SV4D Architecture: Building Sustainable Villages for Developing Countries

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Abstract. The introduction of Information and Communication Technologies (ICT) in a society is known to influence its gross domestic product and human development index. Still, access to ICT is not universal, with the problem being further aggravated in developing countries. In order to fill in this digital divide gap, we present our Sustainable Villages for Development (SV4D) architecture, which is a collection of hardware and software conceived to promote digital inclusion and consequently improve the quality of life of citizens of these underserved communities. We also present a set of preliminary performance evaluation tests carried out in the SV4D testbed deployed in Porto, Portugal, that shows the potential of our proposed architecture for deployment in developing countries.

Keywords: Sustainable Villages · Developing countries · Digital inclusion Intermittent connectivity · Communication for development

1 Introduction

Despite of the evolution on Information and Communication Technology (ICT), the International Telecommunication Union has estimated that still 53% of the world's population remain without Internet access. This problem is even more evident in developing countries (e.g., approximately 75% of the citizens in African countries have no Internet access) [1].

The reason for low-populated, isolated regions not to be covered by operators relates to the high costs per user: the efforts in deploying fibre infrastructure and/or broadband cells do not justify the investment in such regions. Moreover, these regions spread over a large geographical areas, meaning that, once in these communities, citizens may be completely disconnected, with occasional periods of connectivity (i.e., user may access online contents when in a town with connectivity or in a region with cellular coverage).

The lack of infrastructure and disruptive connectivity characterize a rather challenging scenario when compared to a scenario in which a user regularly accesses in large and developed urban areas. Intermittent connectivity, high latency, limited number of equipment, and the non-existence of end-to-end paths between

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communicating parties are just few examples of the challenges to overcome [2]. Furthermore, this reduced and/or non-existent access to ICT (along with poor education and health systems) negatively impact the human development index of a society [3], and contributes to the digital divide that we observe nowadays.

With this in mind, we present our SV4D architecture, which is built based on low-cost, off-the-shelf hardware to provide these underserved communities with a communication for development (Comm4Dev) infrastructure. Additionally, our service framework is intended to cope with this occasional connectivity characteristic, allowing the development of easy-to-use applications destined to citizens with little or complete lack of digital knowledge, focusing on improving their quality of life.

The paper is structured as follows. Section 2 introduces our proposed SV4D architecture, detailing its hardware and software. Section 3 presents preliminary performance evaluation testes carried out on our testbed in Porto, Portugal, to understand the capability of the used technology and to assess the potential of the SV4D architecture for deployment in developing countries. And finally Sect. 4 concludes the paper.

2 SV4D Architecture

Figure 1 presents our SV4D architecture, which focuses on:

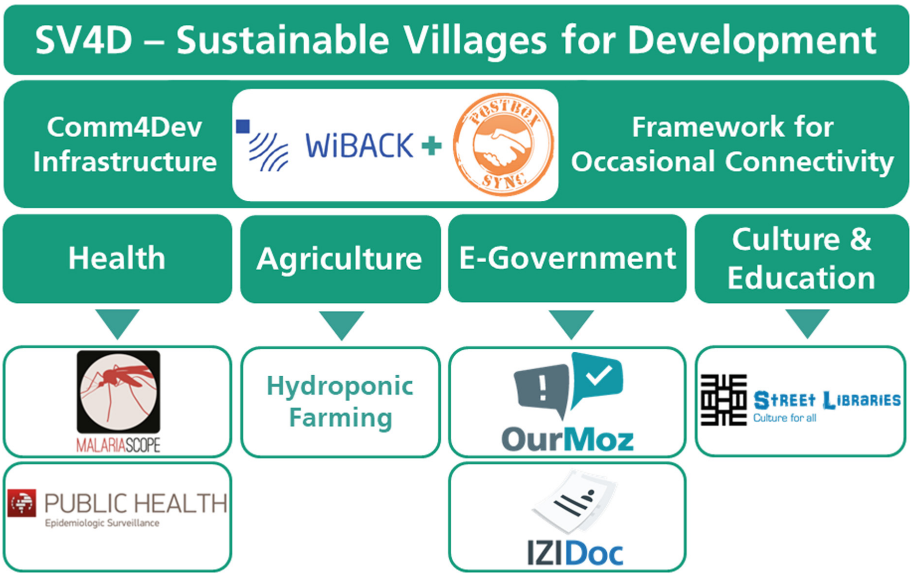

Fig. 1. The SV4D architecture.

