Wireless communication system design for refugee camps and conflict areas

A Degree's Thesis

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by

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Science and Telecommunication Technologies Engineering

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Abstract

The specific goal of this project is to design a telecommunication system for a refugee camp, answering to a Doctors Without Borders' request. The camp is located in an isolated rural area where it is impossible to communicate to the Internet through terrestrial infrastructures, therefore minimum satellite backhaul bandwidth has been estimated. A local network has been designed, including both hardware and internal traffic's management, as well as the energy supply using solar panels. The local network must enable internal communication between doctors while the satellite backhaul must allow external communication. The global aim of the project is to contribute to the improvement of refugees' health trough the supply of communication services for doctors.

Resum

L’objectiu específic d’aquest projecte és dissenyar un sistema de telecomunicacions per a un camp de refugiats a petició de l’organització Metges Sense Fronteres. El camp està situat en una zona rural aïllada i és impossible la comunicació a internet amb infraestructures terrestres, per això s’ha calculat la sortida troncal mínima necessària via satèl·lit. S’ha dissenyat també la xarxa local, tant a nivell de hardware com de gestió del tràfic intern, així com la provisió d’energia utilitzant plaques solars. L’ús de la xarxa WiFi local ha de permetre la comunicació interna del personal sanitari, i la sortida via satèl·lit la connexió exterior. L’objectiu general del projecte és contribuir a la millora de la salut de les persones que viuen al camp a través de la provisió de serveis de comunicació als metges.

Resumen

El objetivo específico de este proyecto es diseñar un sistema de telecomunicaciones para un campo de refugiados a petición de la organización Médicos Sin Fronteras. El campo está situado en una zona rural aislada y es imposible la comunicación a Internet vía infraestructuras terrestres, y por eso se ha calculado la salida troncal mínima necesaria vía satélite. También se ha diseñado la red local, tanto a nivel de hardware como de gestión del tráfico interno, así como la provisión de energía a través de la utilización de placas solares. El uso de la red WiFi local tiene que permitir la comunicación interna del personal sanitario, y la salida vía satélite la comunicación exterior. El objetivo general del proyecto consiste en contribuir a la mejora de la salud de las personas que viven en el campo a través de la provisión de servicios de comunicación a los médicos.

For those who have always been there (and will always be).

Acknowledgements

Many people have contributed to become this project a reality. In first place, Josep Vidal and Eva Vidal, whose advisory and ideas have set the fundamentals of this project. Thank you to both of them for their time and dedication. In second place, Jaume del Olmo, for all his help during the WiFi network calculations and adding his experience in some projects similar to this one. Thirdly, Irene Baeza, who has realized a project that complements this one and has contributed with some interesting ideas. And finally, and not for this reason less important, to all those people who have helped me with the most insignificant details, but without their help this project would not have been possible, especially my parents, my brother and Josep, Pablo and Àlex.

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1. Introduction

Communication in the Emerging Regions is needed as much as in the First World. Not only for interpersonal communication or business purposes, also as a quick mean to generate alarms when there are diseases, epidemics or armed conflicts.

It is not only necessary for autochthonous people, but also for those that spend their lives trying to improve their quality of life. To do so, they need some medicines, food and drinking water, but they need some communications too, that will allow solving some problems before being too late.

But communication in the developing countries is not a simple issue. There are few infrastructures and the mobile coverage is present, in the best scenarios, only in the cities. Although there has lately been a huge increment of the infrastructures and the number of mobile phones through the population, there are still lots of places where telecommunication facilities could be improved[1]. This lack of connection possibilities is seen especially in rural areas. It is caused because one of the most important factors that has helped to raise the possibilities of having a mobile phone and coverage has been the private entrance. It has been allowed by the government for providing mobile telephony, and their main objective is to make business, which they would probably be unable to do in rural areas.

If private companies are not arranged to providing mobile coverage to rural places, there would be the government the one who realizes all this installations, and it is not happening. In addition, we have to know that leasing some satellite bandwidth in some emerging region costs more than 10 times compared to leasing the same satellite bandwidth in some developed country. This makes more difficult for any company to try to establish a communication system in some of these rural places.

During the recent years, there has been one project that consists on establishing a fiber optic undersea cable system connecting the East Africa with the rest of the world. This project, called Eastern Africa Submarine System (EASSy)[2] entered service on July 2010, and although it is very useful for some regions and has help in improving some services, it do not solve the problem in rural areas.

1.1. Motivation

The idea of the project arises from a necessity of the NGO *Doctors Without Borders (Médicos Sin Fronteras),* consisting on the absence of communication that lots of doctors suffer when attending rural zones in emerging countries.

The telephone coverage is only present in large cities, but often MSF personnel have to go far away from the cities to help sick people, especially in conflict zones. In those locations, doctors may need some type of communication with the hospital or with their mates to better deploy their activities.

Something similar happens in refugee camps. If they are small, communication between the people in the same camp is quite easy, but when considering larger camps, of a few tens of thousands of people, communication between doctors is as difficult as needed, to create a quick alert in case of an epidemic or armed conflicts, or to share information about patients and their clinical history.

Another important aspect that we ought to have in mind is that devices should be easy to transport; this means light and small. One of the reasons for that is the presence of armed conflicts, so it is interesting to have an easy way to disconnect and move them to another place in order to keep them save. There are other considerations that we must also take into account: devices should also be tough enough to support harsh atmospheric conditions, they ought to consume low energy, etc.

This will be the framework in which this project is focused. In the following pages, a detailed scenario of the camps, the technical requirements for the communication system to be designed and the figures of merit will be explained.

In conclusion, the aim of this project is to study the different options that exist to establish a communication inside a camp, and a communication between the camp and other places far away –central hospitals, other countries, etc-. The study will include technical, economical and sustainable part in order to decide which telecommunication system would fit the best in each case scenario.

1.2. <u>Work plan and Gantt Chart</u>

<table>
<tr><td>Project: Introduction</td><td colspan="2">WP ref: (P01)</td></tr>
<tr><td>Major constituent: Documentation</td><td colspan="2">Sheet 1 of 6</td></tr>
<tr><td rowspan="2">Short description: Introduction of the project and description of the main objectives of the project.</td><td colspan="2">Planned start date: 19/02
Planned end date: 26/02</td></tr>
<tr><td colspan="2">Start event: 19/02
End event: 05/03</td></tr>
<tr><td>Task T1: Motivation
Task T2: Gantt diagram</td><td>Deliverables:</td><td>Dates:</td></tr>
</table>

<table>
<tr><td>Project: Scenarios and requirements</td><td>WP ref: (P02)</td></tr>
<tr><td>Major constituent: Documentation</td><td>Sheet 2 of 6</td></tr>
<tr><td rowspan="2">Short description: Description of the scenario that we will be focused during the project, with a detailed description about the refugee camp chosen to do the project. There will be explained some criteria that we will use in order to choose a final telecommunication system.</td><td>Planned start date: 26/02
Planned end date: 26/03</td></tr>
<tr><td>Start event: 5/03
End event: 23/04</td></tr>
</table>

Task T1: User scenario: which will be the project scenario? Task T2: Technical scenario: features that the final System should accomplish. Task T3: Figures of merit: peculiarities that we use to evaluate each of the proposed solutions. Task T4: Minimization of costs: Criteria that will make the final decision in case of fulfilling technical requirements.	Deliverables:	Dates:

Project: **Proposed solutions**	WP ref: (P03)	
Major constituent: Investigation	Sheet 3 of 6	
Short description: Detailed description of each of the proposed solutions. They will all be evaluated in order to fulfill the requirements.	Planned start date: 26/02 Planned end date: 7/05	
	Start event: 26/02 End event: 18/06	
Task T1: Access network: study of the best way of communication between the people inside the refugee camp, through a WiFi system. Description of the network system. Task T2: Transport network: study of the best way of communication between people in the refugee camp and the whole world. Description of the network system and ways of contracting this service. Task T3: Recommended applications for each type of communication. Task T4: Solar energy provision	Deliverables:	Dates:

Project: **Costs analysis**	WP ref: (P04)
Major constituent: Investigation	Sheet 4 of 6
Short description: Study of the costs from all the solutions proposed that fulfill the specifications. We have to take into account not only installation costs, but also maintenance ones.	Planned start date: 16/04 Planned end date: 14/05
	Start event: 4/06

	End event: 25/06	
Task T1: Installation costs Task T2: Maintenance costs	Deliverables:	Dates:

Project: **Sustainability**	WP ref: (P05)	
Major constituent: Investigation	Sheet 5 of 6	
Short description: Check if the best solution is economic and social sustainable.	Planned start date: 7/05 Planned end date: 21/05	
	Start event: 18/06 End event: 2/07	
	Deliverables:	Dates:

Project: **Final document**	WP ref: (P06)	
Major constituent: Documentation	Sheet 6 of 6	
Short description: Writing of the final documentation of the project and revision of all the parts of the project.	Planned start date: 21/05 Planned end date: 18/06	
	Start event: 4/06 End event: 11/07	
Task T1: Conclusions and recommendations. Task T2: Final document and final revision. Task T3: Oral presentation.	Deliverables:	Dates:

Milestones:

WP#	Task#	Short title	Date (week)
P01	T1	Motivation and logical framework	Week 1
P01	T2	Gantt diagram	Week 2
P02	T1	Users scenario	Week 7
P02	T2	Technical scenario	Week 9
P02	T3	Figures of merit	Week 4
P02	T4	Minimization of costs	Week 8
P03	T1	Access network	Week 15
P03	T2	Transport network	Week 7
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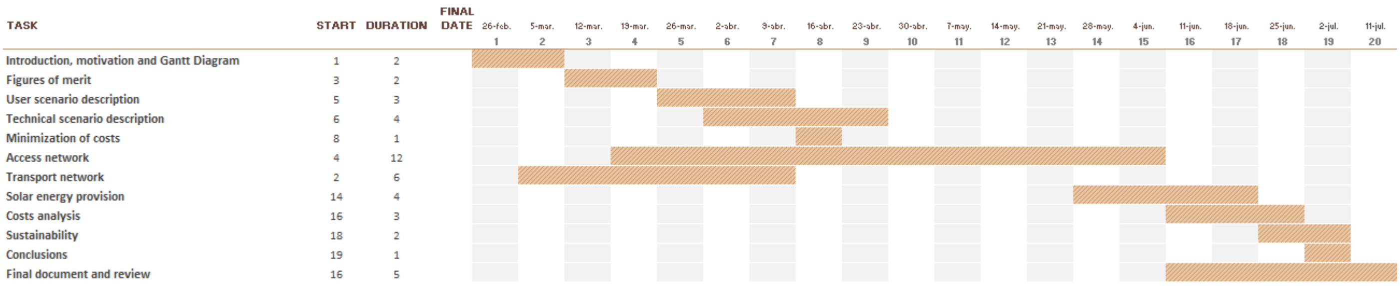
P04	T2	Maintenance costs	Week 18
P05	T1	Sustainability	Week 19
P06	T1	Conclusions	Week 19
P06	T2	Final documentation	Week 20
P06	T3	Oral presentation	Week 18

Gantt diagram:



2. Scenarios and requirements

The scenario in which the project will be focused is a refugee camp in a conflict area. It is usual for these camps to be allocated in an isolated area, so we will have to differentiate between the communication inside the camp and the communication outside the camp.

In order to perform a concrete study of the different possible options, we will take as reference Melkadida camp[3], one of the biggest refugee camps in the World. Melkadida is located in the South region of Ethiopia, called Dollo Ado, 75 kilometres far from the border between Ethiopia and Somalia. There are lots of Somalian people[4] in the different Dollo Ado's refugee camps as a result of armed conflicts in their home country and to escape from hunger[5].

Figure 1 – Localization of the refugee camp

Nowadays, there are near 44.000 people in Melkadida camp. In the following image we can see its shape overlaid on the satellite image.

Figure 2 – Limits of Melkadida Camp

2.1. User scenario description

We have to differentiate the two main services that we would like to offer. First of all, there is the Internet access, which will be useful for connecting to the Internet, receiving e-mails and making VoIP calls to people far from the refugee camp.

Secondly, there is the local network, which will offer the possibility of exchanging information and making local calls in the refugee camp. It is very important that this network should not log in to the satellite in order to reduce costs. If we achieve to have all the local traffic avoiding connection with the satellite we will have a better service in terms of transmission rates and we will need much less satellite bandwidth.

We have to take into consideration that the idea of this network is to be useful, also, for providing Internet access to the doctors when they are trying to update medical history. There is another project[a] working in parallel in which a medical history system is proposed and it uses the network in two ways. First, the Internet access will be used when updating the information of all the medical histories, usually only once a day. The goal of this daily updating is that all the medical histories that has been modified by a doctor during a day can be shared with all the other doctors. Second, for each patient, the idea is to send information about the fingerprint to a server located inside the camp. Both have to be taken into account when estimating the total traffic.

Additionally, we will need some kind of power supply. If there is more than one station, each of them will need power supply. Due to the climate, it is very interesting to think about installing solar panels for providing electricity to the devices installed in each station. They are not cheap, so we will have to look for low consumption WiFi devices and be very accurate in the evaluation of the electricity needs.

