Troubleshooting Wireless Home Networks Using a Portable Testbed

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Abstract

Because of the recent advances in wireless technologies and, consequently the fast growing number of wireless devices that are being deployed in consumer houses, there is a growing demand from manufacturers to develop and deploy tools able to diagnose problems and evaluate the performance of their products prior to releasing them to the market. Such testing tools are required to be quickly deployable in real-life home environments and should support various wireless technologies and use cases. In order to avoid future product service failures and costly complex troubleshooting, the results should offer a full understanding of the product behavior on the field. Different approaches able to fulfill these objectives have been proposed in literature. In this paper, we propose a new portable and highly flexible testbed tool to evaluate the performance of wireless devices in consumer houses. Furthermore we demonstrate the feasibility and operation of the testbed in two real-life home environments for assessing the impact of range extenders on wireless communication performance.

I. Introduction

We are all aware of the growing number of wireless connected devices in our homes. With the emergence of the Internet of Things, allowing any object to communicate and offer its services, there is the expectation that this number of wireless consumer devices will exponentially grow [1].

Further, such products are designed by various unrelated manufacturers and target different application domains, such as home automation, entertainment, etc. The devices need to operate reliably under a wide range of real-life circumstances. At the same time they are required to satisfy specific QoS demands. This difficult task needs to be performed in challenging surroundings, such as home environments with multiple devices and networks contending for the same wireless spectrum. This spectrum scarcity in combination with relatively high bandwidth demands results in reinforcement of these problems in home environments. Next to this, the typical user, lacking the necessary expertise and tools regarding wireless technologies, expects an out-of-the-box installation and configuration, resulting in an optimal service delivery during the entire lifetime of the product. In-field wireless troubleshooting or maintenance activities due to wireless communication issues are impractical and unaffordable by the manufacturers and service operators.

To address the above issues, there has been a strong interest in the area of testing tools and methodologies for wireless connected products [5][6]. Such tools enable manufacturers to evaluate the wireless performance of their connected devices during all product life-cycle stages, starting from the early prototype design and product development up to final acceptance and after-sales support. The target here is that these evaluations create a full understanding of real-life performance. Therefore, these tools should be easily deployable in conjunction with the products in real home environment scenarios.

In this paper we shortly describe a solution for executing a predefined set of experiments in controlled conditions in real home environments. The solution encompasses the realization of a portable wireless testbed with powerful capabilities to easily set up and automate a wide range of wireless experiments. In order to demonstrate the feasibility of the proposed approach, we describe a set of real-life experiments that were performed using our solution.

The remaining sections are organized as follows: Section II explains the related work and the requirements that such a generic portable wireless diagnostic testbed should satisfy. Comparison between current approaches and our portable wireless testbed will be further discussed in this section. We describe our solution infrastructure in terms of hardware and software components in Section III. We consider a particular real-life use case related to wireless audio streaming performance evaluation and diagnostics in Section IV and analyze the initial results achieved in Section V. Finally, main issues observed during our experiments, lessons learned and future work perspective will be discussed in Section VI.

II. Related work

Recent growing interest in wireless performance evaluations in residential settings has pushed the demand of precise, reliable, flexible and low-cost tools for testing consumer connected devices and overall wireless performance inside the consumer's house.

There exist some main assumptions regarding the capabilities of these tools: (a) ability to recreate a representative wireless environment; (b) configuration flexibility, allowing to understand product behavior across a wide range of settings (in multiple environments or different contexts within same environment); (c) possibility to incorporate other connected products; d) test repeatability and automation procedures, for allowing reliable performance observation under controlled parameter conditions; (e) reliability and flexibility of output data, during the gathering, storing and processing of field performance results; (f) local/remote operator access and interface; (g) easy operation and compactness of the tool when used on the field.

We distinguish four different main approaches followed by the manufacturers during wireless performance evaluations: (1) simulation and emulation tools; (2) product built-in diagnostics; (3) specific software based solutions; (4) indoor testbeds.

The first approach offers affordable results during prototype design phase due to the repeatability and easy setup of the tests under some hypothetical home scenario parameters. However simulation and emulation tools cannot cover a wide range of probable issues caused by the complex interactions between real-life environment and the subject under test.

The second approach gives a reasonable indication of the wireless performance to the manufacturer and user from the viewpoint of the device and is mainly useful for diagnostics and troubleshooting of issues that the device faces. However, being a vendor lock-in solution limited to the particular device, this is too limited and insufficient to create a full understanding of the issues caused by the interaction of the device with the rest of the home environment.

