Comm4Dev: Communication Infrastructure for Development

António Sousa, Carlos Resende, André Pereira, and Waldir Moreira(✉)

Fraunhofer Portugal AICOS,
Rua Alfredo Allen, 455/461, 4200-135 Porto, Portugal
{antonio.sousa, carlos.resende, andre.pereira, waldir.junior}@fraunhofer.pt

Abstract. One of the main reasons for the still observed digital divide is the lack of communication infrastructure in regions away from urban centres. As these regions are normally spread over long distances and have small populations (i.e., prospective users), operators see little business opportunities and refrain from large investments to reach these areas. Upon this scenario, our Communication Infrastructure for Development (Comm4Dev) solution was built to offer a low-cost backhaul infrastructure, providing these underserved communities with broadband access. As to allow a wider range of application scenarios (e.g., precision agriculture, industrial production support), our Comm4Dev solution has been updated not only to further promote digital inclusion, but also to allow the development of communities that are in remote areas. To illustrate the potential of our Comm4Dev solution, we validated it in an indoor hydroponic farming testbed.

Keywords: Broadband access · Low-cost backhaul infrastructure · Communication for development · Digital inclusion

1 Introduction

Broadband access in remote areas is not a priority for operators due to the high deployment costs: providing fibre infrastructure and/or broadband cells is expensive and the return of investment in such regions is very low (and even inexistent) given the low number of users and their power of purchase. Moreover, these regions are characterized for being rather disruptive, which means that users in these communities might be completely disconnected, with eventual periods of connectivity. This consequently contributes to the digital divide we witness today [1].

However, off-the-shelf solutions can be considered to provide these underserved communities with a communication for development (Comm4Dev) network, aiming at an easy-to-deploy solution that can be used to improve the lives of the people in isolated areas.

Our Comm4Dev network infrastructure [2] presents a hardware and software solution to address this digital divide challenge. And working on top of such solution, we currently focused on the reduction of its off-grid installation complexity and cost, as

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well as on the inclusion of more high power backhaul interfaces and the integration with Bluetooth Low Energy (BLE) [3, 4] and Global Positioning System (GPS) to allow the inclusion of more demanding scenarios, that is, where (i) energy may not be available; (ii) more links are required (i.e., star topology); (iii) there is the need to interoperate with other communication technologies (e.g., data exchange with temperature/humidity sensors deployed in farm); and (iv) location information is important to pinpoint maintenance needs.

Thus, the capabilities of the wireless backhaul (WiBACK) node evolved into a ready to deploy off-grid module, capable of building multiple backhaul links and easily interface with BLE-enabled devices or networks.

This paper documents such evolution and its validation, and is structured as follows. Section 2 presents the new challenges imposed to WiBACK node, and how its new features and capabilities answer the needs of new envisioned application scenarios. Section 3 presents the validation performed considering the particular case for precision agriculture, where the WiBACK node shall serve as gateway for BLE sensors in an indoor hydroponic farming testbed. And finally Sect. 4 presents conclusions and future work.

2 WiBACK and New Challenges Addressed

Comm4Dev's first version [2] addresses the goal of connecting people in isolated areas by proposing a low-cost and easy-to-deploy hardware and software solution. On the hardware side, the WiBACK technology with its QoS-provisioning, auto-configuration, self-management, self-healing and "Plug & Play" characteristics allows for easy, hassle-free deployment.

However, the installation of WiBACK nodes in off-grid scenarios is still a challenge: considering the use of renewable energy on such locations, the selection and installation of the components to harvest (e.g., solar panels, wind turbines, etc.), manage (e.g., DC/DC converters, MQTT controllers, battery charging and battery protection circuits, etc.) and store (e.g., batteries selection and dimensioning) the energy are complex tasks that still require highly skilled technicians to perform them.

Additionally, Comm4Dev's first version considers an earlier version of the WiBACK node that has only two high power backhaul interfaces. Consequently, in topologies requiring multiple links (e.g., star), different WiBACK nodes would be required to cover different locations. Thus, having one WiBACK node capable of providing multiple links is desired and shall reduce the installation cost and complexity.

