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Development and Integration of a Rapid Deployment Portable Land Mobile Unit for Emergency Communications

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Acronyms

ABSOLUTE	Aerial Base Stations with Opportunistic Links For Unexpected & Temporary Events
3GPP	3rd Generation Partnership Project
AC	Alternating Current
AeNB	Aerial E-UTRA Node B
AP	Access Point
API	Application Programming Interface
ARFCN	absolute radio-frequency channel number
ARM	Advanced RISC Machine
BS	Base Station
CLI	Command Line Interface
CN	Core Network
CPU	Central Processing Unit
CSV	Comma-Separated Values
D2D	Device-to-Device
DC	Direct Current
DDR	Double Data Rate
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
eNB	E-UTRAN Node B
EPC	Evolved Packet Core
E-UTRA	Evolved Universal Terrestrial Radio Access
GPIO	Global Purpose Input Output
GPU	Graphics Processing Unit
GUI	Graphical User Interface
HD	High Definition
HDMI	High-Definition Multimedia Interface
HTTP	Hypertext Transfer Protocol
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
JSI	Jožef Stefan Institute
KPI	Key Performance Indicator
LAN	Local Area Network
LAP	Low Altitude Platform
LTE	Long Term Evolution
MM-UE	MultiMode User quipment
NTP	Network Time Protocol
OS	Operating System
PBX	Private branch exchange
PLMN	Public Land Mobile Network
PLMU	Portable Land Mobile Unit
PPDR	Public Protection and Disaster Relief

PSTN	Public Switched Telephone Network
REST	Representational state transfer
RF	Radio Frequency
SAE	System Architecture Evolution
SBC	Single Board Computer
SD	Secure Digital
SIP	Session Initiation Protocol
SoC	System on Chip
SOC	State Of Charge
SPDT	Single Pole, Double Throw
SSH	Secure Shell
SSL	Secure Sockets Layer
SW	Software
TCP	Transmission Control Protocol
TeNB	Terrestrial E-UTRA Node B
TETRA	TErrestrial TRunked RAdio
TGS	TriaGnoSys
UE	User equipment
UMTS	Universal Mobile Telecommunications System
URI	uniform resource identifier
USB	Universal Serial Bus
UTRAN	Universal Terrestrial Radio Access Network
VoIP	Voice over IP
WAP	Wireless Access Point
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network
XML	Extensible Markup Language

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Resum

Aquesta tesi descriu el procés de disseny i implementació d'una unitat portàtil de comunicacions terrestre amb connexió satèl·lit per a comunicacions d'emergència englobada dintre del projecte ABSOLUTE.

El projecte ABSOLUTE té com a objectiu dissenyar una arquitectura de xarxa futurista de desplegament ràpid que pugui proporcionar serveis de banda ampla i connectivitat a grans àrees afectades per esdeveniments inesperats o desastres naturals i a on la infraestructura de comunicacions terrestre hagi quedat afectada.

La unitat portàtil de comunicacions terrestre és un sistema de comunicacions empaquetat en una maleta robusta i alimentat per bateries amb vàries hores d'autonomia. Els sistemes de comunicació que aquestamaleta ha de proporcionar per al projecte ABSOLUTE són: telefonia mòbil i dades sobre UMTS, telefonia mòbil i dades sobre LTE, radio mòbil sobre TETRA, Wireless LAN IEEE 802.11, recollida de dades d'una Wireless Sensor Network i comunicacions remotes sobre un link per satèl·lit operant a la banda ka.

Donats els requisits i les especificacions del dispositiu aquest ha estat dissenyat, començant per l'estudi de l'estat de l'art i l'elecció dels elements hardware i dispositius de comunicacions necessaris, continuant pel software encarregat de gestionar les comunicacions i finalitzant amb la implementació de part d'aquests elements per realitzar la primera demostració funcional del dispositiu.

El procés de disseny ha estat marcat per la necessitat de minimitzar el consum de potència dels dispositius que l'integrenamb l'objectiu de maximitzar el temps d'operativitat del conjunt així com reduir les dimensions i el pes del mateix. És per això que es presenten propostes i estudis de millora del sistema que no han estat implementades per a la primera versió però que ho estaran en versions futures.

Resumen

Esta tesis describe el proceso de diseño e implementación de una unidad portátil de comunicaciones terrestre con una conexión satélite para comunicaciones de emergencia englobada dentro del proyecto ABSOLUTE.

El proyecto ABSOLUTE tiene como objetivo diseñar una futura arquitectura de red de despliegue rápido que pueda proporcionar servicios de banda ancha i conectividad a grandes áreas afectadas por eventos inesperados o desastres naturales i donde la infraestructura de comunicaciones terrestre haya quedado afectada.

La unidad portátil de comunicaciones terrestre es un sistema de comunicaciones empaquetado en una maleta robusta i alimentado por baterías con varias horas de autonomía. Los sistemas de comunicaciones que ésta ha de proporcionar para el proyecto ABSOLUTE son: telefonía móvil y datos sobre UMTS, telefonía móvil y datos sobre LTE, radio móvil sobre TETRA, Wireless LAN IEEE 802.11, recogida de datos de una Wireless Sensor Network y comunicaciones remotas sobre un link por satélite en la banda ka.

Dados los requisitos y las especificaciones del dispositivo, éste ha sido diseñado partiendo del estudio del estado del arte y de la elección de los elementos hardware y los dispositivos de comunicaciones necesarios, continuando por el software encargado de gestionar les comunicaciones y finalizando con la implementación de parte de estos elementos para la realización de la primera demostración funcional del dispositivo.

El proceso de diseño ha estado marcado por la necesidad de minimizar el consumo de potencia de los dispositivos que lo integran con el objetivo de maximizar el tiempo de operatividad del conjunto así como reducir les dimensiones y el peso del mismo. Es por eso que se presentan propuestas i estudios de mejora del sistema que no han sido implementados para la primera versión pero que lo estarán en versiones futuras.

Abstract

This thesis describes the design and implementation process of a portable land communications unit with a satellite backhauling link for emergency communications as part of the ABSOLUTE project.

The ABSOLUTE project aim is to design rapidly deployable future network architecture capable of providing Broadband services and connectivity for large coverage areas affected by unexpected events or natural disasters where the terrestrial communication infrastructure is unavailable.

The portable land communications unit is a system packed into a rugged suitcase and is a battery-powered device with several hours of operating autonomy. The communication systems that it has to provide within the ABSOLUTE project, are the following: mobile telephony and data over UMTS, mobile telephony and data over LTE, professional mobile radio over TETRA, Wireless LAN over IEEE 802.11, data collection from a Wireless Sensor Network, remote communications over a ka-band satellite link.

Given the requirements and the specifications of the system, it has been designed starting from the state-of-the-art study and the selection of the hardware components and the main communication devices to the software needed to manage the communications and finishing with the implementation of part of these components for the first version of the system functional demonstration.

The design process has been marked by the need to minimize the integrated devices' power consumption with the aim to reduce the overall power consumption as well as the size and weight. That is why some proposals and studies to improve the system are presented although they have not been implemented for the first version they will be present in future versions.

1 Introduction

This document describes the design and integration process of the Portable Land Mobile Unit (PLMU) of the ABSOLUTE network. Although the integration process of this system is still ongoing, so the final result of a finished product cannot be shown in this document, the first steps undertaken for building the system together with some tests results will be detailed.

1.1 Objectives

The aims of this thesis are to design, develop and implement a portable terrestrial network sub-system to achieve the goals of the ABSOLUTE project. Since the scope of this project is very big this thesis was not planned to cover the whole integration process of the PLMU due to the time constraints.

The main development tasks of this thesis for the PLMU design are the following:

- Software and Hardware design of the PLMU
  - Study of the state-of-the-art components and selection of some hardware devices
  - Study of the viability of the designed PLMU system
- Integration of the available communications devices in a single processor unit
- Design the Power Distribution Unit (PDU)
- Investigate techniques and approaches that reduce the power needs of the PLMU in order to maximize the operational time and self-sufficiency

Chapter 9 (Project Status) gives a better idea of the work undertaken during this thesis.

1.2 Structure of the Document

This document is structured in the following order:

Chapter 1 gives a description of the work planned to be done in this thesis.

Then, Chapter 2 presents the ABSOLUTE project and its architecture based in information extracted from the project documents.

After it, Chapter 3 describes the functionalities of the PLMU and presents the design specifications.

Chapter 4 exposes a detailed view of the hardware devices to be integrated in the PLMU, both the ones chosen in the design process of this thesis and those provided by other project partners.

Chapter 5 comprehends the software architecture schema running in the PLMU computing platform and their main role in the PLMU system.

Next, Chapter 6 shows the selection process of the new computing platform and the information about the improvement achieved due to this replacement.

Later, Chapter 7 contains information about the PLMU power system, its design and the main elements composing it.

Chapter 8 presents the device in charge of the energy monitoring system, its performances and how it will be integrated in the system.

Chapter 9 sketches the status of the work undertaken at the end of this thesis in order to give the reader a better understanding of the job done along it.

Finally, Chapter 10 comprises the conclusions reached from the work undertaken in this thesis and the main future tasks to be done in order to complete the PLMU system.

1.3 Methodology

To keep the development and the implementation in the right direction, a weekly meeting was held. A stepwise methodology was used, by reviewing objectives and project plan on a weekly basis.

Two important deadlines were the midterm and final presentation. The midterm presentation allowed a review of the project with staff and management of the company, to make sure that the project development went in the good direction, and to bring new ideas.

Figure 1.1 shows the time organization during the course of the thesis.

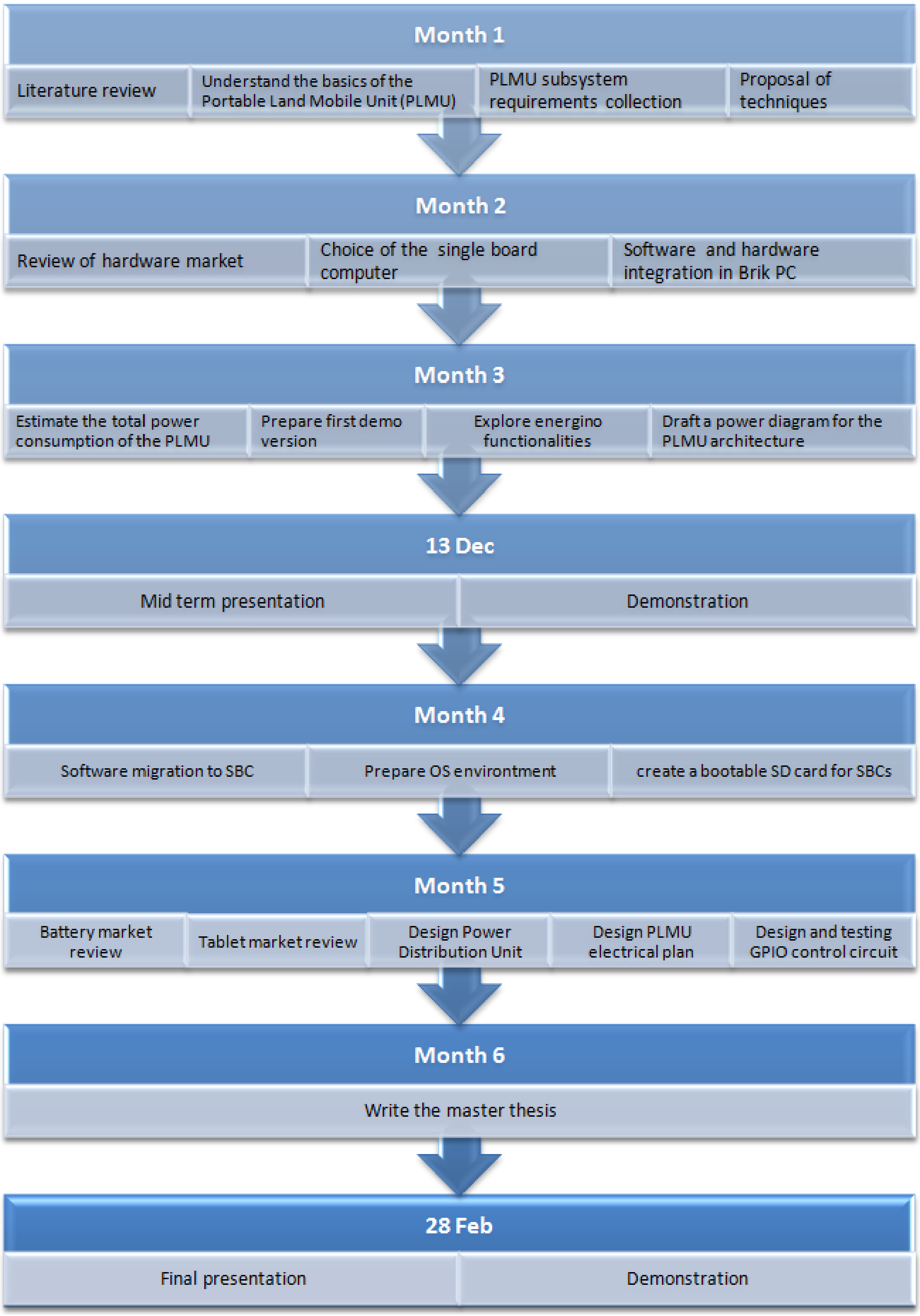

Figure 1.1 – Thesis Chronology.

2 The ABSOLUTE Project

TriaGnoSys currently participates in the European research project ABSOLUTE. The ABSOLUTE [1] project is co-founded by the European Commission under the SEVENTH FRAMEWORK PROGRAMME [2]. This project will introduce a rapidly deployable UMTS and LTE network based on Low Altitude Platforms (LAP) and Portable Land Mobile Units for the support of disaster-relief activities.

2.1 Background

Recent history has shown that in the aftermath of an emergency, disaster or related unexpected events, telecommunication infrastructures play a key role in recovery operations [3]. In most cases, the terrestrial infrastructure is seriously compromised and cannot guarantee reliable services for citizens and rescue teams. It is also well accepted that current public safety networks cannot provide sufficient capacity for broadband applications.

In the consequences of a disaster, the promptness, coordination and effectiveness of support actions can be dramatically improved by the availability of a communication system capable of offering in a quick and reliable manner broadband links to interconnect different devices among each other as well as with remote operation centres. In order to achieve these goals, the ABSOLUTE system has been envisioned and will be developed following an approach that combines terrestrial, aerial and satellite communication capabilities.

2.1.1 Overall ABSOLUTE Architecture

The ABSOLUTE project will design and validate a rapidly deployable future network architecture which is resilient and capable of providing Broadband multi-service, secure and dependable connectivity for large coverage areas affected by large scale unexpected events (or disasters) leading to the partial or complete unavailability of the terrestrial communication.

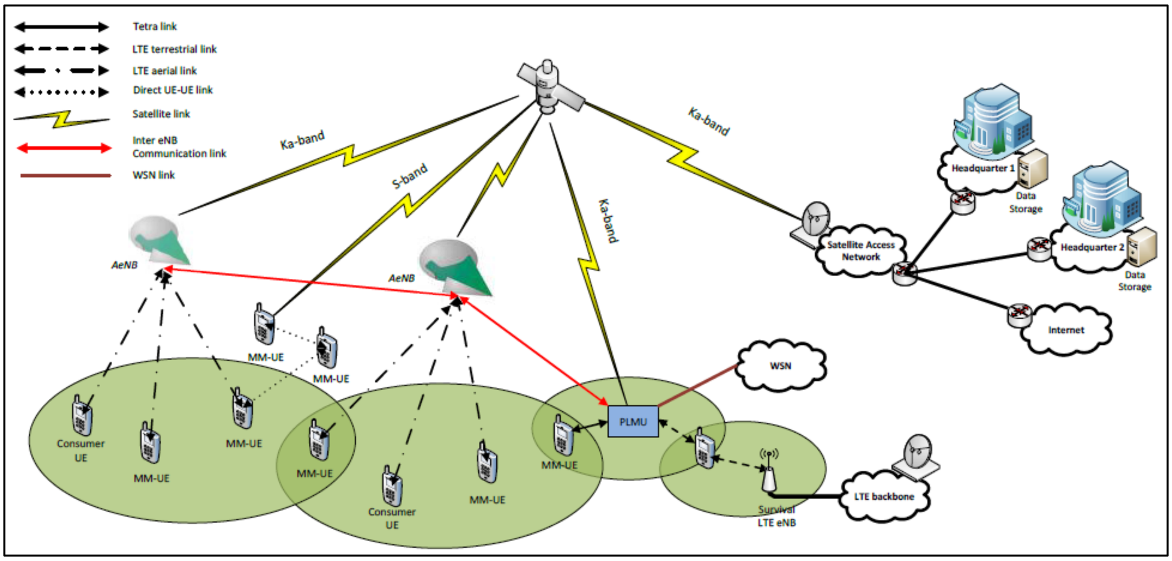

Figure 2.1– Overall ABSOLUTE architecture [4].

A high-level representation of the ABSOLUTE architecture is reported in Figure 2.1. The ABSOLUTE architecture is based on the following elements:

- Low altitude Aerial LTE-A Base Stations (AeNB), embedded in LAPs providing high data rates and coverage over large areas,
- Portable Land Mobile LTE-A Base Stations interoperable with conventional PPDR systems (TETRA base stations) and sensor networks (sensor gateways), enabling dedicated coverage and broadband satellite backhauling capabilities in Ka-Band,
- Advanced multimode LTE-A Professional terminals (MM-UE) enabling direct mode LTE communications (LTE D2D) and direct messaging services via S-band satellite when outside of TeNB or AeNB coverage.