The third approach consists of dedicated wireless performance evaluation tools, such as [11][12]. These are mainly PC software products equipped with custom wireless cards, which the test operator uses in real-life field scenarios for site survey and diagnose of wireless networks. However, the closed software and hardware license of such tools makes this approach limited in flexibility and unable to offer repeatability and automation of large-scale experiments.

The last approach, indoor wireless testbeds, results to be the best choice in terms of experiment flexibility, large-scale operability and repeatability [6][9][10]. With regards to wireless testbeds, we also distinguish two types, fixed testbeds and portable testbeds. In the first case a representative end-user home scenario is carefully reproduced in a lab or in a sample house in order to mimic a typical user house type in terms of surface and walls, network topologies, and to reproduce several basic user cases and interactions. Examples of the most successful indoor wireless testbeds used for this scope are Emulab, Orbit and MiNT fixed testbeds [3][7][8].

Even if this is a more realistic approach, allowing at the same time a flexible and automated experiment setup, it suffers from the fact that it cannot cover a significantly wide range of house environments. The deployment of several real house experiments in a lab could result in an unaffordable and impractical operation in terms of costs and time and effort.

Based on this, we believe that the most practical and convenient approach is the use of a portable testbed which consists of a limited set of generic nodes equipped with measurements interfaces, a flexible controller framework and a robust data management backbone.

III. Our approach

Our wireless portable testbed tool is a modified small-scale version of the generic w-iLab.t Zwijnaarde testbed [2]. The w-iLab.t testbed consists of 60 fixed and 20 mobile nodes, where each node is an embedded PC equipped with several wireless interfaces and the platform is managed by Emulab framework [3] in combination with OMF testbed controller tool [4].

In order to adapt the fixed testbed to the wireless home scenarios we have made some modifications to the hardware and software testbed architecture. Below, we are giving a high level description of the main modifications and the experiment flow, while we refer to the detailed description of the fixed testbed architecture [2] that has remained unchanged and the operation through OMF tool [4] and Emulab framework [3].

A. Hardware and Software

In terms of hardware, compared to the fixed testbed, there were modifications on the nodes, the controller backbone and the way the nodes are powered.

Figure 1 Portable Testbed

The portable testbed, as shown in Fig. 1, consists of seven

Intel NUC nodes [13], embedding an Intel Core i5 4250U processor, Gigabit LAN, 4 USB 3.0 ports, infrared sensor and headphone jack. The nodes are powerful enough in terms of processing power, flexible in terms of ports and interfaces and robust enough to allow a flexible deployment on all field scenarios. Two Qualcomm Atheros AR93xx Wireless Network Adapters (802.11abgn) are installed on each node.

Considering the difficulty of laying wires in a house during an experiment setup and execution, mainly when the nodes need to be positioned in different rooms and floors, PLC adapters were added to the testbed controller backbone. The testbed backbone is totally separated from the wireless communication radios which are used during the experiment. This way the measurement data are not influenced from the testbed management. Depending on the positioning of the nodes in a house, in cases when the nodes are in proximity of the testbed switch, optional PoE splitters are used for powering the nodes through the PoE Ethernet switch. The testbed backbone for usage in a house with three floors is illustrated on Fig. 2.

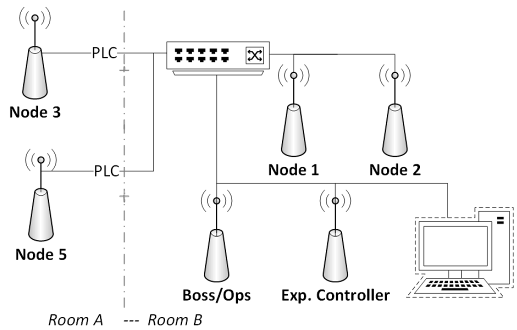


Figure 2. Testbed Controller and Data Management Backbone over wired LAN network (WCs deployment)

In terms of Software, the testbed nodes run the Ubuntu operating system, allowing flexibility in terms of software and hardware that could be added. Emulab allows fast loading of customized operating systems related to the user and experiment. Considering the portability criteria, several optimizations were performed on Emulab and OMF frameworks. A graphical tool based on Flot JavaScript plotting library was added in order to allow fast feedback during testbed experiment runs.

Dedicated experiment description scripts were designed for home wireless evaluations in order to limit the field parameter configurations, allowing a test operator without deep expertise on the testbed to run repeatable experiments.

