2-4.

Figure 2-3: The Conference Venue

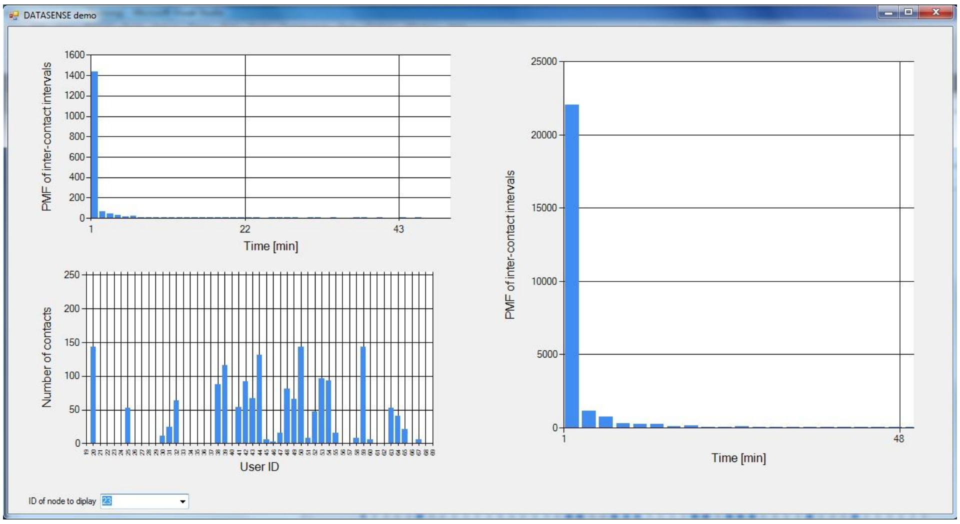


Figure 2-4: Example of Results

2.3.3 Publications

No publications yet (the activity started after EuCNC 2014, held at the end of June 2014).

2.4 JRA#6 "Testing IP-based Wireless Sensor Networks for the Internet of Things"

Danilo Abrignani (CNIT-BO)

Andrea Stajkic (CNIT-BO)

Stefan Mijovic (CNIT-BO)

Chiara Buratti (CNIT-BO)

Roberto Verdone (CNIT-BO)

Sebastiano Milardo (CNIT-CT)

Giacomo Morabito (CNIT-CT)

Gordana Gardasevic (University of Banja Luka) [external entity]

2.4.1 Description of Activity

This Joint Research Activity is among CNIT/UniBO, CNIT/UniCT and an external partner that is the University of Banja Luka.

The objectives of this JRA are: i) the implementation and testing of different upper layers protocols for IEEE 802.15.4 networks and ii) the comparison between two different paradigms for the Internet of Things (IoT). The EuWIn facility used in this JRA is FLEXTOP.

The considered solutions (see Figure 2-5) are: i) the Zigbee standard; ii) the IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) standard and iii) a proprietary solution based on the Software Defined Networking (SDN) paradigm, called Software Defined Wireless Networking (SDWN). The first two solutions are standard de-facto for Wireless Sesnor Networks (WSNs) and implement a distributed re-active routing protocol, while the third solution is based on a centralized proactive routing protocol.

Details can be found in Appendix 4.2.

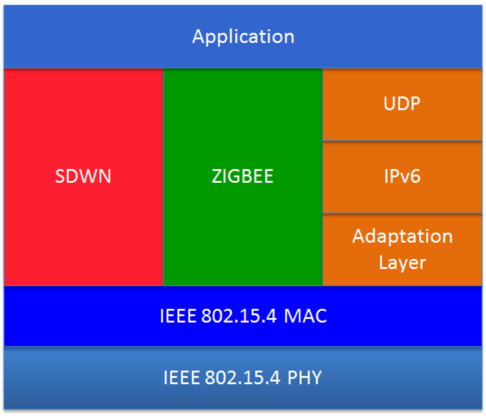


Figure 2-5: IoT protocol stacks under examination

2.4.2 Relevance with the identified fundamental open issues

The Internet of Things (IoT) is an emergent paradigm that deals with things (objects, cars, etc.), equipped with radio devices and unique IP addresses. Sensors are increasingly becoming more pervasive and attempt to fulfill end users needs, thus providing ease of usability in our everyday activities. To the latter aim, sensors and actuators, deployed in households, industrial automation or smart cities, should be directly or indirectly connected to the Internet. The latter could be

provided through two different approaches: i) the capillary approach, where things are managed by a coordinator, which is also a border router of the Internet network and uses Internet Protocol (IP) addresses to query things; ii) the Wireless Sensor Network (WSN) approach, where things are addressed through local addresses known at the coordinator, which acts as gateway to connect things to the Internet. The most used protocol stacks for the above mentioned approaches are 6LoWPAN and Zigbee, respectively. The selection of the best solution, between these two, is still an open issue. Some works in the literature, in fact, provide qualitative comparison between the two standards, while few works deal with comparison of the performance through experimentations, considering very small networks.
More recently a third approach, based on the Software Defined Networking (SDN) paradigm, has been proposed. It is called Software Defined Wireless Networking (SDWN) and it uses a centralized routing protocol. The coordinator/gateway gathers information on the status of the network of things, and brings this knowledge to a controller which can decide on the exploitation of resources within the wireless network. This controller has a centralized vision over the network of things, and can even control things that lie behind several coordinators/gateways. This approach brings the potential advantage of an optimal resource exploitation, even if it could introduce a significant overhead due to signaling back and forth from the controller to the things through the gateway.
The SDWN approach is compared to the distributed approaches as never done in the literature.

2.4.3 Main Results Achieved in the Reporting Period

The three mentioned solutions (described in the Appendix), have been implemented on the Texas Instruments (TI) CC2530 devices of the FLEXTOP platform and a large measurement campaign has been carried out at the University of Bologna in order to compare different performance metrics in different conditions and traffics generated.

In particular, performance has been evaluated in terms of packet loss rate, round trip time and overhead generated in the network, and the comparison have been done considering different network topologies, payload sizes and environmental conditions. As far as the latter item is concerned, most of the experiments were performed during the night, when no people are moving around, to avoid environmental changes and to ensure a perfect fairness in the comparison, being the environment static. However, to measure the level of reactivity of the different protocols to possible changes in the environment, we also compare results in dynamic conditions, letting two people walking over the corridor at a constant speed and following a pre-defined path.
Results demonstrate that all the protocols stacks behave quite well in the presence of environmental changes, and the SDWN is the best solution, providing the lowest round trip time, while guaranteeing a low PLR and keeping under control the overhead.

2.4.4 Publications

The following paper has been submitted to the IEEE Journal on Internet of Things:
C. Buratti, G. Garsasevic, S. Milardo, D. Abrignani, A. Stajkic, S. Mijovic, G. Morabito, R. Verdone, “Testing Protocols for The Internet of Things on The EuWIn Platform”.

2.5 Industrial Activity

Testing the impact of IEEE 802.11 interference on IEEE 802.15.4/Zigbee Networks

This section reports the results achieved in the framework of an industrial contract between CNIT/UniBO and NEC Germany and intend to exploit the resources available @ EuWIn. The aim of the work was to test the impact of interference caused by IEEE 802.11 networks over IEEE 802.15.4/Zigbee networks. Results of the work have been reported by NEC to the HGI (Home Gateway Initiative) and will be also presented in the next months to the Zigbee Alliance. EuWIn/Bologna committed to this activity after the dissemination event held in Heidelberg, Germany, in February 2014, at the premises of NEC laboratories.

Results presented in this section are included in the following Conference paper accepted for publication: D. Abrignani, C. Buratti, L. Frost, R. Verdone, "Testing The Impact of Wi-Fi Interference on Zigbee Networks", Proc. of IEEE Euromed 2014.

We consider a point-to-point IEEE 802.15.4/Zigbee network, composed of a Zigbee Coordinator (ZC) and a Zigbee end-device (ZED). The map with the corresponding identifiers of nodes is shown in Figure 2-6, where nodes underlined with red circles are those nodes selected for the experiments, which are nodes: 22, 45, 33, 50. The Zigbee coordinator was located at the end of the corridor (node 53).

The Home Automation Zigbee profile has been used and a query-based application is implemented using two modalities: i) broadcast and ii) unicast. In both cases the coordinator periodically sends a query packet to the target device, and waits for a reply from it.
In the case of broadcast transmission, the query is sent in broadcast by the coordinator and when it is received by the target device, the latter will use the Ad Hoc On demand Distance Vector (AODV) routing protocol in order to find the route toward the coordinator and to send its reply. In the case of unicast transmission, instead, also the query is sent in unicast from the coordinator to the device, therefore also the coordinator uses AODV (i.e., transmits a route request packet (RREQ) and waits for a route reply (RREP)), before proceeding with the transmission of the first query packet. The procedure is then repeated in the opposite direction, that is from the target device to search for the coordinator and it is also repeated each time, the path is lost by one of the two devices due to many losses in the channel.
For what concerns the IEEE 802.11 network, we will consider two cases:

1. AP1 and AP2, using 802.11.n and using the 40MHz band. The two APs will contemporaneously generate a 10 Mbps video traffic, each, toward two different clients.
2. AP1 and AP2 as (1) above, and also AP3 set to 802.11.b with video traffic at 10 Mbps toward another client.

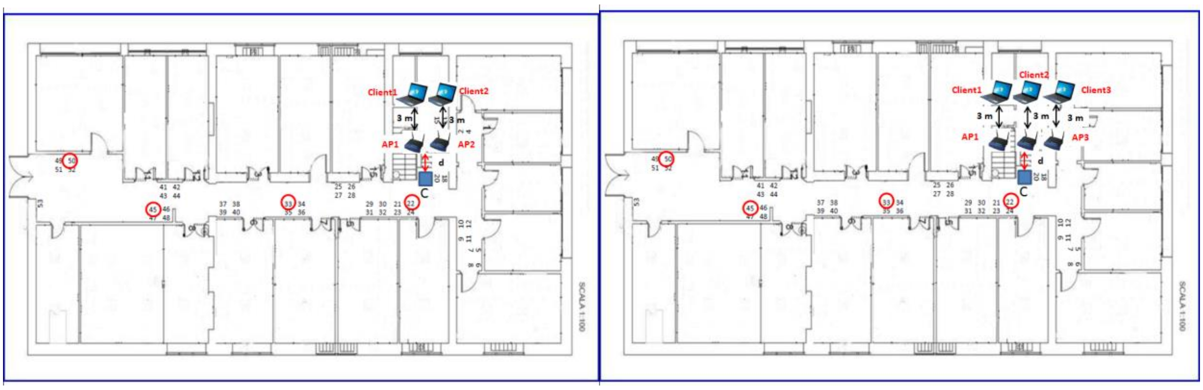


Figure 2-6: The Experimental setup.

The considered performance metrics are: i) packet loss rate (PLR), that is the percentage of packets lost; ii) round-trip-time (RTT), that is the interval of time between the transmission of the query at the application layer of the coordinator and the instant in which the reply is correctly received at the application layer of the coordinator too; iii) overhead, defined as the ratio between the number of RREQ/RREP packets transmitted in the network and the total number of packets.

Moreover, the case of overlapped channel (channel 17) and non overlapped channel (channel 25) are considered (see Figure 2-7).

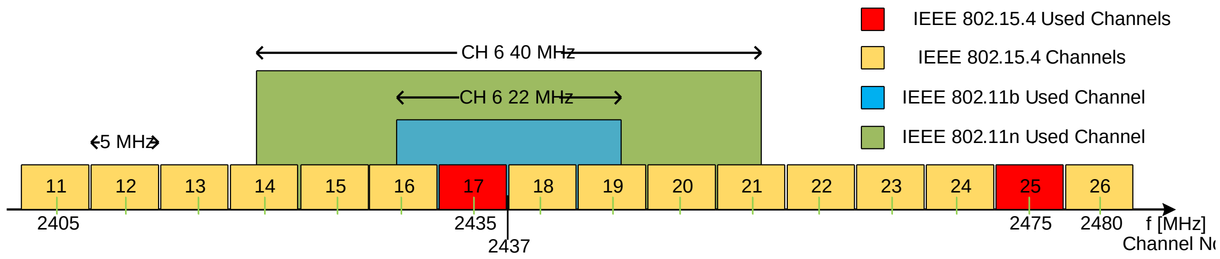


Figure 2-7: The IEEE 802.11 and IEEE 802.15.4 channels.

We first report the *Wi-Fi channel utilization,* which is the percentage of time, with respect to the full duration of the experiment, during which the Wi-Fi signal received over a given Wi-Fi channel by a spectrum analyser, is above a given threshold. The latter is reported in Table 2-1. The utilization for the case of no-interference was equal to 0.1%.

Table 2-1: The Wi-Fi utilization

	2 APs at 3 m	2 Aps at 10 cm	3 Aps at 3 m	3 Aps at 10 cm
CH 17	14	11	48	60
CH 25	0.7	10.4	0.6	1.3

In Figure 2-8 we show the PLR for the different devices and the different Wi-Fi network settings (i.e., different number of APs and distance from the ZC) for the case of unicast transmission and overlapped channel. As can be seen the PLR is strongly affected by the percentage of utilization of the Wi-Fi: when Wi-Fi APs occupy the channel for less than 15% of time, which happens when only two APs are present, the PLR remains below 10%. When three APs are set-up the utilization strongly increases (up to 60%) and the PLR strongly increases too. In Figure 2-9 the case of broadcast is shown. The PLR is still strictly related to the utilization values: by increasing the utilization the PLR increases too. We can note that the use of broadcast transmission in downlink, instead of unicast, improves the performance, since the ZC does not need to find the route toward the ZD, which generates overhead and losses (see below).

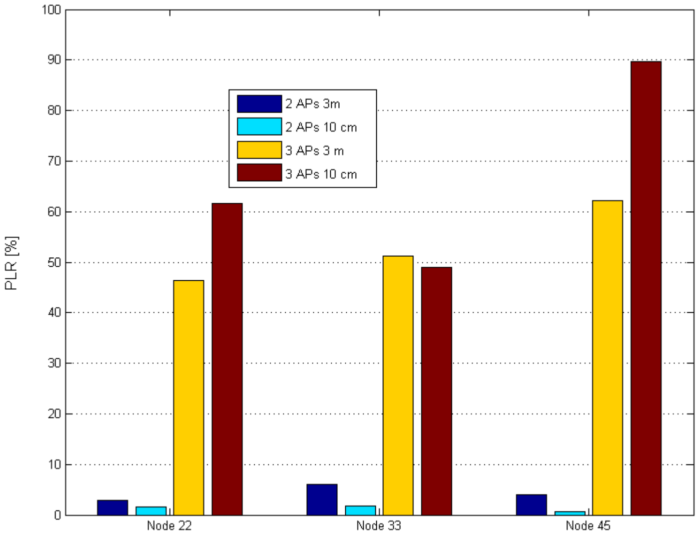


Figure 2-8: PLR for the different devices for overlapped channel and unicast transmission.

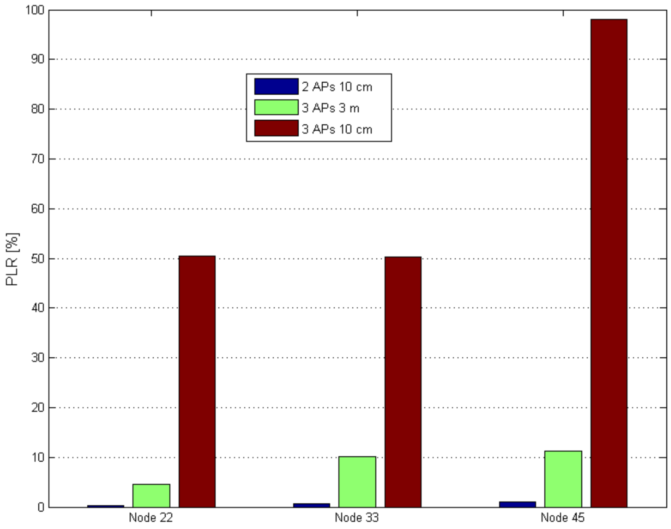


Figure 2-9: PLR for the different devices for overlapped channel and broadcast transmission.

Table 2-2: The Overhead generated in the Zigbee network

	2 APs at 3 m	2 Aps at 10 cm	3 Aps at 3 m	3 Aps at 10 cm
CH 25	11.1	32.9	12.1	36.9
CH 17 - Unicast	34.8	36.3	34.9	36.9
CH 17 - Broadcast	4.5	7.1	8.7	N.A

Table 2-2 shows the overhead for the different cases. In the case of no-interference the overhead was equal to 11%.

In Figure 2-10 we show the average RTT, averaged among devices, in the case of unicast transmission for the different cases (no interference, channels 17 and 25). The logarithmic scale is used for the sake of legibility. For the case of no-interference, being the PLR null, the average RTT is almost constant and it is around 16 ms (8 ms per link, as expected). For the case of overlapped channel, instead, it is almost constant in all cases (about 600 ms) and it is extremely larger with respect to the no-interference case. This is due to the routing protocol: when some packets are lost over a link, due to the interference, the link is considered unreliable and the device will search for a new path to reach the destination. The latter is performed by sending a burst of RREQs, until a reliable RREP is received and only at that point the data packet is transmitted. Therefore, a lot of overhead is generated and many time passes before the device can send the data packet. This is demonstrated by results in Table 2-2: the overhead in the case of overlapped channel is much larger than the case of no-interference, and it is almost constant for the different cases, causing an increase of the RTT, which is constant too. In the case of non overlapped channel the overhead is low when the APs are at 3 m, resulting to a RTT around 16 ms, as in the case of no-interference. When the APs are at 10 cm, instead, the ZC suffers of a larger interference and resulting in an increase of the overhead, which on its turns generates an increasing of the RTT, again almost constant and around 600 ms.

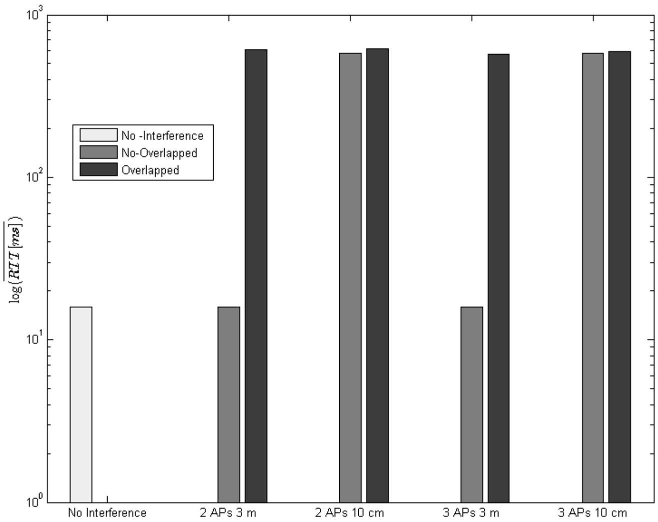


Figure 2-10: RTT averaged among devices for unicast transmission.

In conclusion, performance is strongly affected by the routing protocol: when AODV is used in both direction, the overhead increases and worst performance are obtained with respect to the case of broadcast transmission. The RTT is strongly affected by the overhead: when the overhead is lower than 10% the RTT is in the order of 16 ms; when the overhead becomes larger than 40% the RTT strongly increases (up to hundreds of ms). While the PLR is mainly affected by the utilization of the Wi-Fi network: when the utilization is lower than 15% the PLR is lower than 10%; when the utilization is larger than 40% the PLR becomes larger than 50%. In the case of non overlapped channel, when a distance of 10 cm is considered the ZC still receives some energy over channel 25, generating some interference and causing an increase of the overhead and of the RTT.

2.6 Planned Activities

- WP2.2 JRA#1 will continue, with the goal of a joint paper to be submitted. A big effort will be focused on the algorithm development, in particular on the measurement model. From this viewpoint an introduction of a more complex path-loss model seems to be a proper solution. Eventually switching to fingerprinting approach should be a way to achieve better performances. Another objective for the next year is the full integration of the platform with UWB devices to test high-accuracy localization and environment mapping algorithms.
- The possible set up of a JRA (dealing with scheduling in 4G uplinks) between EuWIn@UniBo and EuWIn@EURECOM within WP2.3 will be discussed in December 2014.
- With reference to WP2.2 JRA#3 the next period will be dedicated to the implementation of the algorithms in the wireless nodes, the collection of experimental results and their validation.
- As far as WP2.2 JRA#5 is concerned, in the third year we will finalise the processing of the data gathered during EuCNC Conference and provide these data as input to the DTN-based network simulator.
- Finally, for what concerns WP2.2 JRA#6 we can consider as closed the experimental activity related to the comparison of the different architectures and protocols, and in Y3 we will mainly work on disseminating the achieved results and on trying to bring the experience we gained in this work to possible other European projects. The latter experience mainly refers to the methodology to be used in order to fairly compare different protocols over a testbed.

3.General Conclusions and Prospects

After a first phase devoted to the set up and test of the EuWIn platforms, the second year of activity has been mainly oriented to the launch and consolidation of JRAs, as described in this document.

Most of the data collected in the experimental campaign will be made available in the EuWIn repository created in the EuWIn website. In particular, we will make available:

- The data measured during experiments carried out at EuCNC 2014, reported in Section 2.3;
- The results of the JRA#6, reported in Section 2.4.
- The results of the activity carried out in collaboration with NEC, reported in Section 2.5;
- The matrices describing the level of connectivity among nodes in the FLEXTOP platform, when considering different levels of transmit power, described in Annex II (Section 5.3).

During the next year the experimental research activity is expected to enforce the synergy with the theoretical activity under development in Track 1. More precise plans are reported in Annex III.

In the meantime the exploitation activity has produced some relevant results, as witnessed by the activity performed on behalf of NEC; the follow up after the dissemination event in Heidelberg, in February 2014, was successful, as NEC requested a number of tests to be performed over the FLEXTOP platform.

4. Annex I: Detailed Description of Main Technical WP Achievements

In this section we report details about results achieved in JRA#1 and JRA#6. Then some other experimental activities carried out at CNIT-BO are reported. The latter refer to: i) design and test of protocols for linear wireless networks; ii) down-scaling of a real testbed over EuWIn and iii) benchmarking of a network simulator.

4.1 Achievements of JRA#1 "*Design and experimental validation of algorithms for active and passive indoor positioning*"

Hardware-software development

The platform is based on the Raspberry Pi, a low-cost, credit-card size embedded system that features an ARM11 processor, 512MB DDR2 RAM and several I/Os that allow to stack on top a wide number of sensors and peripherals.