Promoting the digital inclusion of citizens in isolated and poor communities of developing countries, offering them access to an infrastructure for broadband Internet.

Being far away from urban centres and having low population density make such communities unattractive for operators from a profit perspective, thus contributing to their isolation and increasing digital divide. The SV4D architecture adapts existing technology to connect citizens, filling in this digital gap.

Improving the quality of life of these underserved communities by employing a service framework that provides support to services such as health (e.g., in-situ malaria diagnosis [4]); education (e.g., literacy and access to reading [5]). This framework simulates the notion of permanent connectivity (based on the concept of Delay/Disruption Tolerant Networks [6]), allowing the exchange of data (i.e., emails, documents, e-books, diagnosis) between mobile devices until the information reaches a connected area, and then being forwarded to the desired destination (i.e., citizen, government agencies, schools, doctors).

Reducing deployment costs by allowing flexible and interoperable integration into existing networks, extending their capillarity towards remote communities and refraining from costly investments on infrastructure (i.e., optical fibre).

2.1 Communication for Development (Comm4Dev) Infrastructure

The Comm4Dev infrastructure is based on the WiBACK[1] technology, developed by Fraunhofer FIT/DeFuTech which aims to provide carrier-grade service quality for voice and data transmission over a large area with low-cost wireless technology.

In the context of the Comm4Dev infrastructure, the WiBACK QoS-provisioning, auto-configuration, self-management, self-healing and “Plug & Play” characteristics are an added value, as they allow the network to be setup and maintained by non-technical individuals as long as some basic training on the WiBACK is performed, i.e., expensive and often unavailable technical expertise is not needed.

Fig. 2. WiBACK (a) controller and (b) node.

The Comm4Dev infrastructure has two main components, namely the WiBACK controller and the nodes. The controller is responsible for managing and controlling the Comm4Dev network (cf., Fig. 2a).

The node (cf., Fig. 2b) is the two-radio element used to propagate the radio signal through directional antennas from one node to other neighbouring nodes. It is an outdoor and low power device, so it can be deployed off-grid and power supplied by

[1] http://www.defutech.de/en/wiback-technology/.

renewable energy sources. In non-off-grid installations, the WiBACK node can be powered through Power over Ethernet (PoE) (IEEE 802.3 at).

WiBACK nodes can be used as a relay to propagate radio signal. At an intermediate location, or at an "endpoint" installation (e.g., hotspot) it serves as a bridge to equipment that might be connected to it by Ethernet (IEEE 802.3) and/or Wi-Fi (IEEE 802.11a/b/g/n).

2.2 Framework for Occasional Connectivity – Postbox Sync

Our SV4D architecture also considers the Postbox Web software [7], later dubbed Postbox Sync, which has been improved to provide support to services that promote digital inclusion in the underserved communities.

Usually, in these communities, readily available data connections are limited. Thus, Postbox Sync provides means for a user to request and receive content (e.g., email) even when connectivity is not available. This is done by means of the Store-Carry-Forward (SCF) data exchange paradigm observed in Delay/Disruption-Tolerant Networking (DTN) [6]. Users temporarily store requests for data or the data itself on behalf of others for later forwarding to the target destinations.