B. Experiment Design and Operation

The portable testbed nodes can realistically mimic the behavior of any wireless device and at the same time collect reliable wireless performance data. Each node is centrally controlled by a special node called the Experiment Controller (EC), where an OMF experiment description (ED) Ruby based script (OEDL) runs. The overall experiment then runs in each node in an orchestrated fashion. Also, the measured data is locally collected by each node and is then stored in a structured database for visualization and later post-processing. The nodes can be accessed individually or through the EC.

We chose to split the process in two phases, a first experiment design process and a second field test execution phase. This design choice is due to the fact that the field operator process should be as short and error prone as possible. The operator tasks on the field should be limited to positioning and connecting the nodes to the testbed backbone and run the Experiment Description script. The testbed supports local and remote access. The output data is saved locally on the testbed database and a copy is remotely sent to the user machine for any feedback and real-time visualization.

Considering the unpredictable experiment execution time, we chose to follow an event-driven approach rather than a time-driven approach when running series of automated tests.

For the designer it is required to have some expertise related to the OMF framework in order to design an experiment, by modifying, according to the needs, the three main OEDL ruby based scripts: (1) the experiment definition (ED), that describes the node resources and applications; (2) the application definition (AD), that serves as interface between OMF entities and node applications; (3) the Wrapper, that runs the specified application on the correct node and collects the experiment output, injects it on the database, saves it as log file and visualizes the real-time results on the testbed graphing tool.

The operator of the testbed executes the following steps when running an experiment:

1- Position the testbed nodes and other components at the right locations in the house and physically connect the nodes to the testbed backbone and power.
2- Swap in the desired nodes with the respective OS images from Emulab interface.
3- Once the nodes are installed, run the ED script on the EC machine. Additionally, the operator could be locally or remotely connected to the testbed controller interface.
4- As the OMF experiment is running, observe on the EC command-line the experiment flow. The intermediate results get plotted using the graphing tool.
5- Once the experiment is terminated and the results have been stored in the database, run a new experiment using the steps as above.

IV. Use Case and Experiment Setup

A. Audio Streaming in real-life home

In order to demonstrate the feasibility of the proposed portable testbed solution we considered a frequent use case scenario. In our scenario, a user needs to stream audio files between different locations in his home. The user makes use of a Gateway equipped with an 802.11n wireless access point (AP) for wirelessly connecting his devices. The user uses two wireless devices in the room where the AP is located (Room

A), while two other wireless client devices are located in a remote room where the AP has limited wireless coverage (Room B). The user uses a wireless repeater, which we will refer to as range extender (RE), in mid distance between the AP and room B devices. RE is connected directly to the AP wireless network. Devices in room B are connected to the Gateway AP by making use of the RE network, while devices in room A are connected directly to the network of AP.

B. Experiment Setup

We used as test environment two real-life houses, where we carefully chose very different house types in terms of wireless barriers, dimensions and wireless interferences:

- a three floor house with several division walls separating the rooms, located in a very populated area with approximately 30 wireless neighbor access points operating in 2.4GHz ISM frequency bands, referring here as Worst Case scenario (WCs);
- a one floor house with less division walls, in a more isolated area, with only 3 neighbor wireless access points operating in 2.4GHz ISM frequency bands, referring here as the Best Case scenario (BCs).

Both house plans, the positioning of the nodes and wireless connections are shown in Fig. 3 and Fig. 4, where devices in remote room B are represented by testbed nodes N1 and N2, while room A devices are represented by N3 and N5 nodes.

