Enabling ICT Development with Low Cost High Capacity Wireless Networks in Remote and Underdeveloped Locations

An application to Public Finance Management in Comoros Islands

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***Abstract*— The "Union of the Comoros" is a volcanic archipelago nation in the Indian Ocean, consisting of three islands. About half the population lives below the international poverty line of US$1.25 a day. The interiors of the islands vary from steep mountains to low hills with mostly damaged or unconstructed roads to interconnect the several islets. This situation represents an extraordinary field test: the geographical isolation from other Countries, among the islands and within the same island, the development level of the population and the lack of infrastructures can be efficiently mitigated if a high capacity ICT infrastructure is realized, in order to provide social services (distance learning, telemedicine, financial administration) to the population, together with the possibility to access basic information on the Internet. In this context, we have put into practice a wireless network based on the use of low cost components, optimized for the transportation of large amount of bandwidths (minimum measured throughput is 65 Mb/s). The infrastructure has been made available at no cost for the people, since an extremely small percentage of them can afford regular Internet subscriptions. The network provides interconnectivity among the islets and local Hot Spot facilities at the islet level, free of cost for the end users. The local population has been recruited during the design and installation phase, in order to develop sufficient know how that allows them to maintain and even extend the infrastructure after its completion. Accessibility is guaranteed over the whole Country. To this aim, technical tests have been made in order to verify the affordability and reliability of the solution in the medium and long terms. The project is now being used to vehicle public finance management among the multitude of islets of the islands, under the endorsement of the World Bank.**

Keywords—component; wireless networks, long-haul wireless links, extended Wi-Fi, technological transfer

I. Introduction

The Union of the Comoros is a small archipelago with an estimated population of 734.750 (2010) covering a territory of about 1,800 square kilometers. About 52% of the population lives on the largest island, Ngazidja (or Grande Comore), which is also home to the Union capital, Moroni, the seat of the Union government. The second largest island, Nzuani (Anjouan), has 42% of the population, and the smallest, Mwali (Mohéli), six percent. A fourth island, Mahoré (Mayotte), claimed by Comoros Government, opted against independence from France, in a referendum held on all four islands in 1974.

Comoros has a high population density of about 390 inhabitants per square kilometer and a population growth rate estimated at 2.4%. An estimated 53% of the population is younger than 20-years-old. With a gross domestic product (GDP) estimated at US$540 million in 2010, Gross National Income (GNI) per capita is about US$750. Some 45% of the population lives below the poverty line, but poverty incidence varies significantly across the islands and is generally higher in rural areas and in Anjouan. Comoros ranked 169 out of 187 countries on the United Nations Human Development Index in 2012 .

The "Union of the Comoros" is the only state to be a member of all of the following: African Union, Francophonie, Organization of the Islamic Conference, Arab League and Indian Ocean Commission. However, Comoros is a fragile state with a long history of political and institutional instability. There have been some 21 coups and coup attempts since it declared independence from France in July 1975. In 2001, a reconciliation agreement was signed in Fomboni, capital of Mohéli. In December 2001, a new constitution was adopted creating the Union of the Comoros with considerable autonomy accorded to each of the three islands. While these achievements have allowed the establishment of a more representative institutional structure and a more stable political environment, the resulting administrative structure has proven costly and cumbersome.

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The Country is characterized by a poor transportation network, which results in difficult access to basic services, like health assistance and instruction. This results in disadvantages for the local administration efficiency as well.

In this paper we give an overview on the project for implementing a low cost wireless communication network over the three islands of Comoros, which helps overcoming the major infrastructure limitations, and highlight an example of the usage of this network through implementing a public financial management system proposed by the World Bank.

II. Towards an Effective Intranet/Internet Implementation

In a scenario like the one presented above, the access to health and instruction, as well as the optimization and enhancement of the local administration, can be simplified and improved, by interconnecting remote public sites, through Internet channels [1]. In a standard condition, where Internet connectivity is available, the most efficient way is to setup secure encrypted channels over the Internet (VPN), with high costs and relative exploitation possibility, considering that 3G connectivity is not yet available on the islands, and many villages are not provided yet with ADSL access. To overcome these issues, and to provide the whole State with an independent, high capacity network, we have decided to build it up by means of wireless backbone links, which interconnect the three islands and branch within each island, to ideally interconnect even the most remote villages [2]-[3]. Wireless technology guarantees lower implementation costs, a flexible network infrastructure capable of supporting future expansions and integrations, and with a wide geographical coverage.