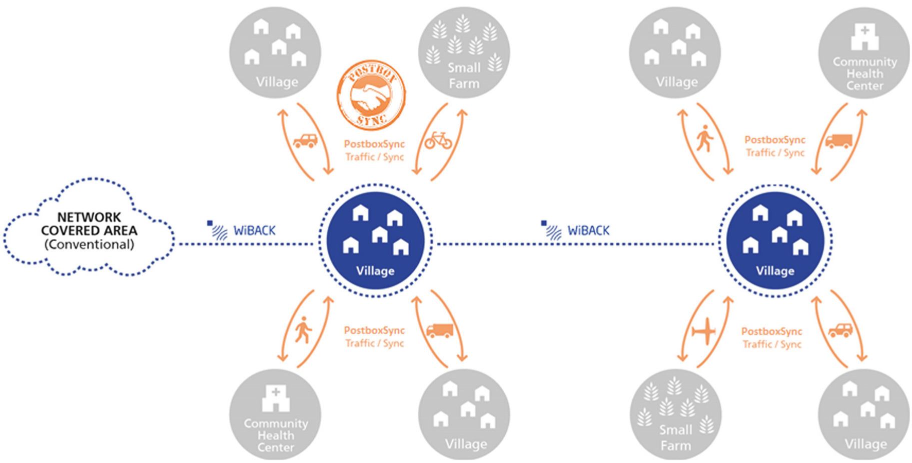

Fig. 3. Postbox Sync and Comm4Dev ecosystem.

This allows the development of services that are able to work offline without disruption, performing whatever tasks when connected in a transparent manner for the user, and that would be otherwise impossible to happen given the lack of continuous connectivity. The Postbox Sync framework considers two main types of users: one living in a partially or entirely disconnected area; and an intermediate one who often travels between connected and disconnected areas, called the Postman[2].

[2] The framework and the intermediate make reference to the postal service in which a box is used to store incoming and outgoing mails (i.e., data), and a postman bringing such mails to destinations.

The main idea is that users create data (e.g., email) on their mobile devices, and later synchronize this data with the Postman's device. When a Postman reaches a connected area, data is sent to the correct destination over the Web.

Figure 3 shows the Comm4Dev and Postbox Sync ecosystem, where the former extends connectivity from a conventional network-covered area to villages that were once offline, and Postbox Sync provides offline network access to smaller villages and localities, where it would be expensive or unnecessary to use additional hardware.

This way, we can effectively build a growing network that expands the existing infrastructure without interfering with it, and ensure that every user is able to send and receive data through the Internet.

3 SV4D Testbed Preliminary Performance Evaluation

The SV4D testbed, deployed in the city of Porto, Portugal, is geographically distributed in the buildings of Fraunhofer Portugal (FhP) and Engineering Faculty of University of Porto (FEUP), and comprises three sites (FhP North, FEUP, and FhP South) as depicted in Fig. 4.

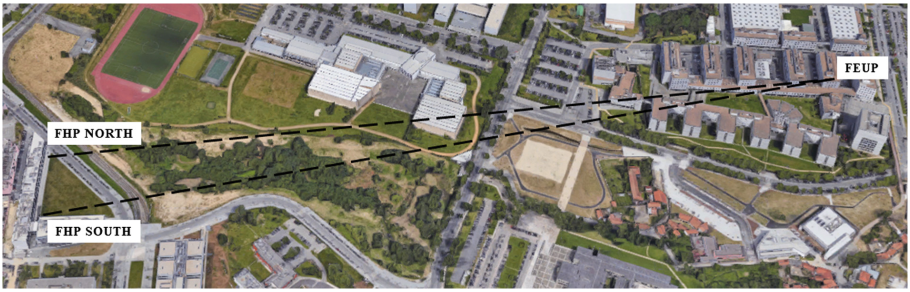

Fig. 4. SV4D testbed installation in Porto, Portugal.

The setup is as follows. The FhP North site is directly connected to the FhP test network by Ethernet, and extends the SV4D network and cellular services to the FEUP site through the Comm4Dev infrastructure based on the WiBACK technology. The FEUP site serves as relay, and extends the Internet and cellular services to FhP South. Finally, the FhP South site is the last hop of the testbed, and it counts with a commercial NanoStation 2 Wi-Fi Access Point (AP) and a GSM Base Transceiver Station (BTS) serving users at the 2nd floor of the office.