As different communication technologies may exist, and upon the need to offer an IoT-compliant solution, a Bluetooth Low Energy (BLE) interface should be considered, as this technology is expected to be the one with the biggest market share [5]. In fact, the choice for the BLE interface is related to the penetration of this technology on the smartphones, sensors, actuators and gateways. Such penetration eases the expansion of the backhaul links by: connecting the WiBACK to multiple manufacturer devices, which can be connected with each other through a BLE mesh network; or by connecting it to smartphones, or other mobile apparatus, equipped with a BLE interface, which in turn can serve as data relays. These scenarios enable the IoT concept to be applied in the Comm4Dev installations.

Finally, GPS capability is desired to enable the node not only to perform GPS tagging on the data being generated at the sites, but also to help in pinpointing those sites that may require maintenance. These are value added features that should be considered.

With such challenges in mind, the WiBACK N4C was developed by Fraunhofer FIT/DeFuTech in partnership with Fraunhofer Portugal AICOS, and includes power management components for off-grid installations, more high power backhaul radios for the creation of multiple links, and BLE and GPS interfaces to broaden the range of application scenarios (e.g., precision agriculture, industry-related solutions).

Regarding the power management unit, WiBACK N4C integrates components that safely and efficiently control the energy harvested, which is then stored on a Lithium Iron Phosphate (LiFePo) battery that can be integrated inside the device's enclosure. With this approach, the installation technician only needs to consider the dimensioning of the harvester (e.g., solar panels power, orientation/positioning) and battery capacity for the location of the site as the N4C comes with a simpler and more compact energy solution for off-grid operation.

In what concerns the multiple links challenge, WiBACK N4C is equipped with 4 high-power 5 GHz radio interfaces, which, using a WiFi based communication protocol, provide the possibility of establishing more links per site with a single node. This improvement provides not only more flexibility to the network design process, but also a reduction on the cost and on the energy footprint, since a single node is now able to have the double amount of links when compared to its predecessor.

The BLE interface is added using a BLE module with Bluetooth SIG mesh [6, 7] capabilities, allowing the connection to BLE devices or networks, opening the possibility to use Comm4Dev solution on IoT-like scenarios, or to use the BLE as a configuration interface for the WiBACK N4C node.

The GPS interface is an added-value feature allowing not only to get the location of the deployment sites which aid in the detection of problematic nodes and fast maintenance, but also geotagging of produced data for more localized understanding of specific sites.

Figure 1 illustrates a Comm4Dev installation where the WiBACK N4C is being used to address these new features in a set of illustrative application scenarios. Node A is an off-grid and multilink node, powered by solar energy and using its 4 backhaul radios operating at its maximum capacity to relay the incoming traffic, linking several sites to the central location (Node B) that connects to the WiBACK controller.

On the edge of the network, the N4C nodes may also be solar powered or directly connected to power grid, and in some situations they may still be serving as a relay to multiple locations. An example is Node E which is in the District administration that locally offers Internet access to citizens through the installed access point (AP) and further extends the internet connectivity to villages 1, 2, and 3.

Moreover, the N4C nodes may be used as a gateway to BLE sensors and actuators on remote monitoring applications, integrating the IoT concepts into the Comm4Dev installation: for instance, Node C is being directly connected to BLE sensors/actuators on small remote monitoring/control scenario (e.g., precision agriculture), while Node D makes use of the BLE mesh network to allow the remote monitoring/control of large installations (e.g., in an industry setting overseeing production lines).