2.2. Technical scenario description

The best way of having Internet everywhere in the camp is through a WiFi network. The installation is quite easy and it is the simplest way of connecting from tablets or laptops. What's more, WiFi frequencies are free in most countries in the world, so no government authorization is required.

GSM (Global System for Mobile Communications) have also been considered, but three main aspects have been decisive for the election of WiFi. First of all, with GSM a special SIM card would be necessary for connecting mobile phones to the network, and the connection through tablets or laptops would not have been as easy as it is using a WiFi network. Secondly, and most important, GSM works in a protected frequency band in most of the countries in the world, so acquiring a license would be necessary. And thirdly, GSM offers less bandwidth than WiFi.

As we have decided to deploy a WiFi network, the frequencies used for the communications will be those established by the 802.11n[6] standard: the 2.4 GHz band and the 5 GHz band. The 2.4 GHz band will be used as the access frequency –the connection between the APs (Access Points) and the final users-, while the 5 GHz band will be used in the point to point installation – those connections between two APs-. It is important to remark that 802.11n WiFi standard offers the possibility of having more than one data stream and using two adjacent WiFi channels (40 MHz). However, none of both

[a] I. Baeza, "Soluciones TIC para el seguimiento de historiales clínicos en campos de refugiados" TFG Project, 2014.

options will be considered. Using more than one data stream requires special devices and in order to avoid interferences it is interesting to use 20 MHz channels. Moreover, we will see that this basic 802.11n configuration will be enough to fulfil the specifications.

Concretely in Ethiopia, WiFi frequencies are also free, but a government authorization is required when installing a WiFi system. In 3.1.1 section some information about Ethiopian regulations about technical aspects of WiFi will be detailed.

The WiFi system will be designed for the access network. However, we also need a transport network that will be designed through a satellite backhaul. In the following figure we can see the red lines that represent the access network and the blue ones that represent the transport network. When requiring some Internet data, the packets queue that have to be sent from the Internet satellite Service Provider to the camp is located in the right of the scheme, and all the traffic that do not require satellite service is managed directly in the camp (left part of the scheme).

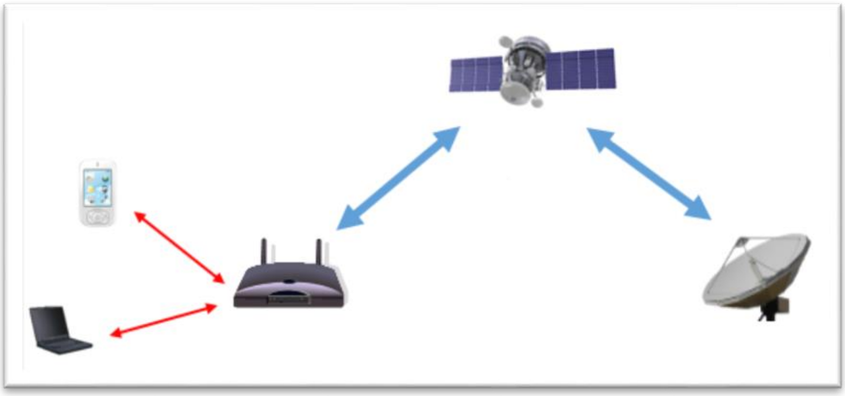


Figure 3 – Arquitecture of the System

2.3. Evaluation of traffic requirements

When evaluating the traffic requirements, it is important to assess the number of users and the traffic generated by each user type. The number of doctors in the refugee camp is changing, so we have taken an average value of 20 international doctors -those who came from European countries and work for *Doctors Without Borders*- and 200 local contributors -people living in the camp that have some knowledge about medicine and help the international doctors.

In order to calculate all the intern[b] and extern[c] traffic in the camp we have first taken into consideration that everyone will have a smartphone, all the international doctors will have a tablet and half of them will also have a laptop. This makes 220 smartphones, 20 tablets and 10 laptops.

We can now see in Table 1 a summary of both the internal and external traffic that in the following sections will be detailed:

[b] Intern traffic: information whose origin and destination is within the group of users in the camp.
[c] Extern traffic: traffic requiring internet connection, hence it requires backhauling through satellite.

	Internal traffic	External traffic
VoIP	1123.2 kbps	93.6 kbps
Internet data		900 kbps
Medical histories	2 kbps	967.68 Mb/day

Table 1 –Traffic requirements summary

2.3.1. External traffic

Let's first talk about the external traffic, which will occupy both the WiFi access network and the satellite bandwidth. Only international doctors will have access to the Internet, so it amounts to 20 smartphones, 20 tablets and 10 laptops. Local doctors will only have access to the local network. As voice and traffic data occupy independent bandwidth, they will be calculated separately. This happens because voice traffic has the highest priority and hence has a fixed backhaul bandwidth allocation, while data traffic is considered elastic and will occupy the remaining bandwidth with variable delays.

2.3.1.1. Data traffic

All the international doctors will be considered as ordinary users, because their job is not to be connected to the internet all day. *Ordinary users* requests an hourly average data rate of 250 Kbps, 31.25 Kbps and 125 Kbps for laptops, smartphones and tablets, respectively[d].

We have to calculate the data traffic generated by the international doctors in the peak hour. We will take that in the peak hour an average of 16 % of the devices are active. With all this information, we can calculate the FTP layer traffic as:

$$R(t) = p\,\alpha(t)\sum_k r_k\, s_k$$

Equation 1

where r_k and s_k are the average data rate demand and the ratio of subscribers per terminal type k respectively, $\alpha(t)$ denotes the percentage of active data users, and p is the total population. As we only take the peak hour:

$$R = p\,\alpha\sum_k r_k\, s_k = 50 * 0.16 * \left(\frac{10}{50} * 250 + \frac{20}{50} * 125 + \frac{20}{50} * 31.25\right) = 900\ kbps$$

Equation 2

In the external data traffic, we should also include the medical histories updating. However, we will not take into account this amount of traffic because it has to be updated once a day (or whatever it is configured, but not in a continuous way), and during the peak hours this traffic would be inactive. During the rest of the day, and knowing that each medical history weights 4 kB (32 kbits), let's estimate if there will be enough bandwidth in order to do all this updating. If each doctor attends 72 patients each day, considering that there are 20 doctors, this makes a total of 1440 patients each day. By multiplying it by 32 we obtain an upload need of 46.08 Mb. The upload need will be the same multiplied by the 20 doctors. That makes a total download need of 921.6 Mb. This is a bandwidth that, distributed

[d] Data obtained from TUCAN3G Project (www.ict-tropic.eu), document D41.

through the day, can be affordable by the network during the non-peak hours without needing any extra dimensioning.

2.3.1.2. Voice traffic

We have to add now the bandwidth reserved for making VoIP calls. We will consider that at peak hour each user generates an average voice traffic of 0.03 Erlangs. This means that the total voice traffic generated at peak hours by the twenty international doctors is 0.6 Erlangs. If we want a blocking probability better than 2%, we can use Erlang B probability and we obtain that the number of channels needed is $N = 3$. Knowing that a VoIP phone call requires 31.2 kbps using the most common VoIP codec (G.729)[7], we can estimate that the bandwidth reserved for VoIP calls through the satellite backhaul is 93.6 kbps.

2.3.2. Internal traffic

Both international and local doctors will have access to the local network. Let's now study voice and data traffic request for the local network.

2.3.2.1. Voice traffic

When talking about the internal traffic, we have to differentiate between local calls and the communication between tablets and the server when trying to identify a patient. For local calls there is not the satellite backhaul bandwidth limitation because they are managed inside the camp. At the time of writing we did not have a precise value of the voice activity, which should be measured onsite by MSF. However, we will consider that during peak hours an average of 16% of voice terminals will be active, which means 36 people. Multiplying them by the bandwidth required for each VoIP phone call makes 1123.2 kbps.

2.3.2.2. Data traffic

Internal data traffic origins from the patient identification traffic. We will consider that each one of the 20 international doctors work 12 hours per day, attending a patient each 10 minutes. This makes 6 patients per hour or 72 patients per day each doctor. This means 1440 patients each day. For each patient the amount of information needed to be transferred is about 150 kB[e]. So, the total information transferred in a day would be of 216000kB. If we divide this by the number of doctors and by the seconds that they are working, and by expressing it in kbps, we can obtain the bandwidth needed: 2 kbps during the working hours.

2.4. Figures of merit

The following figures of merit are chosen in order to evaluate each one of the systems proposed as solutions to the problem:

- Bandwidth for the data service: The total satellite bandwidth that we will be capable to lease and which bandwidth will be offered to each single person in the camp. In the Satellite backhaul bandwidth section (3.2.2) the minimum needs of the bandwidth will be determined.

[e] Information provided by looking at fingerprint images from UPC's Project "Soluciones TIC para el seguimiento de historiales clínicos en campos de refugiados", I. Baeza (2014).

- Energy consumption: As there is not an electrical grid, it is important to have devices with low energy consumption. It is considered when choosing the specific devices in 4.1 section.
- Coverage area for satellite backhauling: In the transport network, the area in which each satellite offers coverage has to be known, and it is the main feature when you want to establish a satellite communication system in some place. It has to be taken into account when selecting the satellite service in 4.2 section.
- Outage transmission rate: the maximum rate on the WiFi air interface that the worst 5% of users will experience. This will provide a measure of the coverage availability for the access network. Evaluated in 3.1 section.
- Weight and size of the instruments: One of the features that must have this telecommunication system is to be the smallest and the lightest possible, because it will make possible to save them in case of a military attack or a sudden change of place. It has to be considered when choosing the specific devices in 4.1 section.
- Costs: Not only installation costs have to be considered, but maintenance costs and operational ones.

2.5. Evaluation of costs

When choosing the equipment needed to build the Internet network, we have to take in consideration two types of costs. First of all, Capital Expenditures –known as CAPEX-, as the ones that cover all expenses incurred during the installation of the network. For example, the cost of the APs, the satellite receiver, the solar panels, all the cabling, etc.

In second place, Operating Expenses –OPEX-, as those costs that have to be paid regularly (e.g. monthly), like the use of satellite bandwidth.

That is why we have to try to minimize the CAPEX, but, mostly, the OPEX, because they are the costs that will suppose more amount of money in the mid and long term. As a consequence, we will try to adjust the satellite bandwidth in order to reduce those OPEX, being the most expensive part of the project.

3. Proposed solutions

In this section we are going to derive the solutions to the two networks explained above: the WiFi access network and the satellite transport network.

3.1. WiFi planning for the access network

The access network is the part of the system that will enable the communication from the user terminals to the satellite backhaul, as well as the internal communication in the camp.

3.1.1. Regulations

In each country, there are regulations about WiFi and its maximum transmission power allowed. In Ethiopia, due to the Article 52, Sub-article 3 of Telecommunication Services Council of Ministers Regulations No.47/1999, in point 14.c it is specified: *The maximum allowed transmitter power shall be 100 mW (mean e.i.r.p) or -10 dBW[8].*

We shall remember that we can obtain the EIRP by simply adding the transmit output power, in dBm, to the antenna gain in dBi -if there is loss in the cable feeding the antenna we may subtract that loss-. It means that maximum power that can be measured at the output of the antenna is 20 dBm. It is a very restrictive law, applied only in Europe and in few other countries in the world.

However, the Federal Communications Commission[9], an independent agency of the United States government, regulates the EIRP not only in the USA, but in many countries in the world. Most of African countries take the FCC regulations because they do not have specific regulation about these aspects. FCC regulations determine two conditions that must be fulfilled in omnidirectional antennas in the 2.4 GHz band:

- Maximum transmitter output power, fed to the antenna, is 30 dBm (1 watt).
- Maximum Effective Isotropic Radiated Power (EIRP) is 36 dBm (4 watt).

As we want to realize a study of a project that could be implemented anywhere in the world, and considering that the camp is far away from the main cities and with no government control, we have decided to take the FCC regulation to do the simulation, because it is the one used in mostly all the developing countries.

The simulation in next sections will also include an evaluation of the differences in WiFi coverage using the Ethiopian regulation.

3.1.2. Deployment

We will adopt Melkadida camp as the working case. We have to observe the orography of the camp. For doing this, Radiomobile[10] is a very useful freeware that calculates the path loss between transmitter and receiver. In Figure 5, we can see the elevation of each point of the camp, seen in Figure 4.

