Design and deployment of a low-cost communication solution in rural areas: case of the Central Region in Mali

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Abstract. Nowadays the central region of Mali is in a total insecurity. Malian army is not able to protect local population. The uses of Telecoms and IT technology can change the daily life of these populations. Each village is not able to prevent threat alone. Neighboring villages can together resist the attacks of bad guys. Because of barriers such as cost and skills/knowledge in ICT, operator's mobile technologies are not adapted for these populations. The most of villages are connected to operator's network. The average rate of mobile device equipment is correct. Our study focuses on the provision of low-cost telecommunications services from access points running on OpenWrt. OpenWrt's ability to transform access points into Linux mini machines is used among other things to integrate IP telephony and VPN services. Thanks to the judicious choice of OpenVPN mode of operation we propose in this article to extend the functionalities of the Zeroconf protocol beyond a local network. This solution enables the reduction of communication costs and access to network services without configuration. Using a Wi-Fi extension of the operators' GSM networks in each village and low-cost devices we propose a solution for increasing security alerts between neighboring villages, developing the efficiency of the farmer's activities and optimizing the distribution of resource.

Keywords: security, low-cost, OpenWrt, VoIP, OpenVPN, Zeroconf, Wi-Fi.

1 Introduction

Communication and information technologies play a major role in all areas of people's social life. It is no longer necessary to demonstrate the influence of these technologies in facilitating the everyday life of peoples. But in order to be effective and efficient, it is important to equip each people with the means of communication adapted to their income and skills/knowledge, that is to say to their needs. The regions in central Mali, including the Dogon country, are today characterized by an unprecedented security crisis. The country's security forces, particularly the Malian army, are no longer able to guarantee the security of the villages located in this region. The villages taken separately are not able to retaliate and repel the aggressors. A system of

alerting and calling for help from neighboring villages in the event of a threat can save lives. Many of these villages are connected to the network of telecommunications operators. The area's mobile phone penetration rate is also relatively high. The major feature in this area is that the majority of the population in this area has very low income and skills/knowledge in ICT. The traditional means of communication available to these populations are not effective in the event of a threat. Lack of communication credit is one of the biggest problems faced by these populations. To effectively meet the needs of the population, the proposed solution must be very low cost and easy to use. We have opted for Wi-Fi access point with OpenWrt firmware and Zero configuration networking (Zeroconf) solutions. The solution proposed in our study is not only satisfy the primary communication needs but also allow each adapted terminal holder by simple action on a reduced combination of keys to alert a set of predefined structures in the short term. In the long term, this solution will be an integrated communication system that would facilitate the daily life of the population.
This is the reason why we propose a solution that facilitate issue threat alerts between neighboring villages, increase the productivity of farmer and make better food distribution among populations.
The proposed system is based on the extension of operator networks in each village through Wi-Fi access points.
The easiness of its implementation and the low-cost device make the efficiency of this solution. It is beneficial for populations by giving a better access to the communication resources for daily life and security. The system can offer the following services:

- Secure voice, video and data calls;
- Caller geolocation.

The rest of this work is organized as follow:
Section II talks about the state of art;
Section III describes the proposed architecture;
Section IV presents the results;
Section V concludes the paper.

2 State of art

2.1 Security problems in the central area of Mali

Since the 1960s, the Republic of Mali has faced a series of multi-dimensional security crisis. Since 2012, linked to the fall of the Libyan regime, the crisis has reached an unprecedented level. Despite the intervention of the UN, African and French forces, the crisis is only getting worse. Today no region is really safe in the whole country. Mainly the north and the center of the country are today in total insecurity as shown in the Fig.1. below [1].

Fig. 1. Security situation of Mali

Very deadly attacks were committed on the civilian population in this central area, particularly in the “Dogon country”. These attacks involve terrorist groups and community militias. This renewed tension has created an inter-communal crisis in this part of Mali.

The lack of adequate means of communication and skills/knowledge in ICT of the population does not allow the affected populations to launch SOS in real time. As is shown below, the provision of suitable communications tools would have facilitated the call for help and thus limited the killings.