The services provided to users located at FhP South site include access to the SV4D network, GSM voice calls, and Short Message Service (SMS). Thus, besides the WiBACK technology that serves the purpose of backhaul and the commercial Wi-Fi AP that allows access to the SV4D network, our testbed comprises (cf., Fig. 5): an OpenEPC++ [8], responsible for managing and controlling the GSM network; and a nanoBTS [9], the GSM BTS allowing user access to our emulated cellular network.

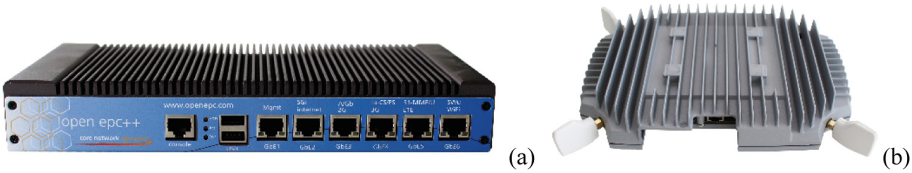

Fig. 5. (a) OpenEPC ++ and (b) nanoBTS hardware for cellular services.

The goals of this preliminary performance evaluation are to (i) understand the capabilities of the links of the Comm4Dev infrastructure; (ii) test the compliance of the Comm4Dev infrastructure with different access technologies (i.e., Wi-Fi and cellular); and (iii) guarantee that the SV4D architecture is able to provide services that can cope with online and offline connectivity.

For the tests carried out during the performance evaluation we used different smartphones (Samsung Galaxy S2, Samsung Galaxy Nexus, LG Nexus 4, and Motorola Moto G) with Android flavours ranging from version 4.1 to 5.1, and a laptop computer.

Regarding the network signal and bandwidth measurement tools we have considered the Network Signal Info and Signal Widget, and iPerf[3].

The tests comprised: iPerf sessions between the smartphones (placed at different distances from the Wi-Fi AP) and the laptop, as well as the users placing calls and sending SMSs to one another at different distances from the nanoBTS. Users could be inside as well as outside the office.

3.1 Testing Link Capability

The testbed was subject to several tests, and generated several iterations on the network configuration. This happened because the first bandwidth results were not in line with the ones claimed by the equipment manufacturer. In fact, the link between FEUP and FhP South was unstable, with intermittent connectivity.

Adjustments on the WiBACK antenna height, tilt, and WiBACK node software version were performed in the Porto testbed. Such optimizations stabilized the WiBACK links and improved the network bandwidth to around 1/6, for upload and download, of what it is specified by the manufacturer (up to 180 Mbps [10]).

By closely troubleshooting, we were able to identify two issues: (i) a misalignment of the emitting and receiving antennas; and (ii) the short distance between the two antennas at FEUP.

Once corrected these installation issues, and updated the software of the WiBACK radios, the links became very stable and the available bandwidth was improved. Only one issue remained, the partial obstruction of the Fresnel zone between the antennas of FhP North and FEUP. As this is not entirely clear of obstacles, the network bandwidth was not performing at its best.

3 https://iperf.fr/.

To overcome such issue, the antennas height should have been increased, but such intervention was not possible since the mast was not long enough. To minimize this issue, the radios at FEUP and FhP North were replaced by a newer hardware version N2C2, which is more resilient to this situations, and helped to improve the network bandwidth but still not as expected.

As these new nodes were running an old version of the WiBACK software, only after updating them '*in loco'* the links capacity as well as the available bandwidth achieved values in accordance to the ones claimed by the manufacturer, approximately 90 Mbps on uplink and downlink.