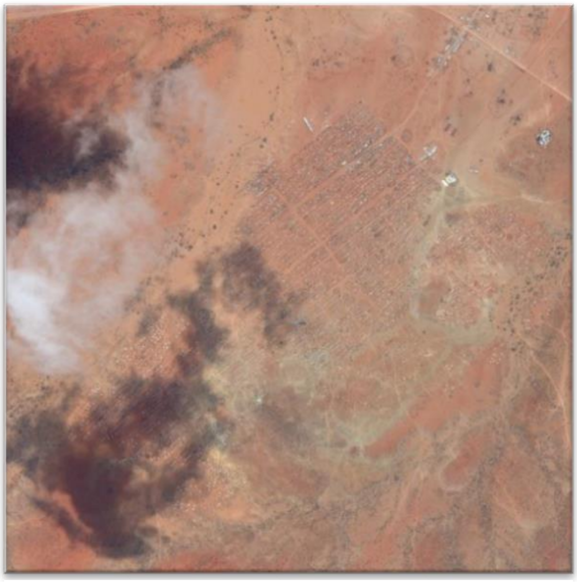


Figure 4 - Map of the camp

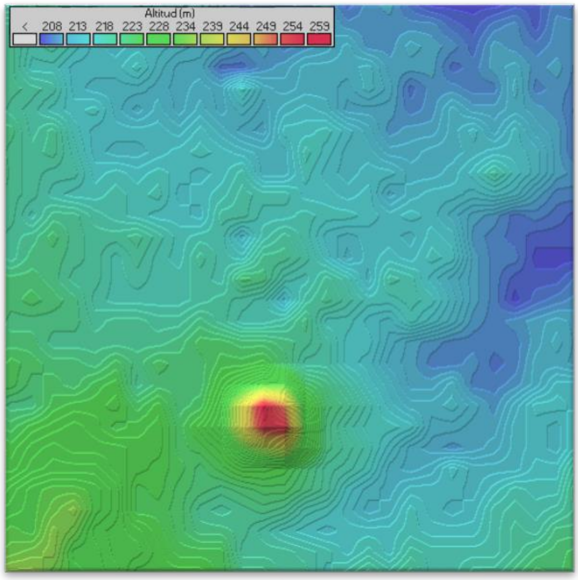


Figure 5 - Orography of the camp

Once this information is known, the following step is to decide how many APs will be needed and where do we have to install them. It is quite rational to think that we should install one AP on the top of the hill, so it could reach far away. However, we have observed that it is not enough to provide a proper coverage to all the camp. We will study, then, the case with two and three APs.

As general consideration for all the calculations, we will suppose that each AP is located at the top of a six-metre aluminium mast. For calculating the maximum possible rate in each point of the camp the link budget equation will be used:

$$P_{rx}(dBm) = P_{tx}(dBm) + G_{tx}(dBi) + G_{rx}(dBi) - PL\,(dB) - A\,(dB)$$

Equation 3

where:

- P_{rx} = received power at detector.
- P_{tx} = transmitter output power.
- G_{tx} = transmitter antenna gain.
- G_{rx} = receiver antenna gain.
- PL = path loss.
- A = miscellaneous attenuation (cable loss, diffraction, rain, etc).

With the information of the received power at the detector we can know which theoretical rate will be offered to the user, knowing that the received power must be higher than the sensitivity established by the 802.11n WiFi standard.

Data Rate[f] (Mbps)	Receive sensitivity (dBm)
6.5	-82
13	-79
19.5	-77
26	-74
39	-70
52	-66
58.5	-65
65	-64

Table 2 – 802.11n Association Data Rates

Let's now study the different deployments.

3.1.2.1. Two APs

In this first structure we have supposed an installation with one AP at the top of the hill and the other one in the middle of the camp, where the medical centre is located, with a greater concentration of doctors and hence a higher density of traffic. This second AP will be connected to the satellite gateway supporting the backhaul to the Internet.

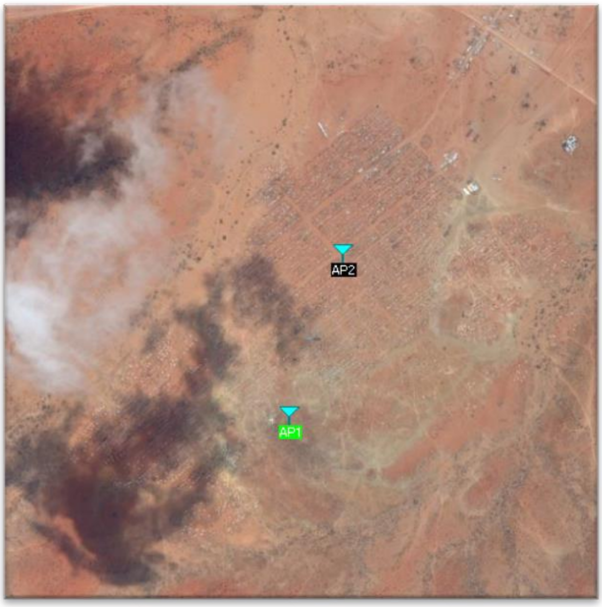


Figure 6 – Distribution of the two APs

For doing all the calculus, we have only taken in consideration the shape of the camp in Figure 6.

[f] Only considering one data stream and 20 MHz WiFi channels.

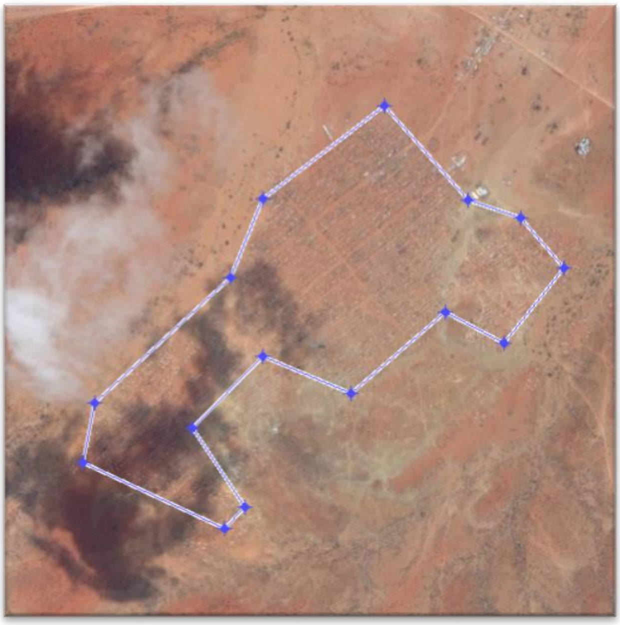


Figure 7 – Shape of the camp considered during the simulations

With this distribution, we have simulated and exported the data of the path loss obtained with Radiomobile. We can the estimate the coverage of the camp by doing some calculus with Matlab: first of all, taking the path loss and loading it to Matlab. After that, applying the link budget equation for each point in the camp. And finally, by linking each received power with the sensitivity following the 802.11n standard explained in Table 2.

As we are doing this simulation following the FCC regulation, we have selected an output power of the AP of 22 dBm connected to an omnidirectional antenna of 14 dBi. Additionally, we have established a total miscellaneous attenuation of 4,5 dB. Cable loss represents 1,5 dB and we have given an additional attenuation in the reception of 3 dB, which can be caused by many aspects (weather conditions, reflections, etc.).

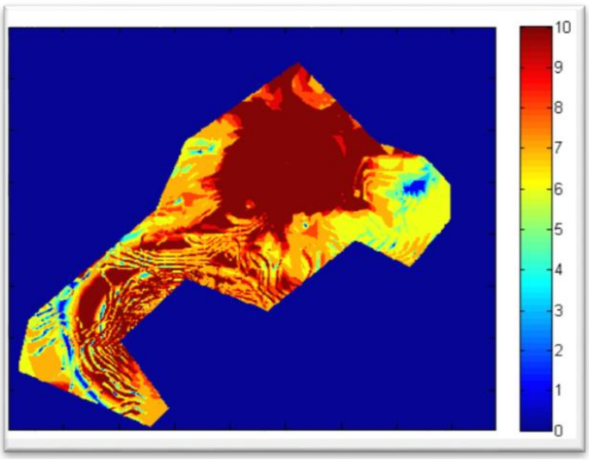


Figure 8 – Estimated rates (two AP)

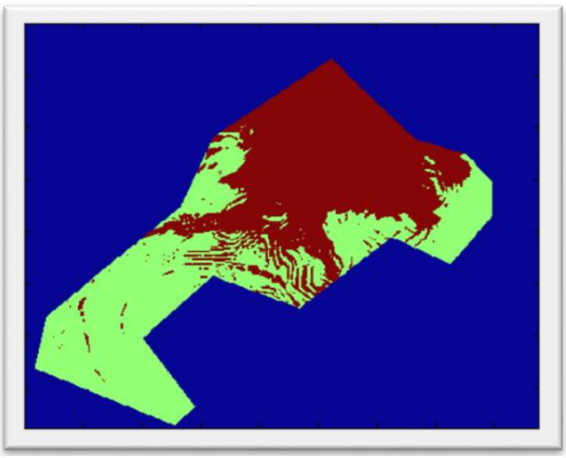


Figure 9 – Corresponding AP (two AP)

In the left image (Figure 8) we can see the estimated rates in each zone of the camp (each points being served by either AP or another), where each color represents one WiFi transmission rate as listed below:

10	65 Mbps
9	58.5 Mbps
8	52 Mbps
7	39 Mbps
6	26 Mbps
5	19.5 Mbps
4	13 Mbps
3	6.5 Mbps
1	No coverage
0	Outside the camp

Table 3 – Colours legend for figure 7

In the right image (Figure 9), the green colour represents area covered by AP 1, and the red one, by AP 2.The blue area represents the outside camp zone. Using this structure we have coverage of above 98% of the camp.

However, it is important to highlight that the rates represented in the figures above are not the real rates that will be offered to the doctors, because they do not take into consideration the time-sharing access policy in WiFi (with detection of collisions in the uplink), and hence the transmission rate depends on the number of users connected instantaneously to each AP. For example, if there are five users connected to an AP, each of them will have one time slot assigned of each five, so the rate received would only be the 20% of the maximum rate shown in table 1.

For that reason, we have studied the cumulative function of the experienced rate *r* for each user when connected to an AP. This calculation has taken into account that doctors are equally distributed through the camp and that the rate request is the one explained in 2.3 (Evaluation of traffic requirements). The expression used for this calculus for each AP is the following:

$$\Pr(r|N \geq 1) = \sum_{N=1}^{Nmax} \underbrace{\sum_{i1=0}^{N} \sum_{i2=0}^{N} \dots \sum_{i8=0}^{N}}_{i1+i2+\dots+i8=N} Pr(r|i1, i2, \dots, i8, N) \cdot Pr(i1, i2, \dots, i8|N) \cdot \Pr(N|N \geq 1)$$

Equation 4

where N_{max} is the total number of users that will have access to that AP and i_i represents the number of users connected in the i area and having a maximum r_i rate. Detailed information about the derivation of this equation can be found in Appendix A. The cumulative distribution function is shown in Figure 10:

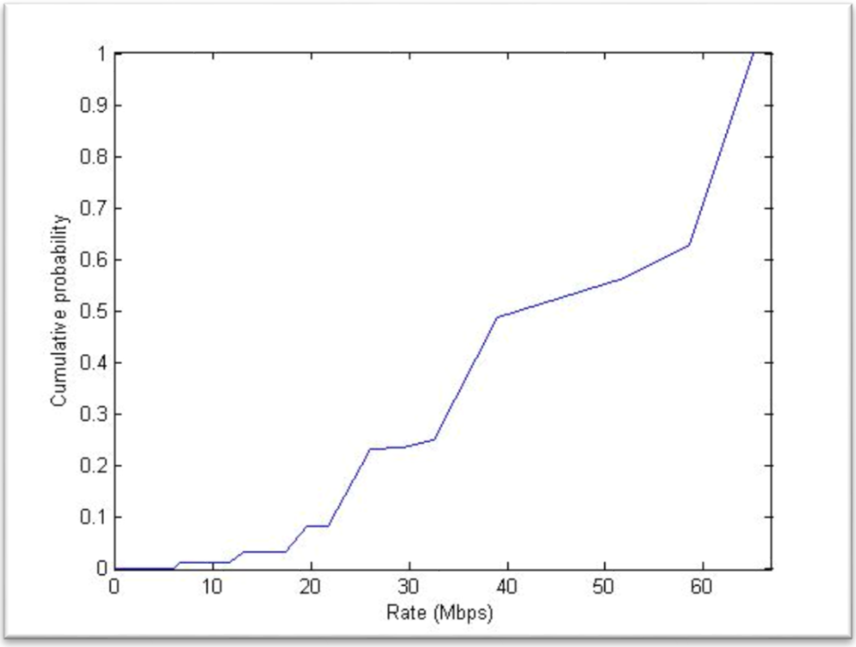


Figure 10 – Cumulative distribution function of the rate probability (two AP)

From this cumulative distribution function we can conclude that the worst 5% connected users (in terms of rate) will have a rate of 17.33 Mbps or less, which is a very high value due to the high capacity of the WiFi system as compared to the generated traffic. This value must not be mistaken with the packet delay when requiring satellite backhaul bandwidth. We could have to wait to receive packets, but once received, the transmission between the AP and the user is very fast.

We also have to study the viability of the fronthaul[g]. We will do this communication in the 5 GHz band in order to avoid interference with the other APs and using directional antennas, so regulations would not be a problem here. We have simulated the point to point connection in Radiomobile, transmitting 19 dBm of output power and with an antenna gain of 17 dBi both in the transmitter and in the receiver. As we can see in Figure 11, the power received is -65.6 dBm, while the sensibility of the receiver is -74 dBm.

[g] Communication between the two APs.