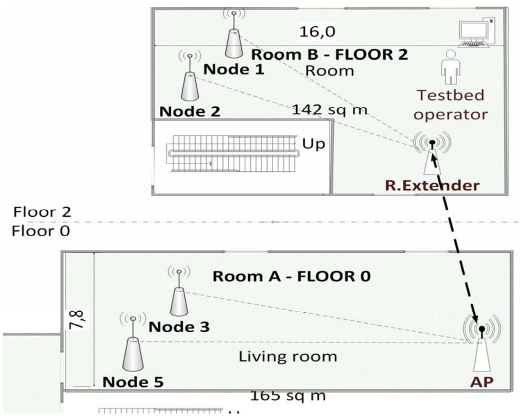


Figure 3. Worst Case scenario (WCs) house plan: wireless testbed topology

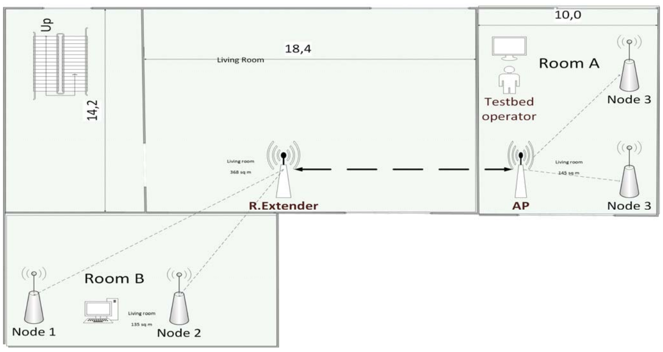


Figure 4. Best Case scenario (BCs) house plan: wireless testbed topology

Besides the evaluation of the functionalities of the testbed under two different home conditions, we also tried to compare the performance of several real-life wireless products commonly used in houses with wireless coverage problems.

In our experiments we made use of five off-the-shelf consumer 802.11n range extenders which operate in the 2.4GHz frequency band. During all our experiments we used a high-end wireless router as the user AP [14].

The same experiment was run repeatedly using one by one all range extenders, in order to compare their performance under controlled home test conditions.

We used iPerf software to generate UDP traffic flows and to measure the bandwidth, jitter and packet losses over the 2.4GHz wireless interfaces, between a source and a sink node, mimicking our audio streaming scenario. The experiment consists of 3 traffic flows as shown in Fig. 5. Depending on the house scenario, iPerf was set to send UDP traffic at 8, 5 and 2 Mbps for each flow consecutively, in both directions.

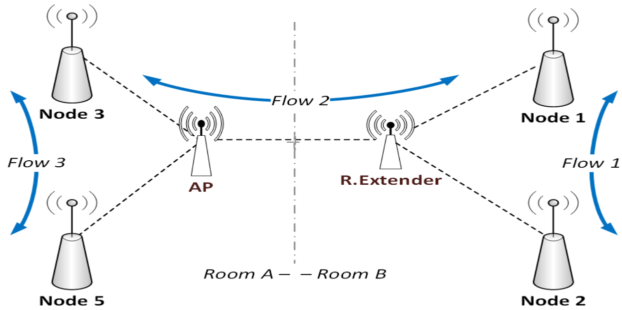


Figure 5. Experiment Wireless traffic flows: a) Flow 1: N1-RE-N2, b) Flow 2: N1-RE-AP-N3, c) Flow 3: N3-AP-N5

The traffic flows were chosen with the purpose to measure the traffic between: (a) two nodes which are both stations of the AP; (b) one node, station of the AP and one node, station of the RE, for testing also the RE-AP link; (c) two nodes which are both stations of the RE.

V. Experimental Results and Analysis

Below we present the measured results of our evaluations in the two different user houses. We evidence the main factors that impact such results by comparing results of tests performed under the same conditions except one: (a) house scenario (WCs vs. BCs); (b) range extender device (RE1, RE2, RE3, RE4 or RE5); (c) traffic flow (Flow 1, 2 or 3) and direction. In all the graphs below, the measured UDP throughput relative to the experiment time is shown (Mbps/s). Tests are run in series, one by one, but consecutive measurements under same conditions are placed on the same graph to facilitate comparison.

A. User House and Environment

The house environment in terms of wireless interferences (approx. 30 APs in WCs vs. 3 APs in BCs), flow path (LOS, NLOS), barriers and house shape (walls type, number of floors and surface) deeply impacts the traffic throughput results. Fig. 5 shows the measured throughput in both houses when using the same experiment parameters, flows, topology and devices (RE1). We can observe that in terms of throughput for BCs, the minimum throughput is measured for Flow 2 (N1-N3) and is still higher than 5Mbps. In contrary, the measured values for WCs are much lower for all flows, independently on the RE that is being used.