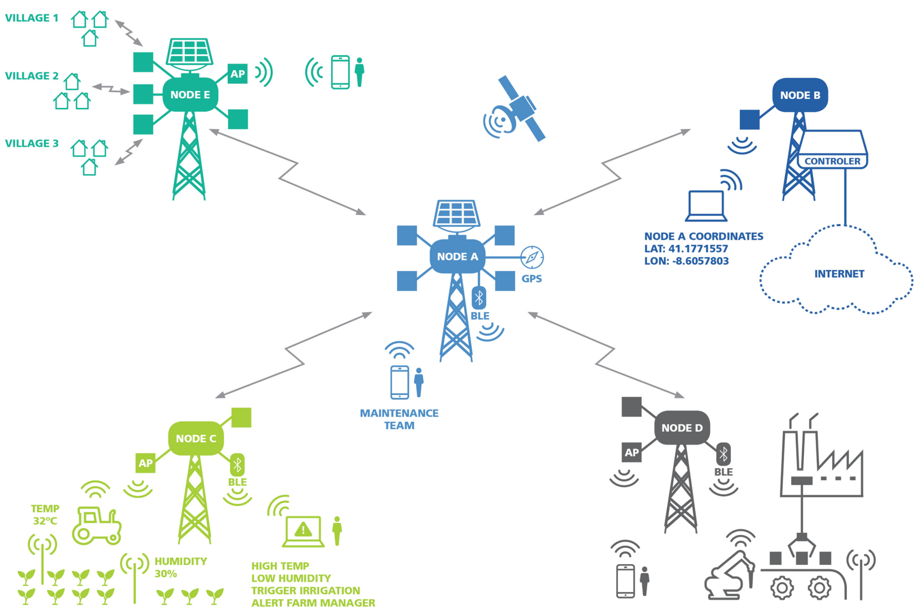

Fig. 1. A Comm4Dev installation based on WiBACK N4C with different application scenarios.

Finally, all the monitored information may be geotagged by the GPS module of the WiBACK N4C, a feature that can also be used in the maintenance process of non-working WiBACK nodes and/or of the site where the nodes are deployed.

3 Sample Application Scenario and Performed Evaluation

Out of the aforementioned application scenarios, we focused on the remote monitored agriculture. This section starts by presenting our indoor hydroponic farming testbed as a sample application scenario considering the BLE capabilities of the WiBACK N4C node. Then, the section details the tests carried out concerning a potential BLE mesh network that can extend the communication capabilities of our Comm4Dev solution.

3.1 Sample Application Scenario

In order to understand the BLE capabilities of the WiBACK N4C, we updated our Comm4Dev Porto network [2]. Figure 2 presents a BLE device (a) that monitors the water temperature, water pH, water electro conductivity, ambient temperature, relative humidity, atmospheric pressure and sensor battery level in an indoor hydroponic farming testbed. The monitored data is transmitted over BLE to the WiBACK N4C (b), which in turn sends it to a remote server for storage and visualization through a web-portal.

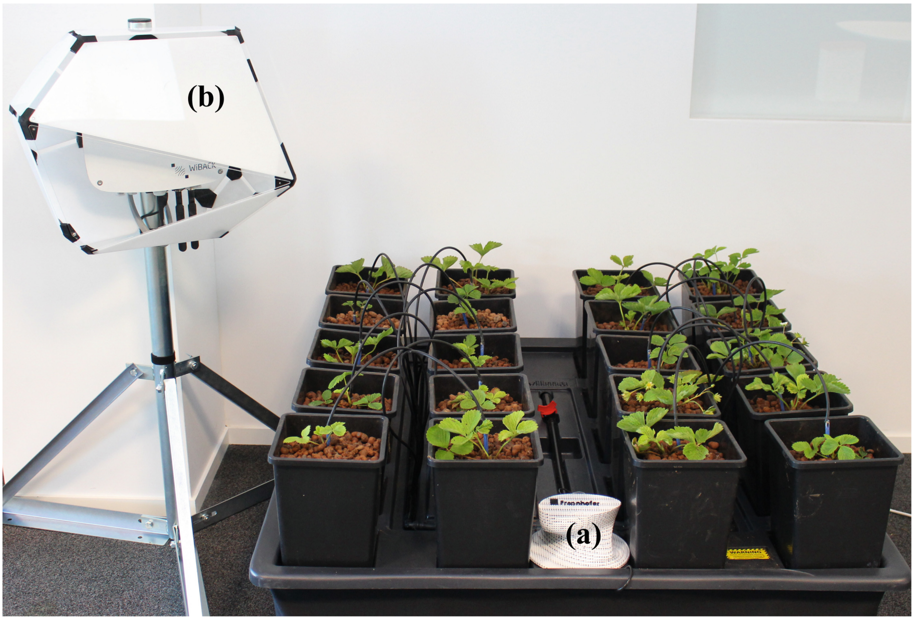

Fig. 2. WiBACK N4C as a gateway for an indoor hydroponic farming testbed.