Raspbian, a Debian Linux distribution, was chosen as operating system, because of its compatibility with the most well known packages and because of its capability to exploit deeply the hardware resources.

In this project, to allow researchers exploiting data-fusion, heterogeneous sensing peripherals were used. In particular the following sensor are now fully integrated in the platform: inertial measurement unit (IMU), IEEE 802.11 network adapter, IEEE 802.15.4 RSS compliant reader.

Depending on the environment and the infrastructure they can be exploited or not.

The IMU adopted is the AltIMU-10, produced by Pololu. It features an accelerometer, a gyroscope and a magnetometer (three axes each) plus a barometer. They are all mounted on a 25x12 mm board; the accelerometer and the magnetometer share the same package while the gyroscope and the barometer are enclosed in separate IC. The I2C bus links the Raspberry Pi and the Pololu AltIMU-10. In Table 4-1 the IC specifications are summed up.

Table 4-1: IC specifications

Vendor	ST Microelectronics			
Model	LSM303DLHC		L3GD20	LPS331AP
	Accelerometer	Magnetometer		
Scale	± [2, 16] g	± [1.3, 8.1] gauss	[250, 2000] dps	[260, 1260] mbar
Axes	3	3	3	1
Output rate	[1, 400] Hz	[0.75, 220] Hz	[95, 760] Hz	[1, 25] Hz
I2C frequency	Normal: 100kHz, Fast: 400kHz			
Supply voltage	[2.16, 3.6] V		[2.4, 3.6] V	[1.71, 3.6] V
Current cons.	110 µA		6 mA	[5.5, 30.0] µA
Bus address	0b0001100	0b0001111	0b0110101	0b0101110

Regarding the WiFi adapter, the TL-WN722N manufactured by TP-Link has been chosen. It's a low-cost, IEEE802.11 b/g/n adapter, with an external high-gain, adjustable antenna.

Several experiments and tests were made to achieve reliable RSS measurements. In particular it was found that exploiting the "Monitor mode" instead of the default "Managed mode" allows to increase the accuracy of the RSS measurements by a factor ten, at least. The following two figures show the difference between the measurements obtained exploiting the interface in "Managed mode" and in "Monitor mode".

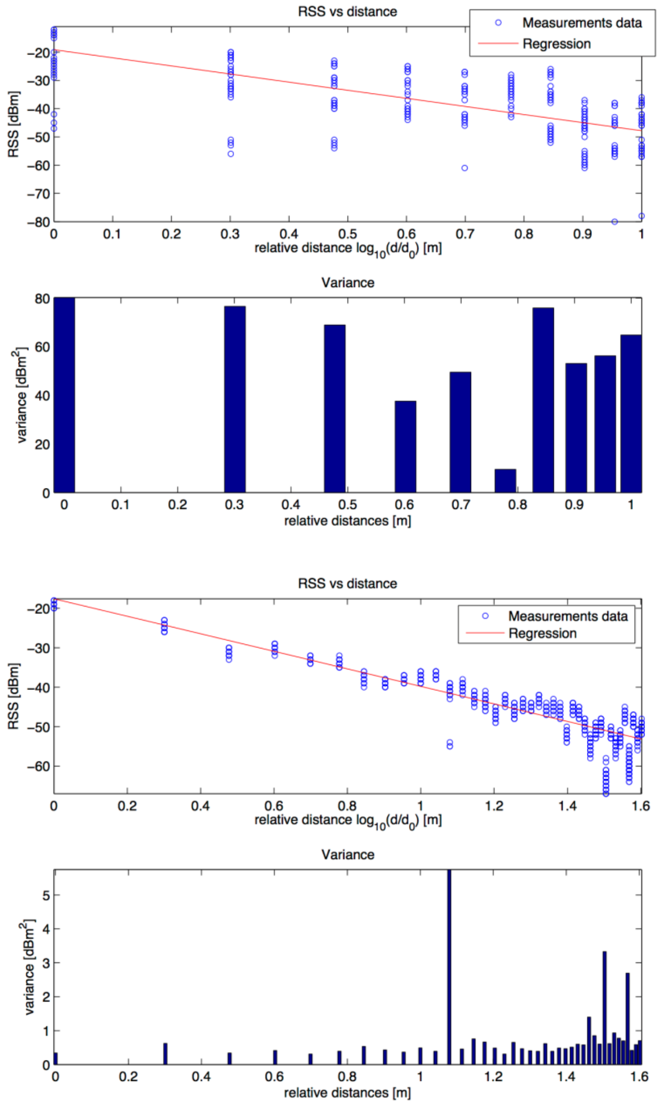


Figure 4-1: RSS Measurements

These improvements could be achieved exploiting the LibPCAP Linux library together with the Radiotap library to extract the packet content coming from the WiFi interface, which contains the actual RSS measured value.

The *IEEE 802.15.4* interface was added at EuWIn@UniBO, exploiting the DATASEN infrastucture. The measurements acquired along the corridor show the variations of the RSS while moving the platform on a straight trajectory. In the following figure RSS values recorded by anchors 1, 5 and 9 (at the beginning of the trajectory, in the middle and at the end, respectively) are shown.

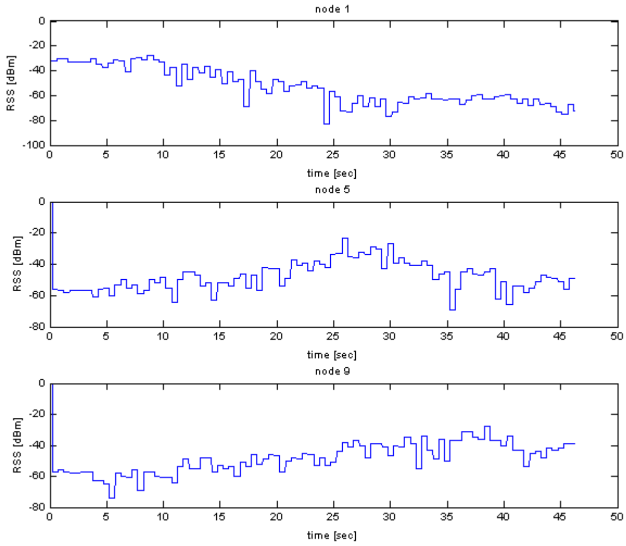


Figure 4-2: RSS Measurements

The maxima in each curves determine the time instants in which the moving platform is closer to the anchor.

Algorithm development

The goal of this activity was to develop an algorithm for tracking robot (or generic wheel equipped object) inside building exploiting data-fusion.

The global framework is that of Bayes filters, in particular sequential Monte Carlo method, also known as particle filters, chosen because of their flexibility in handling non-linear systems.

Given a generic system, its evolution is described by

$$\boldsymbol{x}_k = \boldsymbol{f}_k(\boldsymbol{x}_{k-1}, \boldsymbol{e}_{k-1})$$

where $\boldsymbol{x}_k$ is the system's next state, $\boldsymbol{x}_{k-1}$ is the system's current state, $\boldsymbol{f}_k$ is the dynamic model (possibly non-linear) that describes the system evolution and $\boldsymbol{e}_{k-1}$ is the noise affecting the system. The system state is unknown and cannot be measured. Measurements of some quantities dependent on the current state can be read and are the only information available to infer the current state. In particular, noisy measurements are related to the current state through

$$\boldsymbol{z}_k = \boldsymbol{h}_k(\boldsymbol{x}_k, \boldsymbol{n}_k)$$

where $\boldsymbol{z}_k$ are the measurements coming from the sensor, $\boldsymbol{h}_k$ is a possibly non-linear function of the current state $\boldsymbol{x}_k$ and the noise $\boldsymbol{n}_k$ affecting the measurement system.

Particle filters allow to estimate the posterior density by means of weighted deltas

$$p(\boldsymbol{x}_{0:k}|\boldsymbol{z}_{1:k}) \approx \sum_{i=1}^{N_S} w_k^i \delta(\boldsymbol{x}_{0:k} - \boldsymbol{x}_{0:k}^i)$$

where $\boldsymbol{x}_{0:k}$ is the set of the system states to be estimated and the pair $\{w_k^i, \boldsymbol{x}_{0:k}^i\}$ is the set of weighted randomly generated states used to estimate actual state.

In the current scenario the available sensors are the IMU, which provides accelerations and rotations measurements, and network interfaces that produce RSS measurements. The dynamic model adopted is Newtonian and linear

$$\begin{pmatrix} \boldsymbol{p}_k \\ \boldsymbol{v}_k \\ \boldsymbol{\delta a}_k \end{pmatrix} = \begin{pmatrix} \boldsymbol{I} & T_S\,\boldsymbol{I} & T_S^2/2\,\boldsymbol{I} \\ 0 & \boldsymbol{I} & T_S\boldsymbol{I} \\ 0 & 0 & \boldsymbol{I} \end{pmatrix} \begin{pmatrix} \boldsymbol{p}_{k-1} \\ \boldsymbol{v}_{k-1} \\ \boldsymbol{\delta a}_{k-1} \end{pmatrix} + \begin{pmatrix} T_S^2/2\,\boldsymbol{I} \\ T_S\,\boldsymbol{I} \\ 0 \end{pmatrix} \boldsymbol{a}_{k-1} + \begin{pmatrix} T_S^2/2\,\boldsymbol{I} \\ T_S\,\boldsymbol{I} \\ \boldsymbol{I} \end{pmatrix} \boldsymbol{e}_{k-1}$$

where the $[\boldsymbol{p}_k \quad \boldsymbol{v}_k \quad \boldsymbol{\delta a}_k]$ is the state vector that represents the position, the velocity and the acceleration bias of the platform, respectively; $\boldsymbol{a}_{k-1}$ is the vector of the acceleration measurements coming from the inertial sensor and $\boldsymbol{e}_{k-1}$ is the noise term, which is connected to the noise of the inertial sensor.
As measurement model the WiFi log-distance path-loss model is adopted

$$\boldsymbol{h}_k(\boldsymbol{x}_k, \boldsymbol{n}_k) = \begin{pmatrix} P_1\big(d_1(\boldsymbol{x}_1)\big) + n_1 \\ \vdots \\ P_N\big(d_N(\boldsymbol{x}_N)\big) + n_N \end{pmatrix} = \begin{pmatrix} P_0 - 10\alpha \log_{10}\left(\frac{d_1}{d_0}\right) + n_1 \\ \vdots \\ P_N - 10\alpha \log_{10}\left(\frac{d_N}{d_0}\right) + n_N \end{pmatrix}$$

where P_i is the received power (dBm) from the anchor i, P_0 is the received power (dBm) at the reference distance d_0 and α is the path-loss exponent. $n_i \sim N(0, \sigma_n)$ is a Gaussian random variable accounting for the random fading. To be noticed that this model can be used also for IEEE 802.15.4.
These two models are used in the particle filter. The dynamic model is used to estimate the next status given the current one and the acceleration measurements coming from the sensor. A number N_S of particles is generated through $\boldsymbol{f}_k$. When the RSS measurements from the network interfaces are available a weight for each particle is computed considering the probability

$$p(\boldsymbol{z}_k|\boldsymbol{x}_k^i) = N\left(\boldsymbol{z}_k; P_0 - \; 10\,\alpha \log_{10}\left(\frac{\boldsymbol{d}}{d_0}\right), \boldsymbol{K}_n\right)$$

where $\boldsymbol{K}_n$ is the covariance matrix. If the anchors are independent then $\boldsymbol{K}_n$ is diagonal.
The algorithm was tested both at CTTC (RSS IEEE 802.11) and at UniBO (RSS IEEE 802.15.4).
Before running the algorithm the path-loss model parameters (P_0, α, $\boldsymbol{K}_n$) were determined both for IEEE 802.15.4 and IEEE 802.11 peripherals.
The facilities of EuWIn@CTTC include a four wheel programmable robot, featuring wheel encoders and collision avoidance mechanism, that allows to measure precisely the traveled distance and to achieve high level of experiment repeatability.
The first set of measurements collected at CTTC shows an unexpected behavior regarding the RSS data coming from two of the four links between the platform and the the hotspots. The RSS values increase (instead of decrease) going away from the anchor, where typically one should expect the opposite. The following figure shows the comparison between the expected behavior (computed using the path-loss model) and the real measurements.

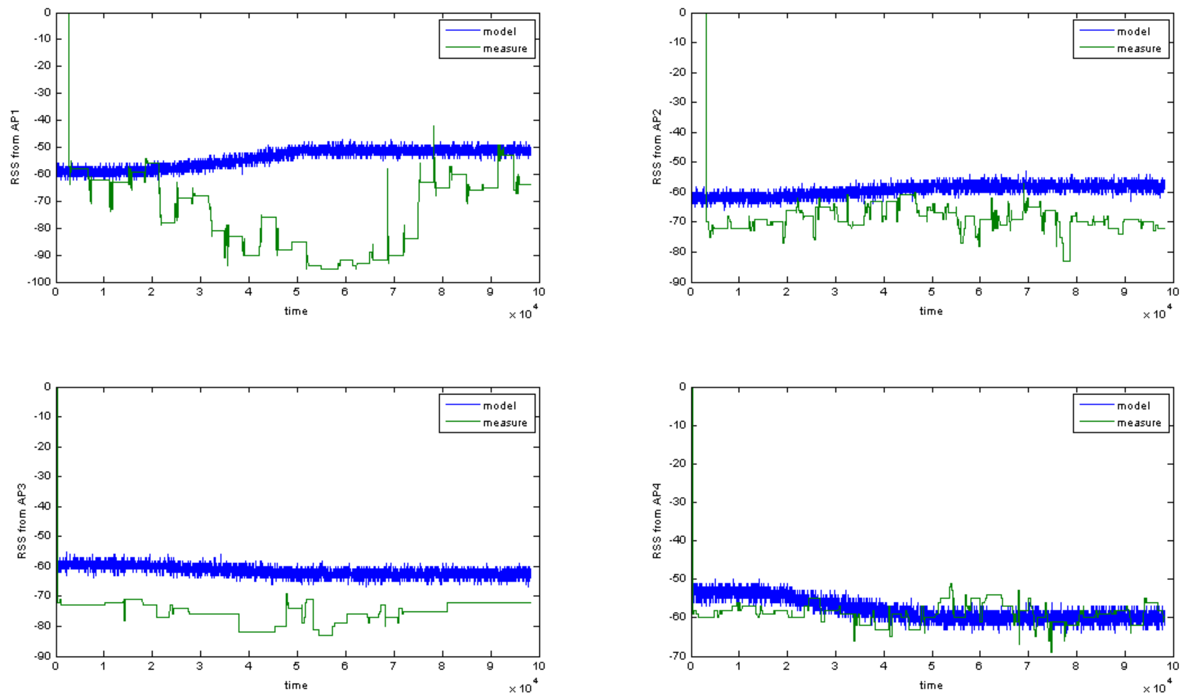


Figure 4-3: RSS Measurements

These values are so distant from the expected output of the model that the filter cannot estimate properly the state of the system, in particular the position. After running several times the algorithm, the error always increases during the time.

To prove the validity of the filter, the algorithm was tested also with the simulated values coming from the model, obtaining errors in the order of 0.4 m.

To reduce the error in the estimation, a map constrained model, featuring walls and doors, was created but the performance (i.e. accuracy and precision) were still not good enough.

To be noticed that, introducing the map constraints, increases significantly the computation time of the algorithm, because the trajectory of each particle has to be checked in order to evaluate if a wall crossing happened. Anyway, a proper implementation of the map constraints seems to be strictly required since it helps to increase the accuracy by means of excluding some not allowed position (e.g. walls, forbidden areas, service areas, etc.) which translates into a reduction of the investigated areas.

At UniBO the algorithm was tested exploting the DATASENS infrastructure made available by EuWIn@UniBO, using a trolley as moving support (following figure).

Figure 4-4: Measurements setup

The algorithm is producing poor results also in this location. Again the problem is related to the quality of the measurement model. In particular, the path-loss parameters obtained during the calibration phase are quite different with respect to the values extracted from the measurements.

4.2 Achievements of *JRA#6 "Testing IP-based Wireless Sensor Networks for the Internet of Things"*

The SDWN Solution

The SDWN protocol stack is show in in Figure 4-5: PHY and MAC layers are those of the 802.15.4, while upper layers are inspired by the SDN paradigm. In a typical SDWN network there is a controller node, a sink node and several other nodes. The controller gathers information from nodes, maintains a representation of the network and establishes routing paths for each data flow, as will be described below. The sink is the only node that is directly connected to the controller and it acts as a gateway to nodes of the SDWN network. In our implementation the sink coincides with the network coordinator. Its protocol stack is totally equivalent to a generic node. The stack of a generic node is divided into three parts: the Forwarding layer (FWD), the Aggregation layer (AGGR), and the Network Operating System (NOS).

In a SDWN network there are six different types of packets:

- Data packet: generated (delivered) by (to) the application layer;
- Beacon packet: periodically sent in broadcast by all nodes in the network;
- Report packet: containing the list neighbors of a node;
- Rule Request: generated by a node upon receiving a packet which does not match any Flow table entry;
- Rule Response: generated by the sink as a reply to the Rule Request;
- Open Path: used to setup a single rule across different nodes.

SDWN protocol requires that each node can request at any time information to the sink on how to handle incoming packets. Therefore the path between the sink and the node for rule requests and rule responses must be chosen effectively, considering both the reliability of the route and its length. Each node constantly stores its distance from the sink in terms of number of hops and RSSI received by the next hop toward the sink. During the initialization of the network each node is in a quiescent state where it can only receive messages. When the sink is turned on it will send a beacon message. When a node A receives a beacon packet, it performs four operations: i) add the source of the beacon and the RSSI received in the list of nodes that are one hop distant from A; ii) analyze the distance contained in the beacon and the RSSI of the received message, then it compares these values with the corresponding stored values: if the number of hops is lower and the RSSI is higher, the source of the beacon is elected as best next hop toward the sink and the values stored in A are updated; iii) the beacon timer is activated and periodically, the node A sends its own beacon message in broadcast; iv) the report message timer is activated; with period greater than the beacon timer the neighbors table of A is sent to the sink node using the best next hop toward the sink. After each sending, the list of neighbors is deleted in order to have an updated view of the network.

The information included in the report messages are used to create a map of the network. By using this representation the controller is able to respond rule requests and decide the routing paths for data packets, while rule request will keep following the previously discovered path.

The actual implementation of the controller uses Dijkstra’s routing algorithm to solve rule requests. The weight of the edges in the topology representation is a function of the received RSSI.

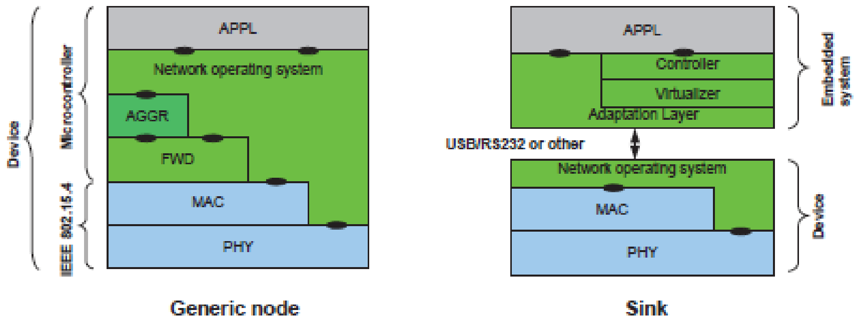


Figure 4-5: The SDWN protocols stack.

The 6LowPAN Solution

The lowest layers of the 6LowPAN protocols stack are based on IEEE 802.15.4 PHY and MAC layers. Due to the fact that the direct integration between IPv6 and IEEE 802.15.4 lower network layers is not possible, the IETF 6LoWPAN working group has specified an adaptation layer and header compression scheme for transmissions of IPv6 packets over IEEE 802.15.4 radio links. The purpose of adaptation layer is to provide a fragmentation and reassembly mechanism that allows IPv6 packets (Maximum Transmission Unit for IPv6 is 1280 bytes) to be transmitted in IEEE 802.15.4 frames, which have a maximum size of 127 bytes. At the network layer RPL is used (see below). For what concerns the transport layer User Datagram Protocol (UDP), providing best-effort quality of service, is used.

According to the RPL protocol, a Destination-Oriented Directed Acyclic Graph (DODAG), where each node may have more than one parent towards the root, is built. One of the parents is called preferred parent, and it is used for routing towards the root. In our case, the coordinator acts as the root. The route is constructed with a goal of optimizing an Objective Function. The topology is set-up based on a Rank metric, which encodes the distance of each node with respect to its reference root, as specified by the Objective Function, which represents the hop count metric in our implementation.

RPL nodes exchange signaling information in order to setup and maintain the DODAG. The construction of DODAG is initiating by the root that sends DODAG Information Object (DIO) messages to its neighbours to announce a minimum rank value. Upon receiving a DIO message an RPL node updates the lists of its neighbors, learns its configuration parameters, computes its own rank value and selects its preferred parent, which is used as next hop on the upward route to the root. After joining a DODAG an RPL node begins to transmit DIO messages to announce its rank value. RPL nodes may also send DODAG Information Solicitation (DIS) messages when join the network to probe their neighbors and solicit DIO messages. DAO messagee are used to propagate destination information upwards along the DODAG. Destination Advertisement Object (DAO) message is sent in unicast by the RPL node to the selected parent to advertise its address. When a node receives a DAO, it updates its routing table and then this information is used by the DODAG root to construct downward routes or paths between pairs of RPL nodes. In our implementation, each router in the path between the node generating a DAO and the DODAG root records a route to the prefixes advertised in the DAO, as well as the next-hop towards these.

RPL uses an adaptive timer mechanism, called the Trickle timer, to control the sending rate of DIO messages. The Trickle algorithm implements a check model to verify if RPL nodes have out-of-date routing information. The frequency of the DIO messages depends on the stability of the network and the frequency is increased when the inconsistency is detected.

Once the network becomes stable, the Trickle algorithm exponentially reduces the rate at which DIO messages are emitted.

The Zigbee Solution

Zigbee-Pro 2007 release is considered and Many-To-One (MTO) is used. MTO routing allows tho establish a tree topology, rooted at the coordinator. In order to form and maintain the tree, the coordinator periodically sends a MTO Route Request (MTORR) packet in broadcast. Each node receiving this packet, before retransmitting it, uses the information provided in the MTO-RR packet to set the next hop toward the coordinator. In particular, the MTO-RR will include the accumulated path cost, that is the sum of the costs of the links of the reverse path toward the coordinator. If a node receives more MTORR packets from different nodes, it elects the next hop node characterised by the minimum total path cost to the coordinator. At the end of this MTO-RR transmission, all nodes in the network are aware of the next hop to be used in order to transmit their data to the coordinator, that is their parents in the tree. However if the coordinator wants to know the path to reach a specific node in the network (or a set of nodes, through multi-casting), MTO routing should be combined to Source Routing (SR). After the MTO-RR transmission, once a node has a data packet to be sent to the coordinator, it first sends a Route Record (RREC) packet through the selected path. Each node in the path, receiving the RREC packet, adds in the relay list field its own address and forwards the new RREC packet toward the coordinator. The coordinator analyzes the RREC packet and stores that information in Source Route Table or Route Record Table. Each time the coordinator has to send a packet to a node it reads the relay list from this table and sends the packet through the selected path.