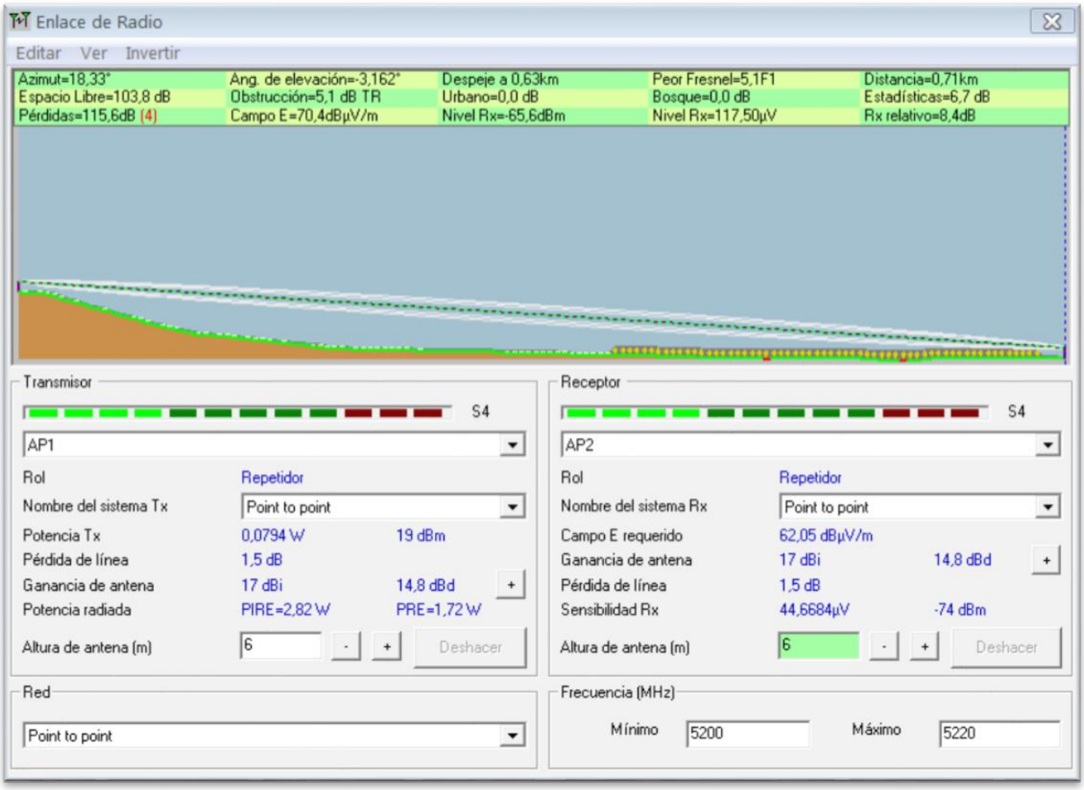


Figure 11 – Point to point communication (two AP)

3.1.2.2. Two APs (Ethiopian regulation)

In this section we repeat the evaluation done before if adopting the Ethiopian regulation. We now take a total EIRP of 20 dBm against the 36 dBm taken in the first simulation, also including a miscellaneous attenuation of 4,5 dBm.

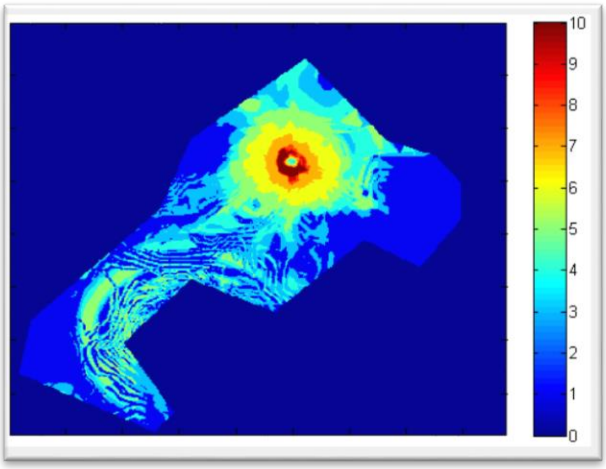


Figure 12 – Estimated rates (two AP – Ethiopian regulation)

We obtain coverage of about 60% of the camp, which does not fit our requirements. As we can see, this could not be implemented properly and a minimum of two extra APs should be installed: one covering the right part of the camp and another one covering the left part of the camp.

3.1.2.3. Three APs

In this second structure we have supposed an installation with three APs: two covering the central area of the camp and the third one in the other part of the camp, as seen below. The satellite gateway will be next to AP1.

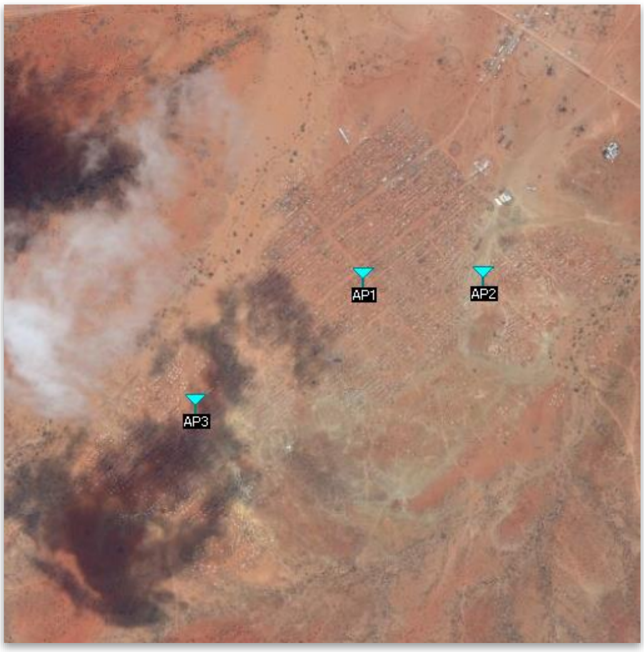


Figure 13 – Distribution of the three APs

Doing the same procedure as in 3.1.2.1, and taking the same values of antenna gain and output power, we obtain the coverage shown in figures 14 and 15.

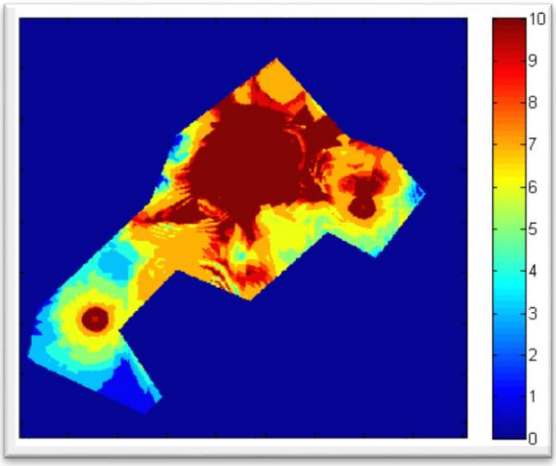


Figure 14 – Estimated rates (three AP)

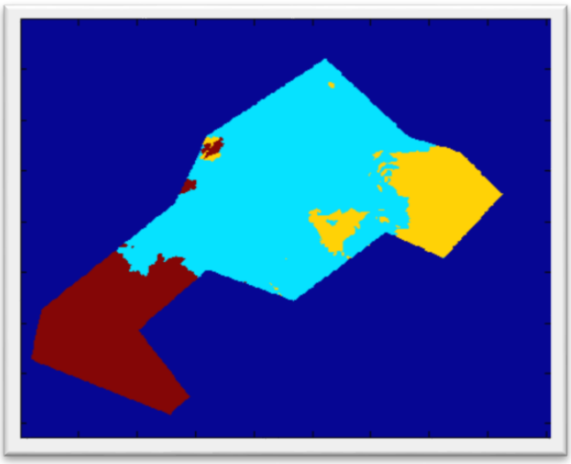


Figure 15 – Corresponding AP (three AP)

Where each colour in Figure 14 represents the transmission rate listed in Table 3.

In the right image (Figure 15), we can see which AP is the best option to connect in each point of the camp. Using this structure we have coverage of about 96.5% of the camp.

As in the two AP configuration, the cumulative rate probability function has been calculated in order to obtain the outage transmission rate.

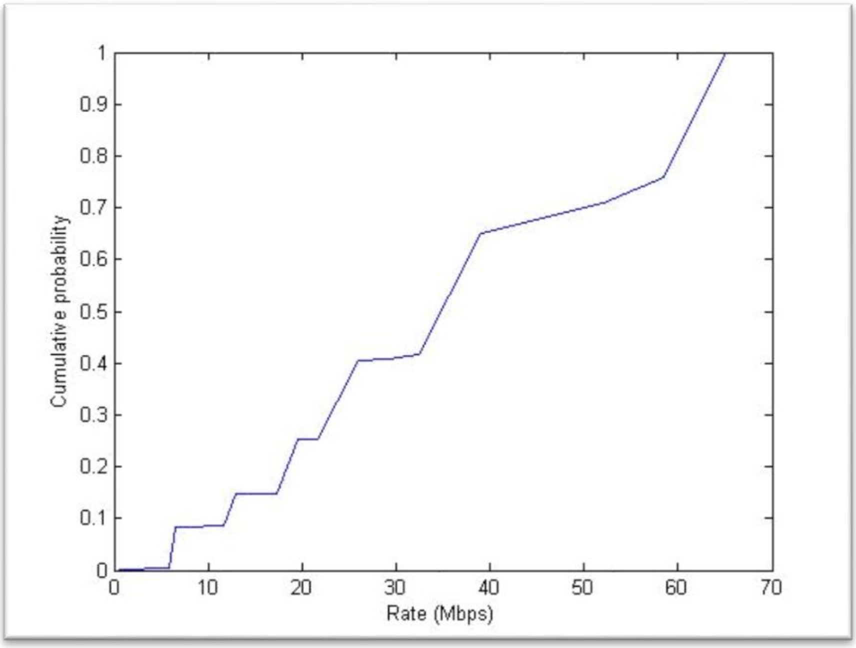


Figure 16 – Cumulative Distribution function of the rate probability (three AP)

In this case, the worst 5% connected users (in terms of rate) will have a rate of 6.5 Mbps or less. As we can see, this value is lower than in the two AP deployment. It is caused by two main aspects: first of all, because AP1 provides coverage to most part of the camp, so as we consider that users will be distributed uniformly through the camp, a lot of users will be connected to one particular AP, and this makes that more users will share the capacity of this AP, reducing their instantaneous rate. Secondly, AP2 and AP3 offer high rates to lower area of the camp compared to AP2 in the first deployment. It is because, although these AP are nearer to the users, they are not as high as the AP located in the first deployment, which is capable to offer higher rates to more area of the camp.

Considering that the main station will be located in AP1, we have to calculate the viability of the fronthaul. We will use the same system as in the two AP structure, in the 5 GHz band and using directional antennas, transmitting 19 dBm of output power and with an antenna gain of 17 dBi both in the transmitter and in the receiver. After simulating this in the Radiomobile, we can see that the worst case is when the received power is -63.7 dBm, so there are no problems with the point to point communication.

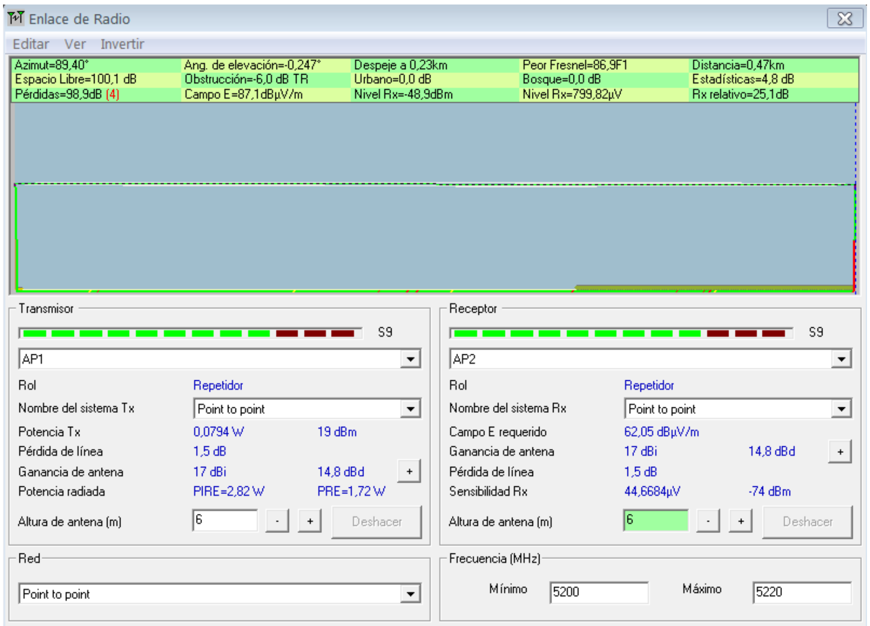


Figure 17 – Point to point communication (AP1-AP2)

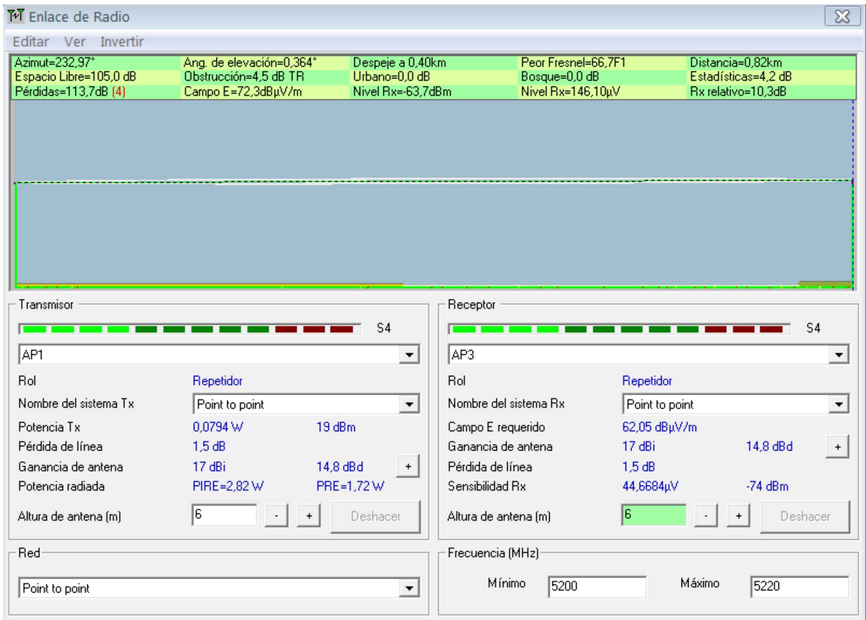


Figure 18 – Point to point communication (AP1-AP3)

3.1.2.4. Three APs (Ethiopian regulation)

We do the same estimation in this case as with the FCC regulation. We now take a total EIRP of 20 dBm against the 36 dBm taken in the first simulation, including a margin of 3 dBm.