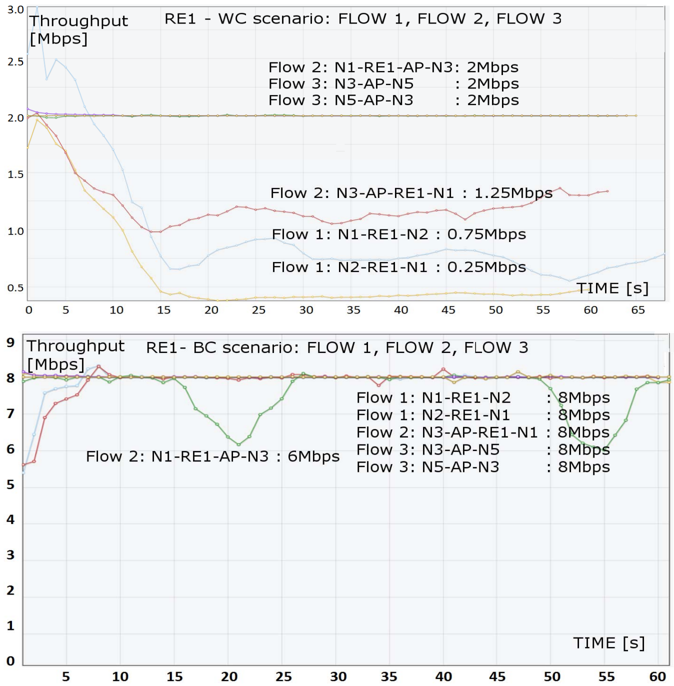
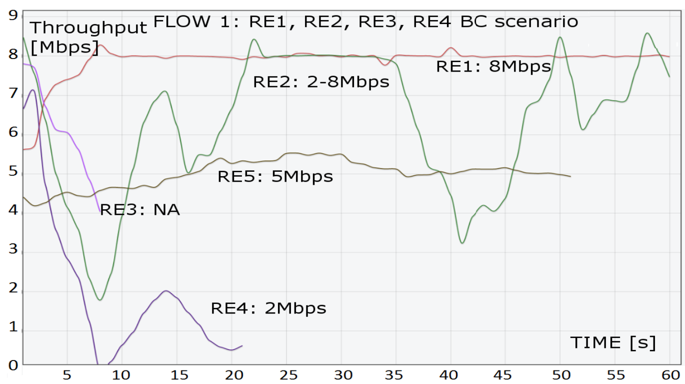


Figure 6. Throughput in function of time for all flows and both directions when RE1 is used in: a) WCs house, b) BCs house

In both house scenarios, when each of the REs was used, it resulted in a more stable and high throughput Flow 3 (N3-AP-N5) if compared to the measured throughput on the other flows, as is shown in Fig. 6a and Fig. 6b for the case of RE1. In relation to the local audio streaming scenario, this suggests that streaming between two devices which are connected directly to the main AP network will result in better QoS than streaming between two devices connected to a RE.

B. Range Extender Device

The achieved results show that the throughput and jitter values are deeply impacted by the type of RE device under test, as shown in Fig. 7a, Fig. 7b and Fig. 8a.



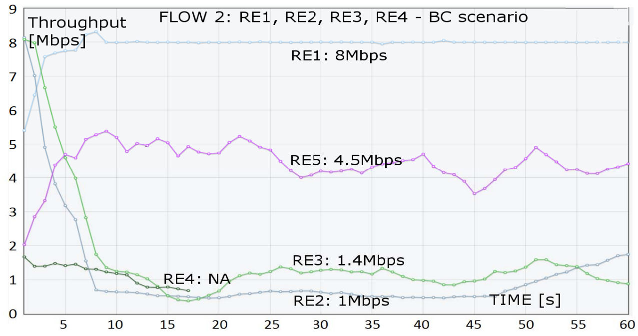


Figure 7. Throughput in function of time: a) Comparing all REs on Flow1 (N2- N1), BCs; b) Comparing all REs on Flow2 (N3- N1), BCs

In all the tests performed, RE1 performs better in terms of stability and throughput than the other range extenders, as is shown in Fig. 7a, Fig. 7b and Fig. 8a. RE4 results to be the less performant, as shown in Fig. 7a and 7b, being unable to satisfy throughput requirements and manifesting continuous crashes during the experiments in both BCs and WCs. Similar crashes were observed also with RE3, as shown in Fig. 7a.