Numerical Results

A network of ten nodes, selected among the 53 available, have been considered. The set of selected nodes is shown in the Figure 4-6, where nodes underlined with red circles are those nodes selected for the experiments, that are: 4, 10, 13, 17, 22, 25, 38, 43, 45, 51.

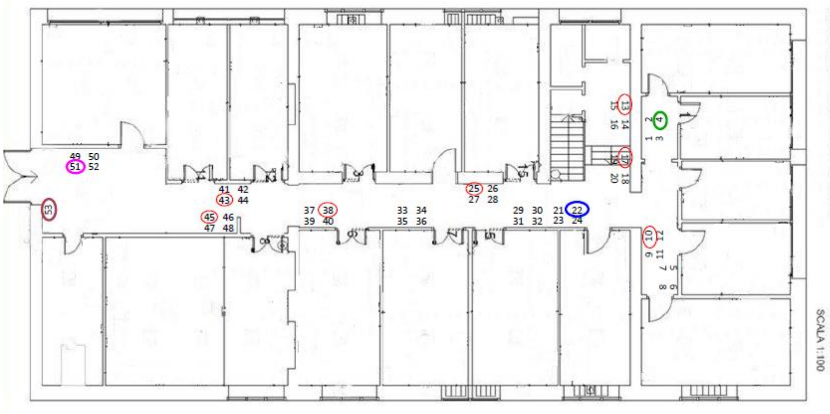


Figure 4-6: The Testbed Setup.

We consider a unicast query-based application were the coordinator periodically sends a query packet, that is a data packet with a given payload, and waits for a reply from the intended receiver, transmitting a data packet, having the same payload. We changed the triggered nodes in the experiments, being connected through a different number of hops to the coordinator. In particular, nodes 51, 22 and 4 are triggered.

To provide an example of results, we report here the round-trip-time (RTT), which is the interval of time between the transmission of the query at the application layer of the coordinator and the instant in which the reply is correctly received at the application layer of the coordinator too.

In the figures below we compare the average RTT for the three solutions by setting the payload size equal to 10 bytes and by changing the number of hops (figure on the left), and the average RTT by considering the one-hop case and by changing the payload size (figure on the right). Measurements were performed during the night when no people were moving around, that is there is no need to react to environmental changes, since no changes were present. In the latter case SDWN is the best solution in terms of RTT.

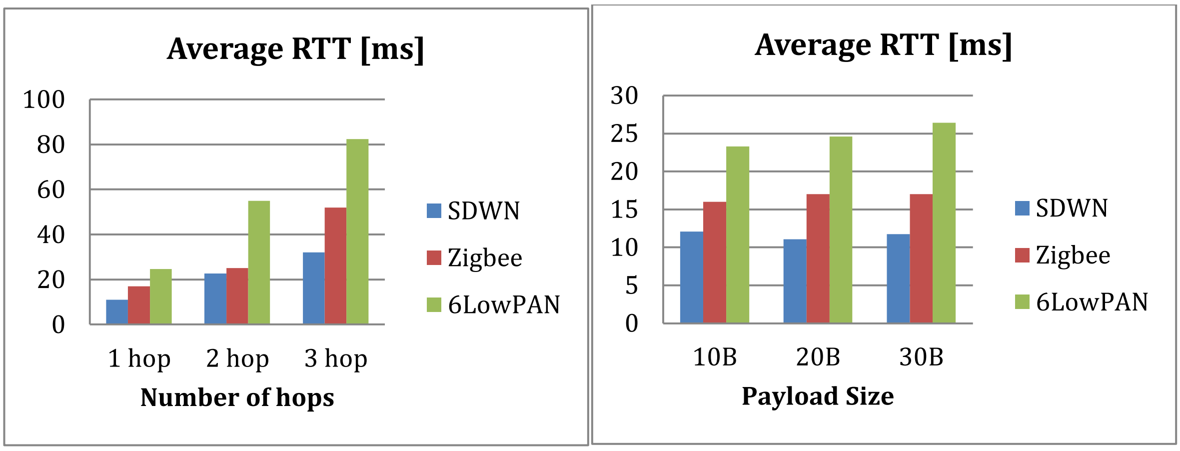


Figure 4-7: Average RTT for the different solutions.

4.3 Achievements of the activity "*Testing Protocols for Linear Wireless Networks*"

We consider a scenario where nodes in the network are distributed along a straight line. This type of networks can come up in many Smart City applications, as nodes can be distributed on lamp posts of the city for example. The peculiarity of the topology of these networks motivates the design of specialized protocols, taking advantage of the linearity property. In particular, we consider the topology shown in the figure below, where we have one or more source nodes that transmit the data via multiple relay nodes toward a final destination. We refer to the case with a single source node in the network as a Linear Wireless Network (LWN), while the case where all nodes in the network generate data is referred to as Linear Wireless Sensor Network (LWSN).

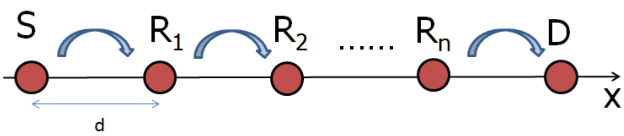


Figure 4-8: The linear network.

Different routing protocols meant for this linear topology are proposed and compared to the Zigbee standard solution, using AODV routing protocol. Two solutions are proposed and compared: i) hop-by-hop and ii) broadcast-based protocol.
In the first case each node in the network is aware of the address of its next hop in the line toward the sink, and it just transmits the data to it. The reception of a data from the rear of the chain triggers (as a sort of token) the transmission toward the next hop.
In the broadcast-based solution a source node in the network transmits data in broadcast, aiming at reaching the coordinator of the network that. Multiple relaying nodes receive packets from the source node, but they forward the data only in case when the received power is under a given threshold and the packet is received from the node that is behind it in the line. In this way, we limit the overhead of the network and avoid flooding of the network since not all nodes that receive packet will forward it, but just those that are farther from the source node meaning closer to the destination.

The above solutions have been implemented on FLEXTOP platform and performance, in terms of packet error rate (PER) and throughput, have been evaluated and compared. Results demonstrate the improvement achieved with the proposed solutions, with respect to the standard case.

The two figures below demonstrate that in case of hop-by-hop solutions, when all nodes in the network generate data packets, it is better to use data aggregation in order to achieve better performance both in terms of PER and throughput.

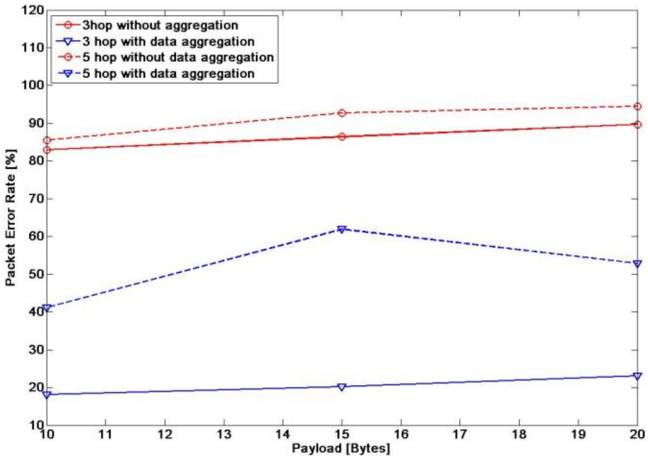


Figure 4-9: PER for the Hop-by-Hop solution.

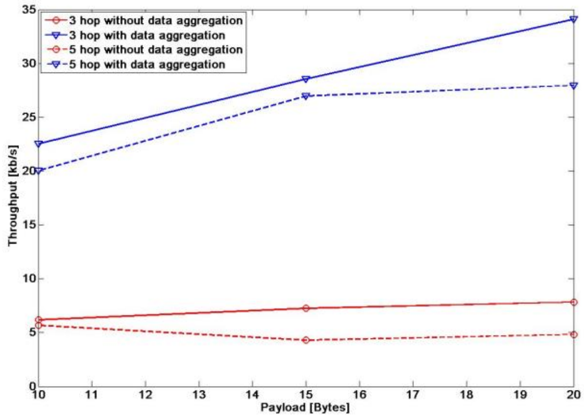


Figure 4-10: Throughput for the Hop-by-Hop solution.

Regarding the comparison of the performance among different solutions, results showing that both hop-by-hop and broadcast-based solutions introduce improvements with respect to Zigbee AODV protocol can be seen in the two figures below.

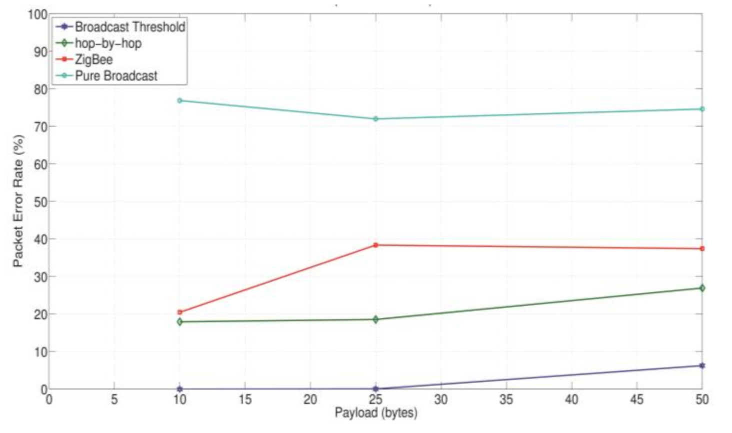


Figure 4-11: PER for the different solutions.

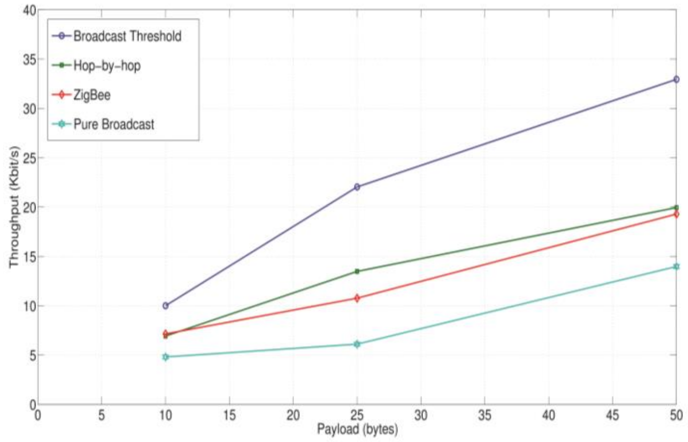


Figure 4-12: Throughput for the different solutions.

4.4 Achievements of the activity "*Down-scaling of a Real Testbed on EuWIn*"

One of the objectives of FLEXTOP is to perform pre- and post- deployment tests, mainly with reference to testbeds developing IoT or smart city applications.
To this aim some preliminary tests have been done at UniBO, in order to compare a smart city real testbed, deployed in the park of the Engineering School at the University of Bologna (see Figure 4-13), with a down-scaled testbed developed using FLEXTOP.
The development of a testbed deployed in the laboratory that is a stable and controllable environment, precisely reproducing a real testbed deployed outdoor, may drastically reduce the costs of the testing and parameters tuning phases in the real deployment.
Results shown in this paragraph demonstrate that EuWIn, and FLEXTOP in particular, is a useful tool with reference to the above-mentioned objective.

The real testbed runs a smart city application, with the aim of developing a smart lighting system, able to properly manage the luminosity generated by the lamp posts, in order to reduce the energy consumed by the municipality. The smart lighting system may also provide some additional services to people or cars or other objects in the street.

Eleven devices were deployed on the lamp posts (see Figure 4-13), using Zigbee/IEEE 802.15.4. Then we wanted to deploy the same network running the same application using FLEXTOP platform. The problem that was imposed in order to achieve the goal was how to choose which 11 devices to use among 53 that are available at EuWIN at the University of Bologna.

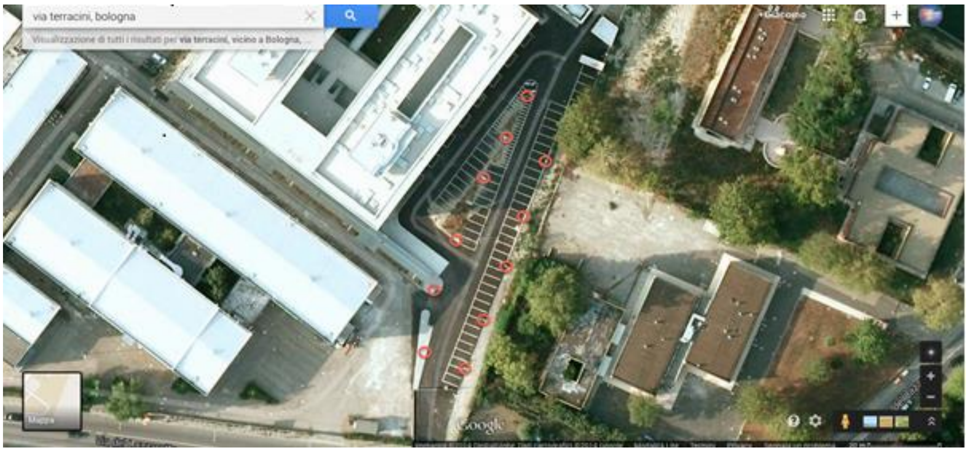


Figure 4-13: The real testbed.

We observed the path loss matrix that was derived both for indoor (**M_r** [53x53]) and outdoor (**M_O** [11x11]) testbed. Each element, r_{ij} (of **M_r** [53x53]) or o_{ij} (of **M_O** [11x11]) represents the power received by node ***i*** when node ***j*** transmits. The algorithm that was used to derive the 11 devices to be use on FLEXTOP was the following: first, we identified all possible [11x11] matrices **M_r'** within the **M_r** matrix**.** Then we observed the objective function f, which was defined as:

$$f = \sum_{i,j=1}^{11} | o_{i,j} - r'_{i,j} |$$

Finally, among all matrices M_r' we choose the one that has the lowest value of f. As a result, we obtained the mapping among devices in outdoor and indoor testbed and identified which devices to use on FLEXTOP platform, as it can be seen in the figure below.

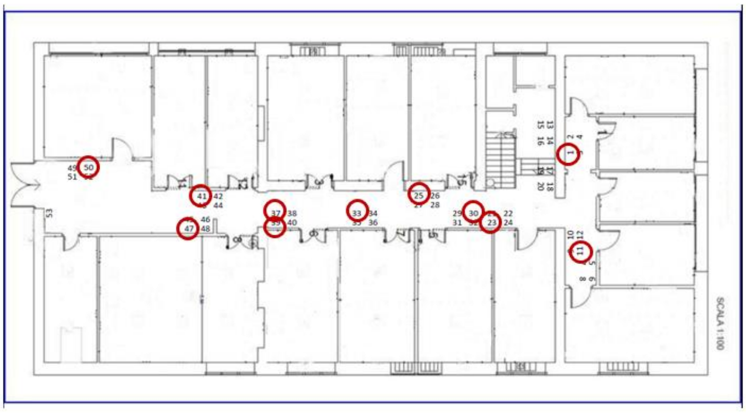


Figure 4-14: The EuWIn map of nodes.

We ran the same application on both testbeds and evaluated the results in terms of PER and throughput that can be seen in the figure below. Apart from the smart city application, we also evaluated the performance of the network using the hop-by-hop protocol described in section 4.3 for different number of hops. Results are shown in the following figures. It can be seen that FLEXTOP appears to be a promising tool for pre-deployment tests that allows avoiding expensive and demanding outdoor tests.

Table 4-2: Comparing the Real Testbed with the FLEXTOP Results

PAYLOAD [Bytes]	Throughput [kbit/s] Indoor	Throughput [kbit/s] Outdoor
Zigbee		
	19,97	15,7868
	45,22	32,1201
	58,7898	48
5 hop LWSN		
5	11,91796	13,55938
10	19,09116	21,70925
15	22,80951	28,28144
20	25,41144	31,1028
4 hop LWSN		
5	12,01108	13,90654
10	20,93603	23,13619
15	26,90595	30,64803
20	31,2672	35,00702
5 hop LWN		
10	6,285675	6,635995
20	11,02514	10,79538
30	14,38742	13,96898
40	17,39549	16,40435
50	19,28825	17,3361
4 hop LWN		
10	6,681807	7,296189
20	11,43777	12,23232
30	14,91472	15,99472
40	17,15315	19,08581
50	19,45759	21,51653

4.5 Achievements of the activity "*Benchmarking of NS-3 Simulator*"

With reference to the objective of FLEXTOP of benchmarking IEEE 802.15.4 simulators, UniBO performed some tests for comparing FLEXTOP results with an IEEE 802.15.4/Zigbee simulator, implemented in NS-3.

The aim of this work is to: i) Validate the network simulator implemented in NS-3; ii) Investigate and discuss the differences between the results, due to the practical issues normally not accounted for in simulations.

Both the NS-3 and the FLEXTOP platform run a very simple multi-hop routing protocol on top of the IEEE 802.15.4. In particular, a multi-hop network composed of a source which has to send data to a destination node n-hops away from it, is considered. The protocol is the hop-by-hop protocol described in Section 4.3.

Performance is evaluated in terms of throughput, that is the number of bits per second correctly received by the final destination when generated by the source, passing through 3, 4 and 5 hops.

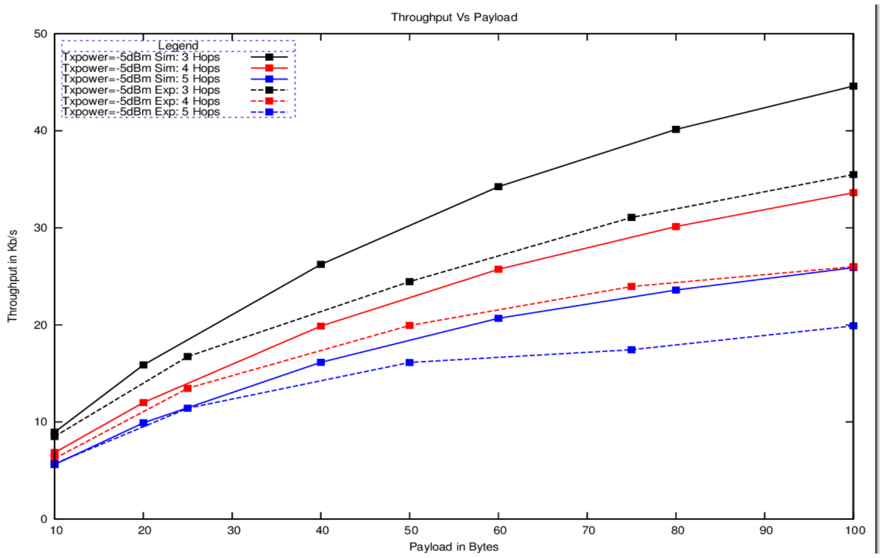


Figure 4-15: NS-3 and Tests Results Comparison

5. Annex II: Validation of Lab Facilities

EuWIn is composed of seven lab facilities (test beds) located in three sites (at CTTC, UniBO, Eurecom). One of the facilities (LOCTEST) in Bologna is not deployed yet, according to plans. The document discusses therefore the validation of the six lab facilities currently in use within EuWIn and Newcom#.

The document first summarizes the approach identified for validation purposes, in Section 5.1. Then, the methodology used and the type of tests designed are shortly described in Section 5.2. Section 5.3 reports the results of the tests. Finally, conclusions are drawn.

5.1 Introduction

The lab facilities made available within EuWIn deal with separate technologies and field of applications, spanning from the Internet of Things to indoor and satellite localization, to LTE; therefore, their validation should follow completely different approaches and paradigms. Moreover, while the facilities at Eurecom and CTTC were already acquired when the EuWIn was established, the hardware in Bologna was bought during the first months of Newcom# (being the software code inherited by previous projects); thus, validation followed different goals in the three cases.

The validation of a test bed or an experimental platform can have different goals, depending on the specific objectives and fields of application of the facility. In some cases, compliance with respect to a standard is the key issue, in others accuracy of some performance indicators is the most relevant aspect.

An attempt to discuss the possible means to validate a lab facility was made; validation of a test bed can refer to one or more of the following properties (non-exhaustive list):

- **Reproducibility** of experiments
- **Accessibility** of the test bed
- **Reliability** of the test bed
- **Functionality** (it works!)
- Values of key **performance indicators**
- **Accuracy** of signal generation or algorithm output
- **Match** of results from the test bed with simulation
- Standard **compliance** of the test bed
- **Stability** of the test bed

A discussion was held within EuWIn regarding the peculiarity of each facility, and the approach to be used for validating the platforms. The key aspect of each of them were identified, and the methodology for validation is summarized below.

EuWIn@CTTC (GEDOMIS) – The key is **accuracy** of signal generation; in this case proper validation requires the measurements of some PHY layer characteristics of the signal generated by the platform.

EuWIn@CTTC (GNSS-SDR and OPENINLOCATION) – The key is position estimation **accuracy**; the facilities dedicated to localization, either via satellite or indoor, should be validated by measuring the accuracy of the SW/HW platform in terms of position estimation.

EuWIn@UniBO (FLEXTOP) – The key here is **reproducibility**; in fact, the facility is designed in order to allow proper comparison of protocols for the IoT, in a controllable radio context.

EuWIn@UniBO (DATASENS) – The key here is **reliability**; the facility will be used to measure different types of physical instances that have to be reliably reported to the coordinator of the network for suitable post-processing.

EuWIn@Eurecom (OPENAIRINTERFACE) – The key here is **compliance** with respect to LTE; the platform is used to test algorithms and protocols suitable for 4G.

5.2 Methodology

For each of the platforms, a short description of the type of test performed is given below.

EuWIn@CTTC (GEDOMIS)

Since GEDOMIS® enables the prototyping of wireless communication system, the best method to test its proper functionality is to implement and assess the performance of a transmitter/receiver pair of a certain given standard (in this case based on IEEE 802.16e). The precise test includes:
T1.A: For the transmitter, ability of a third party equipment (Agilent's VSA signal analysis software) to demodulate the generated signal.
T1.B: For the receiver, assess the EVM-SNR performance of the decoded signal (this test is also implicitly testing the ability of the receiver to demodulate the signal).