2.2 Problems with device usage: Difficulties of configuration of devices

The skills/knowledge in ICT of the population in this area is relatively low. With several successive years of crisis, the population is dropping out of school.
Mobile and smartphone penetration increases in the sub-region is 35% and increases by 5% per year for Mali [2]. The evolution of operators' networks makes it possible to

offer innovative services. The switch from 2G to 3G or from 3G to 4G in some localities has made it possible to generalize VoIP. The use of VoIP applications such as WhatsApp, Viber, etc. by young people revolutionized the rural world. For the configuration, many use the services of other insiders in their localities, or very often in the cities. The maneuverability of the mobile terminals becomes an additional difficult for rural users.

2.3 Overview interconnection and coverage technologies

Several solutions were developed around the world. The main systems are:

The GSM solution. An effective way to connect rural areas is the commissioning of new BTS sites at the level of the villages still not covered and thus connected to the network. A wide range of GSM modems make it easy to access the GSM networks of wireless operators in one or more Wi-Fi access points, depending on the size of the village.

Long Range Wi-Fi. Long-range Wi-Fi is an improvement in the transmission characteristics of the IEEE 802.11 specifications. Long-range Wi-Fi is used for low-cost, unregulated point-to-point computer network connections, as an alternative to other fixed wireless, cellular networks or satellite Internet access.

Long range Wi-Fi has been used in the developing world to link communities separated by difficult geography with few or no other connectivity options. Some benefits of using long-range Wi-Fi for these applications include:

- unlicensed spectrum ;
- smaller, simpler, cheaper antennas ;
- availability of proven free software like OpenWrt;

This solution can be used especially at villages where coverage of operator networks is not ensured. Operators deploy their network only in profitable areas. This solution will solve the problem of access in villages not exceeding a certain distance.

Worldwide Interoperability for Microwave Access (WiMAX). WiMAX is an IEEE standard 802.16x. WiMAX is a technology standard for long-range wireless networking for both mobile and fixed connections. While WiMAX was once envisioned to be a leading form of internet communication as an alternative to cable and DSL, its adoption has been limited primarily owing to its much higher cost compared to Wi-Fi. This technology allows digital data transmission over different high-frequency bands ranging from 2 to 11 GHz. Its main feature is that it supports high-speed data over very long distances, ranging from 10 to 50 kilometers, depending on the obstacles. The ability of WiMAX technology to prioritize the use of available bandwidth between different Internet users can be of great use in multiple circumstances.

Microwave solution. A Hertzien beam is a signal transmission system whose function is to connect two distant points geographically. This communication passes through radio waves with carrier frequencies ranging from 1 to 40 Ghz. Directional antennas allow the signal to be concentrated to facilitate good reception. New generation of this type of wave is no longer sensitive to precipitation and fog. FH can be seen as an alternative to FO to provide a high-speed link. It is an easy to install and suitable solution for rough areas. It is possible to connect different villages by microwave transmission system. It requires high towers and line-of-sight antennas. It’s not very suitable in many communities.

Vsat solution. Very Small Aperture Terminal (Vsat) is a satellite communication technique. It uses a parabolic antenna of relatively small diameter (1 to 3 meters) and requires little ground resources. Vsat can therefore be useful for connecting a small site to communication networks, whether for telephony or for the Internet. This solution relies on the ability of satellites to cover all areas, including the most remote areas. This solution is well suited in very rugged and distant from one another areas.

TV White Space (TV WS) solution. TV White Space refers to the unused TV channels between the active ones in the VHF and UHF spectrum. It has since been researched and proven that this unused spectrum can be used to provide broadband Internet access while operating harmoniously with surrounding TV channels. White Space broadband can travel up to 10 kilometers, through vegetation, buildings, and other obstacles. Tablets, phones, and computers can all access this wireless internet using White Space through fixed or portable power stations. The actual amounts of spectrum vary by region, but White Space spectrum ranges from 470 MHz to 790 Mhz. Portable devices are not yet available, but fixed devices offer internet services in rural areas for businesses, residences, and institutions. Google and Microsoft have invested in TV WS technology in developing countries. Microsoft's 4Afrika initiative is focusing on White Space technology throughout the continent, hoping to bring millions of people online, and has projects in place in Tanzania and South Africa. TV WS will be a good perspective for future broadband access technologies in developing countries, [3, 4].