3.2 Supporting Different Access Technologies

Regarding the cellular service, the maximum distance at which the GSM signal and the GSM services (calls and SMS) are available is at around 200 m. The GSM signal reaches approximately 300 m, but at this distance, even with clear line of sight, the services are not available. This is mainly due to indoor antennas being used on the nanoBTS. By replacing these with outdoor ones, which have higher sensibility, we believe that the range covered by the cells can increase.

To summarize, we could observe that: at distances below 120 m, the lack of clear line of sight is not crucial, but it needs to be taken into consideration, because if there are too many obstacles along the way, the services might not be available at all; at distances between 120 m and 240 m, clear line of sight is imperative for the suitable provision of the services, but it is possible to have signal and services in the presence of some trees; and at distances between 240 m and 360 m only points with clear line of sight can receive the GSM signal. However, most of the time no services are available. In the case when they are available, the observed quality is not as good as with locations closer to the nanoBTS.

As for the access to the SV4D network, the Wi-Fi is usable only in a range of 35 m from the AP, and even in this range the maximum bandwidth achieved was 2.97 Mb/s. Beyond this distance and below 70 m the Wi-Fi signal is available, but the bandwidth is much lower - always below 1 Mb/s.

We could also observe that the quality of the Wi-Fi signal varies with the device being used to connect to it. The Moto G is the device that presents the best results, since it is the most stable of the 3 phones studied and the one that presents the highest bandwidth result - 2.97 Mb/s. On the other hand, the Samsung Galaxy Nexus is the one that presents the lowest results - its bandwidth never reaches 1 Mb/s. This behaviour can be related to the wireless card used in each phone, its antenna sensibility, the number of hosts in the vicinity and so forth.

3.3 Dealing with Intermittent Connectivity

To validate the application in an intermittent connectivity environment, periods of online and offline connectivity were simulated, with three smartphones distributed to different users which were asked to mimic a potential usage scenario of sending Emails (online and offline) to each other.

At each time, one of the users specifically created an Email offline and later paired his device with one of the other users to emulate the scenario where an intermediate user (e.g., Postman, as mentioned in Sect. 2.2) goes to an offline village to gather the villagers' requests.

At a first phase of testing, the users reported an issue related to the time needed to send/receive an Email. In cases when a user tried to open his Email inbox and the Emails had attachments of considerable size, the time to access the information grew exponentially.

The situation was carefully analysed and the problem was identified as an issue with the parsing of Emails inside the Postbox Sync package. After the improvements, the time needed to open the inbox grows linearly (and not exponentially) with the amount of information in the inbox (limited with the available bandwidth), and the time needed to fetch each email decreased in average approximately 50% resulting in a much more pleasant experience to the end user.

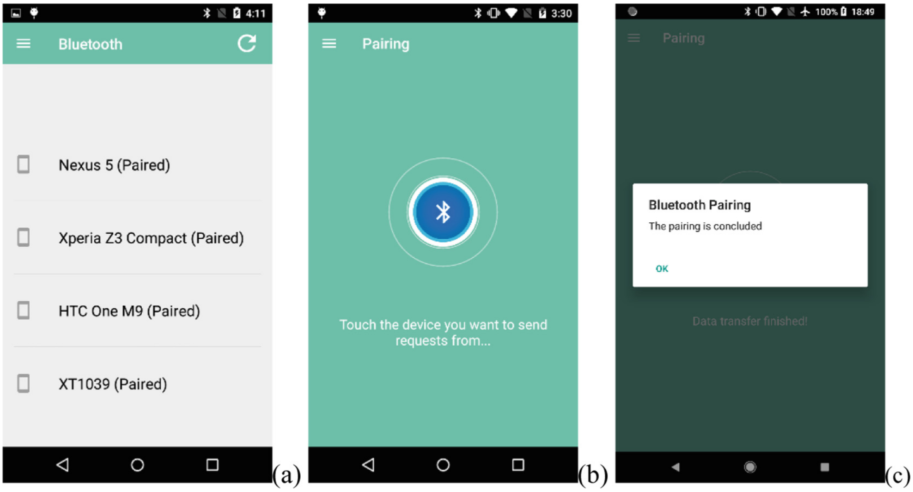

Fig. 6. (a) Device selection screen, (b) Start of data exchange, and (c) Data exchange concluded.