EuWIn@CTTC (GNSS-SDR)

GNSS-SDR's functionality can be assessed by studying its ability to process the signals coming from the GNSS constellation and to compute the position coordinates. Thus, the precise tests are:
T2.A: Check ability of GNSS-SDR to acquire satellite data through the RF front-end calibration
T2.B: Compute position and check that the position error is within the expected value

EuWIn@CTTC (OPENINLOCATION)

The main goal of the OpenInLocation environment is to provide the necessary measurement data to research on algorithms for positioning in indoor environments. In order to do so, the following needs to be achieved/tested:
T3.A: Have a (moving) device, which is able to trace a reproducible route in a given indoor environment.
T3.B: Check the ability of the device to acquire, from different sources, data that can be used for positioning (e.g., IMU readings, RSS measurements).

EuWIn@UniBO (FLEXTOP)

The features of the facility considered are:
1. The experimental environment is known a priori;
2. The experimental environment is stable for the full duration of the experiment and also almost the same from experiment to experiment;
3. It is remotely accessible thanks to over-the-air (OTA) programming.
The first two points above make: i) the experiments reproducible and ii) the comparison among different protocols, even though tested at different time instances, fair.

EuWIn@UniBO (DATASENS)

DATASENS is composed of 50 devices that are in fixed positions in a corridor at the University of Bologna. Devices are equipped, among different sensors, with a temperature sensor. The tests are designed n order to show that the values measured at the sensors are reliably reported to the coordinator of the network.

EuWIn@Eurecom (OPENAIRINTERFACE)

OpenAirInterface claims to be standard compliant to the most important features of the 3GPP LTE standard. A detailed table of compliance can be found D23.2. Standard compliance of the testbed is measured for the different layers of the protocol stack.

5.3 Tests

This section presents the results of the tests described in the previous Section for each one of EuWIn@CTTC lab assets.

EuWIn@CTTC (GEDOMIS)

The following figure shows the successful demodulation of the MIMO signal transmitted by CTTC's real-time FPGA-based MIMO-OFDM IEEE 802.16e transmitter, using Agilent's VSA signal analysis software.

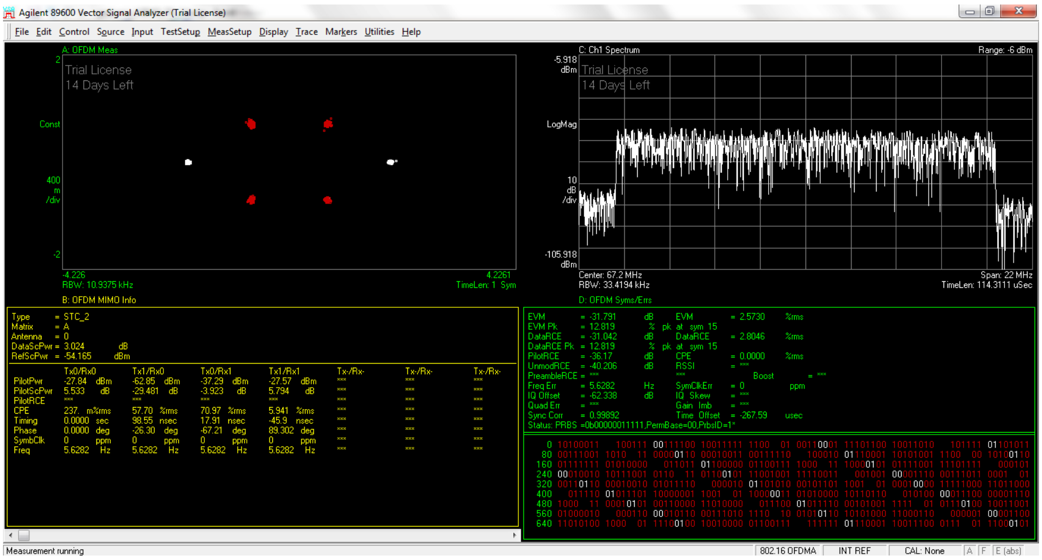


Figure 5-1: Demodulation of the MIMO signal

The following figure shows the EVM-SNR performance plot of the signal decoded by the real-time FPGA-based MIMO-OFDM IEEE 802.16e receiver.

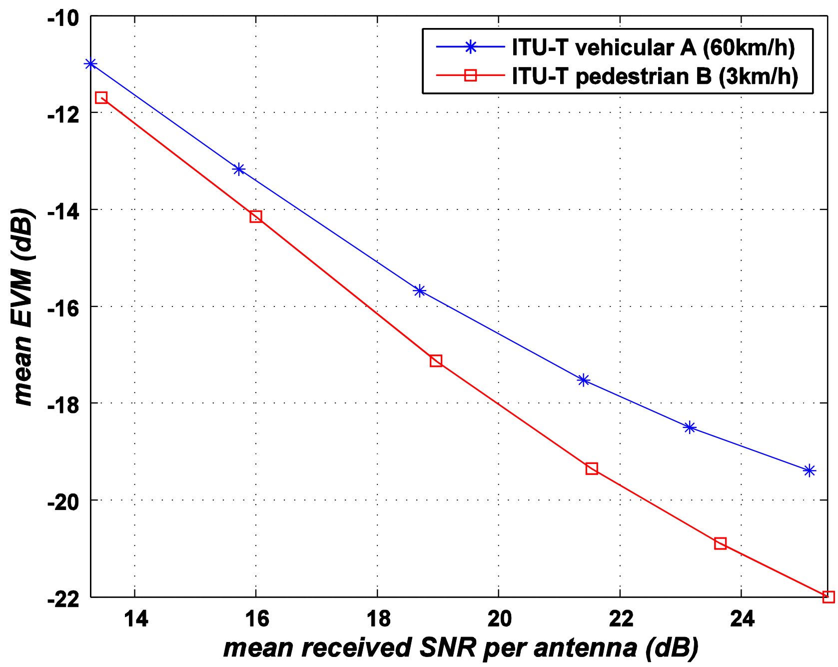


Figure 5-2: EVM-SNR performance

EuWIn@CTTC (GNSS-SDR)

The results of the front-end calibration procedure are summarized in the following table.

Measured Doppler [Hz]	**Assisted Doppler** [Hz]	**Corrected Doppler** [Hz]
-9562.50	2341.76	2226.08
-10625.00	963.65	1163.58
-11500.00	-32.61	288.58
-10812.50	655.78	976.08
-9000.00	2644.15	2788.58
-14000.00	-2053.73	-2211.42
-9125.00 2	2565.4	2663.58
-10125.00	1653.91	1663.58

From this values it follows that the resulting frequency deviation and sampling frequency estimations are ferr = -11788.58 Hz and fs’ = 2000014.97 Hz, which are inside the expected values and which guarantee a successfully calibration procedure.

The computation of the position can be qualitatively visualized in the following figure, where a Google Earth image of the GNSS-SDR positioning results is shown.

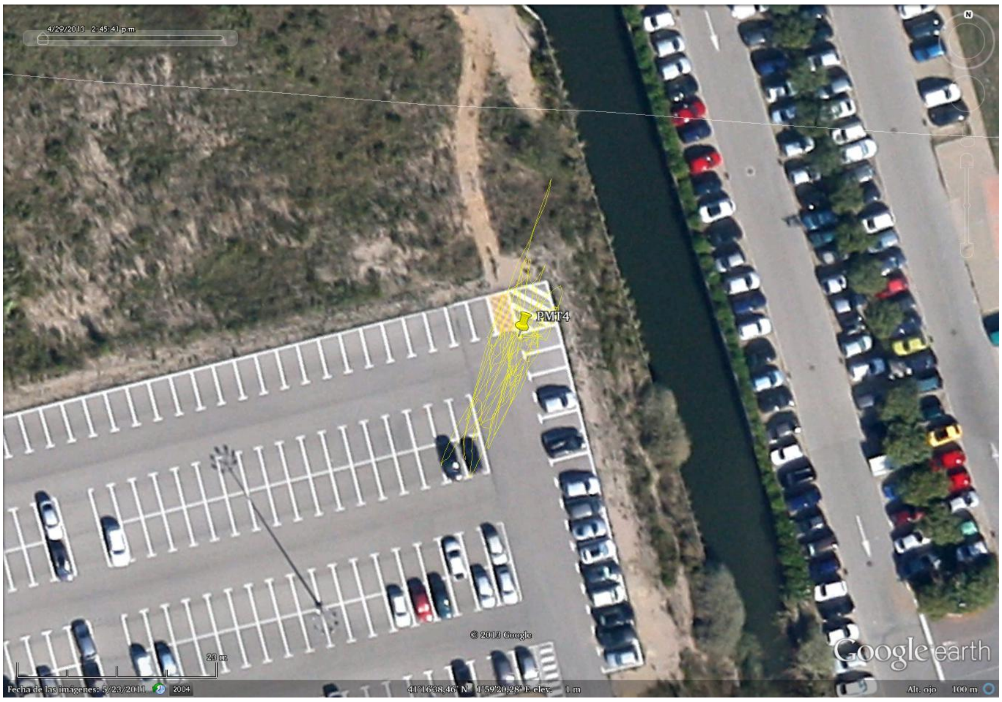


Figure 5-3: Position computation

The precise values for the quantitative performance indicators were 2D DRMS = 3.59 m and 3D MRSE = 7.16 m for accuracy and 2D DRMS = 2.88 m and 3D MRSE = 5.80 m for precision, which fall inside the expected values.

EuWIn@CTTC (OPENINLOCATION)

The following image shows a picture of the moving device, which is able to trace a reproducible route in a given indoor environment.

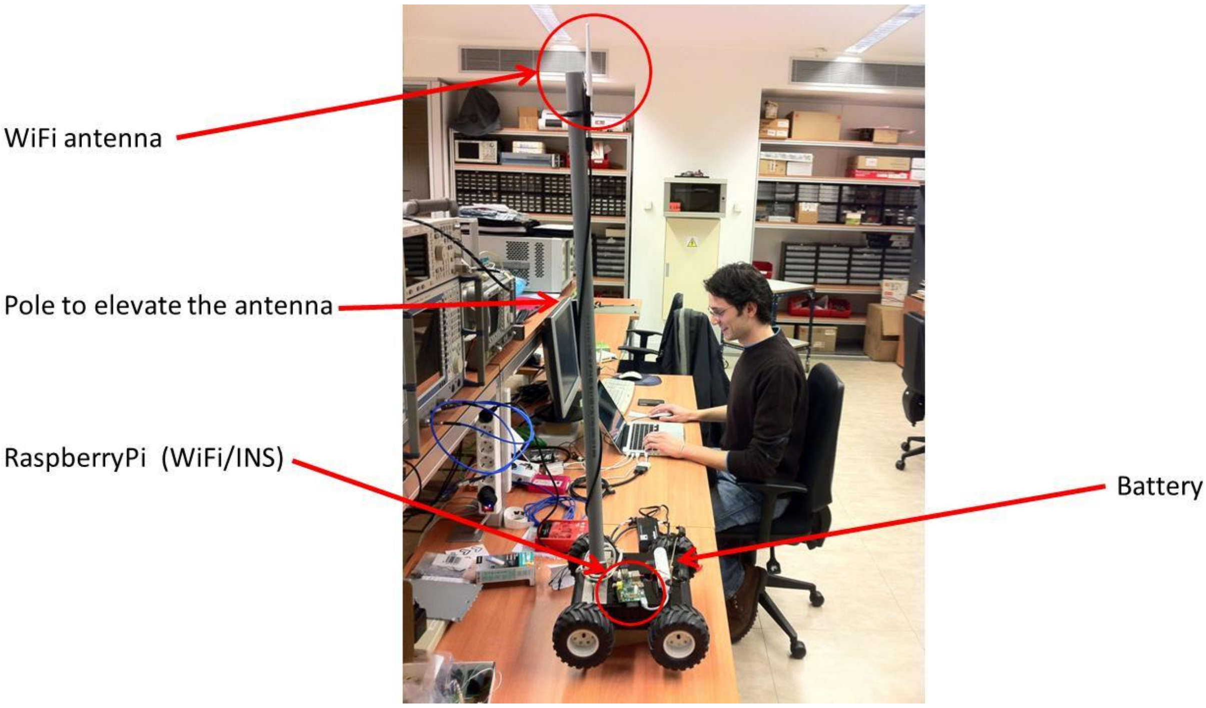


Figure 5-4: Equipment

The following three figures show the measurement data captured by the moving device depicted above. The first figure shows the WiFi received signal strength plotted versus distance to the emitting source and its variance.

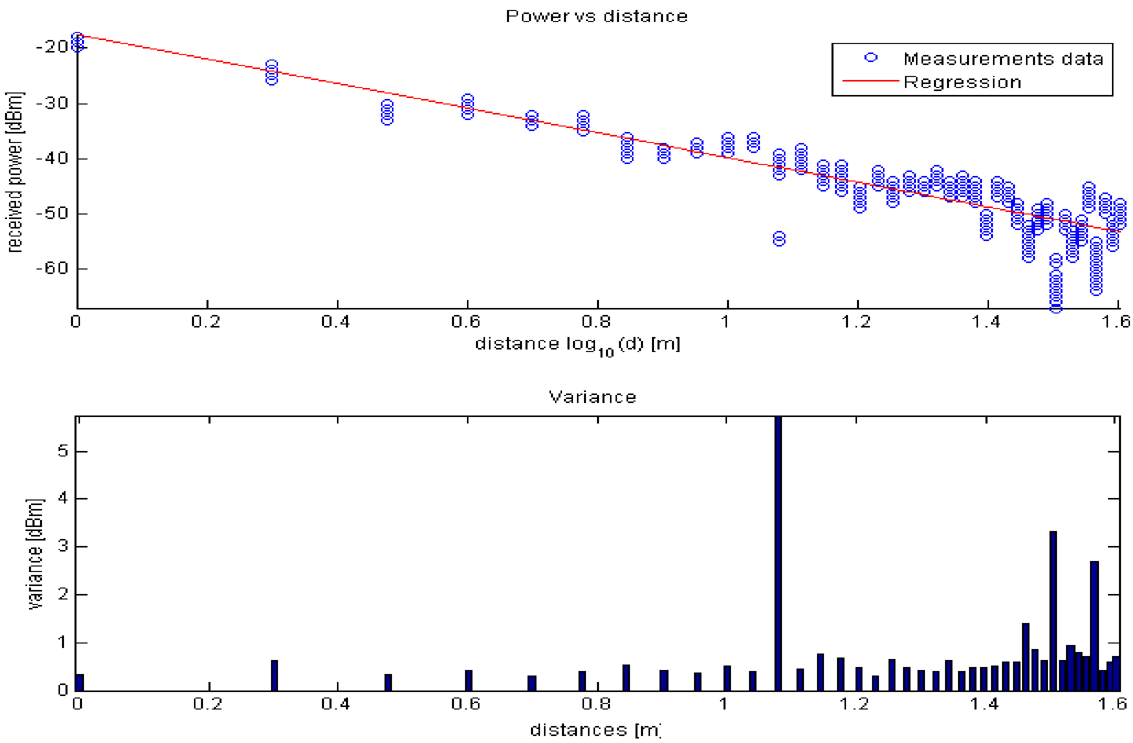


Figure 5-5: Wi-Fi received signal strength and variance as a function of the distance

The next figure shows the data gathered from the accelerometer as a function of time:

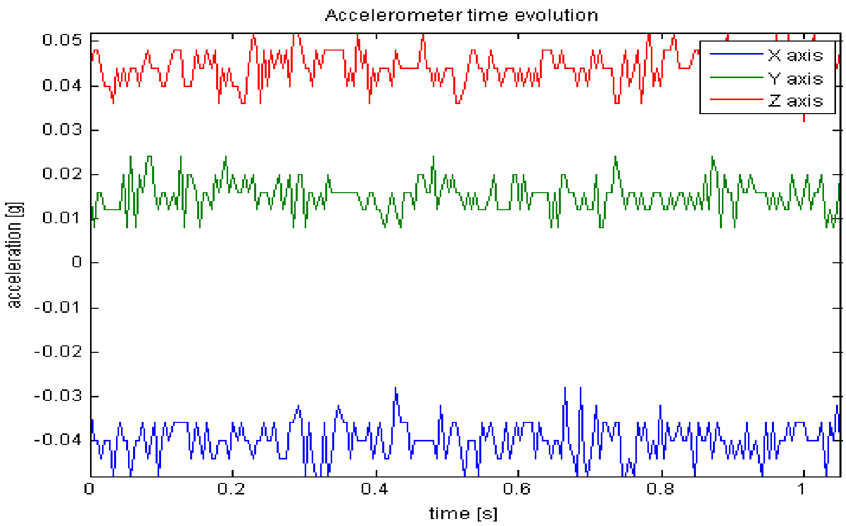


Figure 5-6: Accelerometer data

Finally, the next figure shows the data gathered from the gyroscope as a function of time:

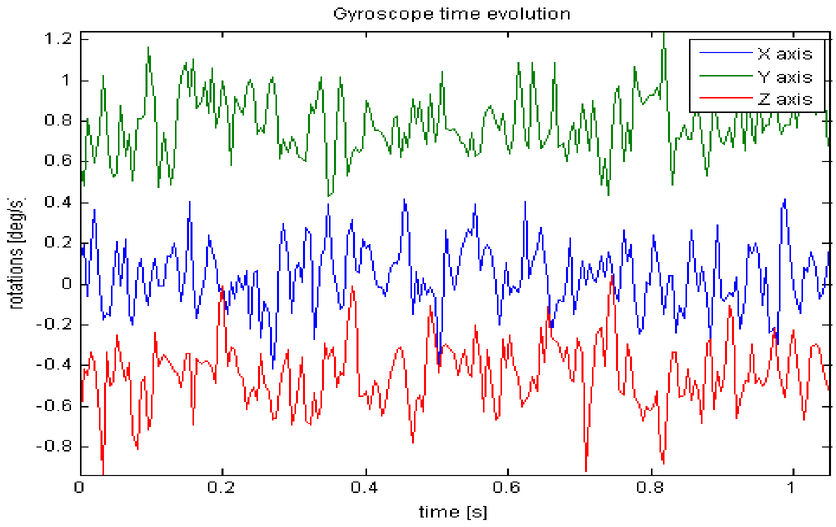


Figure 5-7: Gyroscope data

EuWIn@UniBO (FLEXTOP)

The first two features mentioned in Section 2 are achieved thanks to the following: i) devices are in fixed (into boxes) and known positions (see Figure 5-8 and Figure 5-9); ii) channel gains between each pair of devices are measured at the beginning of each test; iii) experiments are performed during the night, when nobody will be present, avoiding channel fluctuations and changes in the environment, resulting in achieving the same channel gains among nodes, with a good approximation.

Actually 53 devices are located into boxes in a corridor at the University of Bologna, see the figures below, where the map with the ID of the 53 devices and the receptive locations is also provided.

Figure 5-8: The FLEXTOP boxes and devices at the University of Bologna

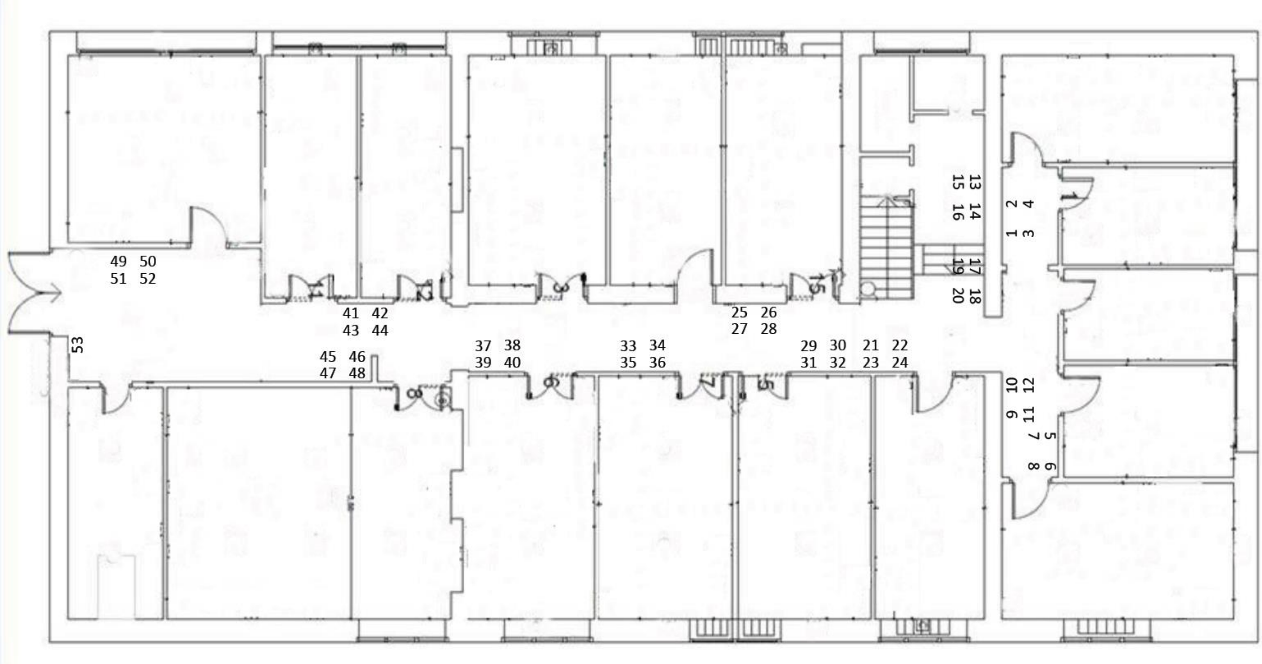


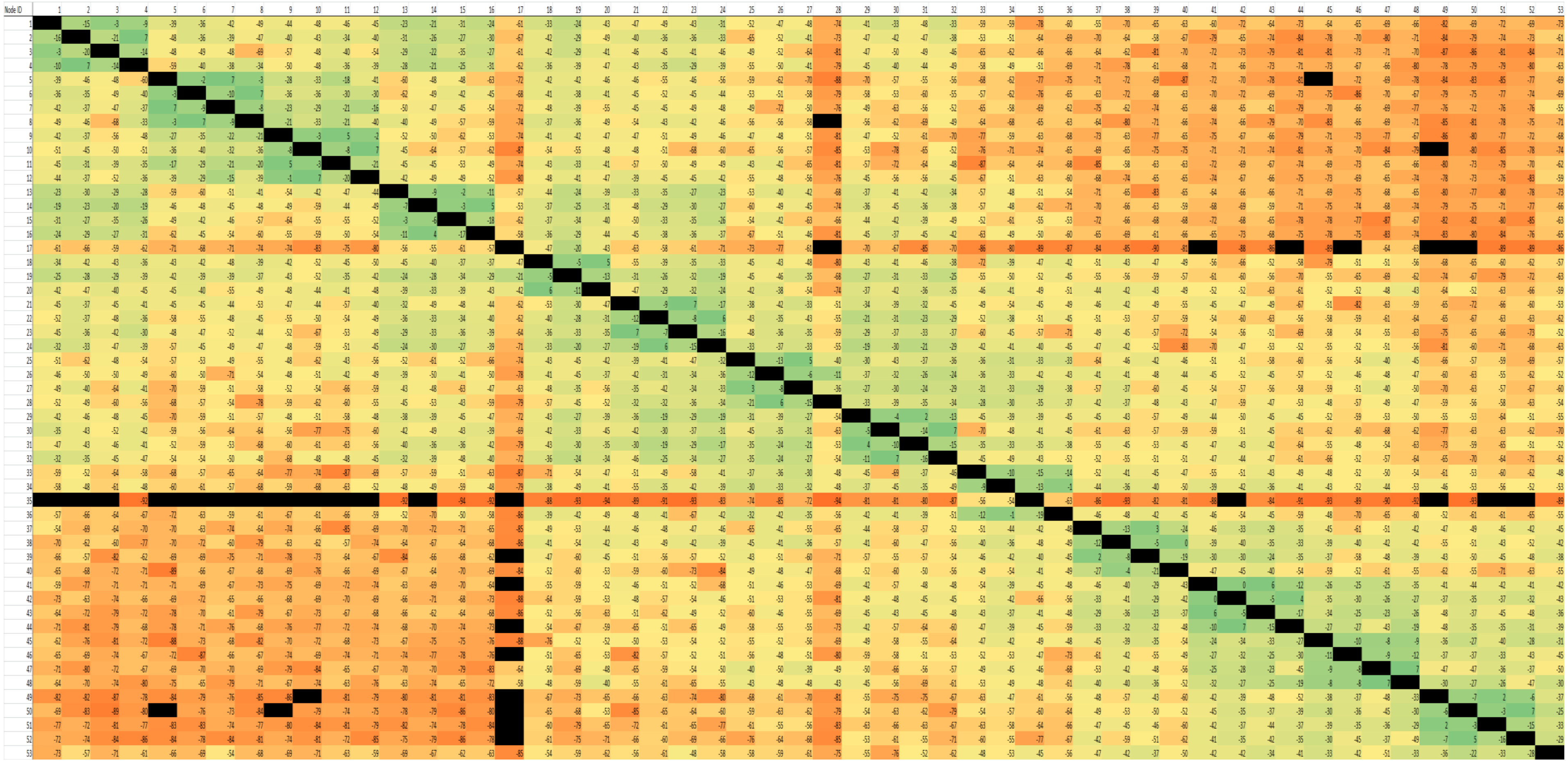
Figure 5-9: The FLEXTOP map and devices positions