2.1.2 Terrestrial Network

The terrestrial network sub-system is a multimode light-weight energy-efficient Portable Land Mobile Unit which is deployed in adverse terrain where dedicated coverage requirements and network coordination are required, but which is not covered by the LAP [3].

In the ABSOLUTE network, voice and data traffic from victims and first responders is routed through the PLMU and backhauled over Ka-band satellite links to the PSTN, the

Internet or to a remote emergency coordination center. In this context, the PLMU aggregates multiple interoperable communication systems steered by the PLMU users.

The PLMU is a standalone and self-sufficient communications platform. Just as the LAP, it provides a variety of communication services to the users of the ABSOLUTE system. The PLMU developed within the ABSOLUTE project should include any combination of the following communication systems:

- Mobile telephony and data over UMTS,
- Mobile telephony and data over LTE/LTE-A,
- Professional mobile radio over TETRA,
- Wireless LAN over IEEE 802.11,
- Data collection from Wireless Sensors Network (WSN),
- Remote communications over a satellite link from *Eutelsat*.

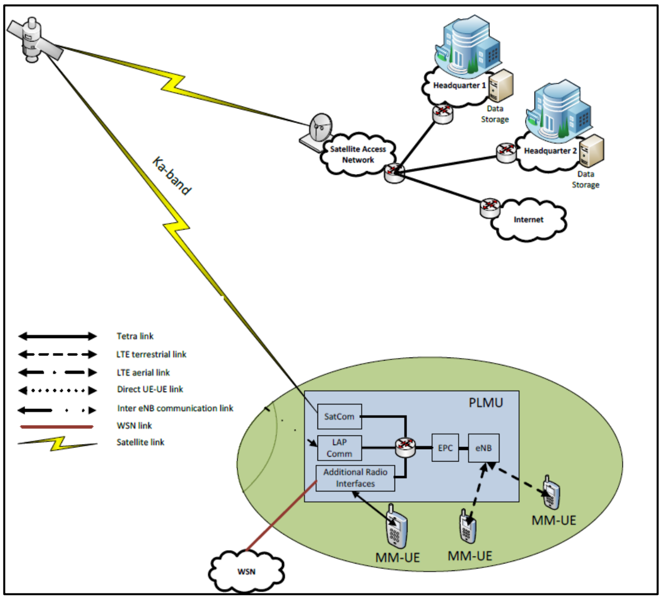

Figure 2.2 – The PLMU in the ABSOLUTE network [4].

3 PLMU Design

The PLMU will have to accommodate multiple systems that provide various functionalities to the holistic ABSOLUTE network. These include, for example, a WLAN access point, a Terrestrial eNodeB, a sensors gateway, an IP router, a TETRA base station, a Ka-band satellite modem, etc. Additionally, the PLMU also includes subsystems that support its main role as a communications platform such as batteries, power supply and a PC that controls all of the PLMU functions.

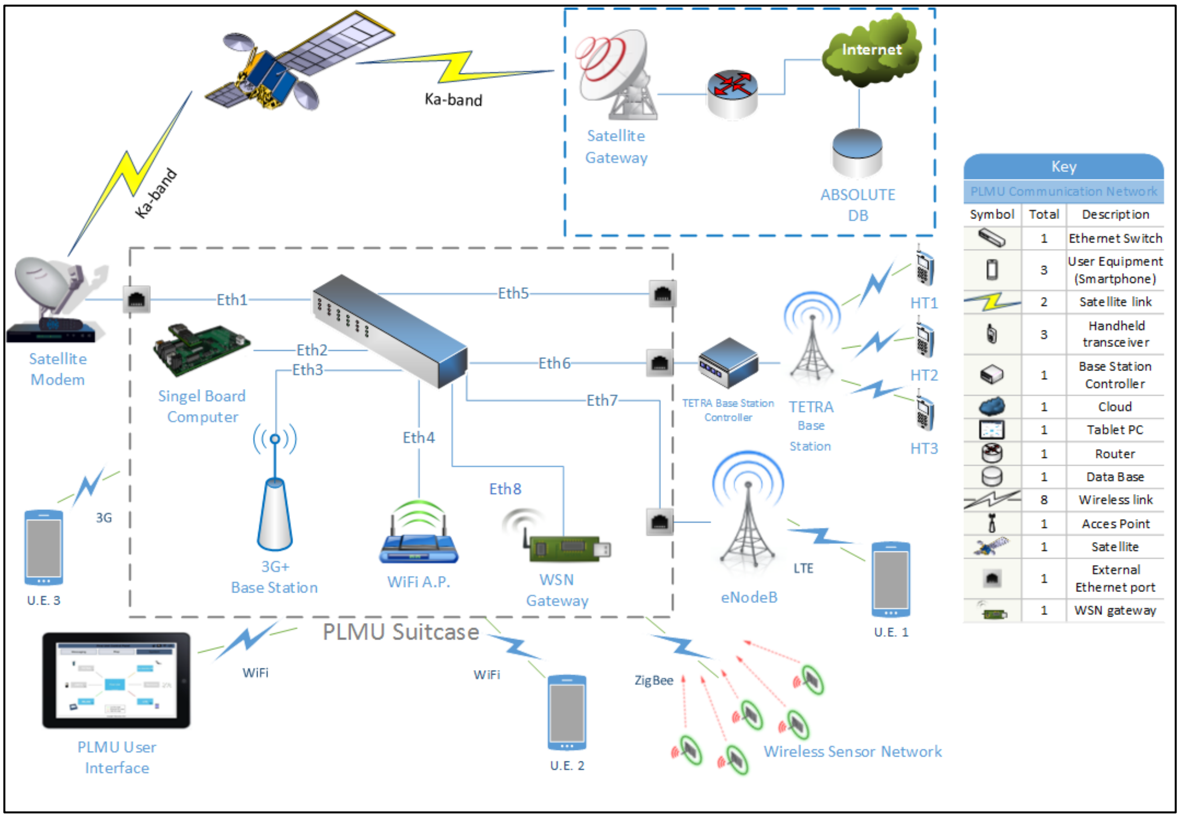

Figure 3.1 – PLMU communication network and devices.

Figure 3.1 shows a detailed diagram of the main communication devices to be embedded in the PLMU. This sketch shows a touch screen, which is the main device used for human interaction (PLMU User Interface).

The PLMU interconnects all communication systems holistically to enable that user terminals of different technologies (i.e. a TETRA and a LTE terminal) communicate through the PLMU. Other examples of this cross-technology communication are, for instance, the transmission of data collected by the sensors through the WLAN interface to mobile users.

Similarly, UMTS can perform calls to the PSTN over the satellite link, and remote users can access the sensors' data also over satellite. Additionally, the computer onboard the PLMU manages the bandwidth of the satellite link to prevent link congestion.

3.1 PLMU Functionalities

This section describes how the PLMU works from the user's perspective. In particular, the interactions between the first responders and the maintenance technician with the PLMU itself are described here. As previously indicated, the PLMU offers a series of functionalities that can be accessed through the touch screen and control panel (see Figure 3.2).

Figure 3.2 – Touch screen with GUI mockup for the management of the PLMU.

- **Management of comms. Systems:** this function allows close users to activate and deactivate one or several of the wireless systems offered by the PLMU.
- **Voice calls into the PSTN:** this function allows close and nearby users to perform voice calls into the PSTN, as well as to receive voice calls from it.
- **Access to sensor's data:** the environmental data collected by the sensors is transmitted back to the PLMU over the wireless sensor network, where it can be accessed by the PLMU users.
- **Access to local media content:** media such as pictures and videos can be easily captured from user terminals such as smart phones, helmet mount cameras

and wearable computers such as, for example, Google Glass. This media is stored in the PLMU.

- **Internet access:** the PLMU is connected to the public Internet through the satellite link. Users connected to the 3G or LTE network can also access the Internet.
- **Wireless communications (UMTS, LTE, WLAN and/or TETRA):** This is the main function of the PLMU, as it provides mobile communications to users.
- **Access to application server:** The PLMU serves a web GUI through which users can use several applications.

3.2 System requirements

The system requirements are the basis of the design process of the PLMU. They can be divided in two categories, the functional and the non-functional specifications. Functional requirements normally describe the requested behavior of the system whereas non-functional ones specify criteria that can be used to judge the operation of the system, rather than specific behaviors.

The main functional specifications for the PLMU are shown in Table 3.1. This list in only showing the mandatory requirements, but there are other optional specifications that may be considered in the design for the final version.

Version	Category	Name	Description
Final	Comms	LTE	It provides LTE voice service
Demo	Comms	UMTS	It provides UMTS voice service
Demo	Comms	LTE Data service	It provides LTE Data service
Demo	Comms	3G Data service	It provides 3G Data service
Demo	Comms	WiFi	It provides WiFi coverage
Demo	Comms	TETRA	It is not integrated in the suitcase itself. It is in a different suitcase
Demo	Comms	Satellite backhaul link	It has a backhauling connection through satellite
Demo	Equipment	Touch screen	It has a touch screen displaying the control GUI.
Demo	Equipment	Batteries	- It can switch between batteries and regular power outlet

			- Batteries recharge during connection to regular outlet - Not possible to switch during working time
Demo	Equipment	SIM Card Reader	It eases the process of registering a new SIM card into the system
Demo	Software	SoftBSC	It is the software implementing the BSC
Demo	Software	Quortus	It is the software implementing the CORE
Demo	Software	Asterisk	It is the software implementing a PBX
Demo	Software	Control GUI	- Shows status for all the subsystems - ARFCN and Power Configurable - Allows to add new SIMs in two ways: manually and through the SIM card reader - 2 languages (English and German)
Demo	Functionality	PSTN reachable	It can use an external SIP provider to reach the PSTN network
Final	Functionality	Voice compression	It uses VoCeM for voice compression on the satellite backhaul link
Final	Functionality	Connection to helpdesk	Allows by pressing a button a remote access for TriaGnoSys for supporting activities
Demo	Functionality	Conference	It allows to start a conference with all the attached devices

Table 3.1 – List of PLMU functional specifications [4].

Table 3.2 shows the mandatory non-functional specifications for the demo and the final version of the PLMU.

Version	Category	Description
Demo	Usability	The PLMU shall weight less than 20 kg
Demo	Usability	The PLMU shall fit within a 50x50x50 cm bounding box
Demo	Usability	The PLMU form factor shall be a rolling suitcase
Demo	Performance	The PLMU shall have a battery-powered autonomy larger than 1 hour.
Demo	Usability	The PLMU "operating" mode shall be that in which at least one of the PLMU RF interfaces is active.
Demo	Usability	The PLMU "standby" mode shall be that in which none of the PLMU RF interfaces is active.
Demo	Usability	The PLMU shall be portable by a one person
Final	Usability	The serial number of the PLMU shall be visible on the casing tag.
Final	Usability	The PLMU shall have a casing tag.
Final	Performance	The PLMU-LTE deployment time shall be lower than 1 hour.
Final	Performance	The PLMU-LTE deployment time shall be lower than 1 hour.
Final	Performance	The PLMU-UMTS deployment time shall be lower than 1 hour.
Final	Security	The PLMU shall be lockable
Final	Reliability	The PLMU shall survive stowage temperatures between -20°C and +40°C.
Final	Reliability	The PLMU shall survive at least five years of unattended storage.

Final	Reliability	The PLMU shall operate as expected after at least five years of unattended storage.
Final	Performance	The PLMU shall be ruggedized
Demo	Usability	The satellite UICC for airtime provisioning shall be replaceable by one person only without the need for additional tools.

Table 3.2 – List of PLMU non-functional specifications [4].

There are specifications that directly impact in the physical design of the PLMU. According to these specifications a first graphical design of a possible suitcase physical aspect has been done (See Figure 3.3). In this sketch only the devices included in the suitcase and the satellite antenna are included for the design, but there will be external parts like the TETRA subsystem or the eNodeB base station that will be out of the suitcase and have to be transported separately.

Figure 3.3 –3D sketch of a PLMU based on a Pelican 1600 case [5].

4 PLMU Hardware Architecture

In this chapter the hardware elements composing the PLMU will be introduced. It is important to remark that not all the system components have been chosen by TriaGnoSys but some of them are contributions from other partners collaborating in the project and they cannot be replaced.

For those elements chosen by TriaGnoSys the same procedure for the election of the best candidate has been done and it will be widely explained as an example purpose in 6 Computing Platform. There are always three valid alternatives for each device so the possibility to replace this device by another is always open in case something unexpected occurs.

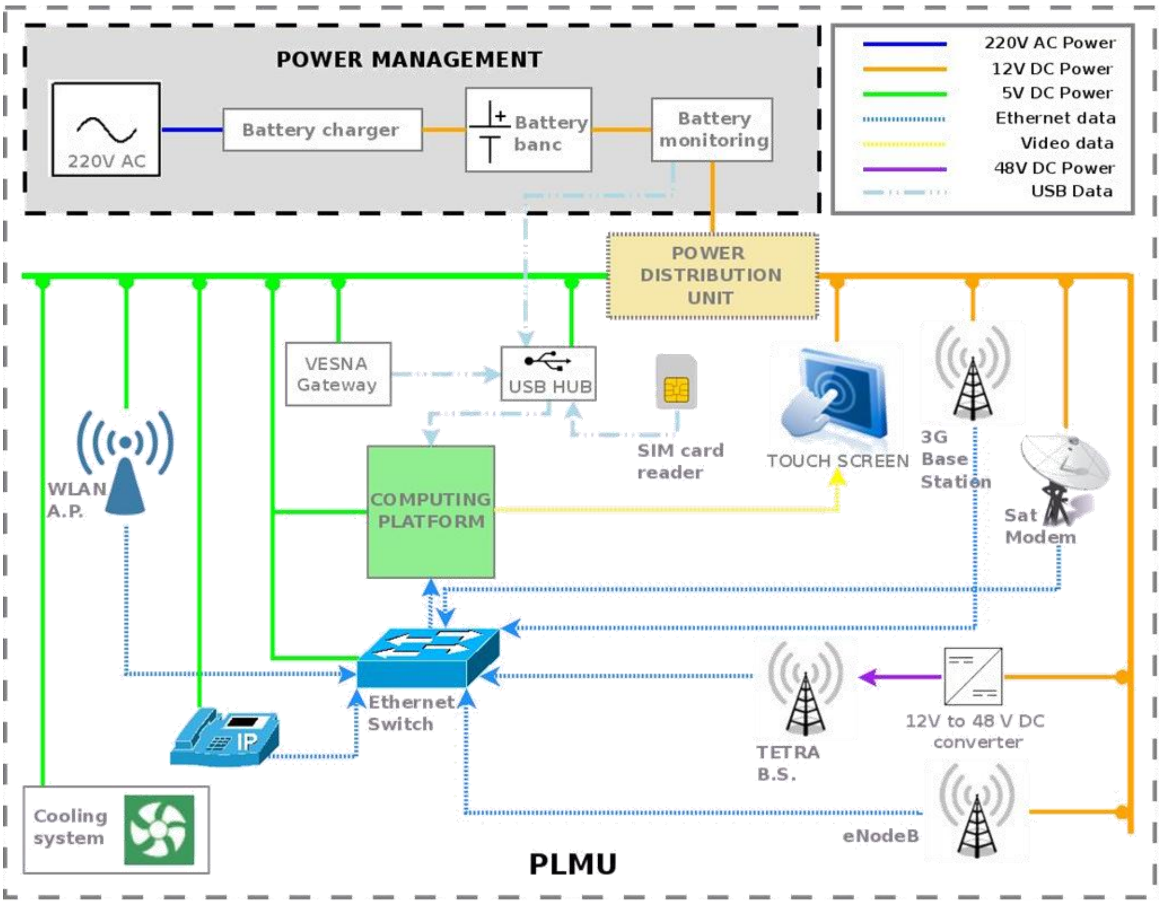

Figure 4.1 –Diagram including all the devices forming the PLMU and its connections

In the figure above a detailed hardware architecture of the PLMU is shown. It helps understanding the overall system functionalities. The interconnection between elements is represented following the colors criteria that can be checked at the figure legend and it provides information about power and data connections for each device in the PLMU. For more information about communications wiring and links (see Figure 4.1) and for detailed information of the electrical connections please refer to Appendix B. Electrical Plan.

4.1 Major Components

In this section a list of features of the most relevant system hardware, from the communications point of view, is presented. These components are the essential part of the PLMU because they are performing its main functionality. There are other elements whose role in the system is trivial and they are not going to be analyzed in detail. The complete list of components that build the PLMU can be found in Appendix C. Electrical Performances.

The elements belonging to the power management, the power distribution unit and the computing platform areas will be reviewed in later chapters (5 and 6).

4.1.1 3G Access Point

The main function of 3G AP is to provide 3G data and voice connectivity through the PLMU network. It will be placed inside the suitcase and connected to the PLMU processing core with an Ethernet cable.

The device used as a 3G AP is a 3G femtocell from *Ip access*, the nano3G® S8 femtocell [6]. It is a small, low-power cellular base station that supports up to 8 simultaneous active users respectively.

Figure 4.2 –nano3G® S8 3G femtocell from *IP access*.

A list of its main features is shown in the table below.

S-class femtocell	
RF output power	20 mW
UMTS bands	1, 2/5, 4
Electrical Power	<8 W +9V DC
External antennas	No
Dimensions	168 x 164 x 52 mm
Network listen	3G & 2G Network listen to support radio synchronisation and RF planning

Table 4.1 – nano3G femtocell main specifications.

4.1.2 eNodeB

The eNodeB is the hardware connected to the mobile phone network communicating directly with mobile handsets (UEs) for LTE connectivity. This element will be placed out of the suitcase due to its large size and its design is in charge of the *University of Duisburg-Essen*, one of the partners of the ABSOLUTE project. For the connection with the PLMU communication core it will use one of the external Ethernet ports in the suitcase.