In a second phase of testing, we identified a possible issue with the communication pairing[4] mechanism, which is an important aspect of Postbox Sync since it allows users to opportunistically exchange data requests with intermediate nodes until these requests reach an area with connectivity.

The identified issue related to a scenario where a Postman had more than one Postbox Sync user waiting to pair its requests.

[4] Postbox Sync pairing refers to the process of establishing the communication link between devices and the exchange of Postbox Sync packages. In this case such process is done over Bluetooth technology.

After receiving the requests from the first user, the user acting as Postman remained on the screen showing that the communication pairing process had finished. In the case another user tried to connect to it (via Bluetooth), the device of the Postman understood this as a reconnect tentative from the former user and tried to re-establish the connection. As the MAC address of the client is different (e.g., a new user is now requesting communication pairing), the process of pairing for this new user would fail.

As this is a particularity of the envisioned scenario, we added a dialog informing the user that the communication pairing (i.e., data exchange) process is finished. Moreover, a button was included to redirect the user to the device selection screen in the case the user wants to initiate a new data exchange, avoiding the reported issue. Thus, after selecting the device for data exchange (Fig. 6a), the user who wants to send/receive data requests must confirm that by touching the screen (Fig. 6b). Once data exchange is concluded, a dialog (Fig. 6b) informs the user that the communication pairing is concluded, and after the user presses the "OK" button, the user is brought back to the device selection screen as shown in Fig. 6a.

4 Conclusions and Future Work

This paper presents our SV4D architecture that aims to promote digital inclusion and improve the quality of life of citizens in underserved communities of developing countries. The SV4D architecture is a collection of hardware and software tailored to answer the needs of such communities, which still lack access to broadband Internet today.

The hardware is based on WiBACK technology that considers off-the-shelf components turning it into a cost-effective alternative since it (i) allows the extension of the capillarity of existing infrastructure towards isolated areas; and (ii) requires little maintenance efforts given its auto-configuration, self-management, and self-healing features.

In regards to the software, the Postbox Sync framework allows the implementation of services to cope with an inherent characteristics of these communities, that is, the occasional connectivity. Thus, users can send and receive data even being offline, with content being forwarded either directly to the Internet once the user is connected, or to an intermediate user (i.e., Postman) who takes the content to a connected area.

The SV4D architecture has been tested and presents a level of maturity that allows for its deployment in real-world scenarios.

By looking at the preliminary performance evaluation tests carried out over the SV4D testbed, we could observer that:

1. Link capability is a product of proper antenna alignment, clear line of sight, and updated WiBACK software, and currently we are fine-tuning our testbed to reach the capability as per manufacturer specification;
2. The Comm4Dev infrastructure does support different access technologies, and coverage and data rates are solely connected to capabilities of the hardware considered and user devices;

3. The Postbox Sync allows users to produce content (i.e., emails) independently of connectivity availability, and may exploit contact opportunities with others to relay the produced content to the desired destination.

These observations show great potential of the SV4D architecture for deployment in underserved communities to allow mitigating the effect of digital divide, consequently improving the quality of life of citizens of such communities in developing countries.

As next steps, we are currently preparing the SV4D architecture for deployment of its first pilot in the Zambézia province in Mozambique. The first phase of this pilot comprises the installation of the Comm4Dev infrastructure, which will provide Internet access to the citizens while they are in schools, formation institutes, hospitals, and administration offices. Once deployed, we will be monitoring the utilization of the SV4D network with the intention to fine-tune it as to allow the best experience for users. In a later phase, applications running on the top of the Postbox Sync framework will be used to offer different services (e.g., education, health, and e-government) for these communities.

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