In order to characterise the environment, we measure the average power received by a device when another one is transmitting. The measure is repeated for all the couple of devices (see below), and it is performed in the absence of interference (form Wi-Fi and from other possible IEEE 802.15.4 devices).
In particular, for our 53-devices network, we derive a matrix, P, of size 53 X 53 of elements, Pi,j , that is the average power receiver, in dBm, by node i, when node j is transmitting. The matrix has been obtained as follows: each device sends 10.000 short packets to let other devices compute the average power received from the transmitter. One by one all the devices will act as transmitters. The set of received powers measured by all the devices is sent to the Coordinator, to create the matrix P.

We report below the matrices obtained for different level of transmit powers used by devices from 20 dBm to -5 dBm with a step of 5 dBm. Black boxes indicate that the device did not receive any packet from a given node.
We can note that: i) by increasing the transmit power the number of non connected nodes decreases; ii) the matrices are symmetric with a good approximation; iii) a decreasing of 5 dB of the transmit power generates in most of the cases a decreasing of 5 dB of the received power. The latter is not true for some cases, being the devices at low distance, such that the far-field conditions are not satisfied.

Moreover, with reference to point 2 above, in order to demonstrate the reproducibility of the results, we report for the case of 0 dBm of transmit power two matrices, obtained at different time instances (different nights). As can be seen, the difference between two corresponding values of the matrices is in the 90% of the cases equal to zero (i.e., we obtained exactly the same average received power for a couple of transmitter-receiver) and in the remaining 10% of the cases the difference in absolute value is equal to 1 dB.

Matrix obtained by setting a transmit power of 20 dBm



Matrix obtained by setting a transmit power of 15 dBm

Node ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
1		-20	-6	-14	-43	-42	-48	-56	-48	-55	-51	-50	-27	-25	-36	-29	-66	-39	-30	-48	-52	-56	-48	-36	-57	-53	-55	-74	-47	-38	-55	-36	-64	-63		-64	-60	-75	-71	-68	-64	-79	-69	-77	-69	-70	-76	-70	-85	-74	-81	-78	-78
2	-21		-25	7	-53	-42	-44	-52	-45	-48	-38	-45	-36	-30	-32	-35	-72	-48	-35	-55	-45	-42	-42	-38	-69	-59	-46	-73	-53	-48	-52	-41	-59	-55	-82	-73	-75	-69	-64	-72	-83	-71	-78	-87	-84	-75	-84	-77	-86	-87	-79	-81	-64
3	-7	-25		-19	-53	-56	-53	-74	-63	-54	-45	-60	-33	-27	-40	-32	-65	-48	-35	-45	-51	-51	-46	-51	-53	-59	-69	-81	-54	-57	-55	-49	-70	-66	-84	-70	-69	-67	-86	-75	-76	-79	-83	-85	-86	-78	-77	-79	-89		-85	-87	-76
4	-14	7	-18		-64	-46	-43	-39	-55	-54	-41	-42	-33	-27	-30	-36	-67	-41	-45	-51	-47	-40	-34	-43	-60	-57	-46	-79	-50	-45	-49	-53	-63	-53	-70	-74	-76	-83	-67	-74	-76	-72	-78	-74	-79	-72	-71	-86	-82	-85	-82	-89	-66
5	-44	-52	-52	-65		-7	2	-7	-33	-38	-23	-45	-66	-54	-55	-67	-77	-48	-47	-51	-52	-62	-52	-62	-63	-68	-76	-88	-76	-63	-61	-60	-73	-65		-79	-75	-77	-74		-76	-76	-83	-84		-78	-74	-82	-86		-87	-87	-71
6	-41	-40	-52	-45	-6		-15	7	-40	-42	-35	-35	-67	-55	-47	-48	-72	-46	-42	-46	-50	-58	-51	-49	-59	-58	-64	-79	-65	-60	-66	-58	-63	-66		-69	-68	-78	-73	-69	-74	-79	-74	-78	-80	-89	-75	-71	-82	-81	-87	-83	-74
7	-47	-42	-50	-42	3	-15		-12	-27	-34	-25	-21	-56	-52	-50	-59	-77	-54	-44	-62	-50	-51	-56	-53	-55	-79	-57	-76	-57	-69	-62	-56	-70	-63	-86	-66	-80	-67	-80	-71	-72	-71	-66	-82	-75	-71	-75	-83	-80	-78	-80	-88	-60
8	-56	-53	-72	-38	-6	7	-13		-26	-39	-25	-44	-45	-55	-63	-64	-79	-43	-42	-55	-60	-48	-47	-51	-61	-62	-64		-63	-68	-74	-54	-69	-72	-83	-67	-69	-84	-76	-71	-78	-72	-83	-74	-87	-71	-73	-78	-87	-87	-81	-85	-73
9	-47	-43	-60	-54	-31	-40	-28	-25		-9	0	-5	-58	-56	-68	-59	-79	-46	-48	-53	-53	-57	-55	-51	-52	-54	-57	-81	-53	-59	-66	-74	-82	-63	-82	-72	-78	-68	-83	-71	-80	-73	-71	-82	-76	-79	-82	-72	-88		-84	-80	-74
10	-57	-50	-54	-56	-40	-45	-37	-41	-12		-12	3	-50	-69	-63	-66	-89	-60	-60	-53	-53	-57	-73	-66	-69	-62	-63	-85	-59	-83	-70	-55	-81	-75	-89	-69	-73	-70	-80	-81	-75	-78	-79	-84	-81	-75	-88	-82		-85	-89	-86	-79
11	-49	-36	-42	-40	-21	-35	-26	-25	0	-9		-24	-51	-49	-60	-55	-80	-49	-39	-45	-63	-57	-56	-55	-47	-47	-71	-81	-64	-78	-70	-52		-68	-82	-72	-87	-64	-69	-69	-76	-75	-71	-78	-74	-78	-70	-70	-84	-79	-85	-78	-67
12	-48	-42	-56	-41	-43	-35	-21	-43	-5	4	-25		-47	-54	-55	-57	-83	-53	-46	-52	-44	-50	-51	-47	-60	-54	-63	-76	-51	-62	-62	-48	-73	-55	-83	-64	-73	-80	-71	-71	-79	-74	-71	-79	-79	-74	-70	-82	-82	-80	-83	-87	-62
13	-27	-36	-32	-33	-65	-67	-57	-45	-59	-48	-52	-48		-13	-7	-16	-62	-49	-30	-44	-39	-40	-33	-28	-58	-45	-48	-68	-43	-45	-48	-36	-63	-53	-71	-59	-75	-70	-87	-70	-68	-72	-71	-75	-75	-80	-74	-68	-84	-83	-86	-81	-75
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Matrix obtained by setting a transmit power of 10 dBm

Node ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
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2	-25		-30	2	-58	-47	-49	-58	-49	-54	-43	-49	-41	-36	-37	-39	-77	-53	-39	-61	-49	-47	-46	-42	-74	-64	-51	-73	-59	-53	-58	-45	-64	-61		-79	-80	-75	-68	-78	-87	-76	-83	-89	-87	-81	-88	-81	-89		-84	-86	-69
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10	-62	-55	-59	-62	-45	-49	-42	-45	-17		-17	-2	-56	-74	-68	-71		-66	-66	-58	-59	-62	-78	-70	-74	-67	-68	-85	-64	-87	-75	-60	-86	-79		-74	-78	-75	-85	-85	-80	-82	-84	-87	-85	-80		-85		-89		-89	-84
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18	-43	-52	-51	-45	-53	-52	-62	-48	-52	-65	-56	-61	-56	-49	-48	-46	-58		-15	-3	-66	-48	-45	-42	-55	-54	-62	-80	-55	-51	-57	-45	-83	-48	-84	-51	-63	-53	-59	-62	-66	-77	-63	-67		-63	-63	-63	-76	-77	-71	-73	-67
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35																								-91	-84	-93	-83	-94	-91	-91	-89	-92	-67	-64		-72	-93		-91	-91	-94		-92										
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52	-82	-85	-90		-90	-87		-89	-84	-89	-83	-89	-85	-88		-87		-72	-85	-82	-77	-71	-80	-77	-85	-75	-80	-85	-65	-72	-66	-80	-71	-65		-76	-52	-69	-63	-73	-49	-45	-52	-42	-40	-55	-47	-57	-15	-3	-25		-39
53	-83	-68	-79	-71	-75	-80	-66	-78	-80	-82	-72	-68	-80	-78	-72	-72		-66	-70	-72	-67	-72	-60	-69	-68	-70	-71	-75	-66	-86	-64	-69	-59	-63	-81	-66	-58	-52	-47	-62	-50	-53	-43	-49	-42	-52	-63	-43	-44	-33	-42	-40	