At first, we have been working in order to identify a technological solution, suitable to solve the digital gap of poor/remote communities within the Country:

- Identifying the best-fit technology among the available ones
- Conducting a detailed survey in the three islands to detect the best locations for a capillary coverage of the whole Country
- Setting up a design and construction methodology to minimize the cost of the hardware, providing the possibility to install more than two times the base stations prevented in the original proposal, with less expenditures
- Putting into practice an efficient technological transfer involving stake holders from the local Institutions and from the local civil society
- Designing an efficient network, offering connection capability to the largest number of local communities, especially the remote ones
- Installing a suitable number of base stations, network links and network hardware, in order to implement the developed design
- Involving the local actors in the implementation process, in order for them to be able to maintain, extend and scale up the constructed network
- Piloting the applicability of the technological solution in the peculiar Comoros context.

Using low cost technology is the most relevant means to easily and rapidly put into practice a performing network. Many projects have been implemented worldwide, by using Wi-Fi cards with modified MAC and routing protocols. Unfortunately, the performance of these realizations is rarely analyzed from a scientific point of view, and most of the times no feedbacks are taken about the sustainability, reliability and durability of the installations. Hence, we have decided to use low cost technology, but we have installed servers to monitor the real time performance, constructing a database useful to analyze and verify limits and opportunities offered by low cost realizations, following an approach similar to that used by researchers doing experiments on community networks [4].

Once designed and realized, the backbone has been primarily dedicated to Intranet applications, but also to bridge the gap between existing telecom infrastructure and the people who need access to e-services, as well as stimulating Internet demand and providing Internet capability for governments and all public institutions. This has been obtained, by interfacing the whole backbone network to a high capacity Internet access.

III. Network Design and Implementation

The infrastructure is composed of a backbone network realized by means of point-to-point (P2P) links and a distribution network realized by means of point-to-multi-point (P2MP) broadcasters.

The implementation of the backbone by means of wireless technology allows to interconnect far locations at a very reasonable cost, which does not increase with the distance, and it is almost independent on the position, even when the locations are far, or even belong to different islands. The specific realization has been carried out in the 3.5 GHz bandwidth, which use has been granted for free by the local Telecommunication Authority (ANRTIC). Compact directive antennas have been mounted, using self-sustained poles, with maximum height 20 meters. MIMO systems implementing polarization diversity have been chosen. To minimize the costs, we have implemented Hyperlan transmitting systems, modifying the frequency of the carrier, in order to match the one authorized by the Ministry.

The distribution network has been realized by means of standard MIMO Hyperlan wireless technology in the 5 GHz bandwidth, implementing polarization diversity (IEEE 802.11h + IEEE 802.11n). This is characterized by limited line-of-site performance, but allows any remote end to connect to the distribution network by means of low-cost equipment.

The choice of the base stations has been made in order to cover the largest portion of territory. To simplify the installation procedure and to take advantage of the existence of power supply facilities, existing poles have been used. Among the available ones, the choice has been made following these general criteria, in order of priority:

- Maximum potential coverage
- Easy accessibility to the site
- Stability and robustness