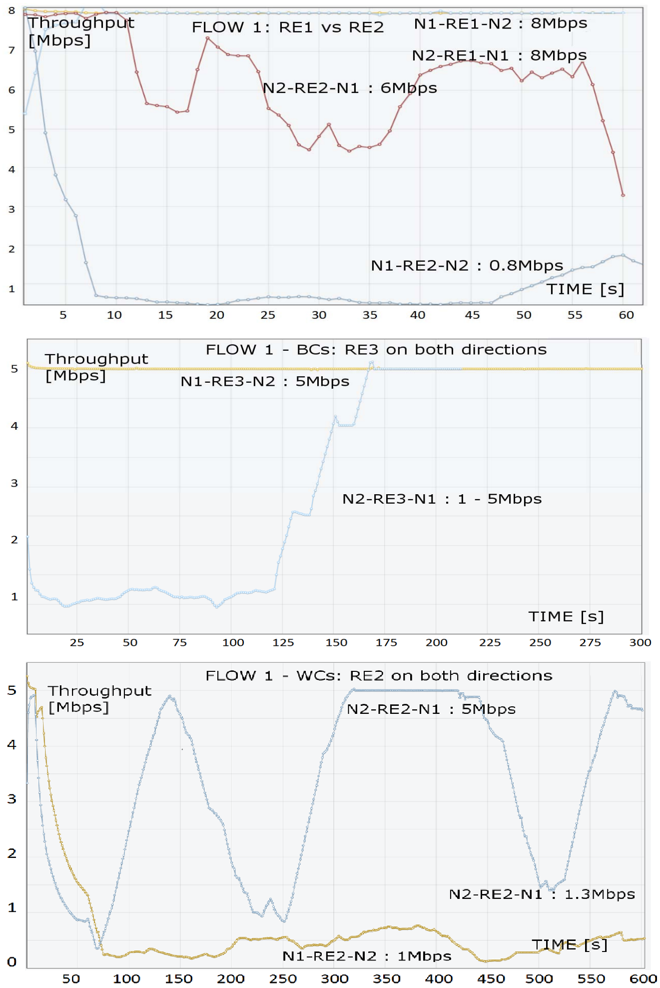


Figure 8. Throughput on Flow1 in both directions: a) BCs, Comparing RE1 vs. RE2: throughput is higher and more stable for RE1 than for RE2; b) BCs, RE3 shows asymmetric behavior and high packet losses when sending traffic in N2->N1 rather than N1->N2; c)WCs, RE2, Flow1 both directions

It was observed a very high asymmetry of the stability and throughput measured values depending on the traffic flow direction for RE2, RE3 and RE4, as shown in Fig. 8a for RE2. Considering our local audio streaming use case, where any two connected devices require high traffic performance in any of the traffic flow directions, this behavior might result in an issue.

During longer runs of experiments it was observed that RE2 and RE3 cannot always maintain a stable throughput value, most likely caused by dynamically adapting transmission settings of the wireless card, as shown in Fig. 8b and 8c.

Considering the local audio streaming use case, the instable and asymmetric behavior of the REs and the further deterioration of the performance due to the neighbor wireless interferences and barriers in a house similar to our WCs, it would be extremely difficult for the user or operator to troubleshoot and improve the final service, without making use of advanced wireless diagnostic tools.

VI. Conclusions

In this paper we have proposed a portable wireless testbed tool as a solution for evaluating the performance of wireless connected devices in real-life consumers' house scenarios.

The testbed consists of six nodes connected to the flexible testbed backbone and the nodes are controlled by a local experiment controller machine executing the experiment script in an orchestrated fashion following either a timeline or an event-driven chain of processes. Each node is a general purpose computer, extensible in terms of radio technologies and interfaces allowing a high degree of flexibility for the experimenter.

In a preliminary analysis we have evaluated the requirements that a testing tool for wireless measurements in residential settings should meet. We have demonstrated the feasibility and operation of the testbed in two real-life home environments for assessing the impact of range extenders on wireless communication performance. Finally, we have analyzed the results and evidenced the main factors observed during our experiments that deeply impacted the wireless performance in the scenarios observed.

VII. Future work

During our first initial activities on the field we tried to evidence the main problems that were met and tried to use the acquired experience in order to improve the testbed for the future. Even if the use of PLC and PoE technologies for the testbed backbone facilitated the operation of the provisioning the nodes remotely in several different rooms of the house, we still found difficulties to find power plugs and to assure a good communication for the PLC adapters in all the planned positions where we wanted to place the nodes.

Therefore, in the future, we plan to deploy a wireless backbone for the testbed nodes. In order not to have interferences with the measured data, the wireless backbone will operate as a mesh network, using another wireless radio interface and operating on a different radio channel.

Another extension that would allow more freedom in terms of portability is the use of batteries for powering each node. Furthermore, this would allow us to collect useful power consumption data during the operation of each node and include these results to our experiment output. Next, in order to support sensor node experiments, an optional 802.15.4 sensor node will be added to the nodes.

Finally, we plan to extend the experiment scripts, in order to gather also physical layer information and correlate these results to the traffic performance results during a test. This information would help to better understand and target the causes of the observed issues during a performance evaluation.

VIII. Acknowledgments

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