On the described installation, the mesh feature of the WiBACK N4C is tested by connecting its BLE interface through a simple one-hop link towards the aforementioned BLE device (e.g., PANDLETS equipped with more sensors – PANDLETS Sensing+ [8]). However, a more complex mesh of BLE devices may be easily integrated to further extend the communication range of the Comm4Dev solution. For this extended scenario, the BLE devices communicate with each other under the Bluetooth SIG mesh specification [6, 7] to reach the central gateway, that is, the WiBACK N4C, and through it connect to the Internet as it already happens in the illustrated scenario.

This sample scenario helps us illustrate the applicability of WiBACK N4C in a precision agriculture setting, where our Comm4Dev solution can be used to further develop underserved communities. Next, we present a performance evaluation on the potential BLE mesh network that can further extend the communication range of our Comm4Dev solution in such applications.

3.2 Performed Evaluation

We studied the BLE mesh capabilities in order to characterize and validate the applicability of this feature to the aforementioned scenario, and also to assess the limits of the network and the possibility of applying it to more demanding applications. To accomplish this, we assessed the minimum time between events considering a couple of Nordic Thingy:52 devices [9], mimicking a BLE mesh network. The choice to test this parameter is based on the need to understand if the BLE mesh network supports the reception of events at a rate that is suitable for the devices that are monitoring and actuating on the described application scenarios (cf., Sect. 2), and if so, understand the limits to which the BLE mesh network can be applied to.

Minimum Time Between Events. For the sake of simplicity, an event is defined as sending a Request message that expects a Response message. This evaluation focused on determining the rate at which a new event could take place without having information loss. The size of the Request/Response messages includes the BLE and Mesh headers with a payload of at most 8 bytes.

Figure 3 depicts the test setup with a two-node Bluetooth mesh network and a computer, where Node 1 sends a Request message, and Node 2 sends a Response message back (i.e., an event). The computer is connected to Node 1 setting the frequency at which Request messages are sent, and keeps track of the minimum time period between events that do not cause information loss.

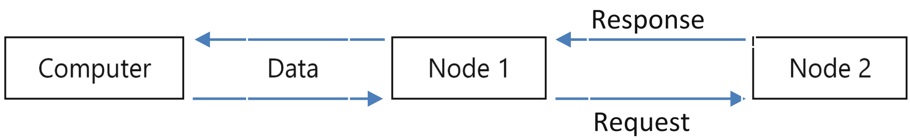

Fig. 3. Laboratory test setup.

Considering this setup, the computer configured Node 1 to send 200 Request messages (i.e., perform a test with 200 events) with an initial time period between events of ∼457.5 ms to Node 2. At the end of each test, the computer checks if all the Request messages received the corresponding Response, i.e., if all the events (pair of Request-Response messages) successfully happened over the network. If successful, a new test cycle with a shorter (more demanding) time period is tested. Otherwise, a higher (less demanding) time period is tested. This process continues with new test cycles until the computer discovers the shortest possible time period between events that do not cause information loss, i.e., all the Request messages received the corresponding Response.

Figure 4 presents the results of this performance evaluation test, where the "Test #" refers to a new test cycle composed of 200 events, and "Event period" is the time period between events considered for each test. The light grey dots represent test cycles at which information was lost (at least 1 of the 200 events failed, i.e., either the Request or Response message was lost during the transmission due to network overload), and the black dots represent test cycles with no information loss.