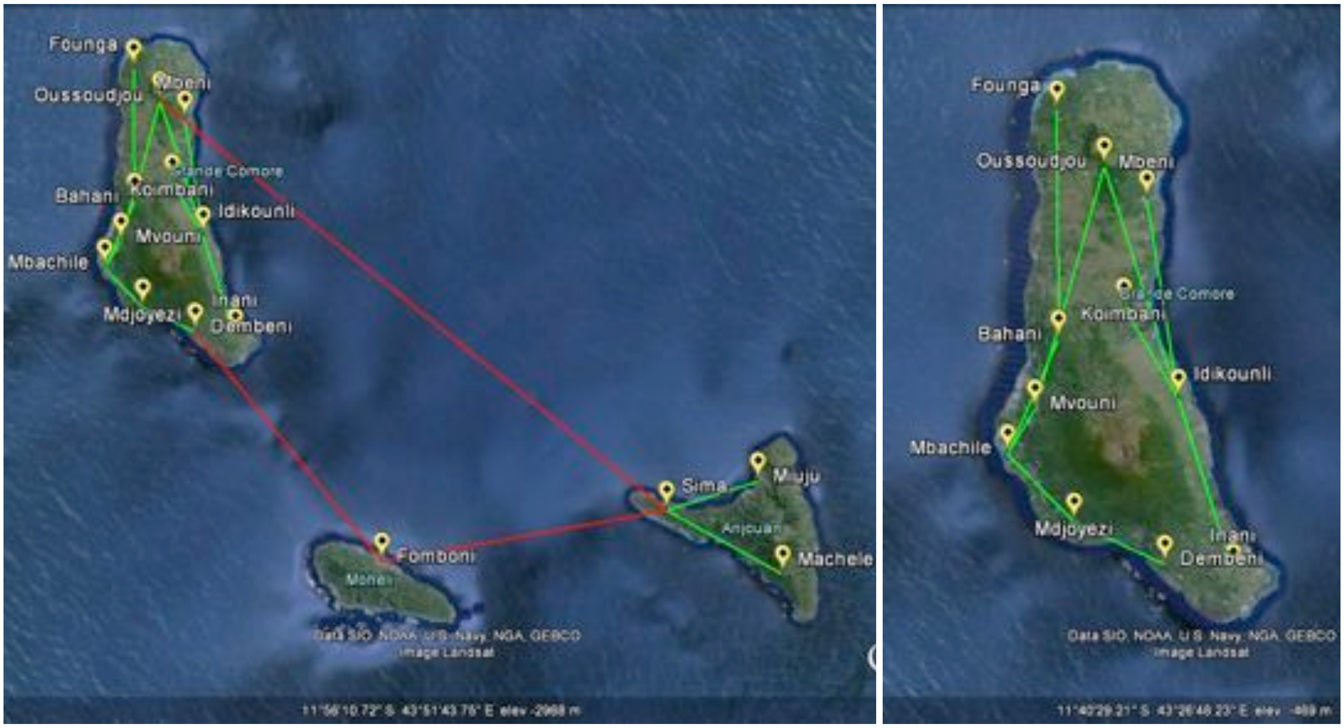

Fig. 1. Network map (background image courtesy of Google Maps. Left: the backbone interconnecting the three islands. Right: the Ngadjzia

All base stations host equipment for the backhaul network and for the distribution network, with the exception of the starting position, which has been located on the ANRTIC building roof. Base station locations allow a Line-Of-Sight (LOS) connection to at least a bordering one.

The territory of Comoros Islands is an electromagnetically tough environment, because of the presence of mountains and hills, particularly the volcano Kartahala on the main island. This has made more complex, but also interesting, the network design and configuration.

Figure 1 presents the map of the network, which includes a ring among the three islands (red line), with three major ramifications in Grande Comore, a single base station in Moheli and two ramifications in Anjouan, for a total of 18 base stations. In particular: 12 base stations in the Main Island, 1 base station in Moheli and 5 base stations in Anjouan (two of which autonomously installed by the locals). All base stations are provided with point-to-point links to interconnect them with the bordering ones, plus point-to-multi-point stations to redistribute the signal in the surroundings of each single base station. The base stations position have been chosen in order to guarantee network accessibility to the maximum number of villages.

IV. Transmitter Design and Implementation

One of the major design constraints has been represented by the need to lower the costs, in order to guarantee manageability, reproducibility, and scalability. On the other side, the cost constraint should not affect the performance and the durability of the system. For all these reasons, we have decided to adopt wireless solutions implementing Qualcomm Atheros [5] transceivers for standard Wi-Fi applications. Since several years Wi-Fi based equipment have been used to construct point-to-point (P2P) and point-to-multipoint (P2MP) wireless networks in digital divided areas, mainly (but not only) in Developing Countries [6]-[8]. Wi-Fi based equipment are easy to install and to configure, devices and subcomponents can be found off the shelf at extremely convenient rates. Despite the demonstrated possibility to carry bandwidths up to 100 Mb/s over 50 km or more [9]-[10], two major limitations have been measured by almost all researchers in all implementations: long term durability and inadequate strength

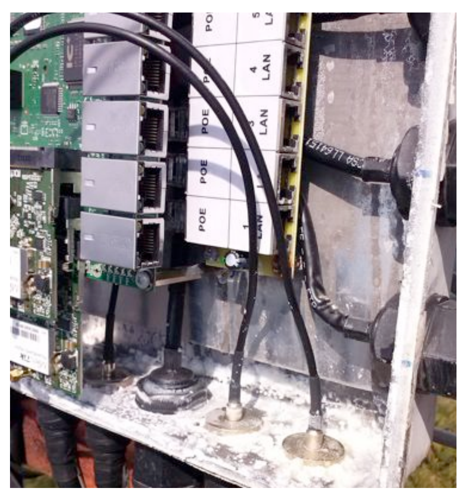

Fig. 2. Transmitter damaged by humidity (Mbachile base station)

Fig. 3. A transmitter positioned on a pole in Mvouni (Grande Comore)

to extreme weather conditions **Error! Reference source not found.**[9].