Matrix obtained by setting a transmit power of 5 dBm

Node ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
1		-30	-16	-24	-55	-52	-61	-68	-61	-66	-63	-63	-37	-36	-46	-39	-76	-49	-40	-60	-64	-68	-61	-46	-68	-65	-67	-74	-59	-48	-67	-47	-75	-74		-75	-71	-86	-81	-79	-75	-87	-79	-86	-80	-80	-85	-81		-85		-87	-87
2	-30		-35	-3	-64	-52	-56	-65	-57	-61	-48	-56	-47	-41	-42	-45	-83	-59	-45	-67	-56	-52	-52	-48	-81	-70	-58	-73	-65	-60	-65	-51	-71	-67		-84	-85	-81	-74	-84		-82	-87			-86		-86			-88	-89	-75
3	-18	-36		-29	-66	-67	-66	-84	-74	-66	-57	-71	-43	-37	-50	-42	-75	-60	-45	-57	-64	-63	-59	-64	-66	-70	-81	-81	-66	-68	-67	-61	-81	-77		-81	-80	-78		-86	-86	-88	-89			-87	-86	-88					-86
4	-24	-3	-27		-76	-57	-55	-49	-68	-66	-52	-54	-43	-36	-41	-46	-78	-51	-56	-63	-59	-50	-45	-55	-71	-68	-58	-79	-62	-57	-61	-65	-74	-65		-85	-86		-78	-85	-86	-83	-87	-85	-88	-83	-83				-89		-78
5	-55	-65	-65	-77		-17	-8	-18	-43	-48	-33	-57	-77	-66	-66	-79	-86	-60	-59	-64	-64	-73	-65	-73	-75	-79	-86	-87	-84	-75	-73	-72	-84	-76		-88	-86	-87	-85		-86	-86				-87	-85						-83
6	-51	-51	-65	-57	-16		-25	-3	-51	-53	-45	-45	-78	-67	-59	-61	-83	-57	-54	-58	-63	-70	-63	-62	-70	-69	-76	-79	-73	-71	-77	-70	-74	-75		-81	-79	-87	-84	-80	-85	-88	-85	-87	-88		-86	-82		-89			-85
7	-59	-53	-63	-53	-5	-24		-23	-38	-45	-36	-30	-68	-66	-63	-71	-86	-66	-57	-73	-63	-64	-68	-66	-67	-87	-69	-76	-69	-78	-73	-69	-81	-74		-77	-88	-79	-88	-82	-83	-82	-77		-85	-83	-86		-88	-87	-88		-72
8	-67	-64	-83	-48	-17	-3	-24		-36	-49	-36	-56	-57	-67	-73	-75	-88	-54	-54	-68	-71	-61	-60	-64	-72	-73	-75		-73	-79	-84	-65	-80	-83		-78	-80		-86	-82	-87	-83		-84		-82	-84	-87					-84
9	-59	-54	-71	-66	-42	-51	-39	-36		-19	-10	-16	-70	-68	-79	-71	-88	-58	-60	-65	-65	-68	-68	-64	-64	-66	-69	-81	-65	-71	-78	-83		-74		-84	-87	-80		-83	-88	-84	-82		-86	-88		-83				-88	-85
10	-67	-62	-65	-67	-50	-56	-48	-51	-23		-23	-8	-62	-80	-73	-77		-71	-71	-64	-65	-68	-84	-76	-80	-72	-74	-85	-70	-89	-80	-66	-89	-85		-80	-84	-81	-88	-90	-85	-87	-88		-89	-86							-88
11	-63	-47	-53	-50	-32	-45	-36	-36	-10	-19		-36	-64	-63	-71	-67	-87	-62	-49	-58	-74	-69	-69	-68	-60	-59	-83	-81	-75	-87	-80	-64		-79		-83		-75	-79	-80	-86	-85	-83	-87	-85	-87	-81	-81		-88		-87	-79
12	-60	-53	-68	-52	-54	-45	-30	-54	-16	-4	-36		-59	-67	-67	-69		-65	-58	-65	-56	-63	-64	-59	-72	-66	-75	-76	-64	-75	-74	-61	-84	-67		-77	-85	-88	-82	-83	-87	-85	-83	-88	-87	-85	-82			-88			-74
13	-37	-46	-42	-43	-76	-78	-69	-57	-71	-60	-64	-60		-24	-17	-27	-73	-62	-40	-56	-49	-50	-43	-39	-70	-57	-61	-68	-54	-57	-60	-47	-74	-65		-71	-85	-82		-82	-80	-84	-82	-85	-85	-88	-84	-81				-89	-85
14	-33	-39	-34	-35	-63	-66	-64	-65	-67	-77	-61	-66	-22		-19	-8	-70	-53	-41	-46	-66	-44	-46	-42	-77	-68	-63	-74	-53	-63	-52	-51	-74	-65		-85	-85	-83	-80	-77	-84	-86	-75	-85	-88	-88	-84				-87		-82
15	-46	-42	-49	-41	-66	-61	-65	-74	-81	-73	-72	-69	-18	-21		-32	-78	-54	-50	-57	-68	-48	-51	-42	-71	-60	-80	-66	-62	-59	-55	-66	-69	-76		-70	-87	-82	-84	-85	-86	-85	-80	-89		-90		-83					-79
16	-39	-44	-40	-46	-78	-63	-72	-76	-72	-76	-68	-71	-27	-10	-32		-74	-52	-45	-61	-63	-55	-53	-53	-83	-69	-65	-81	-64	-54	-62	-56	-79	-66		-76	-81	-85	-78	-83	-80	-88	-84	-88		-89		-87					-80
17	-77	-82	-74	-78	-86	-85	-87	-88	-88		-89		-73	-72	-78	-74		-65	-36	-60	-79	-75	-78	-87	-88	-90	-79		-86	-84		-85															-80	-78					
18	-48	-59	-59	-51	-60	-59	-68	-55	-60	-70	-63	-68	-63	-57	-54	-53	-65		-21	-8	-72	-55	-51	-48	-62	-61	-68	-80	-63	-58	-64	-51	-88	-55		-58	-69	-61	-65	-68	-72	-83	-69	-73		-69	-69	-69	-82	-83	-77	-79	-72
19	-39	-43	-42	-55	-58	-55	-57	-53	-61	-70	-49	-59	-39	-42	-49	-44	-35	-21		-27	-46	-41	-48	-35	-62	-65	-51	-68	-42	-47	-48	-39	-72	-67		-61	-71	-74	-76	-75	-76	-78	-72	-85	-72	-82	-85	-79	-87	-85		-89	-76
20	-59	-65	-54	-63	-62	-58	-73	-68	-66	-62	-58	-66	-55	-48	-55	-60	-59	-6	-27		-65	-44	-48	-40	-58	-55	-73	-74	-54	-60	-52	-48	-64	-56		-68	-61	-60	-61	-68	-68	-71	-79	-76	-71	-70	-65	-58	-79	-70	-81	-86	-79
21	-63	-54	-61	-57	-62	-62	-63	-70	-65	-62	-74	-56	-48	-67	-66	-61	-78	-71	-45	-65		-24	-4	-32	-54	-60	-49	-51	-49	-55	-47	-61	-68	-70		-66	-63	-60	-67	-73	-61	-65	-66	-82	-69		-81	-74	-80		-85	-82	-72
22	-69	-53	-63	-52	-74	-72	-67	-63	-71	-68	-71	-66	-52	-48	-49	-56	-77	-57	-44	-47	-27		-24	-9	-60	-50	-61	-55	-36	-46	-39	-42	-69	-52		-61	-68	-71	-74	-76	-70	-78	-79	-71	-74	-75	-78	-80	-80	-84	-80	-79	-80
23	-61	-53	-57	-45	-64	-65	-69	-61	-69	-83	-70	-66	-44	-49	-52	-54	-79	-52	-49	-49	-7	-23		-31	-66	-53	-52	-59	-45	-53	-48	-51	-76	-61		-86	-66	-63	-74	-87	-70	-74	-67	-84	-74	-71	-72	-88	-88	-82	-82	-86	-68
24	-47	-48	-63	-55	-73	-63	-68	-65	-66	-76	-69	-62	-39	-45	-42	-54	-86	-48	-36	-42	-33	-8	-30		-48	-54	-50	-55	-35	-46	-36	-42	-59	-56	-89	-61	-65	-59	-69		-85	-66	-70	-69	-72	-69	-69	-75		-78		-84	-76
25	-67	-79	-63	-71	-73	-71	-67	-71	-65	-79	-60	-72	-69	-78	-69	-82	-87	-60	-62	-58	-55	-57	-64	-47		-29	-11	-40	-46	-60	-52	-49	-52	-45	-83	-48	-81	-63	-58	-63	-66	-69	-74	-74	-72	-71	-56	-61	-81	-75	-76		-74
26	-63	-68	-67	-67	-77	-68	-87	-72	-65	-70	-58	-66	-55	-68	-58	-67		-58	-63	-53	-59	-47	-49	-51	-27		-22	-11	-53	-48	-41	-38	-51	-47		-60	-57	-59	-66	-62	-62	-71	-62	-72	-70	-64	-65	-65	-75	-79	-71	-80	-75
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28	-69	-67	-75	-73	-84	-75	-72		-76	-79	-76	-72	-63	-71	-60	-75		-74	-63	-69	-47	-47	-52	-49	-36	-9	-31		-48	-56	-50	-48	-43	-43	-85	-51	-59	-54	-65	-61	-63	-77	-63	-68	-65	-74	-67	-63	-74	-74	-78	-81	-70
29	-58	-64	-64	-62	-85	-77	-69	-73	-66	-69	-75	-65	-54	-55	-62	-63	-86	-61	-43	-55	-51	-35	-44	-35	-46	-55	-43	-54		-19	-11	-27	-63	-53	-89	-61	-62	-60	-73	-68	-59	-69	-62	-60	-69	-77	-71	-66	-71	-72	-81	-72	-73
30	-49	-60	-68	-59	-75	-74	-82	-81	-72	-90	-89	-77	-58	-66	-60	-55	-85	-59	-49	-62	-58	-46	-54	-47	-62	-51	-48	-63	-21		-29	-4	-86	-64	-90	-61	-78	-81	-73	-76	-75	-69	-62	-76	-79	-77	-83	-79	-90	-81	-84	-80	
31	-64	-62	-63	-59	-70	-76	-72	-83	-77	-79	-80	-73	-57	-51	-52	-59		-61	-46	-50	-46	-34	-44	-33	-49	-40	-36	-53	-10	-25		-29	-50	-47	-86	-53	-73	-64	-71	-63	-63	-62	-58	-79	-73	-66	-71	-86	-87	-77	-78	-71	-68
32	-46	-51	-60	-65	-71	-72	-69	-65	-85	-66	-65	-62	-47	-54	-65	-56	-86	-51	-39	-49	-64	-41	-50	-42	-50	-40	-43	-54	-27	-3	-31		-62	-66		-68	-69	-73	-69	-69	-63	-62	-64	-76	-82	-69	-74	-78	-81		-83		-79
33	-75	-69	-79	-74	-83	-75	-82	-80		-88		-84	-74	-76	-69	-79		-87	-72	-65	-69	-67	-75	-58	-52	-53	-47	-48	-63	-85	-53	-61		-24	-65	-29	-69	-58	-62	-64	-70	-69	-59	-65	-66	-69	-67	-73	-76	-72	-79	-78	-66
34	-74	-67	-76	-66	-76	-78	-75	-84	-76	-84	-80	-69	-65	-68	-76	-66		-54	-68	-57	-72	-50	-60	-56	-45	-49	-48	-48	-54	-63	-49	-65	-24		-64	-13	-61	-52	-56	-69	-52	-60	-51	-55	-60	-70	-61	-69	-62	-73	-74	-72	-70
35																									-89		-88		-94	-94	-93		-73	-70		-79				-94													
36	-73	-83	-79	-84	-86	-80	-77	-77	-83	-78	-82	-75	-69	-85	-68	-75		-56	-60	-67	-66	-58	-84	-59	-46	-60	-52	-55	-60	-58	-54	-66	-27	-11	-69		-64	-67	-59	-63	-62	-72	-62	-75	-66	-85	-79	-79	-69	-79	-79	-81	-71
37	-71	-85	-79	-86	-85	-81	-89	-81	-88	-84		-85	-86	-87	-86	-81		-68	-72	-62	-64	-66	-65	-64	-82	-59	-74	-65	-63	-76	-75	-68	-69	-60		-65		-29	-10	-39	-62	-49	-43	-48	-63	-78	-74	-57	-63	-67	-63	-59	-65
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39	-82	-74		-78	-84	-85	-88	-86		-88	-80	-83		-82	-84	-78		-65	-77	-63	-69	-73	-74	-69	-60	-69	-78	-71	-74	-73	-74	-69	-63	-57	-89	-62	-11	-23		-35	-45	-47	-39	-48	-53	-73	-64	-54	-59	-69	-63	-70	-54
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41	-75		-85	-86	-85	-85	-84	-87	-88	-85	-86	-88	-80	-85	-85	-80		-72	-77	-69	-63	-69	-69	-84	-67	-63	-71	-69	-60	-74	-66	-63	-70	-53		-64	-63	-57	-45	-61		-16	-8	-26	-42	-41	-40	-48	-56	-62	-57	-58	-58
42	-87	-81	-87	-83	-85	-88	-83	-83	-84	-86	-85	-85	-83	-87	-84	-87		-82	-78	-71	-65	-75	-72	-64	-68	-71	-74	-81	-68	-67	-63	-60	-68	-58		-72	-48	-58	-44	-59	-13		-19	-8	-50	-46	-43	-43	-52	-50	-51	-49	-60
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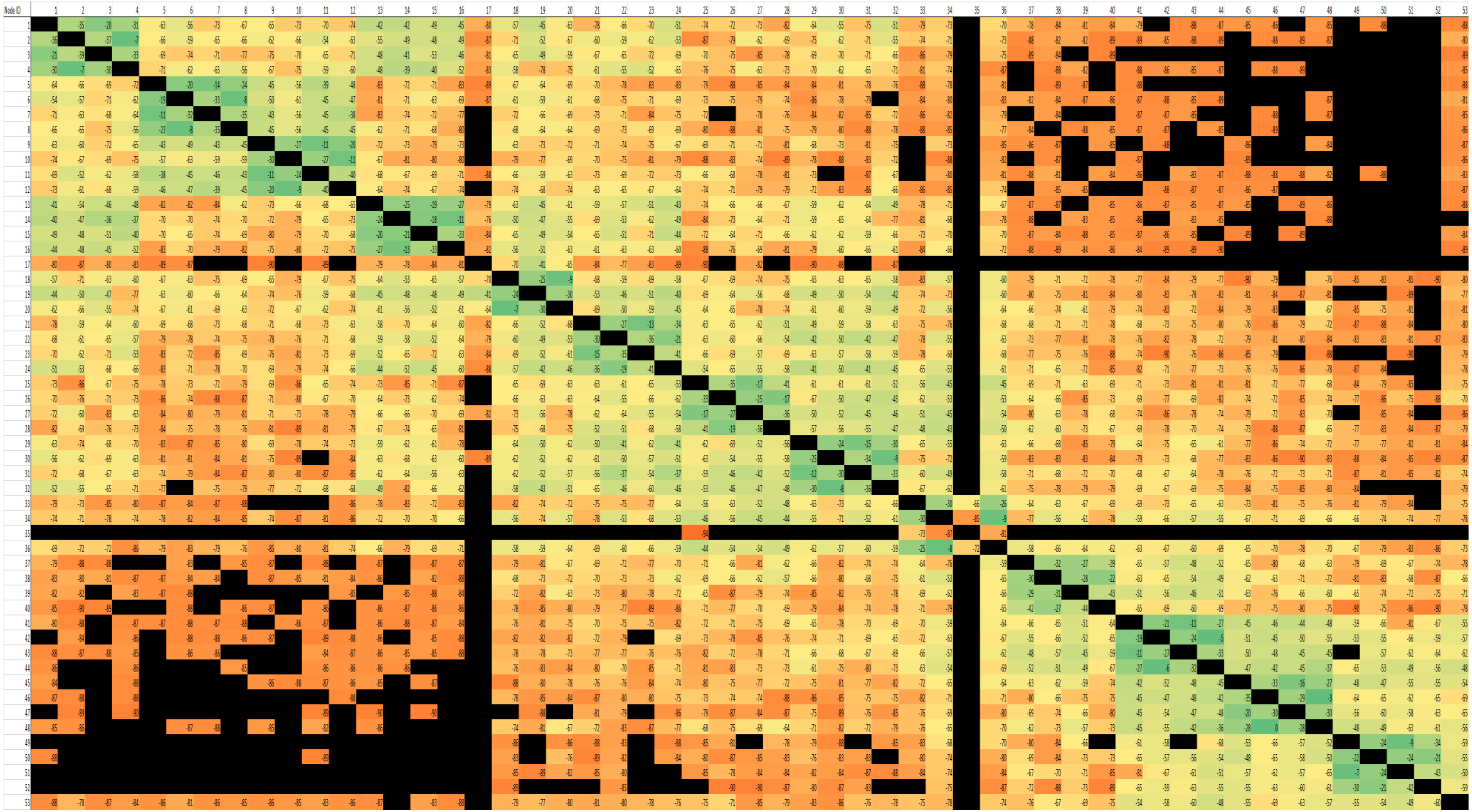
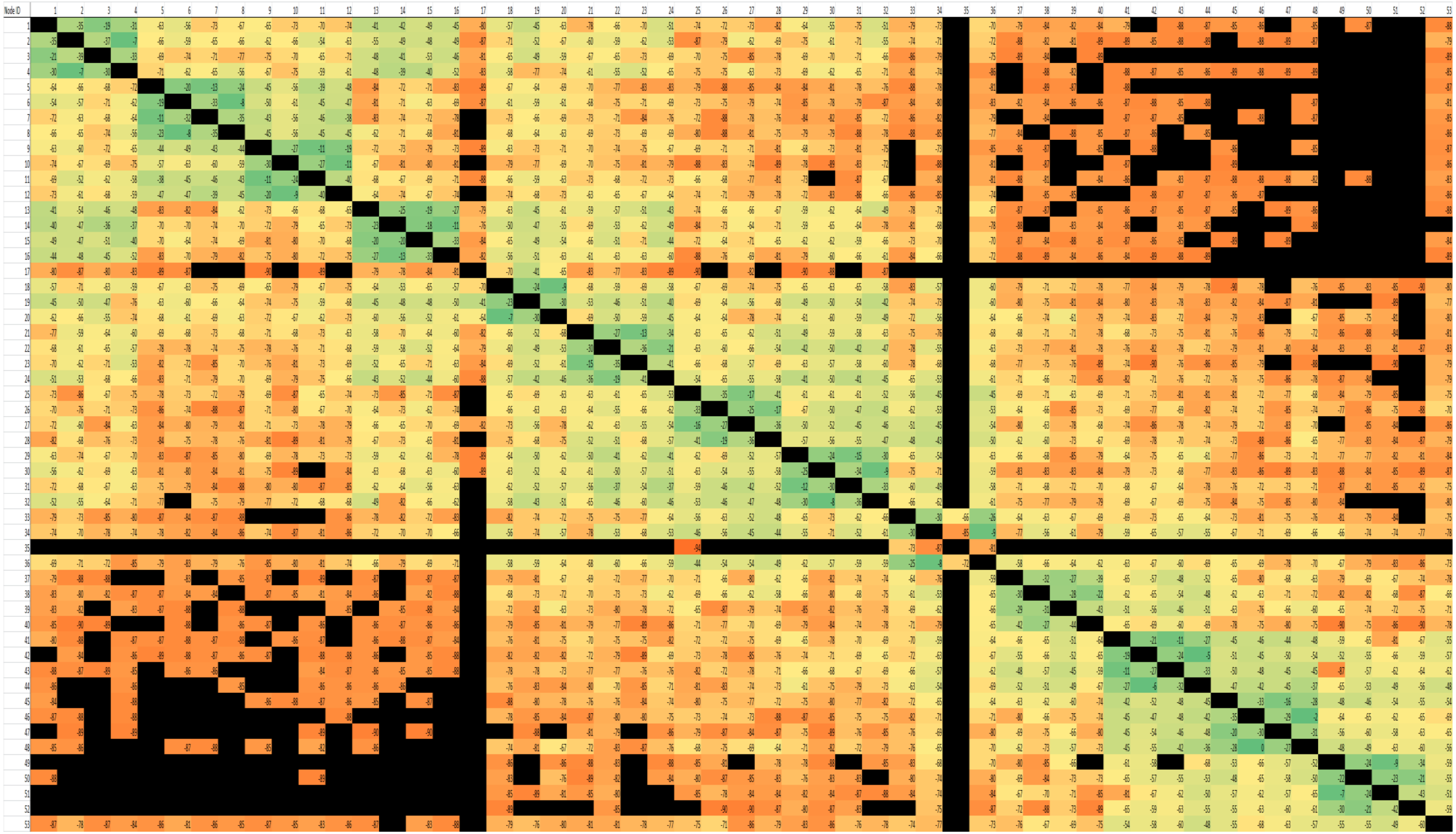
44	-85			-84		-86		-84			-86	-87	-84	-86	-87	-87		-71	-84	-75	-81	-68	-82	-67	-74	-73	-73	-73	-60	-74	-80	-74	-65	-54		-75	-48	-47	-47	-66	-24	-9	-29		-42	-42	-63	-33	-65	-52	-49	-49	-56
45	-79			-87		-88	-85		-86	-88	-84	-87	-84			-88			-70	-69	-68	-71	-72	-69	-72	-70	-74	-69	-68	-76	-73	-80	-64	-58		-65	-61	-56	-50	-72	-39	-50	-47	-41		-24	-23	-25	-49	-43	-52	-44	-46
46	-81	-86	-87	-84	-87		-84	-84	-88	-86	-88	-86	-88			-89		-69	-82	-71		-74	-70	-69	-73	-66	-70	-80	-78	-76	-69	-69	-70	-70		-87	-78	-60	-73	-68	-40	-48	-40	-43	-27		-25	-27	-51	-53	-49	-64	-60
47	-86	-86	-85	-84	-85	-88	-87	-84			-81	-84	-86	-87			-81	-68	-85	-66	-83	-76	-71	-69	-56	-67	-56	-67	-71	-83	-73	-71	-68	-61		-83	-66	-62	-62	-78	-39	-44	-38	-51	-25	-22		-6	-61	-64	-52	-53	-71
48	-81	-85				-80		-87	-84		-81	-88	-79		-83	-86	-76	-67	-78	-57	-74	-80	-87	-71	-59	-66	-67	-60	-65	-77	-87	-78	-73	-68		-80	-55	-57	-50	-67	-45	-43	-38	-33	-24	-24	-4		-44	-43	-42	-65	-46
49																		-83	-88	-81	-82	-80	-88		-83	-78	-86	-81	-72	-89	-89	-81	-78	-64		-71	-66	-74	-60	-77	-57	-57	-65	-68	-54	-54	-65	-48		-23	-12	-23	-53
50	-85						-88				-88	-89						-83	-85	-70		-82	-81	-77	-75	-81	-81	-79	-72	-80	-79		-71	-72		-80	-67	-71	-68	-71	-61	-52	-52	-52	-45	-52	-65	-44	-21		-18	-9	-39
51	-89	-88					-89							-88				-77		-81	-86	-78	-81		-77	-72	-74	-83	-81	-83	-80	-82	-79	-73		-81	-63	-62	-63	-78	-57	-54	-61	-51	-55	-50	-52	-43	-11	-19		-32	-48
52	-87	-89							-89		-87		-90			-90		-78	-90	-87	-83	-78	-86	-83	-89	-81	-85	-85	-71	-79	-72	-85	-77	-71		-82	-59	-76	-69	-80	-57	-51	-59	-48	-45	-63	-53	-65	-21	-9	-30		-45
53	-87	-74	-85	-78	-81	-85	-72	-84	-85	-87	-79	-74	-85	-84	-78	-79		-72	-76	-78	-72	-78	-66	-75	-74	-76	-78	-74	-72		-70	-76	-66	-69		-72	-65	-59	-52	-69	-58	-61	-48	-56	-48	-59	-74	-48	-50	-38	-47	-45	

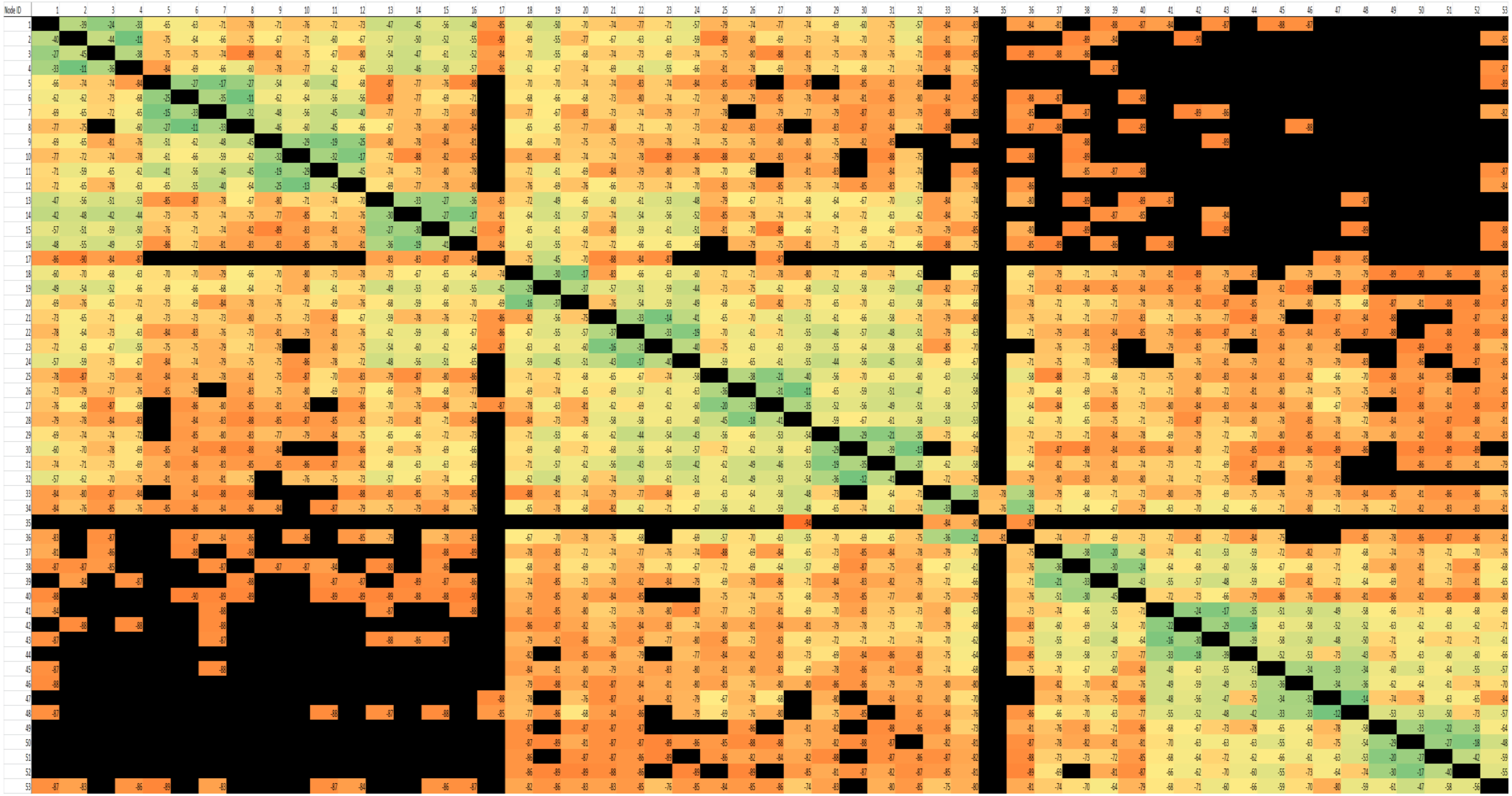
First matrix obtained by setting a transmit power of 0 dBm



Second matrix obtained by setting a transmit power of 0 dBm



Matrix obtained by setting a transmit power of -5 dBm



Finally, with reference to point number 3, that is the OTA programming, we demonstarted its validity and functionality during the third Newcom# Training School, held in Barcelona at CTTC. During the school students had the opportunity to remotely have access to the EuWIn website and through the graphical user interface i) uploading their own software (implementing specific a routing protocol on top of the IEEE 802.15.4); ii) select the devices to be used for the experiment (see the Figure 5-10: T). Through over-the-air programming the software was downloaded on the devices and the experiment started running.

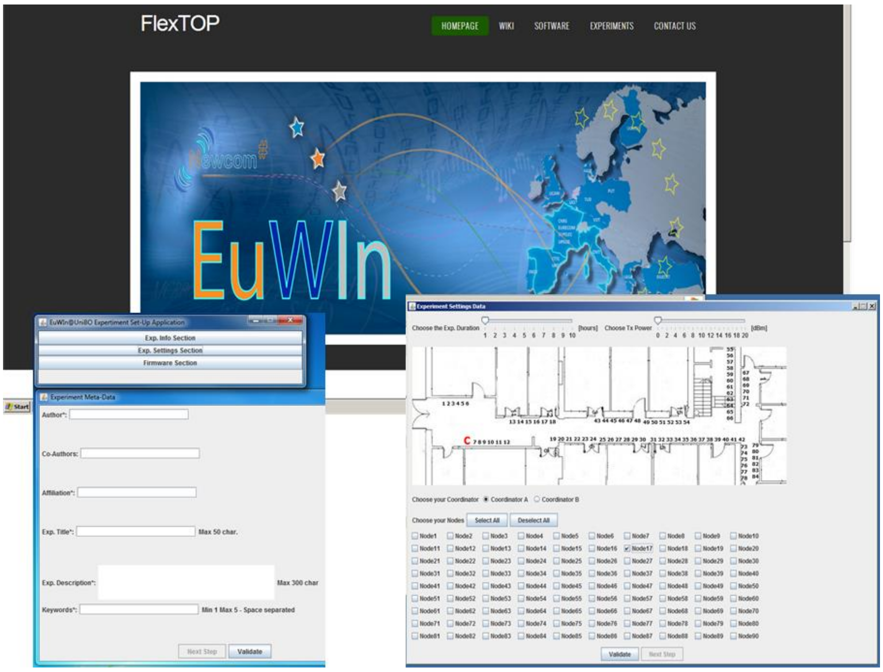


Figure 5-10: The FLEXTOP website and GUI

During the experiment it was possible to visualise, thanks to another GUI (see the figure below), the following: i) the packets received by the Coordinator in the network (the sink in the figure), see Figure 5-11; ii) for each packet the path the packet passed through to reach the coordinator (see Figure 5-12); iii) the level of usage of each node as router (red nodes are those mopre used, green nodes are not used).