All these solutions can be used depending on the characteristics of local area. Our previous work focuses on long-range Wi-Fi technology for remote site interconnection technology. Local coverage will be based on Wi-Fi technology, saving us from interworking.

2.4 Embedded systems: OpenWrt and Asterisk

OpenWrt is a Linux operating system for embedded devices supporting many access points. It allows transform access points into a mini Linux machine, which has many advantages over the original firmware. With more than 3,000 standardized application packages, OpenWrt is not limited to applications provided by the access point's manufacturer by default. Applications available for installation include Asterisk IP Voice Platforms. OpenWrt is used in the research world and its reliability has been proven through several major communication projects in remote areas in England [5], in South Africa [6], etc. The use of OpenWrt coupled with the IP telephony services it implements allows for a low-cost communication solution with low energy consumption [7]. With the sharp drop in solar panel prices and the average monthly sunshine from 284,7 to 322,0 hours in Mali [8], the energy problem is becoming less and less crucial.

2.5 Zeroconf and compatible devices

Zero-configuration networking (Zeroconf), IETF project, is the generic name of a set of protocols to automatically create an IP network that can be used without any particular configuration. Zeroconf is now one of the most widely used technologies for the discovery of services in local networks without prerequisite configuration. Zeroconf is more and more installed on different operating systems and implemented in many network equipment and devices such as smartphones, printers, etc. This allows inexperienced users to connect to a network and expect it to be automatically functional [9].

Multicast DNS (mDSN) and DNS Service Discovery (DSN-SD) are the protocols used by Zeroconf.

DNS Service Discovery is a way of using standard DNS programming interfaces, servers, and packet formats to browse the network for services.

Multicast DNS (mDSN) is a way of using familiar DNS programming interfaces, packet formats and operating semantics, in a small network where no conventional DNS server has been installed [10,11]. These two services are complementary.

The two main Zeroconf implementations are presented below.

Apple Bonjour. Bonjour, also known as Zero -configuration networking, enables automatic discovery of computers, devices, and services on IP networks. Bonjour from Apple uses mDNS and DNS Service Discovery.

Avahi. Avahi implements the Apple Zeroconf specification, mDNS, DNS-SD and RFC 3927. Avahi had already become the de facto standard implementation of mDNS/DNS-SD on free-software operating systems such as Linux.

Zeroconf works only on local network by default.

2.6 VPN Level II: OpenVPN for android and Zeroconf

VPN is a secure tunnel allowing communication between two or more entities through insecure networks. Level 2 VPN encapsulate data in frames that will be conveyed in the point-to-point communication tunnel. Connected to two different local networks, this VPN, running in bridge mode, allows customers to behave as belonging to the same local network. It's necessary to create virtual interface named bridge interface in the VPN server. The configuration in this case requires creating a virtual interface called bridge interface on the VPN server. The physical network interface of the server and the interface created on the VPN server must be connected. In this mode, VPN clients and local network machines exchange Zeroconf messages. In our proposal, we use the OpenVPN server which not only supports bridge mode, but also offers clients on Android. The OpenVPN Connect client supported by all Android and IoS devices allows geographically dispersed users to connect to the server and everything happens as if they are in the same local network. The choice of this particular type of VPN allows extending the functionalities of the Zeroconf protocol, initially intended to work only in a local network.
Users in rural areas who are not in the same geographical area and do not have good ICT skills/knowledge will benefit from the ease of use of the Zeroconf protocol through applications such as Wi-Fi Walkie-Talkie or Blink. Several studies have shown that the ease of use of a technology has a positive influence on its adoption by users [12, 13].

3 Proposed architectures

The experimental area consists of four villages around the main city of Bandiagara. Only the village of Douro does not have good coverage in the case of our study. We present the main coverage extension techniques for villages that have partial network coverage or do not have access to operator networks. Once network access is guaranteed, Zeroconf solutions allow everyone to access all services offered thanks to the widespread use of Wi-Fi and Internet in all villages.