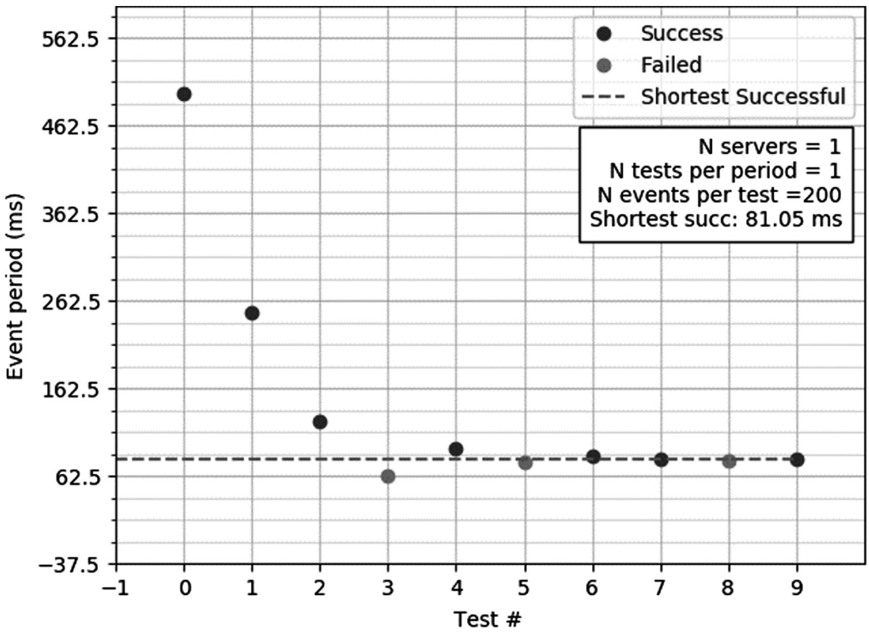

Fig. 4. Test results for the minimum time between events.

It can be seen in Fig. 4 that the minimum time period between events is $\sim$81 ms, achieved on test cycle 9, i.e., Node 1 is able to send a new Request message (i.e., start a new event) every $\sim$81 ms and neither the Request message or the Response is lost.

As more nodes are added to the network, the minimum time period will tend to increase, due to the nodes having to deal with bidirectional message transmission. Nevertheless, such limitation may not be critical in certain application scenarios where real time message exchange is not mandatory, or in scenarios where monitoring does not demand high sampling frequencies, which consequently increases the time period between Request messages.

Agricultural and some industrial applications are some of those scenarios, where temperature, soil characteristics (e.g., humidity, nutrient level, etc.), machine degradation status, among others, are variables that vary slowly in time, and/or the variation does not require an immediate reaction, so sampling frequencies (i.e., time period between data requests) may be above the milliseconds mark. In fact, even scenarios with high sampling rate sensors, or a mixture of high and slow sampling rate sensors, can be considered, as long as the dimensioning of the monitoring solution takes into consideration the observed network limitations, and the inherent energy consumption associated with the amount of data travelling in the network.

4 Conclusion and Future Work

To further ease the deployment of the Comm4Dev solution [2], and to further extend the range of scenarios addressed by it, WiBACK N4C was developed in a partnership between Fraunhofer FIT/DeFuTech and Fraunhofer Portugal AICOS.

The new WiBACK N4C eases the deployment of the Comm4Dev solution in off-grid scenarios by integrating all the complexity related with the safe and efficient management of the harvested and stored energy. The radio interfaces were also improved by doubling the number of WiBACK links the node is capable to provide. The addition of a BLE interface is two-fold: it can be used to configure the node, as well as to integrate IoT concepts on Comm4Dev deployments. Finally, the GPS interface, besides allowing to map deployment sites, helping to detect problematic nodes and to provide fast maintenance, it can also be used to geotag produced data for more localized understanding of specific sites.

Within the scope of this paper, we studied the integration of WiBACK N4C with Bluetooth mesh networks by characterizing the minimum time period between events (i.e., exchange of Request/Response messages). The test results show that the minimum time periods between every new Request message is limited to $\sim$81 ms.

In conclusion, the integration of Bluetooth mesh networks into the Comm4Dev solution to further extend its range is feasible for scenarios where the volume of information to be transmitted is reduced, and where real-time communication is not mandatory. The presented indoor hydroponic farming testbed is one of such scenarios.

Fully integrating the WiBACK N4C in the Porto testbed to test all the new features of the WiBACK node is one of the ongoing next steps, as well as the fully integration of the WiBACK N4C with mesh networks. For that, we plan to extend the Porto testbed by adding more WiBACK N4C nodes powered by solar energy to simulate a multiple-link, off-grid installations.

Moreover, we intend to increase the number of BLE nodes within the mesh to prove the system concept in the field. This is expected to help us further understand the behaviour concerning the minimum time period between every new Request message as well as test other network performance parameters. More knowledge on these parameters will drive the performance improvement of the BLE mesh network, allowing the Comm4Dev solution to answer the technical needs of new specific application scenarios.

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