4.1.3 TETRA Base Station

In the ABSOLUTE project the TETRA BS that will be used is the DAMM's TetraFlex® Outdoor System made by *Damm Cellular Systems* [7] and which consists of the Base Station Transceiver (BS421) together with the Service Box (SB421) containing the base station controller and the power supply (see Figure 4.3).

Figure 4.3 –TETRA Base Station BS421.

Since its dimensions are too big to fit it in the PLMU suitcase, it will be placed out of it. Therefore it will need to use one of the external Ethernet connector in the suitcase. It is the only device powered at 48V DC, so it will have its own power line coming from a DC boost converter. Table 4.2 shows some of its most important specifications.

TETRA BS	
Electrical Power	75 W -48V DC
Dimensions	333 x 246 x 165 mm
Weight	9 kg
RF settings	- TX power 0.5 W to 10 W
	- RX sensitivity -121 dBm
	- Frequency bands: 300, 400 and 800 MHz

Table 4.2 – TETRA Base Station main specifications.

4.1.4 Satellite Modem

The satellite modem and the antenna are the devices in charge of performing the backhauling Ka-band [8] satellite link from the PLMU to the ABSOLUTE DB and the Internet.

The satellite modem to be used is manufactured by *IPcopter* and is a tried and true auto-deploy system based on the *ViaSat Surfbeam* [9] 72cm consumer terminal. This device is fitted in a flightcase that protects the electronics from rain and other environmental issues. It is a contribution to the ABSOLUTE project from partner *Eutelsat* and it will not be integrated in the suitcase. The satellite dish can be placed up to 20 m distance from the PLMU suitcase. The main performances of these components are summarized in Table 4.3.

Figure 4.4 –Satellite dish and modem.

Satellite Modem	
RF output power	3 W
UMTS bands	1, 2/5, 4
Electrical Power	80 W +12V DC
Polarisation	Circular
Dimensions	1000x500x340mm
Weight	32 kg

Table 4.3 – Satellite modem main specifications.

4.1.5 Wireless Sensor Gateway

The WSN gateway will be implemented using the modular sensor node platform VESNA [10] depicted in Figure 4.5. This element of the PLMU acts as a base station of the WSN with much more computational, energy and communication resources and it is the gateway between sensor nodes and the end user as it forwards data from the WSN on the ABSOLUTE network.

To efficiently integrate it in PLMU it will combine the following hardware modules:

- SNC-STM32 core module,
- SNR-MOD radio module with the IEEE 802.15.4 based communication module (e.g. ZigBee),
- SNR-WG gateway module with Ethernet interface.

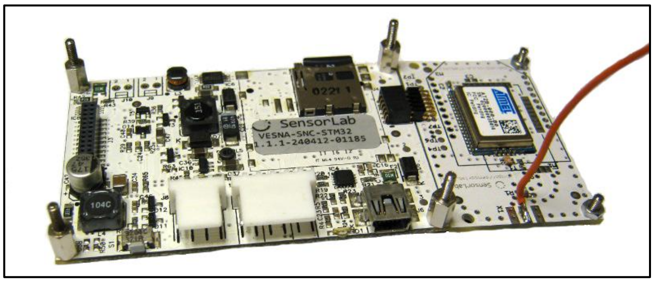

Figure 4.5 VESNA platform – SNC and SNR modules.

From the protocol point of view the system is designed as a client-server, where wireless sensor nodes act as servers and WSN gateway together with the PLMU application has a role of a client. The Ethernet interface on the WSN gateway is configured to acquire the IP address from the DHCP server on host device within the PLMU.

It will be integrated inside of the suitcase and connected to the Ethernet ports in the PLMU. The design of this device is a contribution from *Jožef Stefan Institute* partner.

4.1.6 WLAN Access Point

The WLg-LINK-OEM [11] from ACKSYS module used in AP allows creating a WiFi network from any equipment featuring a 10/100 Ethernet interface.

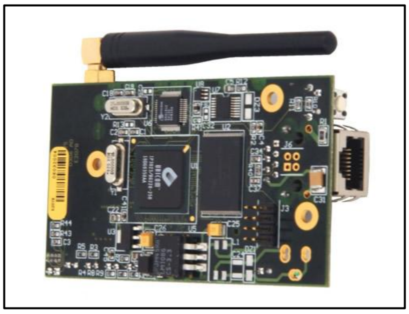

Figure 4.6 WiFi Access Point integrated used for PLMU WLAN.

Product relies on the IEEE 802.11 a/b/g/h standards, its size is extremely compact (L:89 x W:51 x H:20 mm). It can be powered from the DC power source 5V for a 3.5W typical consumption.

Table 4.4 shows a collection of the most relevant performances of this device.

WLAN A.P	
Ethernet link	10/100 Base TX Ethernet interface
WiFi network	Compliant to the IEEE 802.11a/b/g/h 2.4 / 5 GHz standards
Data rate	80 W +12V DC
Polarisation	Up to 108 Mbps
Channels	13 channels (b/g modes), 8 channels (a mode), 11 channels (h mode)
Output power	Transmitter +20 dBm
Power supply	From +3.3VDC or +5VDC
Consumption	3.5 Watts typical, 5 Watts maximum
Dimensions	89 x W: 51 x H: 20 mm, 47 g
Operating temperature	-20°C to +70°C

Table 4.4 – WLAN Acces Point main specifications.

4.1.7 Touch Screen

The touch screen is the device from which the user can interact with the PLMU functionalities. Through the touch screen, the user can activate the various communication systems, change their configuration, receive information about the surroundings as collected by the sensors, and communicate with remote locations.

As an improvement of the system, the idea to replace the touch screen for a Tablet PC has appeared. This change was motivated for a sort of advantages that a Tablet could bring comparing it with a simply touch screen. The main advantages of using a Tablet are:

- Wireless connection to the PLMU computing platform: no video cable needed, so the PLMU user could have some mobility and could walk around carrying the tablet while managing the PLMU.
- Integrated battery: from the power system it will represent one less load because it has its own battery.
- Integrated cameras: the PLMU user could take pictures and record videos in case of need.
- Integrated GNSS: the PLMU position can be located via GPS for example.
- Wireless connectivity (LTE, 3G, WiFi, Bluetooth): so it can be used as another communication device and perform a call with it for instance.

- Light size and weight: tablet's are much thinner and light than industrial frameless touch screens.

In order to select the best device for our application a market research has been done following the procedure detailed in section 6.2 and 6.3 in this document. Table 4.5 shows the three best candidates to be used as the PLMU Tablet PC resulting from this selection process. There are two 10.1" candidates and one 12.2" but the final device is still to be determined at this stage of the project.

KPI	Sony Xperia Tablet Z SGP311	Samsung Galaxy Note 10.1	Samsung Galaxy Tab Pro
CPU	ARM 1.5 GHz Qualcomm Snapdragon S4 Pro	ARM 1.9 GHz Quad core Exynos 5420	ARM 1.9 GHz Quad core + ARM 1.3 GHz Quad core
Dimensions & weight	266 x 172 x 6.9 mm, 495 g	243.1 x 171.4 x 7.9 mm, 535 g	295.5 x 204 x 7.9 mm, 732 g
RAM	2 GB,	3 GB	3 GB
Wireless Conections	WiFi, Bluetooth, infrared, GSM, 3G, LTE	WiFi, Bluetooth, infrared, GSM, 3G, LTE	WiFi, Bluetooth, 3G, LTE, infrared
Camera resolution	8.1 MP (back), 2.2 MP (front)	8 MP (back), 2 MP (front)	8 MP (back), 2 MP (front)
Screen size (inches)	10.1"	10.1"	12.2"
Screen resolution	1920x1200	2560x1600	2560x1600
Price	408 €	485 €	750 €

Table 4.5 – Three best candidates for PLMU Tablet

5 PLMU Software Architecture

This chapter is an overview of the software architecture performing the PLMU functionalities. The characteristics and the role of each of this software will be explained.

The mentioned software is running in the processing platform (refer to 6) which will be placed inside the PLMU suitcase. The system environment needed to perform the designed software architecture is listed below.

- Linux Operating System: first demo running on CentOS 5.3. Migrating to Linaro Alip [12].
- DHCP server: assigns IP addresses to the communication devices connected at the PLMU.
- HTTP server (Apache): needed to access the femtocell's setup GUI.
- NTP server: needed by the 3G femtocell to provide frequency stability to the internal oscillator.
- Iptables: used to redirect tcp traffic.
- Phyton development tools: used to run *Energino's* (chapter 7) script.
- OpenSSL: open source implementation of the SSL protocol needed for Squid configuration.

In Figure 5.1 the overall software architecture managing the PLMU system is depicted. The elements placed out of the Computing Platform square represent the hardware elements that are providing connectivity. The links between the hardware elements and their related software are made following a colour code representing the communication protocol over these links.

Along this chapter we will go through detailed explanations of the main software elements running in the PLMU computing platform.

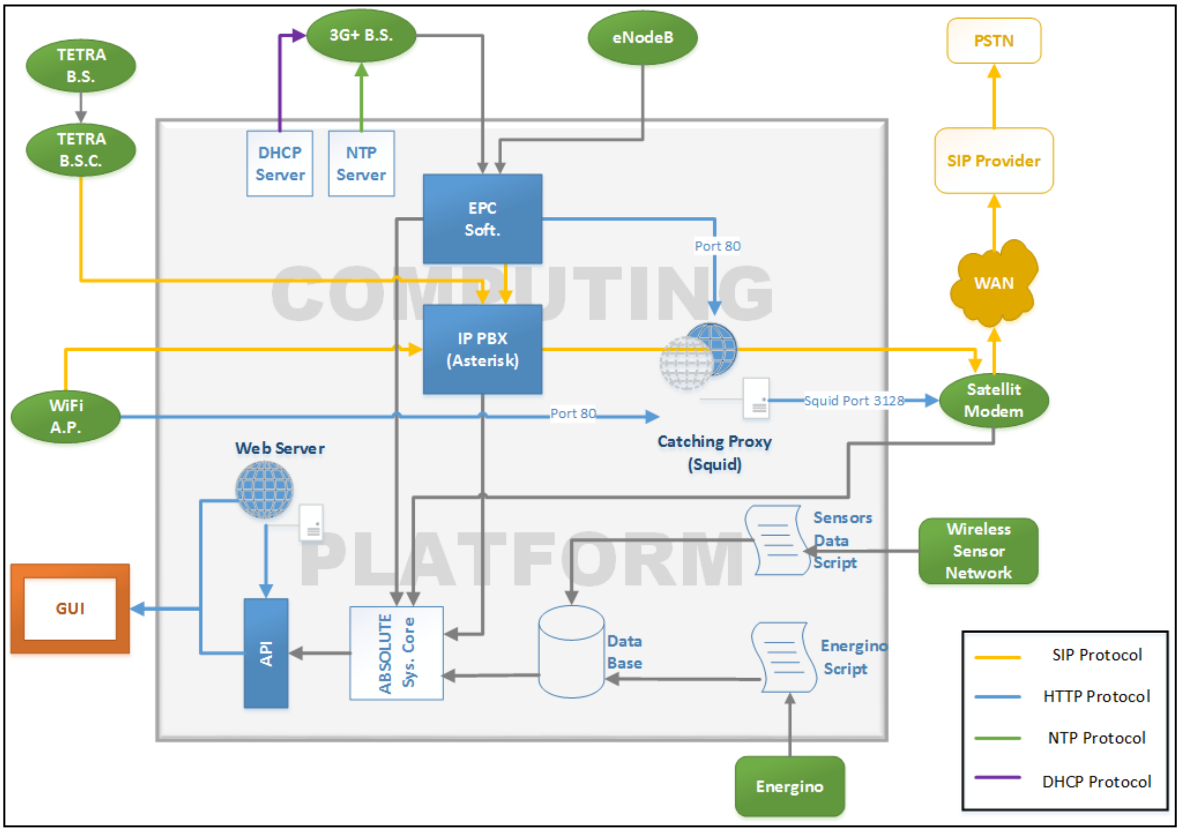

Figure 5.1. Overall Software architecture.

5.1 Communications Software

The PLMU runs software UMTS and LTE Core Network which is fully autonomous. Hence, no dependencies with remote networks are introduced, being all switching, authentication, billing and remaining core network (CN) functionalities performed locally within the PLMU itself.

Figure 5.2 shows an example of 3G Wireless communication schema with the virtual internal connections between the CN, the PBX software and the SIP provider. The 3G femtocell acts as the hardware device providing coverage to the User Equipment connected to the network. The 3G femtocell firmware at its software level is working as a link between the EPC SoftCore and the 3G femtocell device.

Wider information about the PBX and the EPC software is given in the following subsections of this chapter.

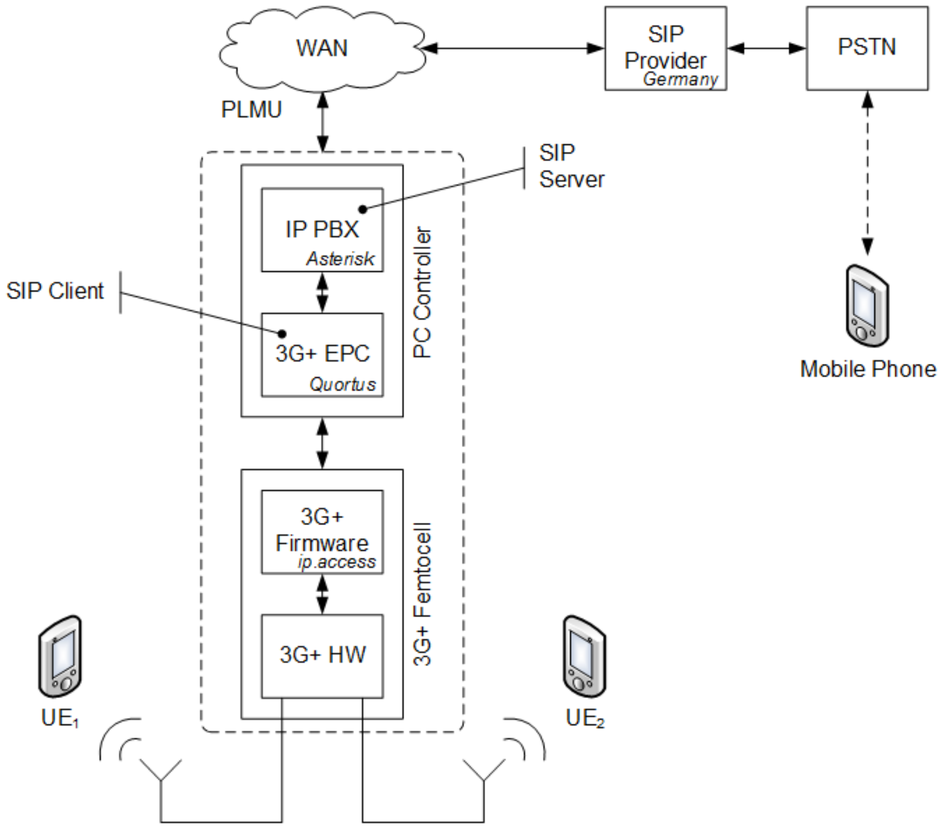

Figure 5.2. PLMU network core architecture.

Voice calls can be made between local handsets and also out over SIP to an external SIP server. The EPC SIP interface allows 3G handsets to register their location and presence information with the IP PBX and use many Enterprise Voice services, resulting in the 3G handset becoming a true extension off the PBX (Asterisk).

5.1.1 IP PBX Software

An IP PBX is a PBX that provides audio, video, and instant messaging communication through the TCP/IP protocol stacks for its internal network and interconnects its internal network with the PSTN for telephony communication [13]. It can be built virtually using a software system.

The software solution used in the PLMU acting as a PBX system is Asterisk [14]. Asterisk is an open-source framework for building communication applications such as PBX functionalities and conference bridges. Asterisk acts as a server and as a client at the same time. The EPC registers to it as a client, in this case Asterisk acts as a server, but it also registers itself to an external SIP provider to provide the users with access to the PSTN, in this case it is a client.

5.1.2 EPC Software

The main component of the System Architecture Evolution (SAE) architecture is the Evolved Packet Core (EPC), also known as SAE Core. The SAE is the core network architecture of 3GPP's LTE wireless communication standard [15].

It is still unclear which EPC is going to be used for the final version, although there are two main candidates: *Quortus* and OpenEPC. For the first demo version *Quortus* was configured and tested.

Quortus architecture is designed to be using an LTE EPC core directly supporting the S1 interface to LTE eNodeB radios and the ip.*access* 3G AP femtocell. The ip.*access* 3G APs themselves are managed by the same *Quortus* CLI mechanism [16].

5.2 Application Server (API)

The API is the front-end application which receives all the requests from the GUIs and makes it possible for the GUIs and the CORE system to interact and share information. It can be implemented in a REST style so that it eases the understanding and building of it. RESTful APIs [17] are defined with these aspects:

- base URI, such as http://example.com/resources/
- an Internet media type for the data. This is often JSON but can be any other valid Internet media type (e.g. XML, Atom, microformats, images, etc.)
- standard HTTP methods (e.g., GET, PUT, POST, or DELETE)
- hypertext links to reference state
- hypertext links to reference related resources

5.3 Control GUI

The GUIs allow human users to interact with the system. The three GUIs that we are going to design are oriented to be used by different communities such as First responders, Victims and Technicians.

The first GUI allows first responders to communicate with one another through text messages and also to visualize and control the status of the overall system and each subsystem. The second GUI is oriented to victims so that they can send a distress message to first responders. The third GUIis for technicians. Using it, they can tune most of the configurable parameters of the system and subsystems.