3.1 Wireless Coverage Extension Techniques for Operator Networks

None of these technologies alone is able to provide optimal interconnection and coverage of the study area. We propose the different options according to the geographical situation of the village.

Villages with network coverage. Depending on the size of the village, we install Mobile Wi-Fi Hotspot dual SIM modems for security measures. Several ranges of access points are available and for all exchanges at Ubiquiti, Netgear, Huawei, Linksys, Dlink or TP-Link. Fig. 2 below shows the configuration of the networks of the villages covered by GSM.

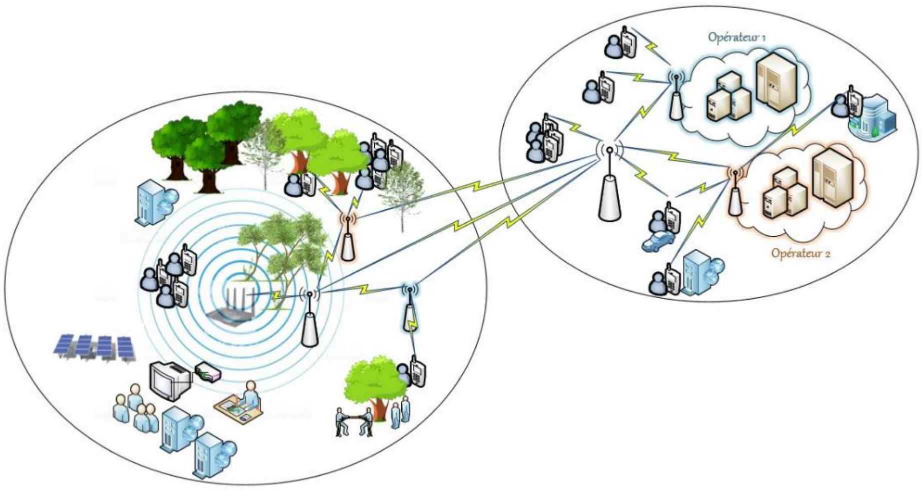

Fig. 2. Coverage of villages with GSM coverage

Villages without GSM coverage in the sparsely hilly area. The coverage of the villages in the sparsely hilly area will be through Long Range Wi-Fi. The figure below shows the architecture of the network of villages not covered but very sparsely rugged. The LAN interface of our access point is connected to the LAN interface of the long-range Wi-Fi. At the remote site, the LAN interface is also connected to the LAN interface of the access point.

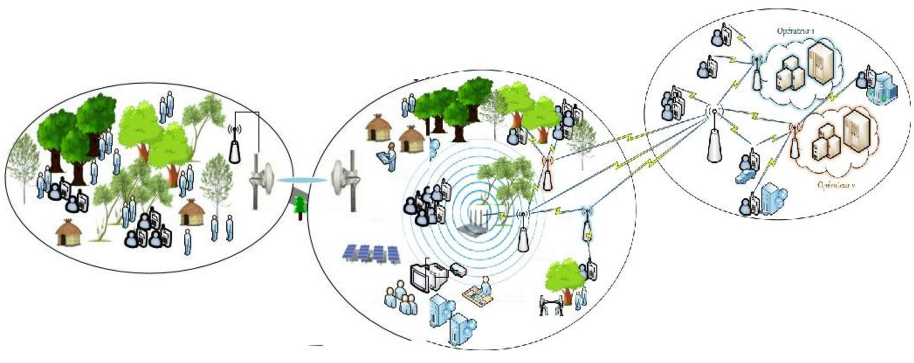

Fig. 3. Coverage of villages in sparsely rugged areas

Villages without GSM coverage in rugged areas. In the Dogon Plateau, the sudden changes in terrain mean that the coverage requires means of transmission that guarantee a total coverage. This is the case for Vsat coverage and to some extent WiMAX.

One of these two technologies will be used to ensure good radio coverage along the cliffs.