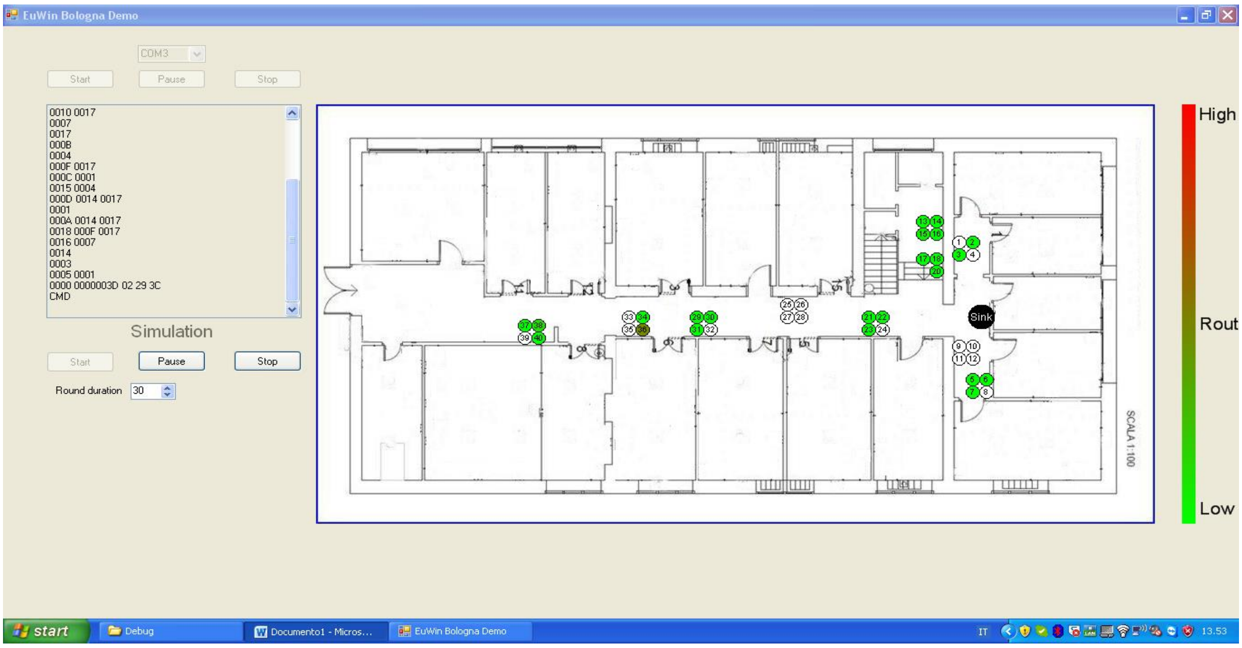


**Figure 5-11:The FLEXTOP GUI: Experiment snapshot.
The black device is the sink and green devices are the selected active node running the application.**

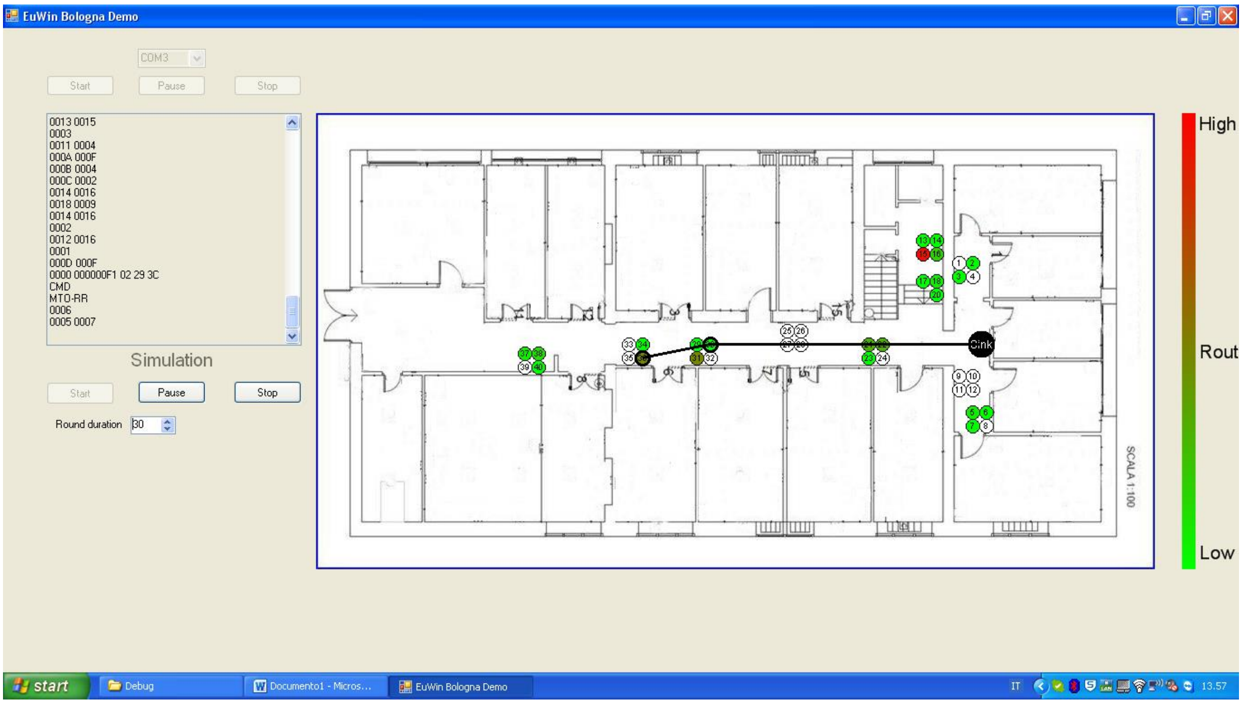


Figure 5-12: The FLEXTOP GUI: Experiment snapshot. On the left it is represented list of packets received by the sink, with the corresponding IDs of the devices the packets passed through before reaching the sink. The path is also shown on the map.

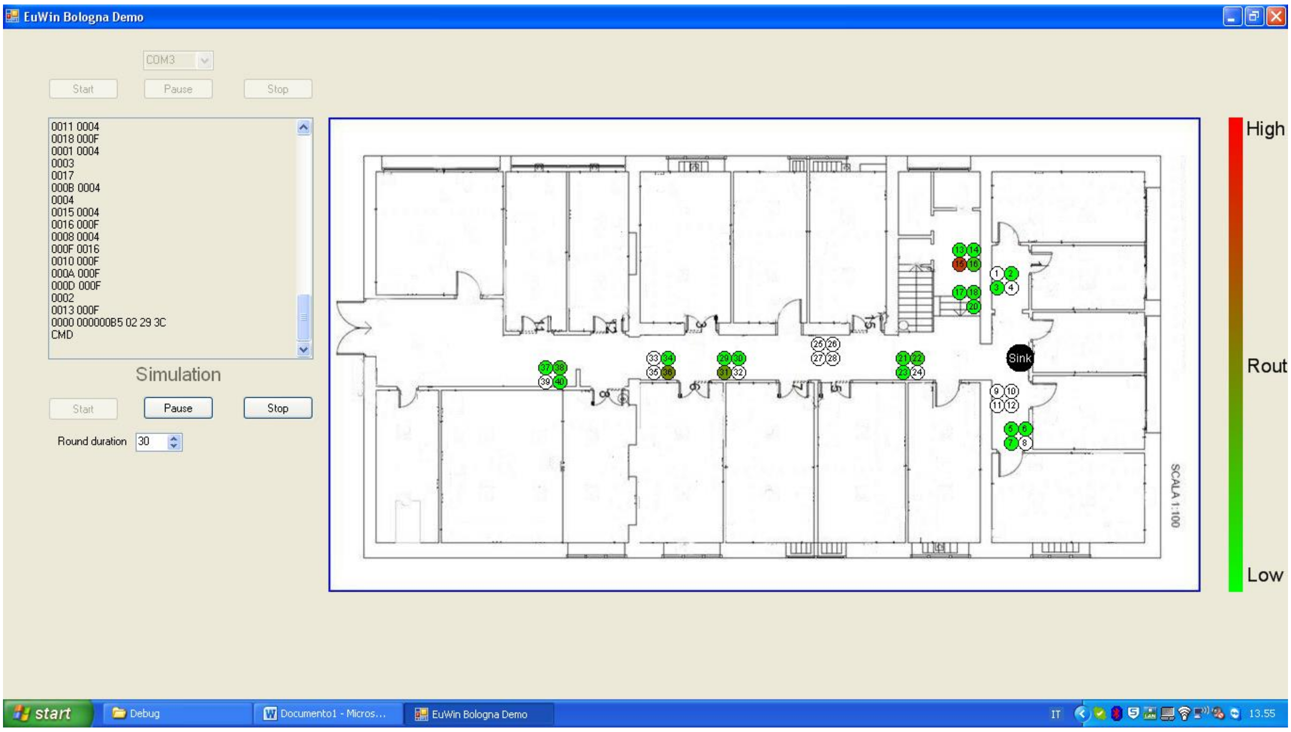


Figure 5-13: The FLEXTOP GUI: Experiment snapshot. Devices became red by passing time, when they are frequently used as routers by the other nodes in the network.

EuWIn@UniBO (DATASENS)

In Figure 5-15: T we show an example of debugging of a device measuring a temperature of 30 degrees (see the blue circle in the figure). A data, containing the measured temperature, is then sent over the air from node with address aabb (the node doing the measurement) to node 0001 (the receiver). A screenshot of the data gathered by the sniffer, sniffing the channel used by the IEEE 802.15.4 devices, is shown in Figure 5-16: . As can be seen, the payload includes the temperature data (1e which corresponds to 30).

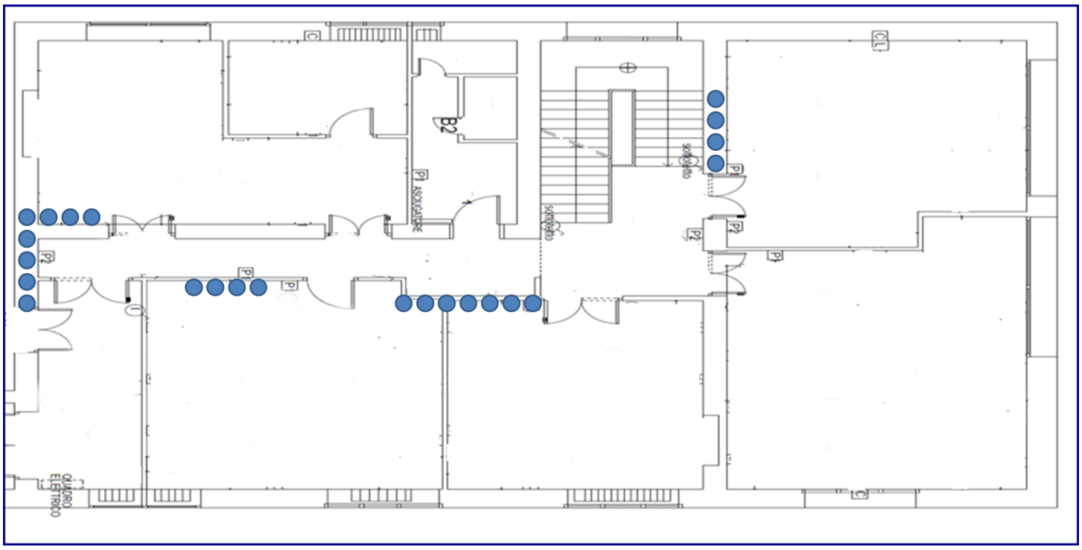
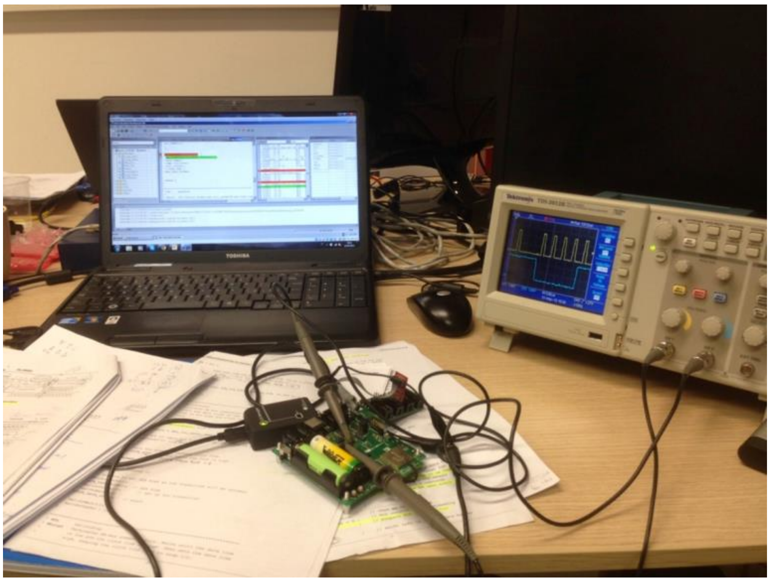


Figure 5-14: The DataSens map



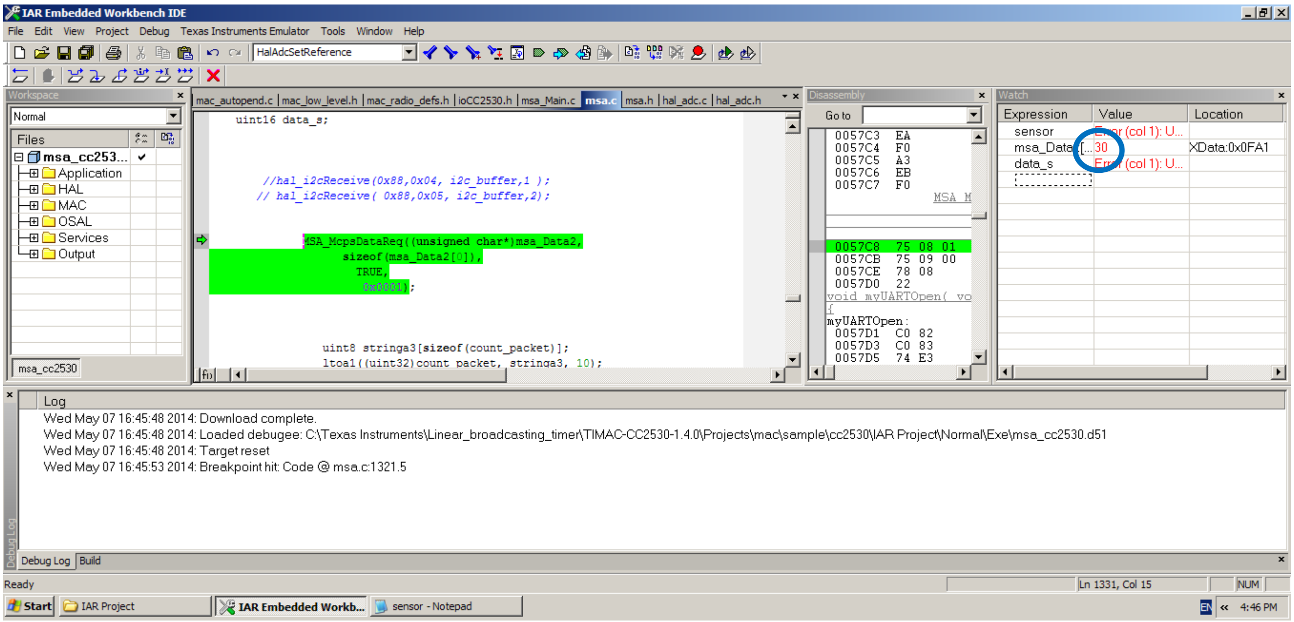


Figure 5-15: The measure of the temperature by the device during debugging

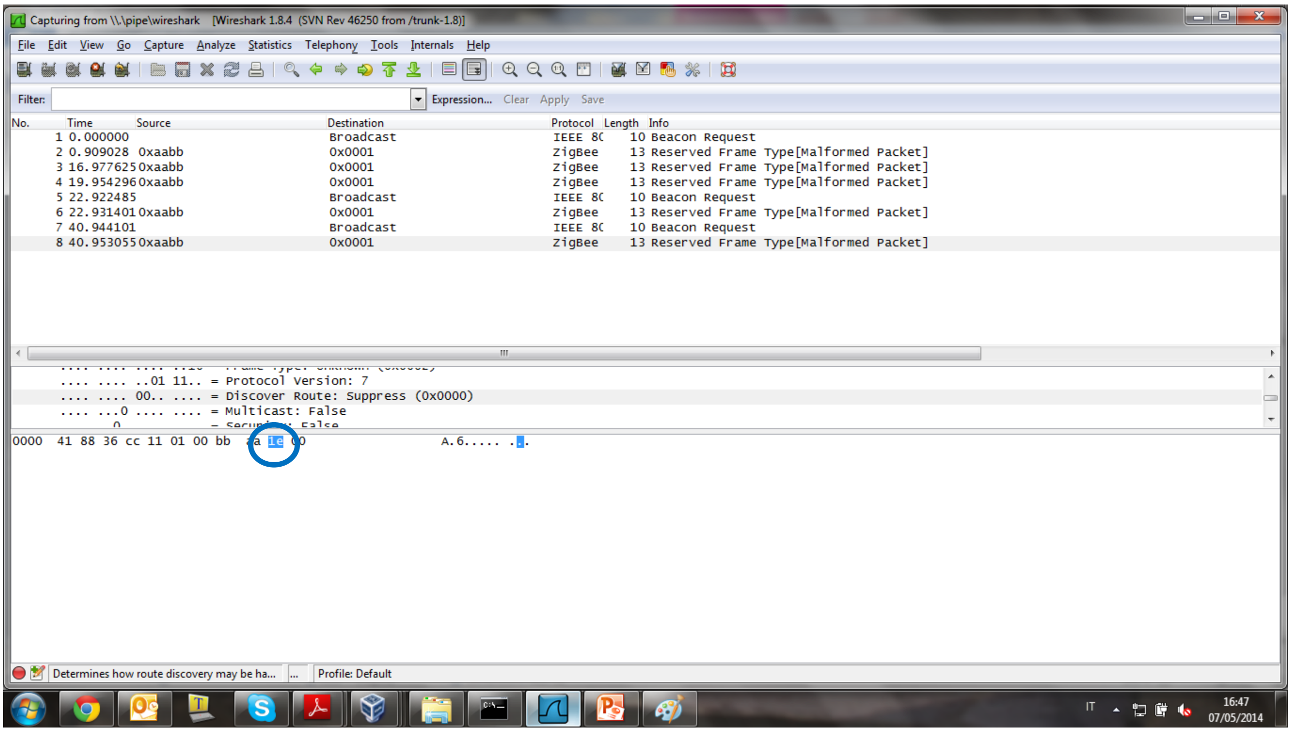


Figure 5-16: A data packet including the measured temperature in the payload is sent over the air by node aabb to node 0001

EuWIn@Eurecom (OPENAIRINTERFACE)

PHY compliance of the UE and eNB transmitter is measured with an Rhode&Schwarz FSQ spectrum analyzer using the LTE option to decode the signals and measure the EVM. Figure 5-17: shows an example measurement for the eNB transmitter.

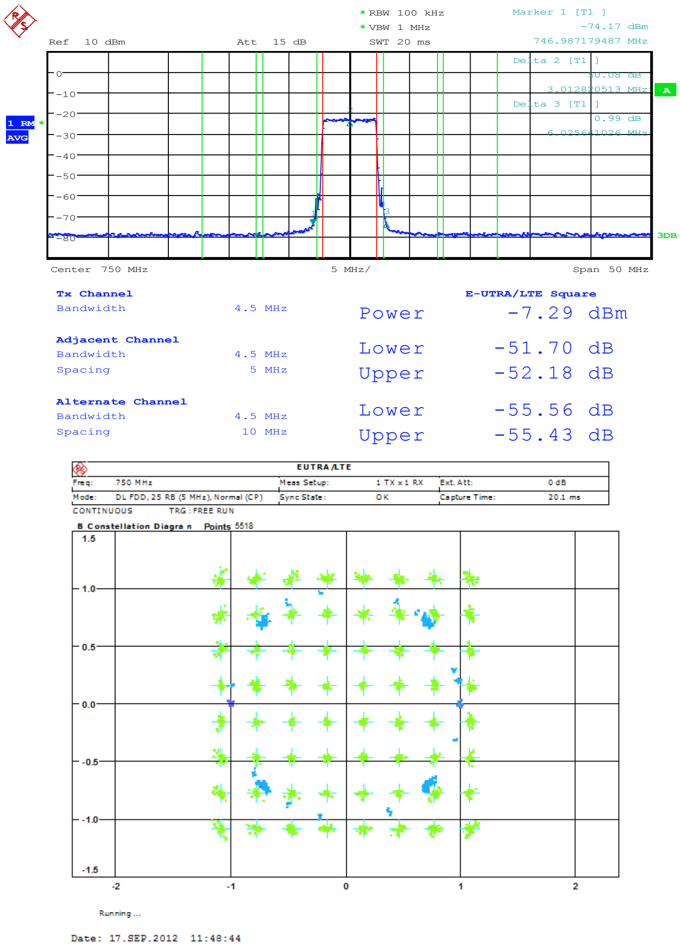


Figure 5-17: eNB TX spectrum and constellation for the PDSCH

Similarly, the PHY compliance of the UE and eNB receiver is measured with a R&S SMBV100 vector signal generator, generating a LTE compliant waveform as a transmitter. This waveform is then received and decoded by OpenAirInterface and the EVM as well as the error performance is measured. As an example we show in
Figure 5-18: the received constellation of a 5MHz PDSCH channel with 64 QAM modulation at a received power level of -70dBm (~35dB SNR).

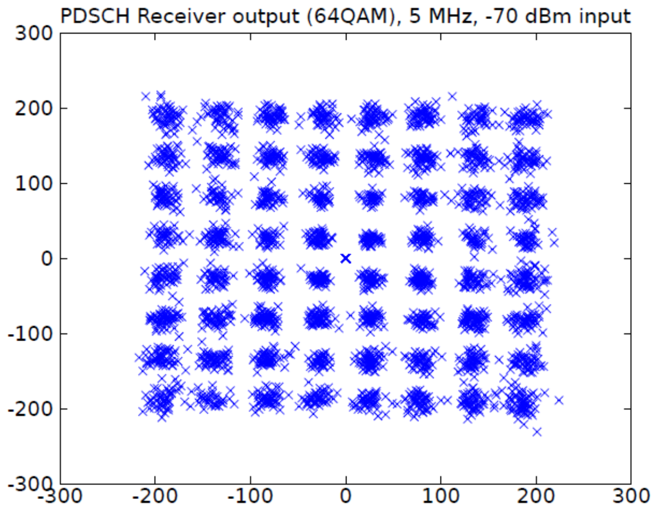


Figure 5-18: UE RX constellation of a PDSCH channel

For more details about the PHY compliance please refer to D2.3.1.

To test the compliance of layer 2 of the LTE protocol stack, tests with the mobipass eNB tester from Ercom[1] have been carried out. In these tests, only the OpenAirInterface eNB was tested, but in a real-time, bidirectional communication. The higher layer configuration (RRC, etc.) was preconfigured and the UE attachment procedure was skipped. The tests showed a successful communication between the OpenAirInterface eNB and one UE configured at the Ercom mobipass (see Figure 5-19).

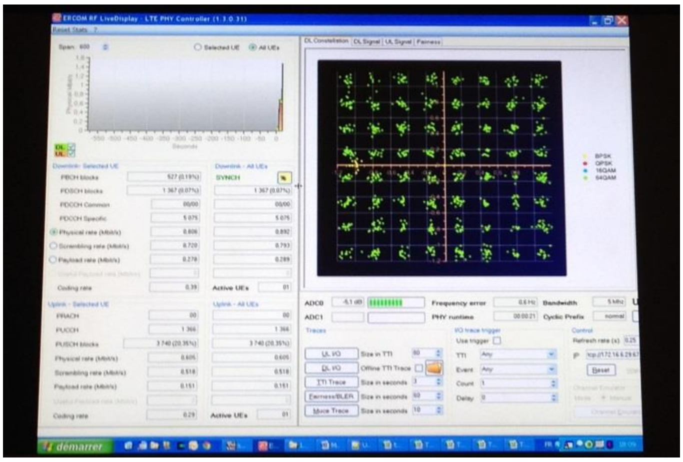


Figure 5-19: Ercom Mobipass UE tester connected with OpenAirInterface eNB

EURECOM has recently collaborated with Agilent China who uses the OAI ExpressMIMO2 platform as an LTE-eNB to perform interoperability tests with a commercial UE (Huawei E392U-12). Both FDD transmission and TDD Configuration 3 transmission have been tested successfully with a 5MHz channel. The attachment process is completed successfully and the UE can get IP address from the eNB and a high-throughput video service was validated. Agilent currently makes use of a commercial LTE-EPC (evolved packet core) interconnected

[1] http://www.ercom.com/products/4-27

with the OAI eNB in order to provide full layer 3 control services for the commercial UE. The work performed shows that the OAI platform is mature enough for industrial applications/deployment.