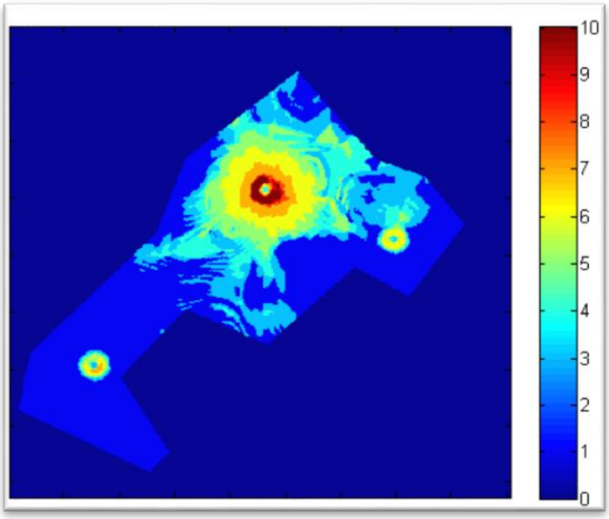


Figure 19 – Estimated rates (three AP – Ethiopian regulation)

We can see that the coverage is about 45% of the total camp area. We should install some more APs with this structure.

3.1.3. Interference considerations

The APs are using the 2.4 GHz band. As there is no other network in the refugee camp, we can optimize the channels of each AP in order to avoid interference. In the following figure we can see the channels available in the 2.4 GHz band. In the two AP configuration we should use channels 1 and 11 for the APs, and in the three AP configuration we may use channels 1, 6 and 11.

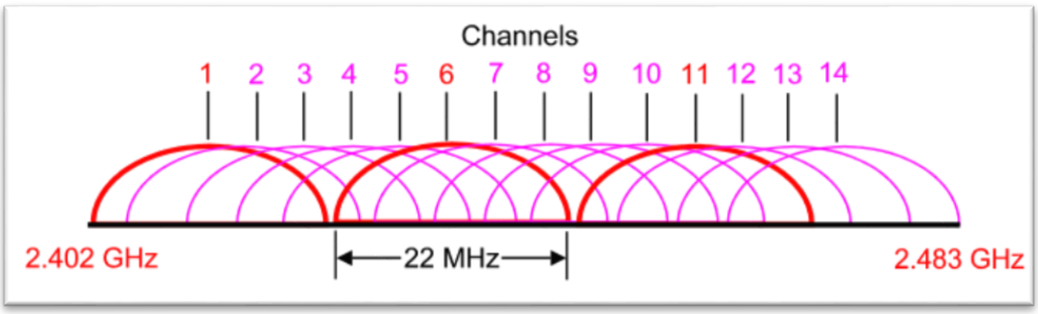


Figure 20 – 2.4 GHz WiFi channels

Another important information that we have to take into account when installing the local network is to configure the APs in a proper way. It is interesting to have a configuration that allows you to roam from one AP to another when moving in the camp without doing manual changes on the phone or tablet.

The way of configuring it is quite easy. First of all, we have to select the same type of security (WPE or WPA2) in all the APs, as well as the same password. Secondly, we have to configure different id address in each AP, but all of them have to be in the range of the router. Finally, all the APs need to have the same SSID.

With this configuration, the smartphones and the tablets will automatically be connected to the AP from which the received power is higher.

3.1.4. Local traffic management

One of the objectives of this project is to create a way of communication between the doctors in the camp. It is quite important that this solution is designed without the necessity of having access to the global Internet, in order to lease the lowest amount of satellite bandwidth possible. This implies that local traffic remains local, without connection to the satellite backhaul if not needed. As an example, VoIP connections through Skype would not be practical.

The solution consists on having a Server on a Linux computer, with Asterisk installed on it. Asterisk[11] is a software implementation of a telephone private branch exchange (PBX). With this free and open source application, we will be able to establish calls among the people in the camp.

Asterisk allows having one extension for each user of the service, so if we consider that both local and international doctors will use this way of communication, 220 extensions will be needed.

Once Asterisk is installed, two steps have to be explained: adding new extensions and configuring Asterisk on our tablet, PC or smartphone.

3.1.4.1. Adding new extensions

Adding new extensions in Asterisk is quite easy. We only have to modify two configuration files: *sip.conf* and *extensions.conf*[12]. They are usually located in /etc/asterisk. We will start explaining the file *sip.conf*. First of all, we have to configure the general features for all the extensions by writing the following text:

```
[general]
context = default
bindport = 5060
bindaddr = 0.0.0.0
srvlookup = yes
disallow = all
allow = ulaw
allow  = alaw
allow = gsm
```

In bindaddr, by writing 0.0.0.0 we determine a dynamic host of the server.

For each new user that we want to add, we should type a text like the following in the text file, and then save the changes:

```
[name_of_the_user]
type = friend
context = user
secret = my_password
```

host = dynamic
quality = yes
nat = yes
dtfmode = rfc2833

After adding all the users that we want in the *sip.conf* file, we have to associate each of them with one extension. That is why we have to edit *extensions.conf* file by writing the following information:

[general]
static = yes
writeprotect = no
autofallthrough = yes
clearglobalvars = no
priorityjumping = no

[global]

And for each user, inside the [user] context, we should write:

[user]
exten => XXXX, 1, Dial(SIP/name_of_the_user,time)
exten => XXXX, n, hangup()

Where *XXXX* is the extension that we want to give to that user and *time* is the seconds that we want to last a call before hanging up if there is no answer.

3.1.4.2. Configuring your softphone

A softphone is a software program for making telephone calls over the Internet. We will use this software for making calls from our tablets, PCs or smartphones[13]. There are lots of programs that can be used for this application. We will now choose one for Windows and one for Android, as they will be the main operating systems used. However, lots of different software can be chosen, and the way of configuring them is quite easy and similar between different programs.

For Windows, our choice is Zoiper. It is a free program that can be downloaded from its original website[14]. Once the program installed, we only have to add a new account, select the type of the account (SIP) and introduce some credentials: user (the name of the user), password (the user's secret password) and domain. We can find this last credential in the asterisk computer, by looking after its IP. Moreover, we can have a list of contacts in Zoiper. It works very similar to a mobile phone.

For Android terminals, a good softphone application would be CSipSimple. It is a free app that can be downloaded from the Play Store and has to be configured using the same credentials as in Zoiper. Moreover, we can integrate CSipSimple with our mobile phone, so we can use the general list of contacts and when calling to a number or contact the device will ask us if we want to use the normal service or the softphone.

3.1.4.3. Running Asterisk

Once all software has been installed , it is time to run Asterisk. We only have to type “asterisk” in the Linux terminal, logged in root mode. For more information, type “asterisk –r” and there are some new commands useful there. The most useful ones are:

- “sip show users”: a list of all the users registered in the configuration files and their password is shown.

- “sip show peers”: a list of all the users registered in the configuration with their actual status is shown.

With this configuration, we will be able to have local phone calls in a very easy way.

3.2. <u>Satellite backhauling</u>

The transport network offers the possibility to connect the refugee camp to the global Internet network. For doing so, we will use a satellite communication. We should know some background information before choosing and hiring a satellite service.

3.2.1. Background information

There are two main aspects that we ought to take into account when looking for Internet through satellite: the band and the technology used.

First, the band[15] refers to the allocated chunk in the electromagnetic spectrum. As a general feature, the higher frequency bands typically give access to wider bandwidths, but are also more susceptible to signal degradation due to rain fade (the absorption of radio signals by atmospheric rain). In this respect, we can distinguish three main satellite frequency bands for commercial use:

- C-Band (4-8 GHz): Commonly used in areas that are subject to tropical rainfall, since it is less susceptible to rain fade than Ku band.
- Ku-Band (12-18 GHz): Commonly used for satellite TV, so it is not always available for Internet through satellite.
- Ka-Band (18-30 GHz): The devices needed are more powerful, so they are more expensive.

The most typical satellite frequency bands are the C and the Ku bands.

Secondly, when talking about technology[16] used, there are the two main alternatives: SCPC (Single channel per carrier) and TDMA (Time Division Multiple Access). The difference between them is that, on the one hand, with SCPC we have a separate dedicated carrier to each remote terminal to receive information from the central site, and another dedicated carrier for each VSAT to transmit information back to the central site. On the other hand, TDMA uses a single high-speed TDM carrier transmitted from the central site, from which many VSATs can receive information.

3.2.2. Satellite backhaul bandwidth required

From the external traffic calculated in 2.3.1 we are going to calculate how much satellite bandwidth is needed for having a good service. It is assumed, as common practice in satellite backhauling, that the voice and traffic data occupy independent bandwidth because delay requirements are different for voice (delay should be zero) and data (there can be some delay). As done before, data and voice bandwidth will be treated as different cases.

For voice bandwidth, we determined that three VoIP channels would be necessary for fulfilling the specifications, and as it is bandwidth reserved to voice service, we will need 93.6 kbps.

For data bandwidth, we have to define some perceptive condition that our backhaul dimensioning must fulfil in order to establish the satellite bandwidth necessity. We have chosen the average delay per FTP packet (τ), which will be a perceptive way of evaluating the service. We have selected $\tau = 0.15\ s$, which means that the average delay time at peak hour of downloading a web page like *http://www.doctorswithoutborders.org/* will be of about 8 seconds, and for a google search about 4 seconds. These are acceptable results considering that the average delay in non-peak hours will be less. However, this delay can be set lower, knowing that the lower the delay, the higher the satellite backhaul bandwidth needed.

With this information, we will use Little's law, from where we can obtain the average number of packets that will be in the queue (for an average FTP packet size of 1500 bits) by multiplying the average delay per FTP packet (τ) by the number of packets per second served (α):

$$W = \alpha \cdot \tau = \frac{900\ kbps}{1500\ bits/packet} \cdot 0.15\ s = 90\ packets\ in\ queue$$

Equation 5

Now we have to relate the number of packets in queue with the traffic request and the traffic served, by doing a Markov chain:

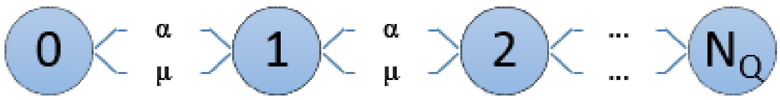


Figure 21 – Backhaul service Markov chain

where N_Q is the maximum number of packets allowed in the queue. As we want our result not to depend on N_Q, we will take a very high value, near infinite. From this Markov chain we can have the following expression:

$$W = 0 \cdot P(0) + 1 \cdot P(1) + 2 \cdot P(2) + \cdots = \sum_{i=0}^{N_Q} i \cdot P(i) = \frac{\rho}{(1-\rho)^2}$$

Equation 6

and ρ being defined as the division between the average bandwidth requested at peak hours (R) and the satellite backhaul bandwidth dedicated to data traffic (R_{bh}):

$$\rho = \frac{\alpha}{\mu} = \frac{R}{R_{bh}}$$

Equation 7

Combining Equations 6 and 7, we can conclude that the satellite backhaul bandwidth required for the data service is $R_{bh} = 1000\ kbps$.

This makes that the total bandwidth needed for the satellite communication is 1093.6 kbps in the download link. It seems logical to take 1.1 Mbps in the download link and 256 kbps (nearly one fourth of the download bandwidth) for the upload link.

3.2.3. Contracting satellite Internet services

Internet service providers (ISP) are companies that take over the business of contracting Satellite Internet. The main steps that we have to follow when trying to lease some satellite bandwidth are:

- Determine the place where the installation will be placed.
- Define the necessity of total bandwidth (upload and download) needed.
- Decide which band will be used depending on the place of the project.
- Choose the technology used (TDMA or SCPC).
- Pick the equipment which fits the project the best.

Internet service providers are usually companies that, with some information about the project, design a complete structure for receiving Internet through satellite in the best possible way. The economical part will be explained in section 4, in the OPEX part.