The choice of radio signal transport technology in villages is made on the basis of geographical location. In all cases, the end user connects to the network via Wi-Fi.

Once the coverage of the different villages is assured, the second step is to configure all network equipment.

3.2 Installation of embedded systems: OpenWrt & Asterisk

We choose OpenWrt compatible Wi-Fi access points and install embedded systems OpenWrt and asterisk as shown below.

For the proper functioning of the system, we use access points with the following characteristics:

- At least 8 Mb of flash memory;
- 64 Mb of RAM.

OpenWrt installation. We downloaded the compatible version of OpenWrt with our access point and installed it via the access point administration interface. Once OpenWrt installation is complete, we process installation of asterisk. After that All WI-FI access points are ready to receive applications based on OpenVPN and VoIP. Below are shown screens of complete installation of OpenWrt (Fig. 4.) and asterisk (Fig. 5.).

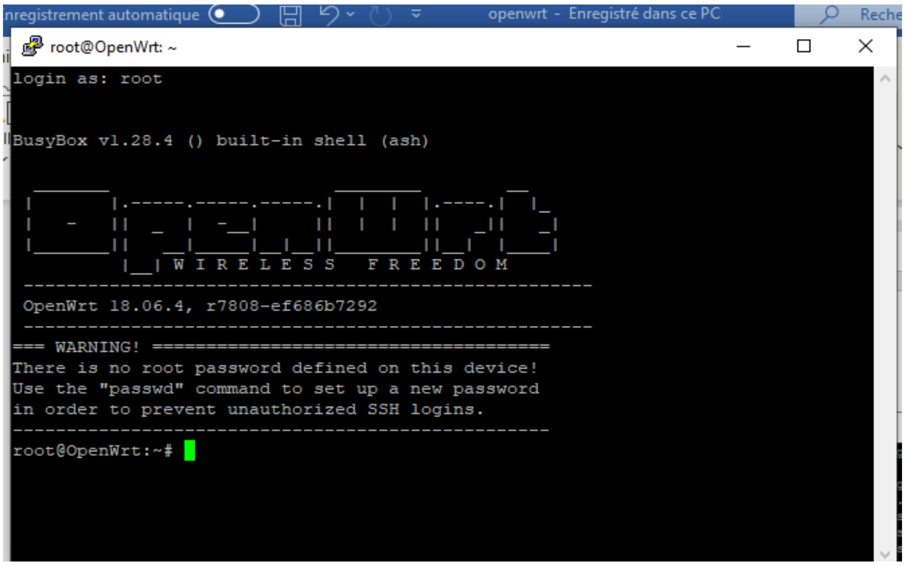

Fig. 4. OpenWrt complete installation screen

Asterisk installation.

```
root@OpenWrt:/etc/asterisk# opkg install asterisk13 asterisk13-codec-ulaw asterisk13-chan-sip
Package asterisk13 (13.20.0-4) installed in root is up to date.
Package asterisk13-codec-ulaw (13.20.0-4) installed in root is up to date.
Package asterisk13-chan-sip (13.20.0-4) installed in root is up to date.
root@OpenWrt:/etc/asterisk#
```

Fig. 5. Asterisk complete installation screen

Create interconnection Asterisk GoIP. To make users be able to communicate with operators customers, it's necessary to create trunk between Asterisk and GoIP. GoIP consists of VoIP GSM gateways and SIM-banks for IP-telephony. The equipment is designed for the direct connection and a VoIP voice traffic transmission via the GSM network. In each Wi-Fi access point after loading asterisk, create in sip.conf user's account.

```
[2001]
username=2001
secret=1234
context=gns
host=dynamic
type=friend

[2002]
username=2002
secret=1234
context=gns
host=dynamic
type=friend
mailbox=2002
```

```
[2003]
username=2003
secret=1234
context=gns
host=dynamic
type=friend
```

Fig. 6. User's account creation

Trunk's account creation. Trunk must be created at the access point and GOIP levels. Below is shown the procedure for creating trunk from the router to GOIP and vice versa: Fig. 6. at access point and Fig. 7 at GOIP levels.

```
[goip]
type=peer
secret=goip
context=gns
host=192.168.1.210
port=5060
insecure=port,invite
canreinvite=no
qualify=yes
dtmfmod=rfc4733
allow=ulaw
```

Fig. 7. Trunk's account creation to GOIP

Fig. 8. Trunk's account creation to modem router

Internal and to GoIP numbering plan definition. The definition of the numbering plan must be at the router and GOIP levels. Below is shown configuration of numbering plan for calls that will be done in each router: Fig. 9. at modem router and Fig. 10. at GoIP levels.