Figure 5.3 GUI mock-ups, from left to right: First responders' GUI, victim's GUI and technicians' GUI

5.4 ABSOLUTE System Core

The ABSOLUTE System core is the module that receives all the requests from the API. It processes them and manages all the sub-modules in order to get the job done. The sub-modules are the following:

- PBX manager: This manager interfaces with the IP PBX software and can configure features related to the conference calls and the PSTN access for all the system users.
- EPC manager: This manager controls the EPC and therefore it is able to register new 3G and/or LTE users into the system and route properly their calls.
- Map manager: It is in charge for handling any client request related to map data.
- Comms. manager: This module manages all the communication subsystems. The subsystems it controls are: LTE, TETRA, WLAN, Sensors, Satellite and UMTS.

- Database manager: This manager interfaces with the system databases.
- Messages manager: This module manages all the messages flowing through the system.
- Common operation manager: This module carries out all the common operations that may exist in any system such as logs creation and error handling.

5.5 Data Traffic Optimization

In order to optimize the bandwidth of the satellite link when HTTP content or, failing that, the encrypted version of the same, HTTPS is accessed, a technique to research optimization and data traffic compression has to be used.

With the objective to reduce the data sent a solution using caching techniques is going to be used running in the PLMU computing platform. This solution is *Squid* Proxy [18]. *Squid* is a caching proxy which can store in its own storage part of the web pages visited and always depending on the website the user has requested. It reduces bandwidth and improves response times by caching and reusing frequently-requested web pages.

Squid can operate in three different modes depending on the user's needs. It brings the opportunity to have a multi-scenario tool to match the administrator's objectives. Three operation modes can be configured in *Squid*: Reverse, Explicit and Transparent mode.

The operation mode that fits more accurately with ABSOLUTE's objectives is the last one. In this case, the users do not have to configure their terminals to route the traffic through it. The proxy is totally transparent for the client because he considers that is talking directly with the server and unknowns Squid's presence.

6 Computing Platform

The computing platform is the device in the PLMU in which the software architecture described in the previous chapter is built and running. Due to its important role in the system a chapter is dedicated.

For the first demo version of the PLMU the computing platform used was the “Lex Brik BK3741S” [19] commonly known as Brik PC, but for the final version, included in the package of improvements of the first version, it is going to be replaced by a Single Board Computer (SBC). The motivations of this changing are basically to reduce the size, weight and power consumption of the computing platform, which are too high in the current version.

The aims of the following sections is to widely explain the undertaken SBC election process and methodology, give an overview of the SBC state of the art, show the final candidate performances and finally evaluate the advantages of the device replacement.

6.1 Prerequisites

After the collection of the system requirements a market review has been started in order to clarify if the use of a SBC can be accepted for the PLMU needs. A list of the PLMU hardware and its requirements to be integrated in the computational platform is shown in Table 6.1

Hardware connectivity	
Device	**Connections**
3G Base Station	RJ45
SNC (Sensor Network Core)	RJ45
SIM Card Reader	USB
eNodeB	RJ45
TETRA base station	RJ45
Power comp. monitoring	USB
Sat modem	RJ45
A.P. WLAN	RJ45
Keyboard	USB
Mouse	USB

Table 6.1 – Hardware in PLMU and connection to the computational platform

In total the number of ports needed to interconnect all the hardware used in the PLMU with the SBC will be:

- 6 Ethernet ports
- 4 USB ports

Since a SBC with 6 Ethernet ports is not available in the market (they normally have just one port) the use of an Ethernet switch has to be considered. This Ethernet switch must be self-powered and its power consumption has to be added to the SBC power consumption in order to make a precise evaluation of the system. However, after the first market study it has been determined that the use of that switch will increase the power consumption between 3 to 5W in average.

The PLMU will also need a permanent storage device which is something that SBCs do not have integrated. As a separate hard drive the use of a SD or uSD card has been decided because it is the default external memory connection provided in SBCs, it does not add any extra power consumption and it can provide up to 64 GB of data storage which seems to be enough for the memory system requirements.

Taking into account the hardware requirements a list of various SBC candidates has been made to create an objective evaluation of them with the purpose to find the best SBC for the PLMU system.

6.2 Single Board Computer

A single-board computer is a complete computer built on a single circuit board, with microprocessor, memory, input/output and other features required of a functional computer [20].

A single-board configuration reduces a system's overall cost, by reducing the number of circuit boards required, and by eliminating connectors and bus driver circuits that would otherwise be used. By putting all the functions into one board, a smaller overall system can be obtained so SBCs are often smaller, lighter, more power efficient and more reliable than comparable multi-board computers.

The decision of using a SBC as the main computational platform in the PLMU is mainly based in their extremely small size and their low power consumption. Size and power management is the highest concern when designing any portable device and in that field SBCs are offering the best market performances without any competitors. Eventually the use of a SBC in the PLMU will result in an improvement of the total weight, power consumption and price.

Advantages of SBCs:

- Compact size
- Quick time-to-market
- More power efficient
- Fanless operation
- Low cost
- Use latest microprocessors
- Most of them are open source

6.2.1 SBC Evaluation Criteria

There are many performance indicators when choosing a SBC but for the use in the PLMU some of them have been considered as the key points in the evaluation according to our requirements. Table 6.2 shows the key performance indicators and their weights in the global evaluation.

KPI categories	Weight ranges
CPU. performance	10
Power consumption	9
RAM memory	8
USB ports num.	7
LAN ports num.	6
Voltage supply	5

Table 6.2 - Key performance indicators categories.

CPU performance is the most important point to consider due to the need of the computational platform to manage different software and hardware in an efficient, reliable and fast way. Therefore a poor performance microprocessor which hangs up or not fast enough might be automatically discarded. The weights in the different CPUs for the competitors in the SBC list is detailed in Table 6.3. and Table 6.4.

CPU speed	Score	RAM	Score	Power consumption	Score
1.6 GHz	10	1GB	10	3 W or less	10
1GHz	9	512 MB	9	from 3,5 W to 5 W	8
700 MHz	8	256 MB	8	from 5 W to 10 W	6
400 MHz	7	128 MB or less	7	More than 10 W	4
300 MHz	6				

Table 6.3 - Scores in SBC Evaluation from left to right: CPU performance, RAM, and power consumption.

For reasons already explained power consumption is one of the highest concerns in the system, so that explains its high score. The evaluated SBCs' power consumptions are shown in Table 6.3.

RAM memory is relatively important in the system and can be compared to CPU performance for some applications. But, as for the kind of application the PLMU will have to run is not so critical it can be evaluated separately from the CPU speed.

Although the number of USB and Ethernet ports is something not critical because an alternative to this number limitation has already been found, the higher number of these ports it is still something to positively consider. Above all, the having more than one USB port will be important but only during the developing and testing of the system not in during the normal functionality.

USB ports number	Score	LAN port number	Score	Voltage supply	Score
4	10	4	10	Others	6
3	9	2 or more	8	12 V	8
2	8	1	6	5 V	10
1	7				

Table 6.4 - Scores in SBC Evaluation from left to right: USB ports, LAN ports and supply voltage.

Voltage supply has been included also in this evaluation because it might not be a restriction but it can be a problem. Basically, 12V and 5V can be accepted because they are widely common in battery's market and we will have more devices in the system with the same supply voltage, so we can create small supply networks for these two values. But other voltage values will add extra DC-DC converters and other power management solutions that will be better to avoid.

Finally, Appendix A. SBC Complete Evaluation contains the complete evaluation with a total of 10 different SBCs, in which it is also included the evaluation of the Brick PC as its performance has to be considered and compared to the new SBCs, since the option to use the Brick PC in this new suitcase as well is not yet discarded.

6.3 SBC Evaluation

Table 6.5 shows the performances of the three best SBC's scores from all the competitors. All three have the same core, ARM Cortex-A8 at 1 GHz. Regarding the rest of evaluation KPIs they all have very similar characteristics laying the main difference in the amount of RAM memory, where the *Gumstix* model double the other's value and in the number of USB ports where the *Beagleboard* can offer 4 whereas *Gumstix* has only one and the *IGEPv2* has 2.

		Beagle board-XM			**IGEP v2**			**Gumstix Overo® COM TidalSTORM**		
Key Performance Indicators (KPIs)	Weights (1-10)	http://beagleboard.org/Products/BeagleBoard-xM	Score	Weighted score	http://www.isee.biz/index.php/products/processor-boards/igepv2-board	Score	Weighted score	https://www.gumstix.com/store/app.php/products/356/	Score	Weighted score
Weighted arithmetic mean score			3rd	**8.909**		2nd	**8.981**		1st	**9**
Architecture	10	OMAP3	10	100	OMAP3	10	100	OMAP3	10	100
CPU	10	1-GHz super-scalar ARM Cortex™-A8 OMAP3525/30 SOC	9	90	ARM Cortex A8 1GHz DM3730 SoC	9	90	ARM Cortex A8 1GHz DM3730 SoC	9	90
RAM	8	512-MB LPDDR RAM	9	72	512-MB LPDDR RAM	9	72	1 GB	10	80
LAN ports	6	1x 10/100 Mb	6	36	1x 10/100 Mb Wifi 802.11 b/g Bluetooth	6	36	1x 10/100 Mb *	6	36
USB ports	7	4x USB 2.0	10	70	2x USB 2.0	8	56	1x USB 2.0 *	7	49

Voltage supply	5	5 VDC	10	50	5 VDC	10	50	5 VDC	10	50
Power comsumption	9	750 mA (3,75 W)	8	72	600 mA (3 W)	10	90	400 mA (2W)	10	90
External memory ports	0	uSD		0	uSD		0	uSD		0
Video out	0	HDMI / S-video		0	HDMI		0	HDMI *		0
Temp. range	0	No info		0	-40°C to 85°C		0	0 to 85° C		0
Price (aprox.)	0	149 USD		0	188 €		0	139 USD + expansion board price		0
Expansion possible	0	No		0	Yes		0	Yes	0	0
TOTAL SUM	55							(*) With Tobi expansion board		

Table 6.5 - SBC evaluation of the 3 best candidates.

Note that the *Gumstix* board has no external interfaces at all (the main board only have the processor, a microSD card slot and a power management chip). To have USB port, Ethernet, etc. an expansion board has to be connected to it. There are several expansion boards compatible with *Gumstix* board and it just have been evaluated one of them as a sample for the evaluation.

6.3.1 SBC Election

The election of the best SBC has been done empirically after purchasing one of each two best candidates and testing them to contrast their performances. These two SBC are the *Gumstix's* OvertoCOM TidalStorm [21] and the ISEE's *IGEP v*2 [22].

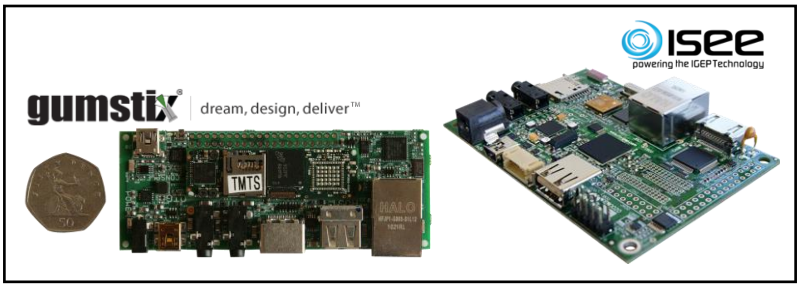

Figure 6.1 – Aspect of the two SBC best competitors: left *Gumstix* Overo COM, right *IGEP v2*

The most significant difference between these two boards is that the *Gumstix's* one has double RAM memory (1 GB) than the IGEP. On the other hand, the IGEP v2 has two extra connectivity interfaces that the *Gumstix's* one does not, Bluetooth and WiFi.

After testing both of them, running the same OS version (Linux Linaro Alip), the final election became the *Gumstix* Board due to its better performance. There was the idea to use the integrated WiFi in the *IGEP v*2 as a WLAN AP so it will let us dispense with the extra AP device. But after the test, it resulted only in a Gateway to remote access to the *IGEP v*2 via ssh connection but no wireless data can be transferred at all, so the *IGEP v2* has been dropped mainly because the extra connectivity it was offering is useless for the PLMU purpose.

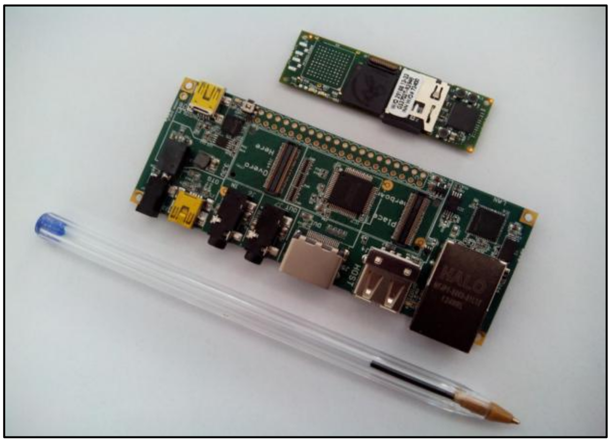

Figure 6.2 – *Gumstix* OveroCOM TidalStorm and Tobi expansion board.

Finally, the candidate to replace the Brik PC will be the *Gumstix* Overo TidalStorm mounted in the expansion Tobi [23] board.

Since the OS used in the Brik PC (CentOS 5.3) is Fedora based and the used for the new ARM platform is Debian based (Linaro Alip) there are several software incompatibilities between both platforms. For the most of them a version for Debian system have been found, but it has not been found a solution for the EPC software (*Quortus*) because the version that TGS has is only executable in an Intel CPU. One possible solution will be install a Virtual Machine in the SBC, but this issue is still under investigation.

6.4 Comparative with Brick PC

It may be interesting to compare the performance that offers the best rated SBC after the evaluation with the performance the Brick PC.

Key Performance Indicators	Gumstix Overo® COM TidalSTORM	Lex Brik BK3741S-00A
Architecture	OMAP3	Intel x86
CPU	ARM Cortex A8 1GHz DM3730 SoC	Intel Atom N270 1.6 GHz Intel 945 GSE
RAM	1 GB	1 GB DDR2 RAM
LAN ports	1x 10/100 Mb	4x 10/100/1000 Mb
USB ports	1x USB 2.0	2x USB 2.0
Voltage supply	5 VDC	12 V
Power comsumption	400 mA (2W) + Ethernet switch consumption (~4W) = ~6 W	30 W
External memory ports	uSD	1x SATA
Video out	HDMI	VGA
Dimensions	58 x 17 mm	145 x 102 mm
Temp. range	0 to 85° C	0 - 60° C
Price (aproximately)	139 USD + expansion board price (i.e. 69 USD Tobi board)	No info
Expansion possible	Yes	No

Table 6.6–Performances comparison of *Gumstix* Overo board and the Brik PC.

The Brik PC is equipped with an Intel Atom processor [19] working at a higher clock speed than the ARM Cortex-A8 found in *Gumstix* Overo. As they use completely different processor architectures it is difficult to compare their speed processor based only their clock speed because it is not always faster the one which has the greater clock speed. Probably the better way to determine the faster one is looking at their performance in MIPS (Mega instructions per second) or GIPS (Giga instructions per second). According to the information in [24] and [25] the ARM Cortex A-8 can make up to 2,0 GIPS and the Intel Atom N270 up to 3,89 GIPS, so the Intel Atom is faster than the ARM. But this is possible at the cost of increase the power consumption of the core which is less than 300 mW in case of the ARM and 2,5W in case of the Intel.

It exist a big difference in the theoretical power consumption of the Brik PC and the one for the *Gumstix* Overo. There is also an important jump in the size of the two boards that will imply also a big difference of weight. And about the other indicators in both cases all of them will be functional and both of them will need extra parts to increase the number of LAN ports and the number of USB ports.

Finally, Figure 6.3 is included to proving the differences in size and form factor between the previously used Brik PC and the *Gumstix* OveroCOM SBC.

Figure 6.3 – *Gumstix* OveroCOM and Brik PC physical aspect.

To conclude a summary of the pros and cons of use an SBC as the computational platform in the PLMU are discussed.

Pros:

- Power consumption can be reduced up to 5 times.
- Size can be reduced up to 15 times.
- Price can be reduced to the half approximately.

Cons:

- Number of parts is increasing due to lack of ports.
- CPU speed will be reduced.

Taking into account this balance of pros and cons it is safe to say that it will be worth to use an SBC for the PLMU computational task although sacrificing some of the CPU performance.

6.5 Using GPIO ports

The *Gumstix's* expansion board Tobi includes a 40 pins General-purpose Input/Output (GPIO) connector. A GPIO is a generic pin on an integrated circuit whose behavior (including whether it is an input or output pin) can be controlled by the user at run time [26]. GPIO pins have no special purpose defined, and most of them go unused by default.

The idea of using the GPIO ports for the PLMU makes it possible to implement the functionality in the GUI to remotely connect and disconnect communications devices such as the 3G femtocell, the eNodeB, etc. Configuring some of the GPIO ports as outputs and modifying its values in the OS, it will be possible to switch ON and OFF the supply of the mentioned devices from the GUI.

6.5.1 Hardware Configuration

The SoC which the *Gumstix's* OveroCOM TidalStorm has (Texas Instruments DM3730) belongs to the 1.8V logic input/output. That means that the control signal that we can use when configuring the pins as an output will be a voltage step where 0V being the '0' logic value and 1.8V being the '1' logic value.

High current devices cannot be driven directly from the GPIO pins so a circuit acting as a buffer is needed as well as to adapt the voltage output level the supply voltage of the communications devices (in that case 12V). The typical circuit for this application is showed in Figure 6.4.