3.2.4. Equipment needed

The equipment needed for installing an Internet Satellite system is:

- Rx/Tx Satellite antenna: as we want to both receive and transmit Internet data, it is important to have an antenna that offer the capability of doing both operations. Depending on the band chosen (C or Ku, generally), the diameter of the antenna will change.
- Satellite router: it usually works as a decoder, as a modem and offers some extra services like the QoS or prioritization capabilities, as, for example prioritization through different type of subscribers or giving priority to some specific applications.
- LNB (low-noise block downconverter): it is a device which function is to receive the microwave signal from the satellite collected by the dish, amplify it, and downconvert the block of frequencies to a lower block of intermediate frequencies.
- BUC (Block Up-Converter): it is part of the transmit chain of the VSAT. The BUC converts the modem's L-Band transmit signal into higher frequency signals (C or Ku band), then amplifies it before it is reflected off the satellite antenna towards the satellite.

In the CAPEX section (4.1) concrete examples of this equipment and their features will be explained.

3.3. Solar energy provision

The power supply system that fits the best in a scenario like the refugee camp is solar panels connected to batteries, because it can act in an autonomous way and we can take advantage of the climate and constant solar radiation in Ethiopia.

For designing a complete solar energy system we have to take into consideration the following aspects:

- The energy consumption will be based on the devices chosen in the cost analysis (4.1). If the devices change there could be some alterations in the final design of the solar energy system, but the changes should not be significant since one of the figures of merit when choosing the devices is that they should have low power consumption.
- All the calculations are made taking as reference the worst month in terms of solar radiation. However, as Ethiopia is very near to the Ecuador, the solar radiation remains quite steady during all the year.

We are first going to detail the energy consumption in a day. This information appears in each device's datasheet. For those datasheets where the power consumption is not detailed, for example in the laptop one, we have realized the following approximations: it has a 41 Wh battery, and knowing that it will last 4 hours (with light brightness in the screen and without WiFi enabled), its average power consumption is about 10 W. Something similar happens with a smartphone or a tablet: if its battery has a total energy of 8 Wh, and it takes 2 hours to charge it completely, this means that 4 W will be needed during two hours. All this information will be detailed in the following table:

Device	Power consumption	Hours working per day
AP	7 W	24
Point to point AP	6 W	24
Server laptop	10 W	24
BUC	18 W	24
Satellite router	20 W	24
Smartphone battery	4 W	2
Tablet battery	3 W	3
Laptop battery	20.5 W	2

Table 4 – General power consumption of the devices

We have to distinguish now between the elements in the central base and the secondary bases.

In the central base there will be lots of connections because, apart from the servers and all the satellite system, both local and international doctors will charge devices' batteries there. This means that the total power needed is:

Device	Power consumption	Number of devices	Hours working per day	Energy consumption per day
AP	7 W	1	24	168 W·h
Point to point AP	6 W	1[h]	24	144 W·h
Server laptop	10 W	2	24	480 W·h
BUC	18 W	1	24	432 W·h
Satellite router	20 W	1	24	480 W·h
Smartphone battery	4 W	220	2	1760 W·h
Tablet battery	3 W	20	3	180 W·h
Laptop battery	20.5 W	10	2	410 W·h
			TOTAL	4054 W·h

Table 5 – Energy consumption of the devices located in the central base

Another important aspect to add is that we have considered that only 55 devices between smartphones, tablets and laptops can be connected simultaneously. It reduces the number of batteries needed, as well as the number of sockets.

Using the PVSOL and introducing all this features, we can simulate the system needed by selecting the place of the installation and the characteristics of the batteries and the solar panels. In this case, we have chosen one 1Soltech Inc. PV module[17] with 350 W of nominal output power and 43 V of MPP Voltage. For the battery, the election has been a Sonnenschein A512[18] with a capacity of 200 Ah and a nominal voltage of 12 V.

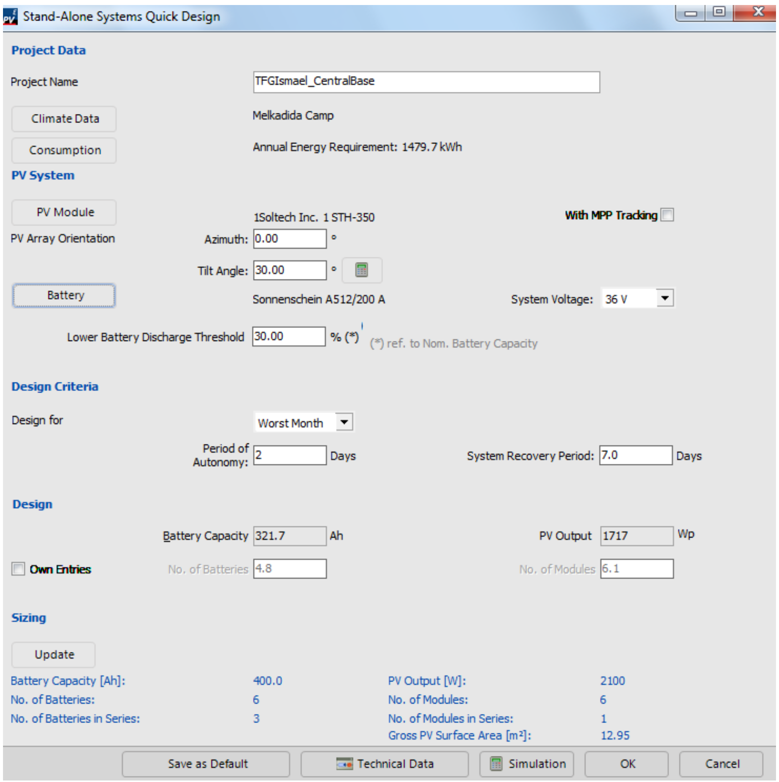


Figure 22 – Solar panels simulation (central base)

According to this simulation, we would need six batteries and six modules. A detailed report of the simulation can be read in the appendix B.

h Depending on the deployment chosen there would be two of this APs needed.

For the secondary bases there are only two devices that need electricity:

Device	Power consumption	Number of devices	Hours working per day	Energy consumption per day
AP	7 W	1	24	168 W·h
Point to point AP	6 W	1	24	144 W·h
			TOTAL	312 W·h

Table 6 – Energy consumption of the devices located in the central base

In this bases, there will not be needed so much powerful batteries and PV modules. That is why in this case the PV module chosen is a GH Solar GH245P156[19] with 245 W of nominal output and 31 MPP V. The battery will be a Sonnenschein A512[20], like in the central base, but with a capacity of 40 Ah.

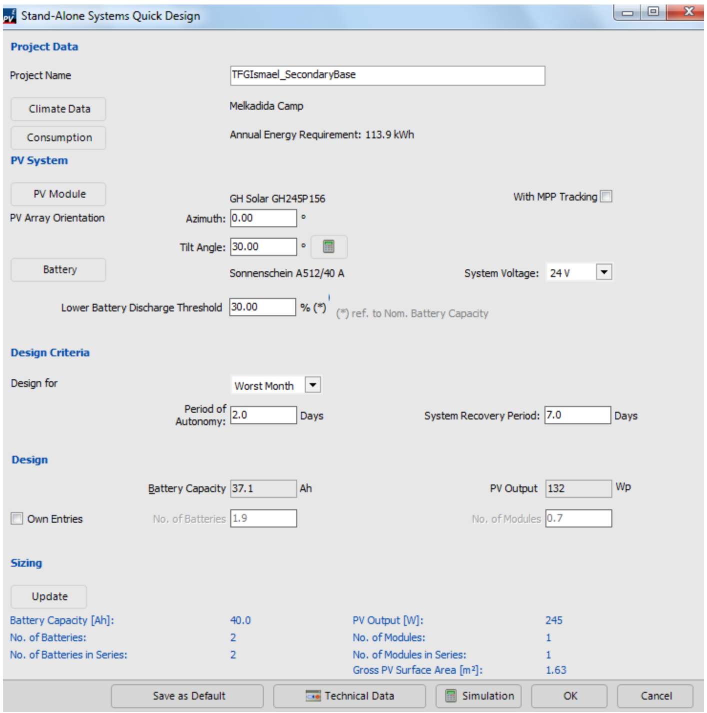


Figure 23 – Solar panels simulation (secondary base)

In the secondary bases there will only be needed two batteries and one module. A detailed report of the simulation can be read in the appendix C.

Two other devices will be necessary in each base: a charge controller and an inverter.

Let's start talking about the charge controller. A charge controller (also known as regulator) is a small box placed between a solar panel and a battery. Its function is to regulate the amount of charge coming from the panel that flows into batteries in order to avoid them being overcharged.

When deciding which regulator has to be chosen, we have to take into consideration two things. Firstly, the intensity of the regulator must be about a 20% higher[i] than the sum of all the parallel PV modules' intensity. And secondly, the maximum voltage allowed at the input of the regulator must be higher than the output voltage of the PV modules.

This means that in our central base the charge controller should fulfil the following specifications:

- $I_{reg} = I_{total_{pv}} * 1{,}2 = I_{pv} * PV\ modules * 1{,}2 = \ 8{,}13 * 6 * 1{,}2 = 58.536\ A$

  Equation 8

  Total intensity of the regulator of about 58.5 A.

- Maximum voltage allowed at the input of the regulator of 43 V or higher.

Meanwhile, the secondary base charge controller should fulfil:

- $I_{reg} = I_{total_{pv}} * 1{,}2 = I_{pv} * PV\ modules * 1{,}2 = \ 8 * 1 * 1{,}2 = 9.6\ A$

  Equation 9

  Total intensity of the regulator of nearly 10 A.

- Maximum voltage allowed at the input of the regulator of 31 V or higher.

Once the regulator defined, it is time to analyse the inverter. An inverter is an electronic device that changes direct current (DC) to alternating current (AC), and it also adapts the output voltage to the standard voltage (230 VAC). For choosing the inverter that best fits in the system, we have to look for the maximum power that will be requested simultaneously, and take a margin of 20% higher.

If we look at the detailed simulation of our project, we can conclude that, on the one hand, the inverter needed in the central base should have about 403 W (336 W of maximum hourly power multiplied by 1,2). On the other hand, the inverted needed in the secondary base should have about 15,6 W (13 W multiplied by 1,2).

Both the charge controller and the inverter chosen will be explained and detailed in 4.1 section.

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[i] It is highly recommended to take more or less a 20% of intensity extra as security margin.

4. Costs analysis

In this section we will take into consideration all the costs associated to the complete installation (CAPEX), as well as the costs associated to the exploitation of services, which include the monthly fees of satellite access (OPEX).

4.1. Installation costs (CAPEX)

The amount of devices that we will need depend on the deployment finally chosen (with two or three AP, according to the solutions described in section 3). However, the devices are the same for both deployments and will be explained below. All the equipment listed here is only one option of devices that fulfil the specifications and fit with the figures of merit established. There are lots of different devices that would perfectly be useful for this project.

4.1.1. AP

Ubiquiti Bullet M2[21] has been chosen. It is an outdoor AP that supports WiFi 802.11n and it is built to work under tough conditions. Furthermore, Ubiquiti Bullet does not have an integrated antenna, so this will allow us to choose the desired antenna. The AP can be configured to have a transmission output power of 22 dBm, as we wanted doing the simulations.

Ubiquiti Bullet M2 costs almost 70 €[22].

4.1.2. Transmitter antenna

We were looking for a 14 dBi omnidirectional antenna, and our choice here will be the MT Omnidirectional Outdoor 14 dBi. This antenna is built by a company called *maswifi* and consists on an outdoor omnidirectional antenna with 16° of vertical opening. We were looking for an antenna with huge vertical opening because if there is an AP at the top of the hill, it will be necessary for sending signal to the nearest users.

MT Omnidirectional Outdoor 14 dBi costs 35 €[23].

4.1.3. Point to point AP

The point to point communications between the different bases of the network will be installed using two APs in each connection: one in each base. These APs, in order to avoid interferences with the users' network, will work at 5 GHz. For this application, we will use Ubiquiti Bullet M5. They are very similar to the Bullet M2 used in the users' connection, but working on 5GHz band. Its maximum output power in transmission is 19 dBm (with the highest data rate).

Ubiquiti Bullet M5 costs about 75€[24].

4.1.4. Point to point antenna

For amplifying the signal sent in the point to point connection we will use a 17 dBi directional antenna. The antenna chosen is AirMax Sector Antenna AM-5G17-90[25], because it was designed originally for Bullet APs, and it can work, as well as Ubuquiti Bullet, under very tough atmospheric conditions.

AirMax Sector Antenna AM-5G17-90 costs about 70€[26].

4.1.5. PC

We need a PC for installing asterisk and to run as a VoIP Server. It should not be a sophisticated machine, so a PC like HP 250 G2 would be enough. With 4 GB of RAM memory, Intel Core i3 microprocessor and a Hard Drive of 500 GB, it would satisfy our necessities.

HP 250 G2 costs about 400€[27].

4.1.6. Aluminium mast

In order to have the APs and the antennas 6 meters above the surface of the camp, we need masts. We could build them with PVC pipes, but the best option would be to buy some telescopic masts made of aluminium. They can be transported easily and are tougher than the ones that we could build ourselves.

Its cost is about 90€[28].