Fig. 9. Numbering plan at access point level

Fig. 10. Numbering plan at GOIP level

4 Results

After implementation of our solution, we did different use cases. Test results demonstrate that the proposed configuration meets the need of population. We present some of our study's results.

4.1 Use case 1: Walkie Talkie over OpenVPN

Fig. 11. Shows screen of two Android mobile phones in different villages using Walkie Talkie application to communicate. Thanks to Zeroconf and OpenVPN LAN solution is available for WAN [14].

Fig. 11. Walkie Talkie communication over OpenVPN

4.2 Use case 2: call between two users located in different villages

Using Blink an user from Songo village calls another one from Doucombo. They discover each other on the network and use call service without any configuration. This call is available thanks to our judicious choice of OpenVPN bridge mode.

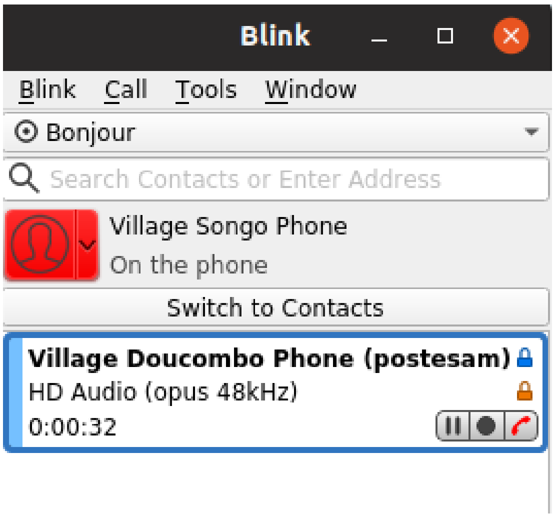

Fig. 12. Call using Blink without configuration

4.3 Use Case 3: File transfer

This case allows transfer image from one village to another. By click on the name of village you can send file or image from one village to another.

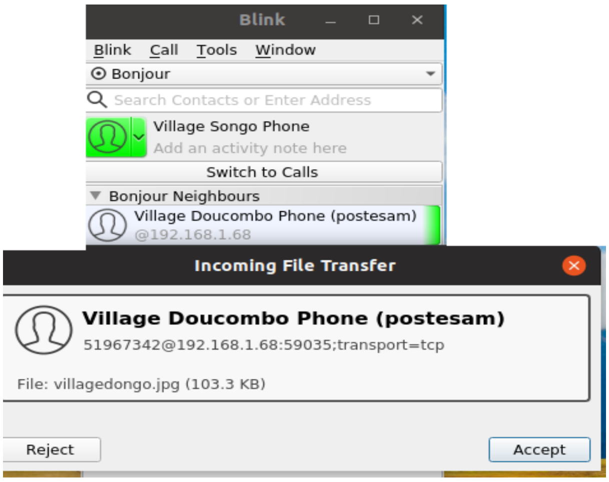

Fig. 13. Image sended by Doucombo to Songo

By clicking on Accept, Songo receives image as shown in Fig.14.