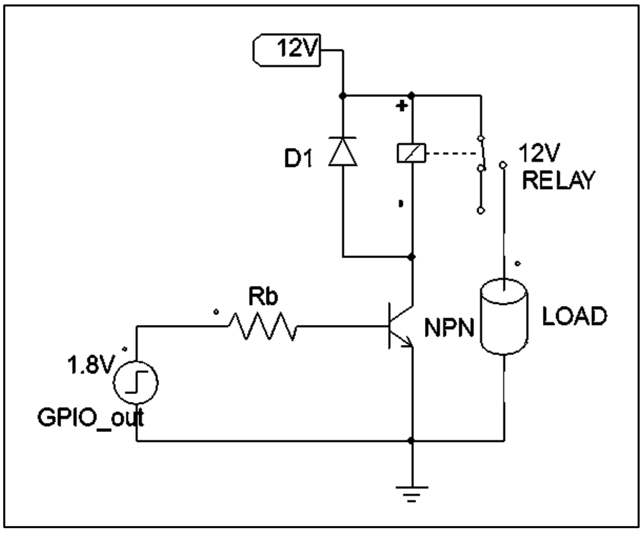

Figure 6.4 – Schematic of the control circuit driving a 12 V load from the a single GPIO output.

In the circuit above the relay is switching at 12 V, which is the voltage value where the communication devices will be connected. The diode D1 is protecting the control circuit (in that case the *Gumstix's* GPIO pins) from the current peaks when the relay switches. The transistor is acting as a solid state switch that is activated with the control signal coming from the GPIO ports. Appendix B. Electrical Plan contains further information about how to connect the control circuit to the electrical plan of the PLMU. Looking at this plan one can see that to control the main communications devices in the system 5 GPIO pins will be needed.

As a control circuit board it is planned to use five Relay controller boards with one single channel as the one showed in Figure 6.5. This board has a single SPDT relay which can switch up to 10A. The relay terminals (C, NC, NO) are accessible through screw terminals. The relay is driven by the MMBT2222A NPN Transistor. Relay coil is rated for 12V DC. A Flyback diode is used to eliminate the sudden voltage spike across the relay load when the voltage is reduced or removed. Opto isolated input is an added advantage of this board which separates the relay circuit electrically from the input.

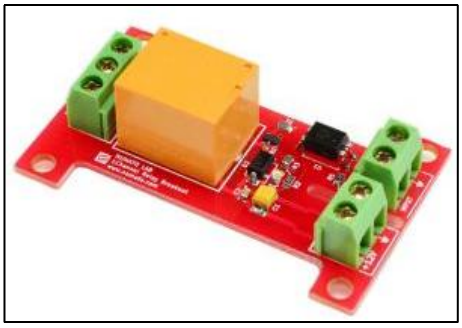

Figure 6.5 – One Channel Relay control board (from *Numato* LAB) [27] .

6.5.2 GPIO Control

The Tobi's expansion board GPIO connector is SV1. Appendix D. *Gumstix's* GPIO shows the details of each pin of this connector. The name of each pin is used to identify them in the OS. According to the information found in [28] there are 3 pins completely available to use them as outputs and 2 other only output pins reserved for the LCD operation but available if no LCD is connected (which is our case). The name of these pins and its corresponding pin number can be checked in Appendix D. *Gumstix's* GPIO. It also includes a detailed sketched of SV1 connector extracted from Tobi's schematics documentation [29].

The Overo kernels support the sysfs [30] GPIO implementation for accessing GPIO from user space. This allows you to control GPIO from the command line. In Appendix D. *Gumstix's* GPIO you can see an example of how pin 27 in the SV1 connector of the Tobi board can be accessed and how to modify its value from the command line.

The commands showed below will be executed by the API so the user can modify the value of the output GPIO and consequently switch the state of the control circuit to connect or disconnect a specific device.

7 Power System

Since the PLMU should be a standalone communication system with several hours of self-operability the power management of the system is one of the most critical design concerns. So the power system needs to be appropriately managed so as to reduce the system power consumption and maximize the battery running time.

The power system comprises all the elements involved in the power supply of the PLMU's components. These elements are:

- The battery,
- The power distribution unit,
- And the energy monitoring system.

In this chapter and in the following these elements functionalities and its design specifications will be analyzed.

7.1 Overall System Power Consumption

The starting point for the design of the power system is the estimation of the overall power consumption. To proceed with this estimation it is necessary to know first the complete list of elements to supply with their electrical specifications.

This list is included in Appendix C. Electrical Performances. It is including all the PLMU components, from the main communication elements to the trivial devices like hubs or switches. The first rows in that list are mandatory elements in the design that cannot be replaced for other options, but the last rows of the list are showing the range of elements that have to be chosen by TGS.

The procedure undertaken to select these elements has been the same as the one showed in section 6.2 and 6.3 in this document. For every single device a list of three different candidates matching with the requirements has been done. That gives a margin to the design process, so for example if one chosen device is discontinued or is not performing as good as it should we can easily move to one of the alternatives.

These three alternatives correspond directly to the three candidates with best score in the selection process mentioned before. As a classification method, category labels to identify the candidates' hierarchy have been used. These category labels are A, B and C, being A the best option, so the option planned to integrate in the system, and C the less favourable option.

Device	Model Name	Supply Voltage [V DC]	Power tag	Power (Typ) [W]	Power (Max) [W]	Power before conversion (typ) [W]	Power before conversion (Max) [W]
3G base station	Ip.acces Nano3G	12		9,90	20,00	9,90	20,00
VESNA gateway	From JSI	5		0,12	7,20	0,14	8,64
eNodeB	From HHI, UDE and NOM	12		45,50	55,00	45,50	55,00
TETRA base station	DAMM TetraFlex®	48		75,00	75,00	90,00	90,00
TETRA B.S controller	DAMM TetraFlex®	48		20,00	20,00	24,00	24,00
Power comp. monitoring	Energino	12		0,25	1,00	0,25	1,00
Sat portable terminal	SurfBeam 2 Pro	12		80,00	80,00	80,00	80,00
Phone IP	Snom 300	5	A	2,71	2,76	3,25	3,31
A.P. WLAN	WLg-LINK-OEM-EVAL	5	A	1,65	5,00	1,98	6,00
Processing platform	Gumstix Overo TidalStorm	5	A	2,00	2,00	2,40	2,40
Switch Ethernet	Xtreme/Gbe 8 ports	5	A	3,00	6,00	3,60	7,20
Cooling fan system	Scythe Gentle Typhoon	12	A	1,00	1,00	1,00	1,00
Hub USB	Dlink DUB-H7	5	A	0,72	2,00	0,86	2,40
			Total	**241,85**	**276,96**	**262,89**	**300,95**

Table 7.1 – Overall system power consumption.

Table 7.1 shows the overall system power consumption estimated on the basis of the elements manufacturers' information. Information about the maximum and typical rates is shown in that table and there are two extra columns with the power values considering the conversion losses (only for non 12V powered devices).

The graph in Figure 7.1 is giving information about the system power consumption divided in category labels; therefore one can see the difference in terms of power consumption between using one category or another.

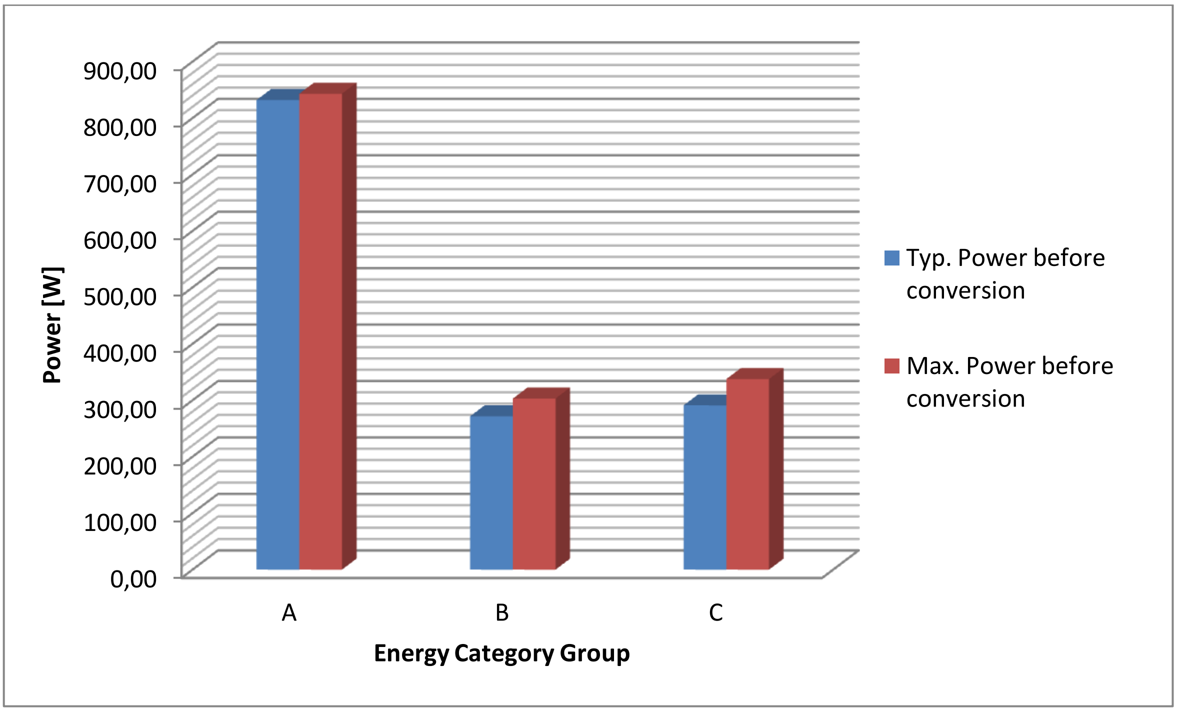

Figure 7.1 – Graph with overall system power consumption in different category labels.

According to the first estimation the maximum system power consumption is around 300 W. It has to be taken into account that this value will rarely be achieved in the real operation mode, so it is more likely to happen as a peak value. In a normal operation mode not all devices will be working at the same time, and if they are, not all of them will be working at their maximum capacity.

For designing the wiring of the power system the maximum rates have been considered to be on the safe side. Further information about the design of the power system can be found in the next section.

As a future task different operation modes and system power consumption profiles must be determined empirically when the overall system will be built and it could be tested.

7.2 Power Distribution Unit

The power distribution unit (PDU) is the group of devices in charge of the voltage conversion and the power adaption of the different voltage levels found in the PLMU. In the PLMU elements with three different voltage levels can be found: 5V, 12V and 48V.

Table 7.2 shows a summary of the total power consumption of these three groups of voltage levels and the maximum and typical current they will drain from the battery. On the other hand, Figure 7.2 is showing the power consumption of the different networks but in a graphic form. Note that for the 48V network there is only one device to supply, which is the TETRA system, and there is no catalogue information about its typical power consumption so only the maximum value is considered.

	Current (typ) @12V [A]	Current (max) @12V [A]	Current (Typ) [A]	Current (Max) [A]	Power (Typ) [W]	Power (Max) [W]	Power before conversion (Typ) [W]	Power before conversion (Max) [W]
All	22,05	24,87	16,16	20,2	248,59	280,63	264,62	298,41
12 V	11,81	13,51	11,81	13,51	141,73	162,08	141,73	162,08
5 V	1,14	2,26	2,37	4,71	11,86	23,55	13,64	27,08
48 V	9,1	9,1	1,98	1,98	95	95	109,25	109,25

Table 7.2 – Power consumption and current by groups of voltages sub-networks.

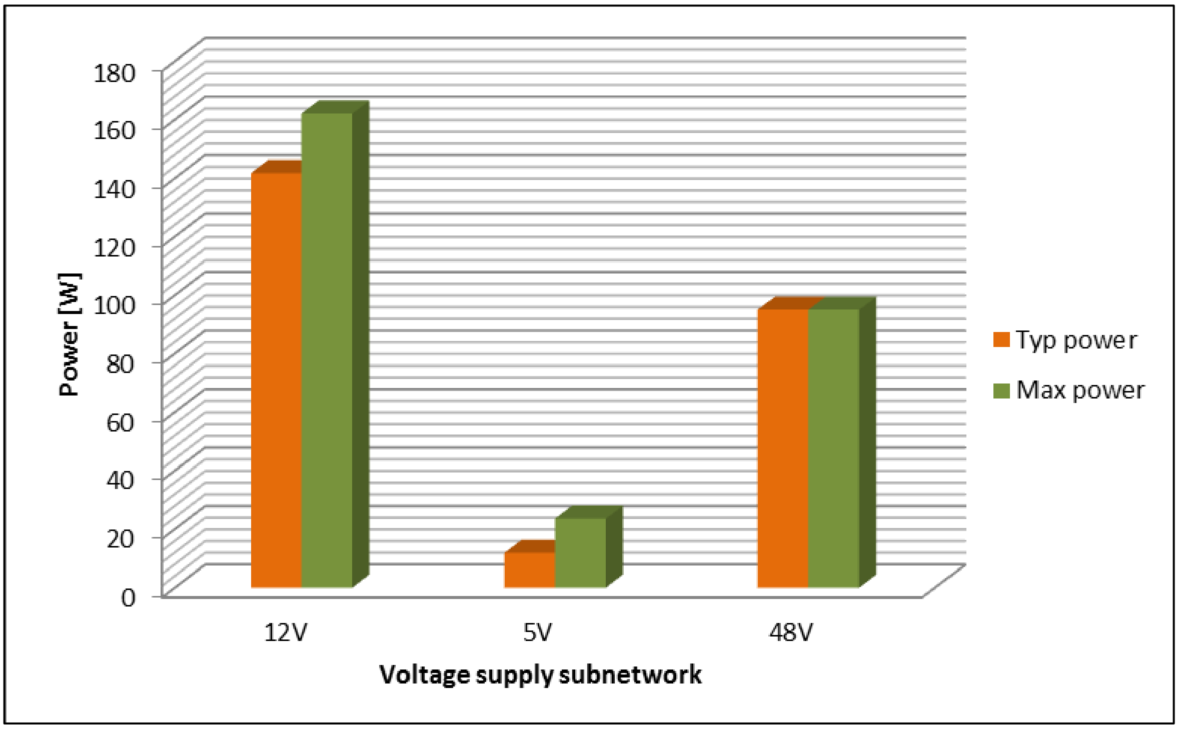

Figure 7.2 – Typical and Maximum power consumption by voltage sub-networks.

A first design of the power distribution in the PLMU is shown in Figure 7.3. One can see that the battery chosen to supply the whole system is a 12V battery which will be studied in detail in section 7.3. The PLMU shall have the option to connect to the AC power network, so a switch will be allow this operation mode. The device named

Energino will be acting as an in-line power meter (see section 8) and will be placed in the main line coming from the battery output so the total current through this line can be measured. For further information about the electrical design of the PLMU refer to Appendix B. Electrical Plan where the electrical plan is shown.

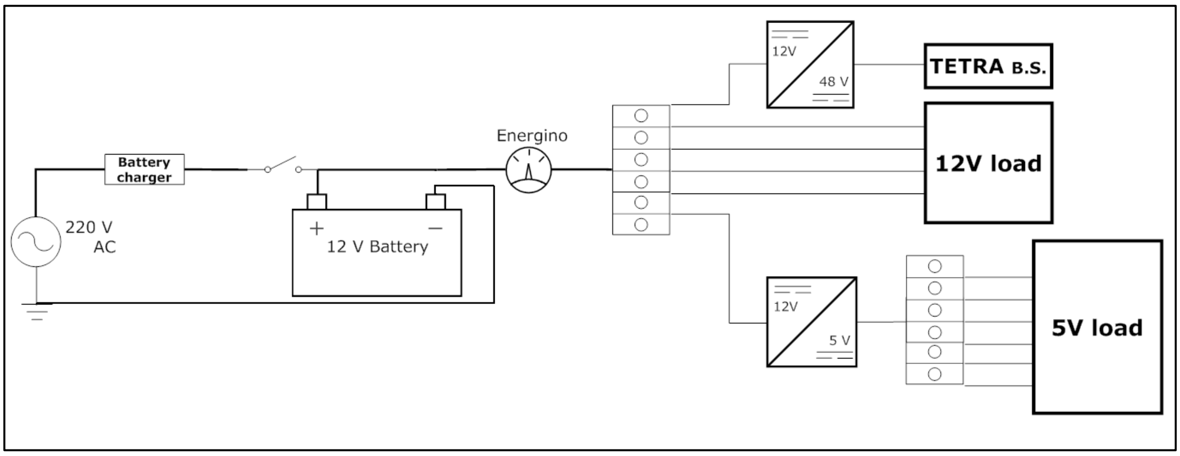

Figure 7.3 – Simplified wiring schema of PLMU power distribution

To adapt the voltage levels required by the different elements, first they will be grouped for their voltage and two DC to DC converters will be used to power them with the appropriate voltage. The 12V sub-network can be directly connected to the main battery output line.

The selection of the DC-DC converters is determined to the total amount of current that they have to deliver in their output that means, after the voltage conversion. For the 12V to 5V buck converter, if we look to the maximum current value required by the 5V load after the conversion we can see it is 4.71 A. Therefore the 12V to 5V step down converter has to be capable of deliver this current value at its output. Similarly, for the 12V to 48V boost converter we can see that the output maximum current value is 1.98 A.

It is highly important to choose the converters with the higher efficiency value since saving power is a big concern in the design of the PLMU, so the higher the efficiency the lower the power losses that they introduce in the system. The specifications and a detailed explanation of these two converters will be given in the following sections.

7.2.1 Step down Converter

The proposed 12V to 5V step down converter is a regulated switching power converter designed to be very rugged electrically and can be operated continuously at 75°C (see Figure 7.4).