4.1.7. Rx/Tx satellite antenna

The satellite antenna chosen depends on the election of the frequency satellite band. We will take Ku band because it needs smaller antennas, so it would be better to transport there and install them. We could use Skyware Global Antena 1.2m Tx/Rx Ku Band Type 122 Class 1[29].

It costs about 160€[30].

4.1.8. Satellite router

A satellite router that is highly recommended by some Internet Satellite Service Providers is iDirect 3000 series[31]. There is the 5000 series version, but the first one would fit correctly in our project, providing all the features needed in the satellite router.

Its cost is 920€[32].

4.1.9. LNB

Any LNB with a good Noise Figure would be useful here. We will take one with 0,1 of Noise Figure which costs about 6€[33].

4.1.10. BUC

A NJR BUC Ku Band Universal 3W[34] will be chosen. It costs about 180€[35].

4.1.11. Solar panels

As explained in 3.3, there has already been chosen the PV modules and the batteries. For the central base, we have:

- 1Soltech Inc. STH-350, which costs about 385 €[36] each one.
- Sonnenschein A512/200, which costs about 899 €[37] each one.

For the secondary base we have:

- GH Solar GH245P156, which costs about 142 €[38] each one.
- Sonnenschein A512/40 A, which costs about 103 €[39] each one.

4.1.12. Charge controller

In the central base, a regulator that fulfils the specification could be the Morningstar TS60[40] and costs about 230 €[41].

In the secondary base, a charge controller that would fit is the Kemo M063N 12-48V/10A, with a cost of nearly 20 €[42].

4.1.13. Inverter

For the central base, the inverter needed would be one like XANTREX 500W[43], which costs about 132 €.

For the secondary base, one like a SCHNEIDER micro-inverter would be useful and costs only about 38 €[44].

4.1.14. Summary

Once we have detailed all the components, a summary table will be written with all the components needed in each of the two possible deployments – using two APs and three APs-. When defining how many of each devices will be necessary, we have taken the double of the estimated number of devices needed, because there will be tough atmospheric conditions there due to the high temperature and humidity and it could be necessary to replace them by some new devices. Moreover, using solar energy produces that sometimes there could be voltage rises that can damage devices. So, we will have doubled the APs, the antennas, all the satellite equipment, etc, but not the solar panels and the batteries. Due to their long lifetime and because it is more difficult to have them damaged, we will only consider necessary one or two extra solar panel and battery – two extra devices for the central base and only one extra for each secondary base.

Product	Unit price	Two APs		Three APs	
		Number of devices	Total price	Number of devices	Total price
Bullet M2	70 €	4	280 €	6	420 €
MT Omnidirectional	35 €	4	140 €	6	210 €
Bullet M5	75 €	4	300 €	8	600 €
AirMax Sector Antenna	70 €	4	280 €	8	560 €
Laptop	400 €	2	800 €	2	800 €
Mast Aluminium	90 €	2	180 €	3	270 €
Satellite antenna	160 €	2	320 €	2	320 €
iDirect 3000 series	920 €	2	1840 €	2	1840 €
LNB	6 €	2	12 €	2	12 €
BUC	180 €	2	360 €	2	360 €
PV Modules (central)	385 €	8	3080 €	8	3080 €
Batteries (central)	899 €	8	7192 €	8	7192 €
PV Modules (secondary)	142 €	3	568 €	6	852 €
Batteries (secondary)	103 €	2	206 €	4	412 €
Charge controller (central)	230 €	2	460 €	2	460 €
Charge controller (secondary)	20 €	2	40 €	2	40 €
Inverter (central)	132 €	2	264 €	2	264 €
Inverter (secondary)	38 €	2	76 €	4	152 €
TOTAL			16398 €		17844 €

Table 7 – CAPEX costs summary

4.2. Operational costs (OPEX)

The main OPEX to take into consideration is the satellite service costs. As it is explained in (3.2), service providers are very reluctant to show their satellites services fees easily, so there has been no way of studying offers from different service providers and compare them. Only one company, Avanti, has told us an approximation of the monthly cost of leasing a Mb: 1500 €. Nevertheless, this cost could differ a lot comparing to other service providers for some reason.

First of all, Avanti is a company that has recently deployed –and is still in process in some other places- a network of high throughput satellites (HTS), the new generation of satellites. In this case, they operate mainly in the Ka-band, which differ from many other companies that operate basically in C and Ku band.

Secondly, Avanti is a wholesaler. It means that they do not offer service if you do not lease a minimum of 2.5 Mb in one single beam. If the required bandwidth is less, you can use their satellite by contracting through one of their retail vendors. This could raise the final price of the service. Moreover, if there was another refugee camp in the same spot beam of Melkadida that we would like to deploy a telecommunication system like the one described in this project, we could lease the total bandwidth directly from Avanti if it is equal or higher to 2.5 Mb. Let's put an example: if there was some interest in doing a similar project to one of the other refugee camps in Dollo Ado - for example Kobe Camp or

Bokolmanyo Camp, both near Melkadida and with very similar population and characteristics-, the total bandwidth could be leased through Avanti using the same satellite spot. One advantage of sharing bandwidth through two camps is that traffic aggregation is possible: if there is no bandwidth request in one of them, the other can take more bandwidth than the initially estimated, thus obtaining some trunking gain.

Being a wholesaler also includes the fact that the customer care is not the same as other companies. This means that someone that will work in the project should do a training with Avanti in order to know how to use the platform, how do they work, how to install the devices and some information about solving the most basic incidents. This is another reason why other companies are more expensive, because they offer some of this maintenance services too.

Finally, the duration of the contract is an important factor to think about. Avanti usually signs three-year contracts, and if the intention is to establish a shorter duration of the service maybe the price could change.

In conclusion, this part of leasing satellite bandwidth should be studied by comparing between different service providers, but knowing that it would cost around 1500 - 2000 € per Mb each month. In our case, as we need 1.35 Mb, around 2025 - 2700 € per month would be needed.

Apart from the satellite service that we have to pay each month, maintenance costs consists on having a control in all the devices installed in the refugee camp and to assure that they work correctly. For this, an engineer should visit the camp when needed, spending a few days there for solving all the possible problems. It is difficult to estimate how many times a year there will be necessary the presence of a technician, but between two and three would be a good estimation. It is not necessary to contract a European engineer, it would be cheaper to contract an Ethiopian one, so we could minimize this costs. Considering that for each trip to the camp all the transport and the services offered cost about 500 €, we will have 1000-1500 € each year dedicated to this maintenance cost.

Moreover, we have estimated that in two years most of the equipment (excluding solar panels and batteries) has to be changed because due to the harsh atmospheric conditions it is highly likely that the original devices have been damaged. That is why it has to be predicted that about 5000-6000 € extra funding would necessarily be spent each two years.

In conclusion, we can estimate the OPEX but depending on many factors that make impossible to make a precise calculus about the total expenditures (possible broken devices, necessity of the engineer more often than three times a year, final price of the satellite operator):

Product / service	**Price**	**Payment term**	**Expenses in two years**
Satellite bandwidth	2025 - 2700 €	Each month	48600 – 64800 €
Engineer assistance	1000 - 1500 €	Each year	2000 – 3000 €
Replacing devices	5000 - 6000 €	Each two years	5000 – 6000 €
		TOTAL	55600 – 73800 €

Table 8 – OPEX costs summary

This makes a total amount of money of 55600 – 73800 € each two years. If we distribute them through each month, we obtain an average monthly expenditure of 2300 – 3000 € approximately.

5. Sustainability

When talking about sustainability, we have to focus in three aspects: economic, social and environmental.

5.1. Economic

From the economic point of view, this project is not quite sustainable. Considering that there are about 14000 € of initial expenses and a monthly OPEX of about 2700€, apart from some maintenance costs, and knowing that this project does not have any economic return, it seems very clear that the aim of this project is not to start a business or make money. Nevertheless, *Doctors Without Borders* is a NGO that pick up money from individual donors and private funders and this money could be used to finance a project like this. In addition, nowadays it is the only way of providing Internet service to the doctors on site.

5.2. Social

This telecommunication system in a refugee camp without any previous communication is a huge advantage from the social point of view. Not only for the international doctors, that will have most of the advantages, but also for the local doctors, that will be able to communicate to each other in a very easy way. This things impact in the quality of life of the refugee camp's inhabitants: better organization through all the doctors, possible alarms can be alerted quickly, some facilities for the doctors when trying to order medicines or food and, of course, the possibility of having a shared medical history from all the patients through all the doctors.

5.3. Environmental

Environmentally there are both advantages and disadvantages. On the one hand, the fact that there has to be installed a lot of devices such as APs, routers, some antennas, etc. produces an environmental impact that has to be considered as negative. Moreover, lots of these devices have a short lifetime –about two years long-, so when they are replaced it would be interesting to recycle them in order to avoid contamination due to the materials that these devices are made of, that can be very dangerous for the environment. Something similar happens with solar panels and batteries. Solar panels produce contamination during the manufacturing process, while batteries are highly contaminant when wasted and must be properly recycled.

On the other hand, the energy chosen to provide electricity to all the installation is the solar energy. It is a renewable energy that takes advantage of the solar radiation and it is not necessary any other energy source apart from the sun. It does not provide any rubbish when functioning, but need a very careful operation when being changed, as explained before. However, one positive aspect about solar panels and batteries is that their lifetime is longer than in other devices such as APs or routers. Solar panels usually work correctly about 10-15 years before they must be replaced, and batteries last for 4-5 years correctly before being damaged.

6. Conclusions and future development

The objective of this project, consisting on the demonstration of the viability of a voice and data telecommunications system in a refugee camp, has been accomplished successfully. In this project we have considered a specific camp in Ethiopia (Melkadida), but the project could be applied in any other refugee camp in the world. Of course, all the calculation should be studied for each particular case, but the methodology would be the same. Moreover, all the calculations have been based on information taken from other projects and that could have particular circumstances. Before implementing a solution, a complete study of the data and voice traffic request should be done onsite in order to optimize the satellite backhaul.

In this case, we decided to evaluate two possible options for the access network: using two or three APs. Through all the studies, we can conclude that the best option for Melkadida Camp would be the deployment of two APs. Not only for economical reasons –the economic difference between the two deployments is minimal-, but also because it offers better coverage and better outage transmission rate. However, installing a station at the top of the hill is not free of risks. For example, the lack of human presence and control makes very easy to steal.

The idea of establishing an intern VoIP communication through an Asterisk server installed in the central base of the camp has been very important to reduce the satellite bandwidth, which, as we have seen, is the most expensive part of the project. Nevertheless, some other measures could be taken in order to reduce more this bandwidth necessity, such as installing a proxy server that could reuse the data downloaded for one user to other users that request the same data. When configuring the server, one aspect that could be taken in consideration is to find some way of limiting local doctors' connection. They have WiFi access like international doctors but they may not have access to the satellite Internet (because the bandwidth required would be much bigger), and some way of preventing their connection should be designed.

Finally, before implementing the project in a refugee camp some real tests should be done in terms of reach distance of the APs with different types of antennas. We have done some tests but the APs were not the same as the ones chosen and the orography and conditions were not the same as Melkadida ones. Although these tests proved that our estimations could be pretty good, it must be guaranteed that this part of the project function perfectly before implementing the definitive deployment, because it is the basis of all the other parts.

I would like to remark that this project presents the fundamentals of how all the telecommunication system in a refugee camp should be, but most parts of the project could be studied more depth in some future development. This project could be separated in four different projects:

- Detailed analysis of the satellite backhaul, including the study of different options for the frequency band and the technology used, not only from the economical point of view but also in terms of user's service.
- Real WiFi coverage simulations using different AP and antenna models and with the most similar conditions to the camp.
- Telematics study of the servers needed in the camp, as well as the service prioritization for the backhaul access and for the local VoIP service.
- Ways of improving the solar panel dimensioning, trying to reduce the surface covered by the panels and a better exploit of the great solar radiation in Ethiopia.

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Appendices

APPENDIX A

For the calculus of the cumulative probability function we have to take into account that each AP will be studied separately. Considering that the users will be distributed uniformly through the camp, we can calculate how many users will be connected to each AP by knowing the area covered by each of them. Once we have the maximum users that can be connected to each AP, defined as N_{max}, we obtain the cumulative probability function for each AP and then we do a weighted sum of the probabilities depending on the users connected to each AP.

When calculating the probability of, once one user is connected to an AP, having a particular rate, we need to determine the possible rates. For obtaining this, we have to split the transmission rates (linked to each sensitivity) by the users connected simultaneously to the AP. For example, let's take the highest rate in 802.11n WiFi standard: 65 Mbps. There will be as possible rates: 65 Mbps, 65/2 Mbps, 65/3 Mbps,…, 65/N_{max} Mbps. The same happens with all the rates defined in Table 1. As there are 8 different maximum rates depending on the power received, this means that we will have a total of 8·N_{max} possible rates.

Now we have to calculate the probability of having each of these rates. The following expression is used:

$$\Pr(r|N \geq 1) = \sum_{N=1}^{Nmax} \underbrace{\sum_{i1}^{N} \sum_{i2}^{N} \ldots \sum_{i8}^{N}}_{i1+i2+\ldots+i8=N} Pr(r|i1, i2, \ldots, i8, N) \cdot Pr(i1, i2, \ldots, i8|N) \cdot \Pr(N|N \geq 1)$$

Equation 10

where each part of the expression is described below.