In an equatorial Country, weather is an issue. Problems are never generated by extreme temperature variations; temperature, on the contrary, is almost stable, and it never reaches values as cold as in a European winter or as hot as in a Middle East summer. The major problem in Comoros Islands is represented by water and humidity. During the rain season rain occurs frequently and precipitation conditions are extremely heavy. Humidity percentage reaches values constantly set around 100%. Fig. 2 shows an accident that happened in the very first stage of the project (November 2012). One transmitter was left open by mistake by an external person who climbed a mast in Mbachile. As a consequence, the electronics inside were irreversibly damaged.

Under these conditions, we have adopted simple and easily replicable manufacturing technique that allows to keep the electronic parts isolated from humidity. Waterproofing methodologies have been tested and verified. These procedures have been progressively adapted and after the first installations they have become a must for all new constructions (Fig, 3).

Fig. 4. Training Sessions: Network Designing (left) and Hardware Manufacturing (right)

V. TECHNOLOGICAL TRANSFER

One of the focal points of the project has beem the technological transfer to the local communities. For this reason, a great effort has been dedicated to the organization of courses to local selected people, in order to provide them with an adequate know-how to further manage the network. Thanks to the courses, the same persons have developed adequate design skills, as well as the capability to expand the network from scratch. In this way, not only the maintenance, but also an efficient scalability and extension of the project will be possible.

This training phase has been carried out through:

- selection of local technicians with basic technical skills and high motivations;
- organization of a one week, full-time course at the University of Qatar, during which the technicians have been inserted in a dedicated class with Qatari and Italian students belonging to the Colleges of Engineering; the course has been equally dedicated to the instruction on planning and design software tools, and the instruction on mounting, assembling and programming wireless transmitters (Fig. 4, left)
- enrolment of the same technicians into all phases of the network construction, from the identification of locations to the functionality verification (Fig 4, right).

After the completion of the infrastructure, a forum platform has been activated. Since then, the local technicians have had the possibility to connect to network experts who provide assistance and share experience through the Web, by means of a combined Wiki/Forum platform accessible through the iXem Labs Foundation web site [12].

VI. ASSESSMENT OF NETWORK PERFORMANCE

Thanks to the availability of about 20 microwave P2P links and 36 P2MP distributions (two per base station), it has been possible to assess the system, mainly its reliability, but also the overall technical performance, in a large variety of possible scenarios (radio links over forest, soil, hills, ocean) and for a wide range of possible distances, up to 130 km. Table I shows, for each P2P link, its length and associated landscape, the operative frequency, the expected received signal in LoS, at the higher modulation available for the specific link. Moreover, the difference between the measured situation and the ideal one is reported, together with the maximum throughput obtained on each link. As one can see, the situation is always good, the minimum available bandwidth is at least equal to 65 Mb/s, and the tough landscape is never affecting significantly the link with more than 10 dB additional attenuation, with one single exception (15 dB), because of a clear Non-Line-Of-Sight (NLOS) conditions.

TABLE I. P2P LINKS ASSESMENT

Link	Link characteristics					
	Length [km]	*Landscape*	*Freq GHz*	*Rx dBm*	*Add Att [dB]*	*Speed Mb/s*
ANRTIC Mvouni	4.06	City	3460	-46.4	-5	135
Mvouni Mbachile	6.02	Forest	3520	-49.3	-4	122
Mbachile Bahani	14.24	City+Forest	3700	-56.0	-3	101
Bahani Founga	26.12	Volcanic Soil	3480	-70	-8	86
Mbachile Msjoyezi	10.89	Forest	3440		-9	109
Msjoyezi Dembeni	11.38	Forest	3500	-55.3	-7	108
Mvouni Oussoudjou	29.62	Forest + Volcain Soil	3540	-54.4	-10	88
Oussoudjou Inani	49.82	Forest + Volcanic Soil	3440	-61.6	-15	76
Inani Idikounli	20.72	Volcanic Soil	3420	-68.7	-8	92
Idikounli Koimbani	11.45	Volcanic Soil	3460	144.7	-9	106
Idikounli Mbeni	22.98	Forest	3480	-61.9	-8	90
Dembeni Fomboni	57.99	Ocean	3500	-55.3	-9	65
Fomboni Sima	57.00	Ocean	3520	-54.4	-6	65
Sima Miuju	18.84	Sea + Forest	3540	-61.5	-10	88
Sima Machele	25.89	Forest	3420	-62.9	-2	86
Machele Jandza	3.08	Forest	3440	-55.9	-4	142
Jandza - Domoni	6.3	Forest	3460	-50.2	-4	127
Oussoudjou – Sima	129.13	Ocean	3500	-76.1	-8	62