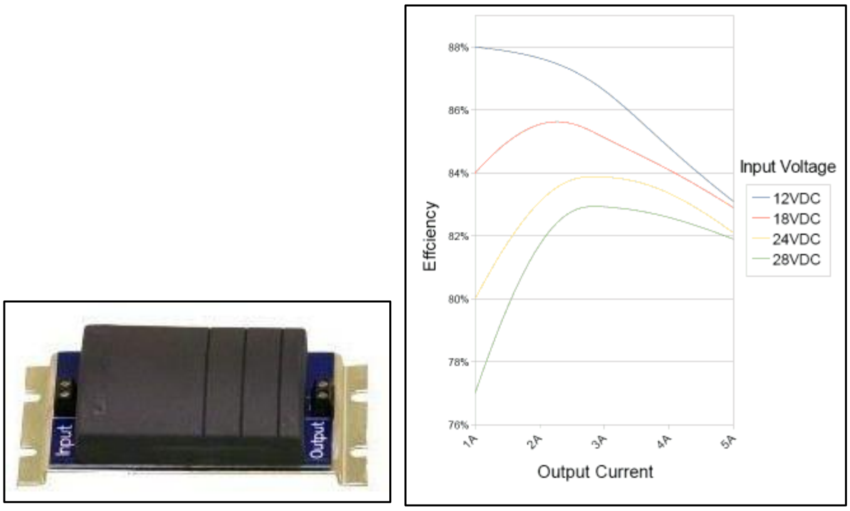

Figure 7.4 – Left: 12V to 5V step down switching power converter. Right: Efficiency curves for the 5VDC 5Amp DC-DC converter [31].

It can deliver 5A at its output and its minimum efficiency is around 83% (see Figure 7.4). The following table gives more specifications about this device.

Output Voltage	5.0 VDC ± 0.1 VDC
Maximum steady state input voltage range	8 VDC to 36 VDC
Nominal continuous output current when input voltage is between 8VDC and 20VDC	5.0A
Line regulation	± 0.5%
Load regulation	± 1.0%
Minimum input voltage for load regulation of 10 %	7 VDC (20% sag) (1 minute duration)
Maximum output ripple	25mV p-p
Maximum switching noise level	90mV p-p
Maximum operating temperature range	-40°C to 65°C (-40°F to 149°F)
Maximum storage temperature range	-40°C to 90°C (- 40°F to 194°F)
Minimum efficiency	77% 24 VDC input, 1A load
Maximum efficiency	88% 12 VDC input, 1.0A load
Dimensions	120x55x33 mm
Isolation	Common ground, the negative input is tied to the negative output. The frame is isolated.

Table 7.3 – 12V to 5V power converter electrical specifications [31].

7.2.2 Step up Converter

The selected option to be used as the 12V to 48V boost converter is a device from *Vicor Micro* series. It admits an input voltage range from 9 to 36V and delivers 48V at its output.

The *Micro* family can manage up to 100W loads and it is providing 2.08A at its output, so it is enough for our requirement which is a maximum of 1.98A. The electrical specifications of the device are shown in Table 7.4.

Figure 7.5 – 12V to 48V step up switching power converter.

Output Voltage	48.0 VDC ± 1%
Maximum steady state input voltage range	9 VDC to 36 VDC
Nominal continuous output current when input voltage is between 8VDC and 20VDC	2.08 A
Line regulation	± 0.2%
Load regulation	± 0.2%
Maximum output ripple	157mV p-p
Dissipation standby	7.4W
Maximum operating temperature range	-55°C to 100°C
Maximum storage temperature range	-65°C to 125°C
Minimum efficiency	78.2% Nominal input, full load
Maximum efficiency	79.7% Nominal input, full load
Dimensions	57.9x36.8x12.7 mm
Isolation	3000 Vrms in output

Table 7.4 – 12V to 48V power converter electrical specifications [32]**.**

7.3 The Battery

The battery is probably the most important element in the power system. In accordance with the estimated overall system power consumption, it has to be able to deliver a peak output current of about 25A and support a maximum load of approximately 300W during the maximum time as possible.

To accomplish these strong specifications a market research has been undertaken together with a study of the state of the art of batteries technologies to go for the best market solution. The result of this research is summarized in Table 7.5 where a comparison of different batteries technologies can be found.

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer
Gravimetric Energy Density(Wh/kg)	45-80	60-120	30-50	110-160	100-130
Internal Resistance (includes peripheral circuits) in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h
Overcharge Tolerance	moderate	low	high	very low	low
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]
Cell Voltage(nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V
Load Current*					
- peak	20C	5C	5C[7]	>2C	>2C
- best result	1C	0.5C or lower	0.2C	1C or lower	1C or lower
Operating Temperature(discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[8]	not req.	not req.
Commercial use since	1950	1990	1970	1991	1999

Table 7.5 – Batteries technologies comparison [33].

*C refers to battery capacity, and this unit is used when specifying charge or discharge rates. For example: 0.5C for a 100 Ah battery is = 50A+
1. Internal resistance of a battery pack varies with cell rating, type of protection circuit and number of cells. Protection circuit of Li-ion and Li-polymer adds about 100mΩ.
2. Cycle life is based on battery receiving regular maintenance. Failing to apply periodic full discharge cycles may reduce the cycle life by a factor of three.
3. Cycle life is based on the depth of discharge. Shallow discharges provide more cycles than deep discharges.
4. The discharge is highest immediately after charge, then tapers off. The NiCd capacity decreases 10% in the first 24h, then declines to about 10% every 30 days thereafter. Self-discharge increases with higher temperature.
5. Internal protection circuits typically consume 3% of the stored energy per month.
6. 1.25V is the open cell voltage. 1.2V is the commonly used value. There is no difference between the cells; it is simply a method of rating.
7. Capable of high current pulses.
8. Maintenance may be in the form of ‘equalizing’ or ‘topping’ charge.

From this table one can see that the best and the latest market available battery’s technology are Lithium-ion and Lithium-Polymer. Both technologies have their advantages and disadvantages, but they will perform the best behaviour in our system.

Advantages of lithium-ion:

- High energy density - potential for yet higher capacities,
- low self-discharge - self-discharge is less than half that of nickel-based batteries,
- no periodic discharge is needed; there is no memory,
- Specialty cells can provide very high current.

Disadvantages:

- Subject to aging, even if not in use - storage in a cool place at 40% charge reduces the aging effect,
- Expensive to manufacture - about 40% higher in cost than nickel-cadmium.

Advantages of lithium-polymer:

- very small form factor,
- Lightweight - gelled electrolytes enable simplified packaging by eliminating the metal shell,
- Improved safety - more resistant to overcharge; less chance for electrolyte leakage.

Disadvantages:

- Lower energy density and decreased cycle count compared to lithium-ion,
- Expensive to manufacture.

7.3.1 Battery Election

Having done a wide market research of different batteries that match with the systems needs, the best two candidates are shown in this section. They are both Lithium-ion batteries technology and are designed in portable form factor since the PLMU battery should be transported separately of from the PLMU suitcase.

Figure 7.6 – Two battery candidates: left *Hellpower* battery 150Ah, right *Tracer* battery 100Ah [34] [35].

KPIs	HellPower HE-MP-12V-150Ah-P1450	Tracer 12V 100Ah LiFePO4
Type	Lithium Manganese (LiMn2O4)	Lithium Iron Phosphate ($LiFePO_4$)
Nominal Voltage	11,1V	12,8V
Capacity	150 Ah	100 Ah
Charge Time	10 h	10 -15 h
Cicle number	300	1400
Dimensions (mm x mm x mm)	410x330x175	430 x 341 x 244
Weight (kg)	15,5	14
Maximum discharge current	150A	30A
Maximum Charge current	30A	-
Charging Voltage	12,6 V	14,6V
Discharge Cut-off Voltage	7,5 V	8V
Temperature Range (charging)	0°C . . . +40°C	0°C . . . +40°C
Temperature Range (discharging)	-10°C . . . +60°C	-10°C . . . +60°C
Price (aprox.)	tbd	1.333 €

Table 7.6 – Specifications of the two best battery candidates.

The final election is the *Hellpower* model due to its bigger capacity that will be translated in a bigger system operation time. It is also important to know the charge and discharge profiles of the battery so they are illustrated in graphs in Appendix E. Charge and Discharge Battery Profiles [36].

7.3.2 Battery Run Time Estimation

If the battery was a perfect power source and behaved linearly, the discharge time could be calculated according to the in-and-out flowing currents. What is put in should be available as an output in the same amount. For the battery to use in our system, if this rule was valid we could estimate the battery running time as:

$$t = \frac{C\ (A{\cdot}h)}{I\ (A)} \tag{7-1}$$

Where:

C is the rated capacity at that discharge rate (in ampere-hours),

I is the actual discharge current (in amperes),

t is the actual time to discharge the battery (in hours).

Using the numbers of the battery to use in the PLMU and the discharge current value as the maximum current value calculated in section 7.1, we can estimate the time to discharge the battery from equation (7-1) to:

$$t = \frac{150\ Ah}{24.87\ A} = \boldsymbol{6.03\ hours}$$

But this value is not possible to achieve because of the battery's intrinsic losses. The output is always less than what has been put in, and the losses escalate with increasing load. High discharge currents make the battery less efficient. The efficiency factor of a discharging battery is expressed in the *Peukert Law* [37]. The *Peukert Law* takes into account the internal resistance and recovery rate of a battery.

A better approach of the real battery discharge time considering the Peukert Law can be calculated as follows:

$$t = \frac{C_N}{I_N}\left(\frac{I_N}{I}\right)^k \tag{7-2}$$

Where:

C_N is the storage Capacity (in amper-hours),

I_N is the nominal discharge current (in amperes),

I is the actual discharge current (in amperes),

k is the *Peukert* constant (dimensionless),

t is the actual time to discharge the battery (in hours).

Similarly, we can calculate the real battery capacity using this equation:

$$t \cdot I = C_N \left(\frac{I_N}{I}\right)^{k-1} \tag{7-3}$$

In the battery under study I_N is 10A, C_N is 150 Ah and the real discharge current will be 24.87A. Considering the *Peukert* constant equal to 1.05, which is the most common value in Lithium-ion batteries technology [38] and using equation (7-2) we can determine a better approach of the battery running time:

$$t = \frac{150\ Ah}{10\ A}\left(\frac{10\ A}{24.87\ A}\right)^{1.05} = \mathbf{5.76\ hours}$$

And using equation (7-3) we can calculate the real battery capacity as:

$$t \cdot I = 150\ Ah\left(\frac{10\ A}{24.87\ A}\right)^{1.05-1} = \mathbf{143.32\ A \cdot h}$$

A *Peukert* constant value close to one 1 indicates a well-performing battery with good efficiency and minimal loss; a higher number reflects a less efficient battery. The *Peukert* constant varies according to the age of the battery, generally increasing with age. The equation does not account for the effect of temperature on battery capacity.

8 Energy Monitoring System

In the emergency recovery scenario, it can be relevant for estimating the battery capacity of the PLMU and to prevent the PLMU from running out of power or to devise relevant replacement strategies.

In the PLMU the estimated operational time and the battery remaining capacity will be calculated and showed to the users in a graphical way via GUI. For this purpose a power meter is needed to measure the real-time power consumption of the whole system and the battery status. This power device is called *Energino* [39] which performances will be introduced in this section.

8.1 *Energino*

In this Section *Energino* is introduced [5], an affordable solution for real-time energy consumption monitoring in wireless networks. *Energino* is a plug-load meter designed to monitor the energy consumption of DC devices. It is a contribution from CNET (Center for Research and Telecommunication Experimentation for Networked Communities) one of the partners in the ABSOLUTE project. In addition to provide the device to measure the power consumption of the PLMU, they will be in charge to perform the algorism to estimate the battery remaining operating time.

It consists of hardware and software components both based on the Arduino platform. A management backend written in Python is used to configure *Energino's* operating parameters, i.e. sampling rate and resolution, and to gather the energy consumption statistics.

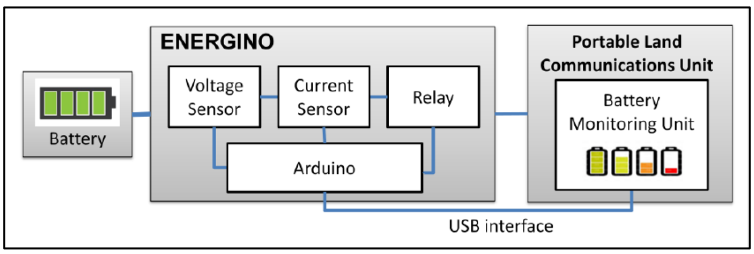

Figure 8.1 – *Energino* integrated in the PLMU [5].

The main features of *Energino* are:

- Arduino-based,
- High sampling rate, up to 10000 voltage/current samples per second;
- High resolution, configurable from 26 mA down to 1 mA;
- Low cost/low power,

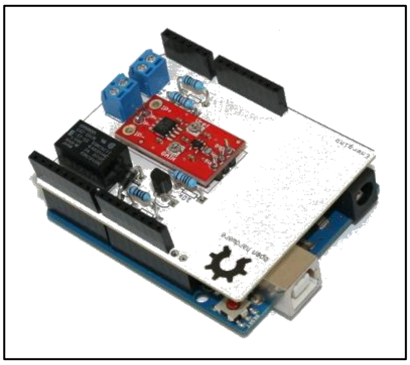

Figure 8.2 – *Energino* internal aspect with USB connection module.

8.1.1 *Energino* Measurements

As explained in above section *Energino* will be connected to the PLMU processing platform by USB. Once it is plugged it can start to measure, the way to start its measurements using the command line interface is:

```
root@overo# ./energino.py -i 100
```

This line will execute the Phyton script that manages the Arduino board and will give us power consumption measurements every 100 ms. It will produce an output in the command line interface that will be printing information continuously. The information will be also stored in a CSV file.

The information stared in this file it is displayed in real-time using the *LiveGraph* [40] application and it is producing an output in a graphical way that will be shown in Figures 8.7, 8.8 and 8.9.

When executing the mentioned script the current *Energino* version will be used to measure the following parameters:

- Battery Terminal Voltage,
- Battery Discharge Current,
- Instant Power Consumption.

Using this data the battery State of Charge (in %) can be calculated. But the currently available *Energino* version has some limitations that have to be eliminated, so the future version will present new features:

- The Hall effect current sensor will be replaced from the actual version, Sparkfun ACS712 designed for +/- 5A to one designed for 25A.
- It will include a temperature and an humidity sensor: high temperature increases battery's self-discharge [41].
- A new measurement output in the Phyton script will be included: it will be the estimated battery remaining operation time.

Finally, Figure 8.3 shows the schema of how the future *Energino* version will be connected in the PLMU system.

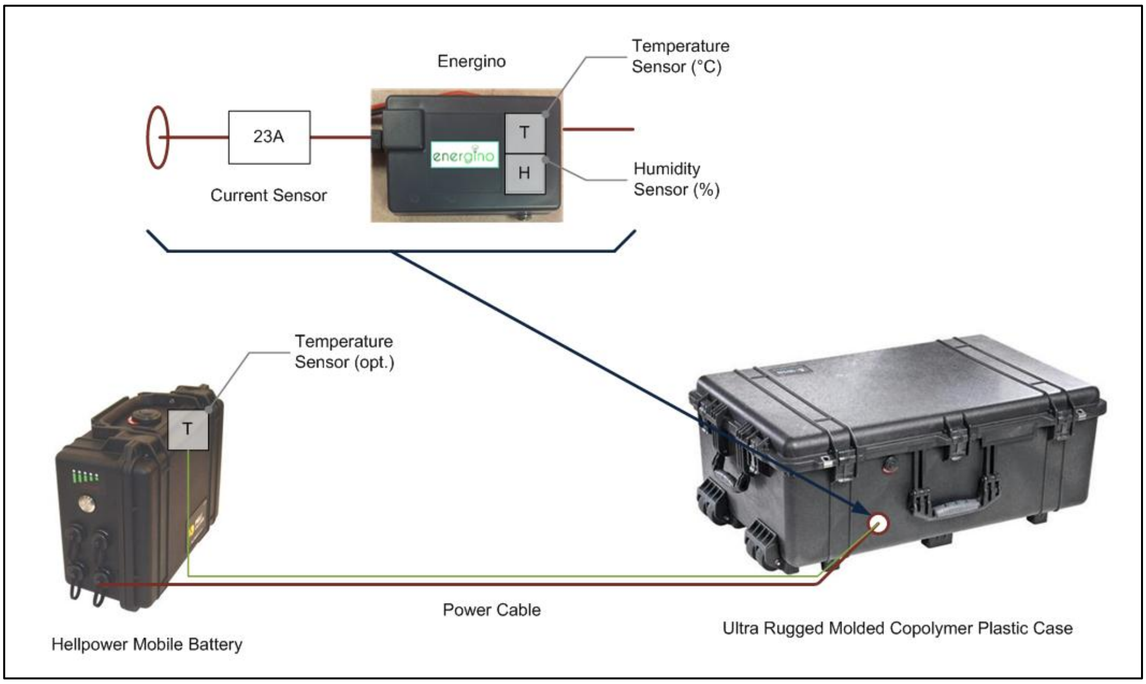

Figure 8.3 – Schema of *Energino's* integration in the PLMU.

8.2 *Energino* Validation

In this section the procedure for measuring the power consumption of some of the integrated devices in the PLMU is described together with the data collected from these measurements. The purpose of these measurements is to build a framework for the power consumption global estimation and to contrast the *Energino* measurements with other power meters to determine its reliability.

8.2.1 Measurement Process

For the power consumption measurement three devices in the PLMU have been chosen: the Brik PC, the 3G Femtocell and the USB hub [42]. The data provided by *Energino* will be compared with the manufacturer specifications' data, the data provided by a commercial plug power meter and the data of a professional laboratory power meter.