In $Pr(N|N \geq 1)$ we calculate the probability of having *N* users connected simultaneously, given that at least one is connected. As the access is by time sharing (both in UL and DL) we have calculated this expression using a Markov chain M/M/1 which can be represented by the following figure:

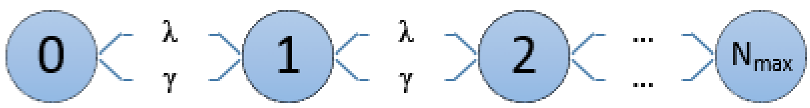


Figure 24 – Markov chain M/M/1

Where λ represents the packets requested per unit time and γ the rate at which we can serve those packets in packets per unit time. First of all, as λ we have taken the average traffic needed at peak hour calculated in 2.3, and γ has been calculated as $\gamma = \sum_{j=1}^{8} B_j \cdot r_j$, where B_j is the percentage of the area of the camp where we have the theoretical rate r_j ($B_j = \frac{A_j}{A_T}$) and r_j is the transmission rate of all possible modulation and coding schemes of WiFi (from table 1).

The division between λ and γ is named as ρ. From this Markov chain, we can obtain the probability of being at each state, so:

$$\Pr(N|N \geq 1) = \frac{P_N}{1 - P_0} = \frac{\frac{\rho - 1}{\rho^{Nmax} - 1}\rho^N}{1 - \frac{\rho - 1}{\rho^{Nmax} - 1}}$$

Equation 11

And N will take all the values between 1 and N_{max}.

In the second part of the global expression ($Pr(i1, i2, \ldots, i8|N)$), we want to calculate the probability of having each possible combination of users connected to the AP in each area of the camp. Remember that we only consider the cases when i1 + i2 + i3 +…+ i8 = N, because by this expressions we only study that, when *N* users are connected simultaneously, how many of them will be in each area. The expression for this part is the multinomial density function (considering that all the doctors are uniformly distributed through the camp):

$$Pr(i1, i2, \ldots, i8|N) = \frac{N!}{i_1! \cdot i_2! \cdot i_3! \cdot i_4! \cdot i_5! \cdot i_6! \cdot i_7! \cdot i_8!} B_1^{i_1} \cdot B_2^{i_2} \cdot B_3^{i_3} \cdot B_4^{i_4} \cdot B_5^{i_5} \cdot B_6^{i_6} \cdot B_7^{i_7} \cdot B_8^{i_8}$$

Equation 12

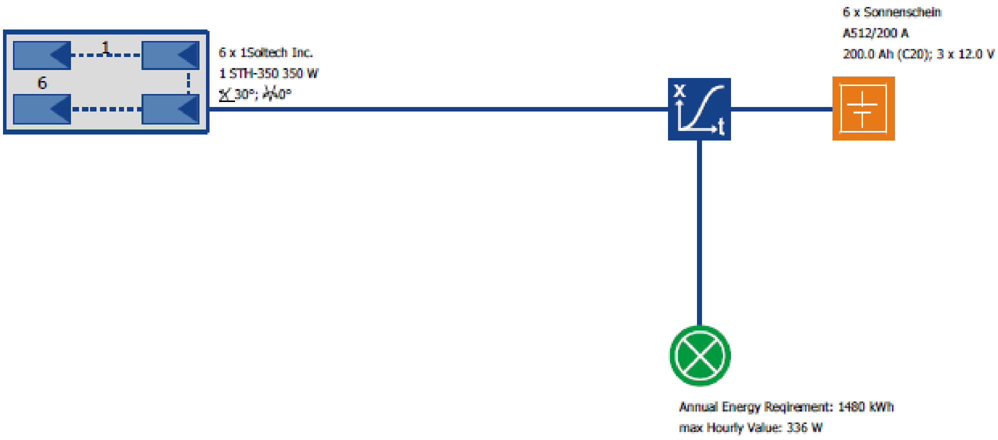
Finally, the expression $Pr(r|i1, i2, \ldots, i8, N)$ represents the probability of having one of the particular rates knowing the number of users connected and in which area are each of those users. If we know that in a particular moment there are N users connected to the AP and i_k of those *N* are in the area *k*, corresponding a theoretical rate r_k, we will be able to calculate the probability of having the correspondent rate r_k/N by:

$$Pr(r|i1, i2, \ldots, i8, N) = \frac{i_k}{N}$$

Equation 13

APPENDIX B

Project Name:	TFGIsmael_CentralBase	02/07/2014
Variant Reference:	System Variant	



Location:	Melkadida Camp
Climate Data Record:	Melkadida Camp (1986-2005)
PV Output:	2.10 kWp
Gross/Active PV Surface Area:	12.95 / 12.94 m²

PV Array Irradiation:	24,675 kWh
Energy Produced by PV Array:	2,955.1 kWh
Consumption Requirement:	1,479.7 kWh
Consumption Covered by Solar Energy:	1,477.6 kWh
Consumption Not Covered by System:	2.1 kWh

Solar Fraction:	99.9 %
Performance Ratio:	36.9 %
Specific Annual Yield:	703.6 kWh/kWp
CO2 Emissions Avoided:	908 kg/a
System Efficiency:	6.0 %
PV Array Efficiency:	12.0 %

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

Project Name:	TFGIsmael_CentralBase	02/07/2014
Variant Reference:	System Variant	

System in Stand-Alone Operation

Location:	Melkadida Camp	PV Output:	2.10 kWp
Climate Data Record:	Melkadida Camp	Gross/Active PV Surface Area:	12.9 m² / 12.9 m²
Number of Arrays:	1		

Array 1: Array Name

Output:	2.10 kW	Ground Reflection:	20.0 %
Gross/Active Solar Surface Area:	12.9 m² / 12.9 m²	Output Losses due to...	
PV Module	6 x	deviation from AM 1.5:	1.0 %
Manufacturer:	1Soltech Inc.	deviation from Manufacturer's Specification:	2.0 %
Model:	1 STH-350	in Diodes:	0.5 %
Nominal Output:	350 W	due to Soiling:	0.0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	16.2 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	43 V		
Orientation:	0.0 °		
Inclination:	30.0 °		
Mount:	with Ventilation		
Shade:	No		

Battery

Manufacturer:	Sonnenschein	Mean Charge Efficiency:	85.0 %
Model:	A512/200 A	Mean Discharge Efficiency:	99.0 %
Nominal Voltage:	12.0 V	Charge Controller	
C20 Capacity:	200.0 Ah	Lower Battery Discharge Threshold:	30.0 %
Self Discharge:	0.1 %/Tag		

Individual Appliances Total Consumption: 1,480 kWh

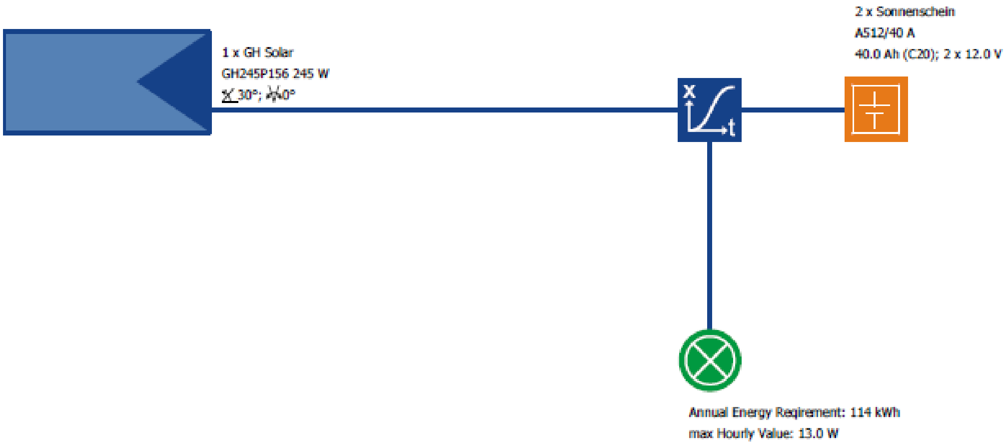
Asterisk laptop	Model: User-Independent Appl.	175 kWh
Access Point	Model: User-Independent Appl.	61 kWh
AP Access Point	Model: User-Independent Appl.	53 kWh
BUC	Model: User-Independent Appl.	158 kWh
iDirect Router	Model: User-Independent Appl.	175 kWh
Mobile Battery 2	Model: User-Dependent Appl.	161 kWh
Tablet Battery	Model: User-Dependent Appl.	66 kWh
Laptops Battery	Model: User-Dependent Appl.	150 kWh
Mobile Battery 1	Model: User-Dependent Appl.	161 kWh
Mobile Battery 3	Model: User-Dependent Appl.	161 kWh
Mobile Battery 4	Model: User-Dependent Appl.	161 kWh

Simulation Results for Total System

Irradiation onto Horizontal:	25,840 kWh	Battery Charge:	1,069 kWh
PV Array Irradiation:	24,675 kWh	Battery Losses:	172 kWh
Irradiation minus Reflection:	23,478 kWh	Charge Condition at Simulattion Start:	87.7 %
Energy Produced by PV Array:	2,955 kWh	Charge Condition at Simulattion End:	87.7 %
Consumption Requirement:	1,480 kWh	Solar Fraction:	99.9 %
Direct Use of PV Energy:	581 kWh	Performance Ratio:	36.9 %
Consumption Not Covered by System:	2 kWh	Final Yield:	1.9 h/d
PV Array Surplus:	1,305 kWh	Specific Annual Yield:	704 kWh/kWp
Consumption Covered by Solar Energy:	1,478 kWh	System Efficiency:	6.0 %
Battery Discharge:	897 kWh	Array Efficiency:	12.0 %
Battery Efficiency:	83.9 %		

APPENDIX C

Project Name:	TFGIsmael_SecondaryBase	02/07/2014
Variant Reference:	System Variant	



Location:	Melkadida Camp	
Climate Data Record:	Melkadida Camp (1986-2005)	
PV Output:	245.0	Wp
Gross/Active PV Surface Area:	1.63 / 1.63	m²

PV Array Irradiation:	3,115.3	kWh
Energy Produced by PV Array:	375.24	kWh
Consumption Requirement:	113.88	kWh
Consumption Covered by Solar Energy:	113.88	kWh
Consumption Not Covered by System:	0.0	kWh

Solar Fraction:	100.0	%
Performance Ratio:	24.4	%
Specific Annual Yield:	464.8	kWh/kWp
CO_2 Emissions Avoided:	70	kg/a
System Efficiency:	3.7	%
PV Array Efficiency:	12.0	%

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

Project Name:	TFGIsmael_SecondaryBase	02/07/2014
Variant Reference:	System Variant	

System in Stand-Alone Operation

Location:	Melkadida Camp	PV Output:	245.0 Wp
Climate Data Record:	Melkadida Camp	Gross/Active PV Surface Area:	1.6 m² / 1.6 m²
Number of Arrays:	1		

Array 1: Array Name

Output:	0.24 kW	Ground Reflection:	20.0 %
Gross/Active Solar Surface Area:	1.6 m² / 1.6 m²	Output Losses due to...	
PV Module	1 x	deviation from AM 1.5:	1.0 %
Manufacturer:	GH Solar	deviation from Manufacturer's Specification:	0.0 %
Model:	GH245P156	in Diodes:	0.5 %
Nominal Output:	245 W	due to Soiling:	0.0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	15.1 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	31 V		
Orientation:	0.0 °		
Inclination:	30.0 °		
Mount:	with Ventilation		
Shade:	No		

Battery

Manufacturer:	Sonnenschein	Mean Charge Efficiency:	85.0 %
Model:	A512/40 A	Mean Discharge Efficiency:	99.0 %
Nominal Voltage:	12.0 V	Charge Controller	
C20 Capacity:	40.0 Ah	Lower Battery Discharge Threshold:	30.0 %
Self Discharge:	0.1 %/Tag		

Individual Appliances Total Consumption: 114 kWh

Access Point	Model: User-Independent Appl.	61 kWh
AP Access Point	Model: User-Independent Appl.	53 kWh

Simulation Results for Total System

Irradiation onto Horizontal:	3,262 kWh	Battery Charge:	75 kWh
PV Array Irradiation:	3,115 kWh	Battery Losses:	12 kWh
Irradiation minus Reflection:	2,964 kWh	Charge Condition at Simulattion Start:	91.8 %
Energy Produced by PV Array:	375 kWh	Charge Condition at Simulattion End:	91.8 %
Consumption Requirement:	114 kWh	Solar Fraction:	100.0 %
Direct Use of PV Energy:	51 kWh	Performance Ratio:	24.4 %
Consumption Not Covered by System:	0 kWh	Final Yield:	1.3 h/d
PV Array Surplus:	249 kWh	Specific Annual Yield:	465 kWh/kWp
Consumption Covered by Solar Energy:	114 kWh	System Efficiency:	3.7 %
Battery Discharge:	63 kWh	Array Efficiency:	12.0 %
Battery Efficiency:	83.9 %		

Glossary

MSF - Médecins Sans Frontières / Doctors Without Borders

AP – Access Point