As far as stability is concerned, after one year it has been possible to estimate the amount of interruption times, as a percentage over the total operational time of each single base station. As one can see, one of the major causes of interruptions has been determined by lack of maintenance. Meteorological factors are almost common. After the first damages, we have developed realization schemes that evidenced better robustness, particularly in presence of rain. Additional causes are given by power outage (whenever solar backup equipment are not present). Animals caused also one interruption, tentatively assimilating telecom equipment to food.

VII. APPLICATION TO PUBLIC FINANCE MANAGEMENT

Among all applications for which the infrastructure has been designed for, at the moment all efforts have been concentrated to the implementation of public finance management, under the umbrella of the World Bank activities in the area.

Through its technical assistance on Economic Governance Support project, the World Bank has supported the recent

TABLE II. BASE STATIONS ASSESSMENT

Link	Link haracteristics	
	Non Intentional Off Time [%]	*Major Reasons*
ANRTIC	93	Anattendance, Rain (damages)
Mvouni	95	Anatendance, Rain
Mbachile	92	Poer outage, Rain (damages)
Bahani	91	Anattendance
Founga	91	Anattendance, Rain(damages)
Msjoyezi	90	Anattendance, Rain(damages)
Dembeni	92	Power outage, Rain
Oussoudjou	89	Power outage
Inani	91	Anattendance, Animals
Idikounli	92	Anattandance, Rain
Koimbani	93	Anattandance, Power Outage
Mbeni	100	-
Fomboni	91	Anatendace
Sima	100	-
Miuju	92	Anattendance, Rian
Machele	93	Rain

reforms on public finance management and the strengthening of the public sector. As a result, the civil servant census is now finalized and several reforms on public finance management, including the reorganization of the Treasury, are being implemented. The World Bank continues to support its community development project which is poverty reduction oriented in rural area through cash for work program and community development program. This has provided important interventions to disadvantaged communities and vulnerable groups, including women and youth. It has also increased access to basic schooling for Comoros children and enabled the people of Comoros to participate in the local development process. The Bank is also engaged with the government and the people of Comoros, as well as with other development partners, in knowledge sharing and dialogue on critical issues such as debt forgiveness, public sector reforms and climate change to enable the Country to develop foundations for sustainable development. Additional efforts were put to improve the efficiency, accountability and transparency of public financial management, as well as the management of civil service human resources and wages.

In this scenario, the network infrastructure supports the computerization of public finances, broadening the scope of support for Civil Service Reform (CSR) to go beyond the technical fulfillment of the organic frameworks. More specifically the project will: (a) address the financing needs related to the strengthening of the public finance legal, institutional and organizational framework, including the acquisition and deployment of key Integrated Financial Management Information System (IFMIS) components; (b) develop a comprehensive reform strategy of the civil service management; (c) finance additional demand-driven activities to support the development of leadership skills, consensus building, and change management; and (d) finance additional operational costs to cover the extension of the closing date for 30 months.

These development objectives can be successfully exploited though broadband networks. The computerization of public finances provides connecting all public institutions of Finance (Union and Island) including treasures, public functions to the Computer Centre set up within the Ministry of Finance. All these activities are being addressed thanks to the availability of the wireless infrastructure while it is being developed and tested. In particular, the World Bank will finance (a) membership and participation in the FLY-LION3 cable -- the link between Comoros, Mayotte and Madagascar-- under a Public-Private Partnership (PPP) arrangement, which will ensure connectivity with LION-2; (b) advance purchase of additional broadband capacity from East African Submarine System (EASSy), FLY-LION3 and/or LION2 and its use to provide demand stimulation measures by providing affordable bandwidth to key users such as the university, schools, hospitals, etc.; and (c) additional measures to stimulate demand including by promoting the creation of local ISPs and establishing a carrier-independent Internet Exchange Point (IXP).

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