Figure 8.4 shows the commercial power meter used for the test. The procedure to get the power consumption from this kind of devices is extremely simple, the AC power connector has to be plugged in the device and the power consumption of the device, in Watts, will be showed automatically by the integrated display.

Figure 8.4 – Commercial power meter.

The laboratory device used as a power meter is illustrated by Figure 8.5. It is a DC power supply which shows voltage and current data of a connected device. Therefore, the power consumption of the device under test can be calculated multiplying the data (voltage and current) displayed on the power supply as in (8-1). Since all the devices under test have a 2.5mm power jack as power input connector and the power supply's power output is a "banana" connector type, it has been necessary to adapt this output to a 2.5mm DC jack (please refer to Figure 8.6).

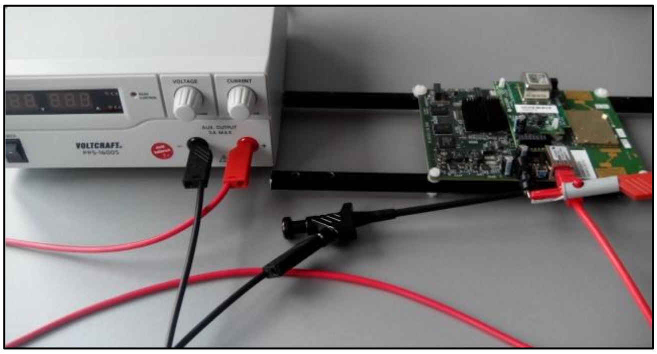

Figure 8.5 – Measurement performed with the DC power supply and the 3G Femtocell.

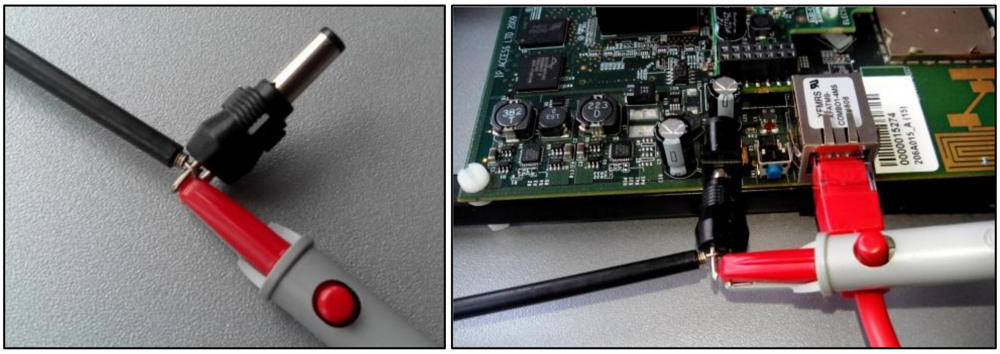

Figure 8.6 – Adaptation of the DC power supply connector.

Figure 8.7 shows how the *Energino* is connected for the measurement. In the example shown in the picture it is measuring the power consumption of the USB hub.

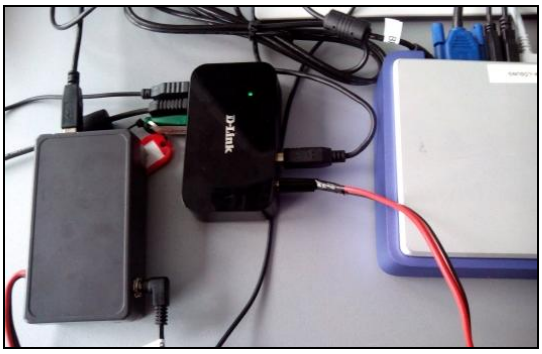

Figure 8.7 – Measurement performed with the *Energino* and the USB hub.

8.2.2 Results

For the results of the measurement, the resolution of each power meter has to be taken into account:

- *Energino*: 0.01 W
- Commercial power meter: 0.1 W
- DC power supply: 0.01 W

The power measurements have been performed under three different conditions:

- Idle: the device is powered but is not "used"
- Normal: normal operation of the device
- Burn: above-normal operation of the device

The specific operation mode for each device will be described later in the result table. For each of the power consumption devices and each of the above-mentioned conditions, measurements have been done three times and averaged.

The table with the data collected in the test is shown below (Table 8.1). Note that there are comments defining the test mode for each device (Table 8.2)

Commercial power meter						Professional power meter				*Energino*			
Device &Model Name	**Specs Power (Max)**	**Supply voltage**	**Power in Idle mode [W]**	**Power in Normal mode [W]**	**Power in Burn mode [W]**	**Supply voltage**	**Power in Idle mode [W]**	**Power in Normal mode [W]**	**Power in Burn mode [W]**	**Supply voltage**	**Power in Idle mode [W]**	**Power in Normal mode [W]**	**Power in Burn mode [W]**
3G B.S. nano3G	20 W	12 V	7,2	10,8	11	9 V	6,3	9	9,9	12.3 V	5,36	9,28	9,62
			7,3	10,4	10,9		6,3	8,9	9,79		5,77	9,36	9,63
			7,3	10,7	10,9		6,5	8,9	9,79		5,27	9,32	9,66
		Average:	**7,27**	**10,63**	**10,93**	**Average**	**6,37**	**8,93**	**9,83**	**Average**	**5,47**	**9,32**	**9,64**
Lex Brik PC BK3741S	30 W	12 V	16,7	17,7	18,1	*				11 V	12,41	13,54	15,93
			15,4	17,1	17,3						12,36	14,53	15,66
			15,6	15,9	18,4						12,23	13,27	16,33
		Average:	**15,9**	**16,9**	**17,93**	**Average**	0	0	0	**Average**	**12,33**	**13,78**	**15,97**
USB HUB Dlink DUB-H7	3.5 W	5 V	0,6	1,6	2,3	5.1 V	1,02	1,53	2,04	4.64 V	0,76	1,43	1,79
			0,7	1,7	2,4		1,02	1,53	2,04		0,76	1,42	1,79
			0,7	1,7	2,4		1,02	1,53	2,04		0,75	1,47	1,8
		Average:	**0,67**	**1,67**	**2,37**	**Average**	**1,02**	**1,53**	**2,04**	**Average**	**0,76**	**1,44**	**1,79**

*Not measured since no suitable DC power connector was available.

Table 8.1 - Results of the power consumption measurements.

Device	Idle mode	Normal mode	Burn mode
3G base station	Powered but not transmitting or receiving data.	Operative and accessible but without data exchange from any connected device.	With one device (mobile phone) connected to it and transmitting data and voice information with the device in use.
Brik PC	With the O.S loaded but with not all services running and no applications opened.	With the minimum number of applications running and the needed services for the PLMU functionality running	With several applications, all services and strong web browsing running.
Hub USB	Powered with nothing plugged.	Using 4 of its USB ports (minimum USB devices needed by the PLMU).	Using all 7 USB ports.

Table 8.2 - Operation conditions for each device under test.

As can see in Table 8.1, the devices are not powered necessarily with the same voltage. Anyway the power remains the same and is equal to the voltage U, expressed in volts, times the current I, expressed in Amperes, as follows:

$$P = U\ I \tag{8-1}$$

8.2.3 Power Consumption Graphs

The following graphs were captured using the application *LiveGraph* while measuring the power consumption of the tested devices with *Energino*. They help to represent in a graphical way the power consumption evolution in every operation mode.

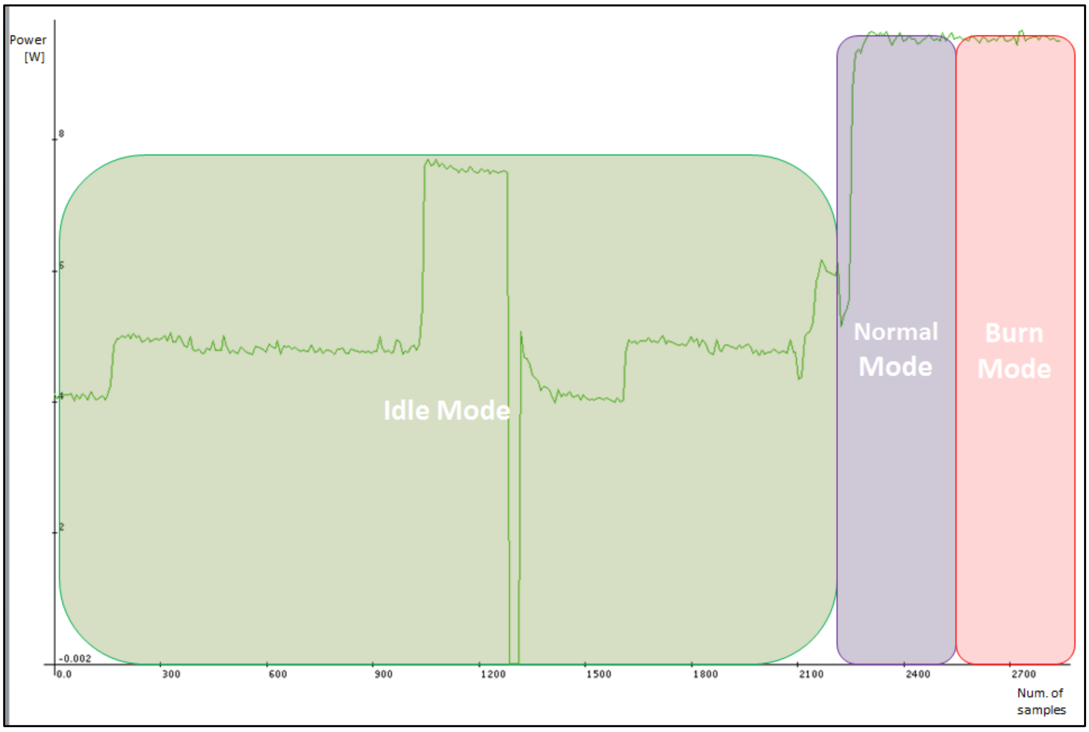

Figure 8.8 – 3G Femtocell power consumption evolution.

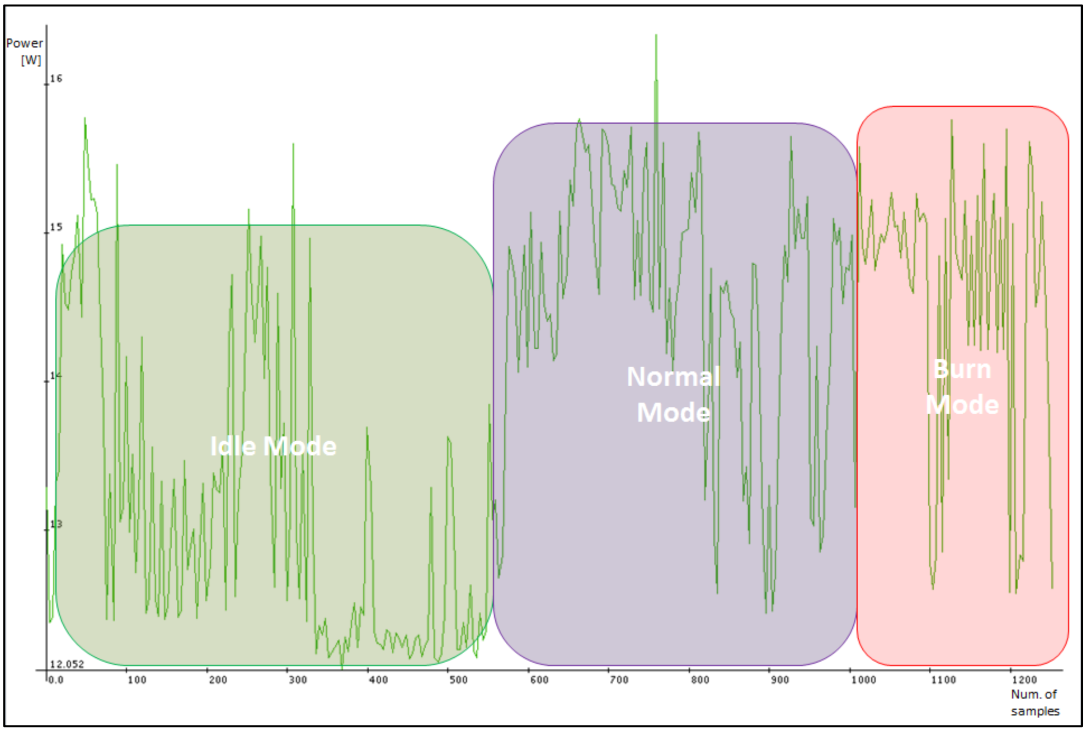

Figure 8.9 – Brik PC power consumption evolution.

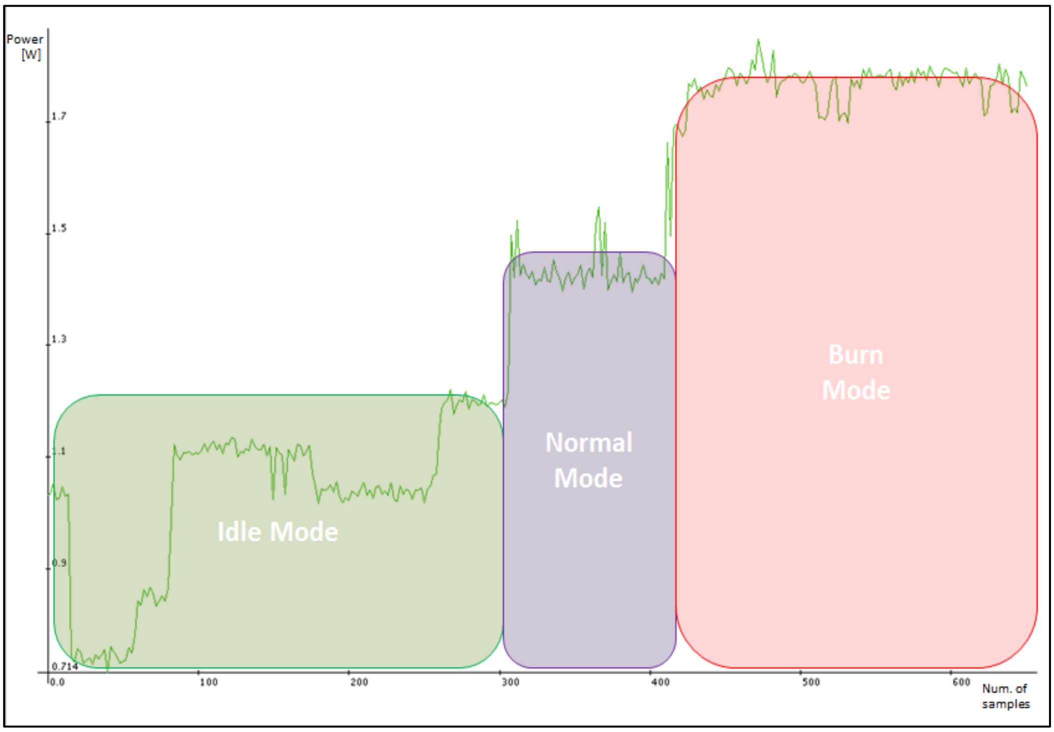

Figure 8.10 – USB hub power consumption evolution.

Power measurements were realized so as to assess the accuracy of *Energino* for a future integration in the portable land mobile unit (PLMU). It has been shown, through the results of Section 8.2.2 that *Energino* provides measurements which are quite close to the ones given by a professional power supply (difference of 2 to 10%). The commercial power meter, on the other side, indicates power consumptions which are bigger of at least 12%.

The *LiveGraph* allows observing in real time the modification of the power consumption depending on the utilization of the device (Section 8.2.3). It has to be remarked that the x-axis represents the samples which have to be configured carefully otherwise the output looks "bursty" (e.g. Figure 8.9).

After these verifications, *Energino* can be integrated in the PLMU in order to measure the power consumption of the devices. Especially the purpose is to plug the *Energino* between the battery (power supply) and the PLMU so as to estimate the power consumption of all devices plugged to the PLMU and therefore derive the remaining battery time.

9 Project Status

The aim of this chapter is to present an overview of the current status of the PLMU integration and to clarify the contribution of this thesis. For this purpose Figure 9.1 is used. It shows the architecture of the demonstration performed in the final presentation of this thesis at TGS.

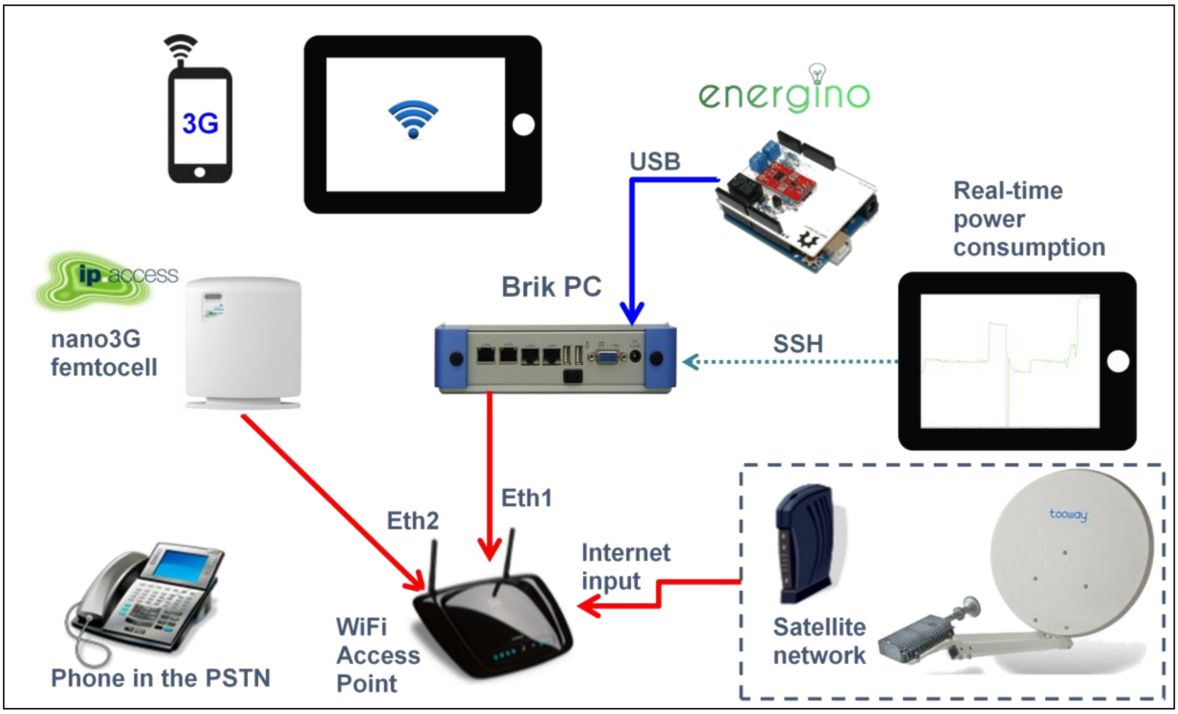

Figure 9.1 – Final presentation demonstration architecture schema

The devices integrated up to now in the PLMU system are:

- The 3G femtocell,
- the *Energino*,
- the satellite modem,
- and the AP WLAN.