The equivalent setup at EURECOM is shown in Figure 13, where the eNB is a standard mini-ITX PC equipped with the ExpressMIMO2 board. The rest of the testbench comprises a 2.6GHz FDD UE (Huawei E392 dongle) interconnected with ExpressMIMO2 via a cabled variable attenuator and duplexing filters. A snapshot of the receive uplink signal (here QPSK) is also shown in the following figure. EURECOM currently does not have an equivalent LTE-EPC and can therefore only test L1 and L2 functionality. The OAI development team is in the process of releasing an open-source EPC in order to allow for full EUTRAN functionality with commercial UEs.

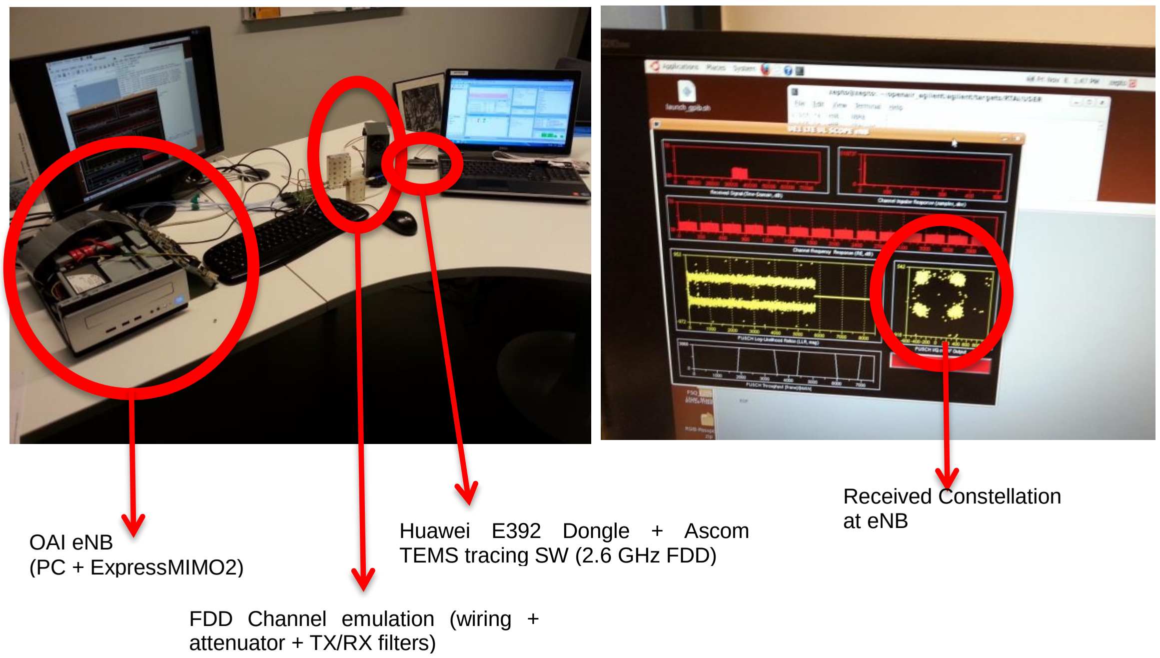


Figure 5-20: OAI IOT Testing Setup

5.4 Conclusions

The complexity of the platforms under use within EuWIn make the discussion of their validation a complex issue. However, this document discussed the peculiar aspects of each of them, and the approach used to validate the key features. The main conclusion that can be drawn is that the platforms work properly and are proven to be a valuable tool for testing algorithms and protocols for the next generation of wireless communication systems and networks.

6.Annex III: Integration Document

6.1 Introduction

NEWCOM# is fostering through EuWIn the development of a new generation of researchers aiming at both fundamental and experimental research activities. The two mottos of EuWIn summarise the main scopes of EuWIn activities; “Fundamental Research Through Experimentation” and (more oriented to innovation and as such to the industry) “An Open Platform for Innovation”.

To achieve this general goal, a number of activities have been performed, which have involved all three components of EuWIn: the sites in Bologna, in Barcelona and at Sophia-Antipolis. Since these activities have been conducted jointly, they are reported through this Annex that is common to the three Deliverables D21.3, D22.3 and D23.3.

6.2 Integration among the sites

The three sites perform activities that are, on purpose, related to separate fields of wireless communications. Nevertheless, some point of contacts have been sought, and some activities have been performed jointly, in order to achieve a higher degree of integration.

It is worth noting that there is no reason to seek for an integration among the three sites, besides the implementation of joint experimental works. In fact, the exchange of data among the sites does not require the use of specific networking tools (like e.g. GEANT) or other infrastructural means to integrate the separate laboratories.

The rest of this subsection summarises the activities that were performed under this integrated approach among the three sites.

1) Both EuWIn@UniBo and EuWIn@CTTC provide experimental platforms for indoor localisation. For this reason, JRA#1 has been set up, to integrate software tools, and to achieve a common open source platform for indoor localisation. Details are given in the body of D22.3.
2) The possible set up of a JRA (dealing with scheduling in 4G uplinks) between EuWIn@UniBo and EuWIn@EURECOM is currently under discussion.
3) The three sites of EuWIn have been presented jointly by the EuWIn Director in a number of meetings organised by EC during 2014 (in the context of the Expert Group of the Networld2020 platform and at concertation events). This has led to the joint participation to a consortium that is currently preparing a project proposal for Call1 of the ICT challenge on 5G (to be submitted on November 25, 2014).
4) All dissemination events during the first two years of Newcom# have been participated by several EuWIn researchers, in all cases through a presentation given by the EuWIn Director (or a delegate) followed by three presentations, one per site. The ability to provide a synergic and diversified environment was always properly emphasised.In the next subsection, these events are recorded.
5) In November 2013 a training school was organised in Barcelona, specifically dedicated to the interplay between experimentation and fundamental research; the school was very successful and permitted the development of a consolidated and shared approach to experimental research through the three sites of EuWIn. This training activity is described in subsection 6.4.

6) EuWIn participated to EuCNC 2014 through a number of actions that were all organised jointly by the three sites: a workshop, a demo stand and a special session. This activity is summarised in subsection 6.5.
7) The plans for the third year have been jointly devised by the three sites. They are reported in subsection 6.7.

6.3 Dissemination

NEWCOM# Researchers participated to the following Dissemination events in order to disseminate EuWIn results and aims.

Dissemination event at Orange Labs, June 17, 2013.

The following presentations related to Track 2 have been given:

The European Laboratory of Wireless Communications for the Future Internet
Roberto Verdone, CNIT/Bologna, Italy
EuWIn@CTTC: Radio Interfaces
Miquel Payaro, CTTC, Spain
EuWIn@UniBO: IoT and Smart City Applications
Davide Dardari, CNIT/Bologna, Italy
EuWIn@Eurecom: Flexible Radio Technologies
Raymond Knopp, EURECOM, France

The following posters have been also presented:

Poster – Radio Interfaces for Next-Generation Wireless Systems
Miquel Payaro, CTTC, Spain
Demo/Poster – Networking Technologies for the IoT with Mobile Clouds
Andrea Stajkic, CNIT/Bologna, Italy
Demo – Flexible Communication Terminals and Networks
Raymond Knopp, EURECOM, France

Dissemination event at NEC Europe Labs, February 19, 2014.

The following presentations related to Track 2 have been given:

The European Laboratory of Wireless Communications for the Future Internet
Roberto Verdone, CNIT/University of Bologna, Italy
EuWIn@CTTC: Radio Interfaces
Roberto Verdone, CNIT/University of Bologna, Italy
EuWIn@UniBO: IoT and Smart City Applications The Internet of Humans and 5G
Roberto Verdone, CNIT/University of Bologna, Italy
Testing IP-based Wireless Sensor Networks for the Internet of Things
Chiara Buratti, CNIT/University of Bologna, Italy

Dissemination event at AVEA Labs, April 4, 2014.

The following presentations related to Track 2 have been given:

The European Laboratory of Wireless Communications for the Future Internet
Roberto Verdone, CNIT/University of Bologna, Italy
EuWIn@CTTC: Radio Interfaces,
Roberto Verdone, CNIT/University of Bologna, Italy
EuWIn@UniBO: IoT and Smart City Applications The Internet of Humans and 5G
Roberto Verdone, CNIT/University of Bologna, Italy
Testing IP-based Wireless Sensor Networks for the Internet of Things
Chiara Buratti, CNIT/University of Bologna, Italy
EuWIn@Eurecom: Flexible Radio Technologies Cloud RAN Architecture and Platform
Raymond Knopp, EURECOM, France

The Workshop closed with a demo on “Testing IP-based Wireless Sensor Networks for the Internet of Things through the FLEXTOP Facility”, given by CNIT-BO.

Dissemination event at Nokia Networks, October 29 2014.

The following presentations related to Track 2 have been given:

The European Laboratory of Wireless Communications for the Future Internet
Roberto Verdone, CNIT/University of Bologna, Italy
IoH: the Internet of Humans
Roberto Verdone, CNIT/University of Bologna, Italy
Testing Protocols for the IoT on the EuWIn Platform
Andrea Stajkic, CNIT/University of Bologna, Italy
Towards Truly Open-Source 5G Networking
Raymond Knopp, EURECOM, France
Testbed for Experimentation on Positioning Systems
Pau Closas, CTTC, Spain

6.4 Training

In November 2013 a IC1004 and Newcom# Winter School on “Beyond 4G Networks in Cities: from Theory to Experimentation and Back” took place at CTTC, Barcelona.

The focus of the school was on interactions between fundamental research (theory) and experimentation (practice) in the fields of channel modeling, localization, and mesh networks; have a hands-on approach in experimental methods supervised by the scientists that lead European practical research. In particular the emphasis was on: i) the role of experimentation as means to characterize the radio environment and test system performance in real contexts; ii) the interplay between theory and experimentation, fundamental to an accurate and efficient system design; iii) the relevance of a multi--disciplinary approach to research, requiring knowledge of channel, link and network aspects.

The school program will evolve around four Tracks:

T1) B4G networks and the 2020 City: technology bricks, requirements, applications, network scenarios, research challenges;

T2) Hybrid Localization: from satellite to heterogeneous localization techniques for B4G networks;

T3) Multi-Hop Networks: MAC and routing aspects for the IoT component of B4G networks in the 2020 City;

T4) Radio Channel Characterization: estimation and modeling in urban environments, with the purpose of PHY assessment.

In particular T2 and T3 provided two laboratories, where students had the opportunity to do some experiments.
In the framework of T2 an hands-on approach to the signal processing involved in satellite-based navigation receivers, was exposed to students. The approach was based on the use of GNSS-SDR, an open source project that implements a global navigation satellite system software defined receiver in C++. With GNSS-SDR, users can build a GNSS software receiver by creating a graph where the nodes are signal processing blocks and the lines represent the data flow between them. The software provides an interface to different suitable RF front-ends and implements the entire receiver's chain up to the navigation solution. Its design allows any kind of customization, including interchangeability of signal sources, signal processing algorithms, interoperability with other systems, output formats, and offers interfaces to all the intermediate signals, parameters and variables.

With reference to T3 during the laboratory experience students used the EuWIn facilities and in particular the FLEXTOP platform, composed of 50 IEEE 802.15.4 / Zigbee devices deployed in a corridor at the University of Bologna. Students had the opportunity to modify a software implementing a smart city application, download the modified software on the devices in the FLEXTOP platform and wait for the results, to process them. The throughput in a multi-hop point-to-point network has been first computed through experimentations. While as a second experiment, a smart city application run on 30 devices. Results in terms of topologies generated in the network and packet loss rate will be analyzed and processed.

The school was attended by 64 people from 11 different countries, including the lecturers (14 people).

We refer to http://www.euracon.org/b4gc2013 and to D32.2 “Report on education and training activities during year2” for more details.

6.5 Participation to EuCNC 2014

EuWIn participated very actively at EuCNC, the European Conference of Networks and Communications, organized in Bologna, Italy, on June, 23-26, 2014, and participated by more than 500 attendees. In particular, the three EuWIn sites jointly organized a workshop, a special session and a demo stand. The three snapshots below are taken from the final programme of the conference.

- Workshop: “Fundamental Research Through Experimentation”, June 23, 2014. Attended by nearly 30 participants.
- Special Session: “From Theory to Practice: Experimental Research Activities in Newcom#'s EuWIn Labs”, June 26, 2014. Attended by nearly 50 participants.
- EuWIn Demo Stand. Based on a questionnaire distributed among attendees at the conference, it was very well received, being one of the best 20% appreciated stands.

EUROPEAN CONFERENCE ON NETWOKS AND COMMUNICATIONS 2014

WORKSHOP 11: FUNDAMENTAL RESEARCH THROUGH EXPERIMENTATION

MONDAY, 23 JUNE 2014, 14:00-17:50, ROOM DA VINCI

ORGANIZER: DAVIDE DARDARI, CNIT

•Chair: Davide Dardari (CNIT/UniBo, Italy)

The workshop is organized and supported by the European Laboratory of Wireless Communications for the Future Internet (EuWin) funded by the EC through the Network of Excellence in wireless communications Newcom#. The EuWin facilities are distributed over three sites: at CTTC in Barcelona (Spain), at the University of Bologna (Italy) and at the Eurecom institute in Sophia-Antipolis (France). They are open for access by any scientist worldwide. EuWin is an integrated laboratory able to address, under a common environment, the various topics of wireless communication technologies for the future Internet. The laboratory activities aim at creating a new generation of researchers in wireless communications believing in the motto "Fundamental Research Through Experimentation". EuWin addresses topics and techniques related to the systems and networks that will drive the evolution of wireless communications in the years to come: LTE/4G, the Internet of Things, GNSS. Digital signal processing, radio access and network protocol aspects, are studied through the available lab facilities.

Within this context, the workshop will give a unique opportunity to the attendees to learn in detail the facilities offered by the 3 EuWin sites and how experimental activities can be carried out from them. Emphasis will be given to the role of experimentation as means to characterize the radio environment and test system performance in real contexts, to the interplay between theory and experimentation, and the relevance of a multi-disciplinary approach to research, requiring knowledge of channel, link and network aspects.

14:00 - The EuWin@CTTC site facilities: Testing an interference management algorithm in GEDOMIS®, Miquel Payaro (CTTC, Spain)

14:50 - The EuWin@Unibo site facilities: Testing Smart City applications Thought Flextop, Davide Dardari, Chiara Buratti (CNIT/UniBO, Italy)

16:10 - The EuWin@EURECOM site facilities, Raymond Knopp, Florian Kaltenberger (EURECOM, France)

17:00 Technical session
Network Protocols for Linear Wireless Sensor Networks for Smart City Applications, Andrea Stajkic (CNIT/UniBO, Italy), Chiara Buratti (CNIT/UniBO, Italy), Roberto Verdone (CNIT/UniBO, Italy)
OpenInLocation: a platform to test indoor positioning algorithms, Ana Moragrega, Javier Arribas, Pau Closas, Carles Fernández-Prades (CTTC, Spain), Giacomo Calanchi, Davide Dardari (CNIT/UniBO, Italy)
eMBMS Experimentation in TV White Spaces, Raymond Knopp, Florian Kaltenberger, Dominique Nussbaum (EURECOM, France) Oliver D. Holland (KCL, United Kingdom)

17:45 End of workshop

Excerpt from EuCNC'14 final programme: EuWIn workshop

THM4: FROM THEORY TO PRACTICE: EXPERIMENTAL RESEARCH ACTIVITIES IN NEWCOM#'S EUWIN LABS

THURSDAY, 26 JUNE 2014, 09:00-10:30, ROOM MARCONI

•Session Chair: Miquel Payaró (CTTC, Spain)

Testing Protocols for the Internet of Things on the EuWIn Platform
Sebastiano Milardo (Università degli Studi di Catania, Italy), Gordana Gardasevic (Università di Bologna, Italy), Melchiorre Danilo Abrignani, Andrea Stajkic, Stefan Mijovic (Università di Bologna, Italy), Giacomo Morabito (Università degli Studi di Catania, Italy), Chiara Buratti, Roberto Verdone (Università di Bologna, Italy)

A VLSI Implementation of the Belief PropagationAlgorithm Applied to the Decoding of Polar Codes
Andrea Biroli, Guido Masera (Department of Electronics and Telecommunications, Politecnico di Torino, Italy)

Measurement Based Modeling of Time-Variant Fading Statistics in Indoor Peer-to-peer Scenarios
Evgenii Vinogradov (ICTEAM/Electrical Engineering, Université catholique de Louvain, Belgium), Joseph Wout (Dept. of Information Technology (INTEC-WICA), Ghent University/IMinds, Belgium), Claude Oestges (ICTEAM/Electrical Engineering, Université catholique de Louvain, Belgium)

RSS based localization: Theory and experimentation
Ioannis Dagres (Institute of Accelarating Systems and Applications, National Kapodistrian University of Athens, Greece), George Arvanitakis (Eurecom, France), Adrian Kliks (Poznan University of Technology, Poland), Andreas Polydoros (Institute of Accelarating Systems and Applications, National Kapodistrian University of Athens, Greece)

Exploitation of TVWS measurements in indoor/outdoor scenarios for HetNets deployment
Jordi Perez-Romero (Universitat Politècnica de Catalunya, Spain), Adrian Kliks (Poznan University of Technology, Poland), Anna Umbert

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EUROPEAN CONFERENCE ON NETWOKS AND COMMUNICATIONS 2014

(Universitat Politècnica de Catalunya, Spain), Pawel Kryszkiewick (Poznan University of Technology, Poland), Ferran Casadevall (Universitat Politècnica de Catalunya, Spain)

Excerpt from EuCNC'14 final programme: EuWIn Special Session

EUROPEAN CONFERENCE ON NETWOKS AND COMMUNICATIONS 2014

EuWin

Exhibition stand 10: The European Laboratory of Wireless Communications for the Future Internet addresses two separate goals: on one hand it aims at supporting industries, providing an *Open Platform for Innovation*; on the other it fosters a new generation of scientists willing to perform research through both theoretical and experimental approaches, under the motto *"Fundamental Research Through Experimentation"*. The EuWin facilities are distributed over three sites: at CTTC in Barcelona (Spain), at the University of Bologna (Italy) and at the Eurecom institute in Sophia-Antipolis (France). They are open for access by any scientist worldwide. EuWin is funded by EC through FP7 / the NoE in wireless communications Newcom#, for the first three years of its activity, till October 2015. EuWin addresses topics and techniques related to the systems and networks that will drive the evolution of wireless communications in the years to come: LTE/4G, the Internet of Things, GNSS. Digital signal processing, radio access and network protocol aspects, are studied through the available lab facilities.

Excerpt from EuCNC'14 final programme: EuWIn Exhibition Stand

6.6 Plans for Y3

During Year 3 EuWIn will pursue a number of tasks. Most of them share a common goal, while some are strictly related to the list of JRAs active within the specific site.

Common activities/goals.

1) The three sites of EuWIn will be presented jointly by the EuWIn Director in **meetings organised by EC** (in the context of the Expert Group of the Networld2020 platform and at concertation or similar events). It is expected that at least three presentations will be made during the third year of the project. The scope is to further increase visibility of EuWIn within the EC.
2) All **dissemination events** during the third year of Newcom# will be participated by researchers presenting the three sites of EuWIn. The scope is to create additional follow-ups with large industries (contracts or collaborations with industry, joint participation in project proposals, etc).
3) Contacts will be pursued during the third year of Newcom# with **SMEs** and associations of SMEs; in particular, CATAPULT, a British association involving a large number of SMEs in the field of ICT and IoT, has been recently contacted. There is the intention to meet in person in Bologna with the founder of the association. The scope is to better pursue the goal of supporting SMEs in innovation.
4) In February/March/April 2015 a **training school** will be organised in Sophia-Antipolis, specifically dedicated to the interplay between experimentation and fundamental research. The scope is to repeat the success of the school organised in 2013.
5) EuWIn will participate to **EuCNC 2015** through a number of actions that will all be organised jointly by the three sites: a workshop, a demo stand and a special session will be proposed.
6) EuWIn will act as one of the main drivers for the **survival of Newcom# community** after the end of the project; EuWIn will deliver specific plans for survavibility after Octorber 2015, during the dedicated internal workshop planned in Athens, on January 22, 2015. The scope is to let EuWIn act as a tool for keeping the Newcom# community spirit after the end of the NoE.

Activities in the context of JRAs.

WP2.1

- As far as WP2.1 JRAs are concerned, plans for Year 3 are described in the body of D21.3.

WP2.2

- WP2.2 JRA#1 will continue, with the goal of a joint paper to be submitted. A big effort will be focused on the algorithm development, in particular on the measurement model. From this viewpoint an introduction of a more complex path-loss model seems to be a proper solution. Eventually switching to fingerprinting approach should be a way to achieve better performances. Another objective for the next year is the full integration of the platform with UWB devices to test high-accuracy localization and environment mapping algorithms.
- The possible set up of a JRA (dealing with scheduling in 4G uplinks) between EuWIn@UniBo and EuWIn@EURECOM within WP2.3 will be discussed in December 2014.

- With reference to WP2.2 JRA#3 the next period will be dedicated to the implementation of the algorithms in the wireless nodes, the collection of experimental results and their validation.
- As far as WP2.2 JRA#5 is concerned, in the third year we will finalise the processing of the data gathered during EuCNC Conference and provide these data as input to the DTN-based network simulator.
- Finally, for what concerns WP2.2 JRA#6 we can consider as closed the experimental activity related to the comparison of the different architectures and protocols, and in Y3 we will mainly work on disseminating the achieved results and on trying to bring the experience we gained in this work to possible other European projects. The latter experience mainly refers to the methodology to be used in order to fairly compare different protocols over a testbed.

WP2.3

- As far as WP2.3 JRAs are concerned, apart from JRA5 and 6, all others will be active during Y3, with the goal of publishing the results consolidated after the measurement campaigns performed during Y2. Details are reported in Deliverable D23.3.

6.7 Conclusions

EuWIn intends to go beyond the spatial and temporal borders of Newcom#. In the former case, a number of follow-ups after the dissemination events organised by the NoE at the premises of large industries, have shown the ability of EuWIn to create and pursue new collaborations. For the latter case, the third year will be fundamental, in defining the path towards full survivability.

EuWIn has shown an ability to attract researchers and to succeed when presenting the three sites jointly, as they cover different aspects of wireless communications and are highly complementary.

The first year of Newcom# was mainly devoted to the set-up of laboratory facilities. During the second year, consolidation of many activities was pursued. The deep integration of the three sites is now the main goal of the third year of the project.

Comments and suggestions for the improvement of this document are most welcome and should be sent to:

project_office@newcom-project.eu

http://www.newcom-project.eu