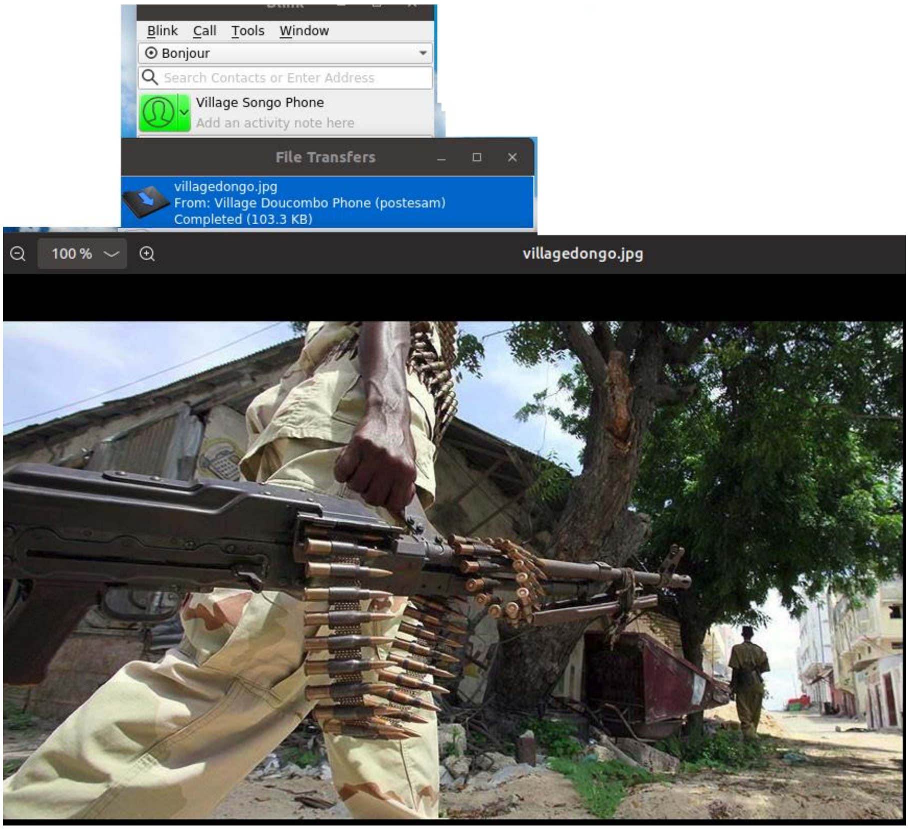

Fig. 14. Image received by Songo from Doucombo

4.4 Use case 4: Call using softphone

In this use case, one user calls from softphone device to mobile phone via operator's network. Communication is made via GoIP located in any place thanks to OpenVPN.

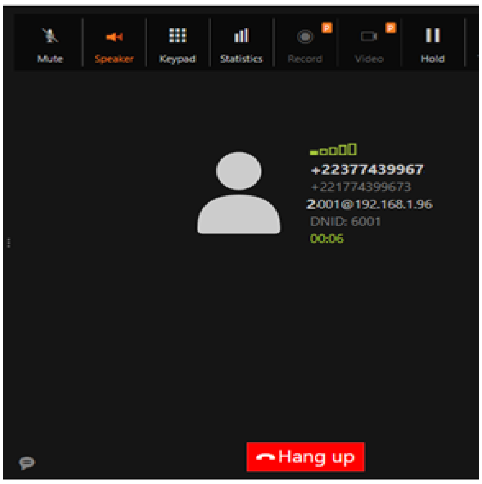

Fig. 15. Call from Softphone to operator's user

5 Conclusion

After a detailed study of desert techniques in less favored areas, we propose a low cost solution. This solution is based on Long Range Wi-Fi technologies for the transport of signal between villages. The last mile is built only on Wi-Fi technologie. All access points works with embedded software OpenWrt, Asterisk and OpenVPN. This allows easy maintenance of guarantees low consumption.

Use Walkie Talkie application is very useful for low ICT Skills/Knowledge population of rural area. This application allows call alerts in case of threat by simple clicking on a touch. Thanks to OpenVPN user located in any network can benefit all available services.

At any time or moment user can initiate or receive calls to or from any operator's network thanks to a GSM gateway and OpenVPN.

If, at first, priority is given to voice and video communication, other applications will be developed very quickly to improve the living conditions of the populations in these areas.

Prioritization of applications and users in saturation situations remains our next objective. These objectives will enable us to size the network in order to guarantee end-to-end quality of service in line with standards. No less important factor is the awareness of vulnerable populations who need reliable means of communication.

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