These devices are currently managed by the software installed in the Brik PC, which has the role of the processing platform, so the software and the network configuration to manage the integrated devices has also been implemented in the framework of this thesis.

The functionalities provided by this version of the PLMU, in which all data and voice traffic is backhauled over satellite, are:

- Phone calls from the PSTN to a 3G or WiFi device,
- Phone calls from 3G to a WiFi device,
- Conference call between PSTN, 3G and WiFi devices,
- Power consumption measurement using *Energino*,
- Real-time power display in a Tablet PC using *LiveGraph* application and over an ssh connection to the Brik PC.

10 Conclusions

Along this thesis the hardware design of the PLMU architecture has been done. Market researches of state-of-the-art components have been performed in order to select the most suitable devices. The power system has been designed and some improvements to reduce the power consumption of the system have been suggested, such as the replacement of the computing platform and the addition of the control system to switch on and off the different devices remotely.

Regarding the integration process, the software and hardware of the first version of the PLMU has been validated and tested. It concerns the following communications devices: 3G Base Station, WiFi Access Point, energy monitoring system and satellite modem. It has been proved the usability of the first version of the PLMU to perform data and voice traffic over a backhauling satellite link.

Before achieving the definitive designed version of the PLMU several tasks still need to be performed: design the layout and embed the hardware components in the suitcase, assemble and test the Power System, migrate the software system to the SBC and integrate and test new sub-components (TETRA, eNodeB, Sensor and Battery).

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Appendices

Appendix A. SBC Complete Evaluation

		Aria G25			Mini210s		
Key Performance Indicators (KPIs)	Weights (1-10)	http://www.acmesystems.it/aria	Score	Weighted score	http://www.friendlyarm.net/products/mini210s	Score	Weighted score
Weighted arithmetic mean score				**8,23**			**8,2**
Architecture	10	ARM9	10	100	ARM11	10	100
CPU	10	ARM9 @ 400Mhz Atmel AT91SAM9G25	7	70	1 GHz Samsung S5PV210	9	90
RAM	8	256 MB DDR2	8	64	512 MB DDR2	9	72
LAN ports	6	1x 10/100 Mb	6	36	1x 10/100 Mb	6	36
USB ports	7	3x USB 2.0	9	63	1x USB 2.0 1x mini USB 2.0	7	49
Voltage supply	5	3,3 V	6	30	5 VDC	10	50
Power comsumption	9	210 mA (0,69 W)	10	90	No info	6	54
External memory ports	0	uSD		0	uSD		0
Video out	0	No		0	mini HDMI		0
Internal Memory	0	No info		0	4 GB NAND flash		0
Temp. range	0	-20 ° to 70 °C		0	No info		0
Price (aproximately)	0	43,56 €		0	159 USD		0
Expansion possible	0	Yes		0	No		0
TOTAL SUM	55						

		iMX233-OLinuXino-MAXI			Raspberry pi Model B		
Key Performance Indicators (KPIs)	Weights (1-10)	https://www.olimex.com/Products/OLinuXino/iMX233/iMX233-OLinuXino-MAXI/open-source-hardware	Score	Weighted score	http://en.wikipedia.org/wiki/Raspberry_Pi#Specifications	Score	Weighted score
Weighted arithmetic mean score				**7,52**		5	**8,47**
Architecture	10	ARM9	10	100	ARM11	10	100
CPU	10	iMX233 ARM926J @ 454 MHz	7,5	75	700 MHz ARM1176JZF-S Broadcom BCM2835	8	80
RAM	8	64 MB	7	56	512 MB	9	72
LAN ports	6	1x 10/100 Mb	6	36	1x 10/100 Mb	6	36
USB ports	7	3x USB 2.0	9	63	2x USB 2.0	8	56
Voltage supply	5	6 - 16 VDC	6	30	5 VDC	10	50
Power comsumption	9	750 mA @10V (7,5 W)	6	54	700 mA (3,5 W)	8	72
External memory ports	0	SD		0	SD / MMC / SDIO card slot		0
Video out	0	Composite video		0	Composite RCA, HDMI		0
Internal Memory	0	No info		0	No info		0
Temp. range	0	No info		0	No info		0
Price (aproximately)	0	45 USD		0	35 USD		0
Expansion possible	0	No		0	No		0
TOTAL SUM	55						

		Beagle board-XM			IGEP v2		
Key Performance Indicators (KPIs)	Weights (1-10)	http://beagleboard.org/Products/BeagleBoard-xM	Score	Weighted score	http://www.isee.biz/index.php/products/processor-boards/igepv2-board	Score	Weighted score
Weighted arithmetic mean score			3	**8,91**		2	**8,98**
Architecture	10	OMAP3	10	100	OMAP3	10	100
CPU	10	1-GHz super-scalar ARM Cortex™-A8 OMAP3525/30 SOC	9	90	ARM Cortex A8 1GHz DM3730 SoC	9	90

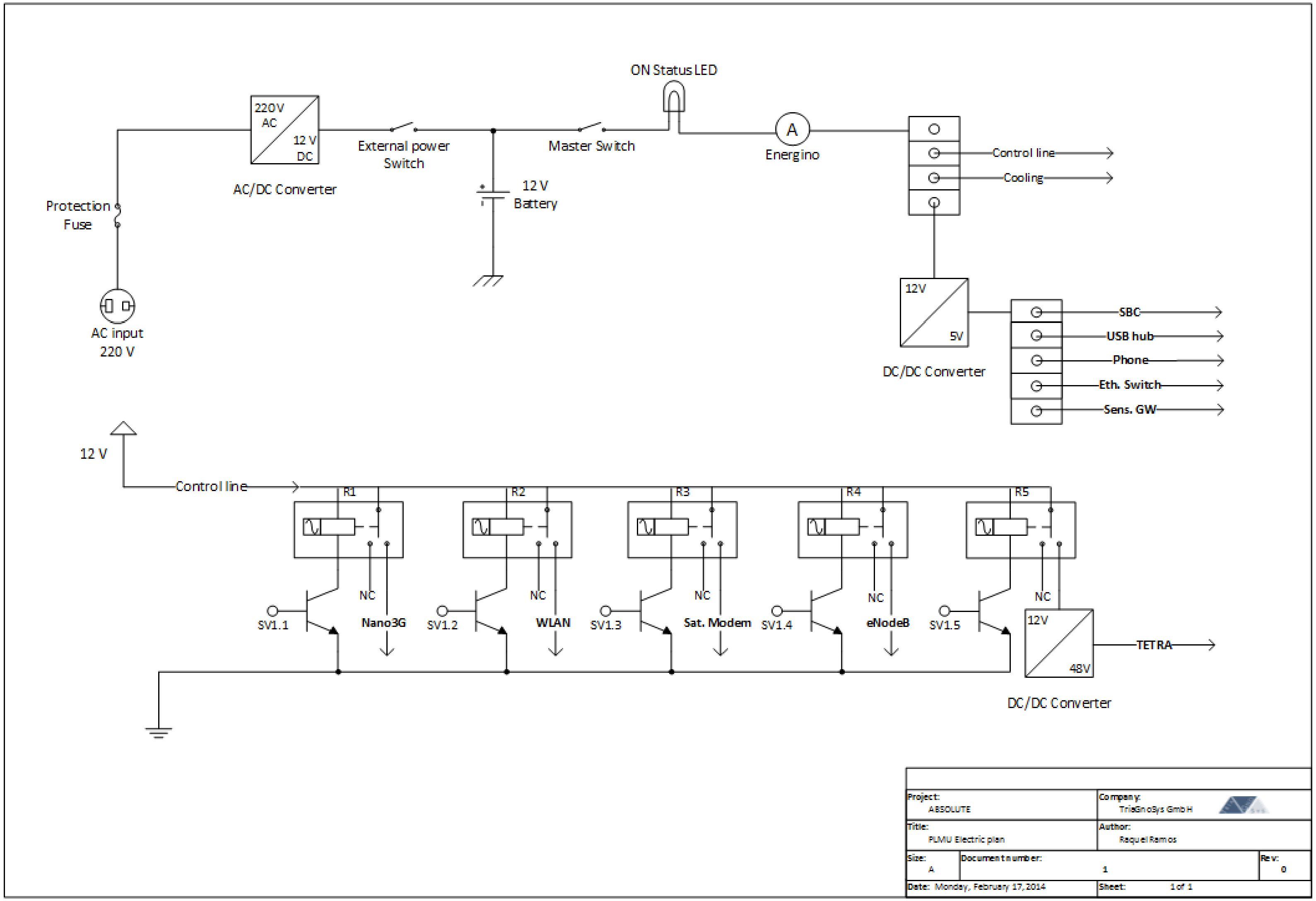
RAM	8	512-MB LPDDR RAM	9	72	512-MB LPDDR RAM	9	72
LAN ports	6	1x 10/100 Mb	6	36	1x 10/100 Mb Wifi 802.11 b/g Bluetooth	6	36
USB ports	7	4x USB 2.0	10	70	2x USB 2.0	8	56
Voltage supply	5	5 VDC	10	50	5 VDC	10	50
Power comsumption	9	750 mA (3,75 W)	8	72	600 mA (3 W)	10	90
External memory ports	0	uSD		0	uSD		0
Video out	0	HDMI / S-video		0	HDMI		0
Internal Memory	0	No info		0	512 MB NAND FLASH		0
Temp. range	0	No info		0	-40°C to 85°C		0
Price (aproximately)	0	149 USD		0	188 €		0
Expansion possible	0	No		0	Yes		0
TOTAL SUM	55						

		Gumstix Overo® COM TidalSTORM			**Hawkboard**		
Key Performance Indicators (KPIs)	Weights (1-10)	https://www.gumstix.com/store/app.php/products/356/	Score	Weighted score	http://elinux.org/Hawkboard	Score	Weighted score
Weighted arithmetic mean score			1	**9**			**8,01**
Architecture	10	OMAP3	10	100	ARM9	10	100
CPU	10	ARM Cortex A8 1GHz DM3730 SoC	9	90	300-MHz ARM926EJ-STM RISC CPU OMAP-L138 SoC	6	60
RAM	8	1 GB	10	80	128 MB DDR2	7	56
LAN ports	6	1x 10/100 Mb *	6	36	1x 10/100 Mb	6	36
USB ports	7	1x USB 2.0 *	7	49	1x USB 2.0	7	49
Voltage supply	5	5 VDC	10	50	5 VDC	10	50
Power comsumption	9	400 mA (2W) *Confirm	10	90	500 mA (2,5W) if porwered with USB	10	90
External memory ports	0	uSD		0	SD / MMC card slot, SATA RS232 Serial port		
Video out	0	HDMI *		0	VGA and Composite RCA		
Internal Memory	0	No info		0	128 MByte NAND FLASH		
Temp. range	0	0 to 85° C		0	No info		
Price (aproximately)	0	139 USD + expansion board price		0	139 USD		

Expansion possible	0	Yes	0	0	No		0
TOTAL SUM	55	(*) with Tobi expansion board					

		Minnow board			soekris net6501 - 50		
Key Performance Indicators (KPIs)	Weights (1-10)	http://www.minnowboard.org/technical-features/	Score	Weighted score	http://soekris.com/net6501-50-board.html	Score	Weighted score
Weighted arithmetic mean score			5	**8,47**			**8,34**
Architecture	10	Intel x86	10	100	Intel x86	10	100
CPU	10	Intel® Atom™ E640 (1GHz, 32bit)	9	90	1 Ghz Intel Atom E6xx	9	90
RAM	8	1 GB DDR2	10	80	1 GB DDR2	10	80
LAN ports	6	1x 10/100/1000 Mb	6	36	4x 10/100/1000 Mb	10	60
USB ports	7	2x USB 2.0 1x mini USB 2.0	8	56	3x USB 2.0	9	63
Voltage supply	5	5 VDC	10	50	6 - 25 VDC	6	30
Power comsumption	9	greater than rasp pi (6 W estimated)	6	54	30 W	4	36
External memory ports	0	uSD, SATA			2x SATA		
Video out	0	HDMI			No info		
Internal Memory	0	4 MB SPI Flash			8 Mbit BIOS/BOOT Flash		
Temp. range	0	No info			0 - 60° C		
Price (aproximately)	0	199 USD			329 USD		
Expansion possible	0	Yes			No		
TOTAL SUM	55						

Appendix B. Electrical Plan



Appendix C. Electrical Performances

Device	Model Name	Power tag	Supply Voltage [V DC]	Current (typ) @12V* [A]	Current (max) @12V* [A]	Current (typ) [A]	Current (max) [A]	Power (Typ) [W]	Power (Max) [W]	Power before conversion** (typ) [W]	Power before conversion** (Max) [W]
3G base station	Ip.acces Nano3G		12	0,83	1,67	0,83	1,67	**9,9**	**20**	**9,9**	**20**
VESNA gateway	From JSI		5	0,01	0,69	0,02	1,44	**0,12**	**7,2**	**0,14**	**8,28**
eNodeB	From HHI, UDE and NOM		12	3,79	4,58	3,79	4,58	**45,50**	**55,00**	**45,50**	**55,00**
TETRA base station	DAMM TetraFlex®		48	7,19	7,19	1,56	1,56	**75**	**75**	**86,25**	**86,25**
TETRA B.S controller	DAMM TetraFlex®		48	1,92	1,92	0,42	0,42	**20**	**20**	**23**	**23**
Power comp. monitoring	Energino		12	0,02	0,08	0,02	0,08	**0,25**	**1**	**0,25**	**1**
Sat portable terminal	SurfBeam 2 Pro		12	6,67	6,67	6,67	6,67	**80**	**80**	**80**	**80**
Phone IP	Snom 300	A	5	0,26	0,26	0,54	0,55	**2,71**	**2,76**	**3,12**	**3,17**
	Aastra 53i	B	48	0,36	0,37	0,08	0,08	**3,75**	**3,84**	**4,31**	**4,42**
	Cisco Linksys SPA941	C	5	0,58	0,61	1,2	1,27	**6,02**	**6,35**	**6,92**	**7,3**
A.P. WLAN	Ubiquiti picostation2	C	12	0,33	0,33	0,33	0,33	**4**	**4**	**4**	**4**
	Ubiquiti ministation	B	12	0,42	0,42	0,42	0,42	**5**	**5**	**5**	**5**
	WLg-LINK-OEM-EVAL	A	5	0,16	0,48	0,33	1	**1,65**	**5**	**1,9**	**5,75**
Processing platform	Gumstix Overo TidalStorm	A	5	0,19	0,19	0,4	0,4	**2**	2	**2,3**	**2,3**
	Igep v2	B	5	0,29	0,29	0,6	0,6	**3**	3	**3,45**	**3,45**
	Brik PC	C	12	1,25	2,5	1,25	2,5	**15**	30	**15**	**30**
Switch Ethernet	Xtreme/Gbe 8 ports	A	5	0,29	0,58	0,6	1,2	**3**	6	**3,45**	**6,9**
	Epsilon 8-port	B	5	0,52	0,52	1,08	1,08	**5,4**	5,4	**6,21**	**6,21**
	HTF HT-GS108F 8 ports	C	12	1	1	1	1	**12**	12	**12**	**12**
Cooling fan system	Scythe Gentle Typhoon	A	12	0,08	0,08	0,08	0,08	**1**	1	**1**	**1**
	Noctua NF-P12	B	12	0,09	0,09	0,09	0,09	**1,08**	1,08	**1,08**	**1,08**
	Enermax T.B. silence	C	12	0,15	0,15	0,15	0,15	**1,8**	1,8	**1,8**	**1,8**
Hub USB	Dlink DUB-H7	A	5	0,07	0,19	0,14	0,4	**0,72**	2	**0,83**	**2,3**
	Belkin ultra-slim 7 ports	B	5	0,1	0,29	0,2	0,6	**1**	3	**1,15**	**3,45**
	könig electronic 7 ports	C	5	0,1	0,29	0,2	0,6	**1**	3	**1,15**	**3,45**
DC/DC 12 to 5V buck converter	PST-DCZ0503	A	80%								
	Vipac Array (2 outputs)	B	85%								
	DROK SR	C	90%								
DC/DC 12 to 48V boost	Vicor Micro/Mini series	A	80%								

converter	Vipac Array (2 outputs)	B	85%								
	Car power boost module	C	90%								

* Beforeconversions

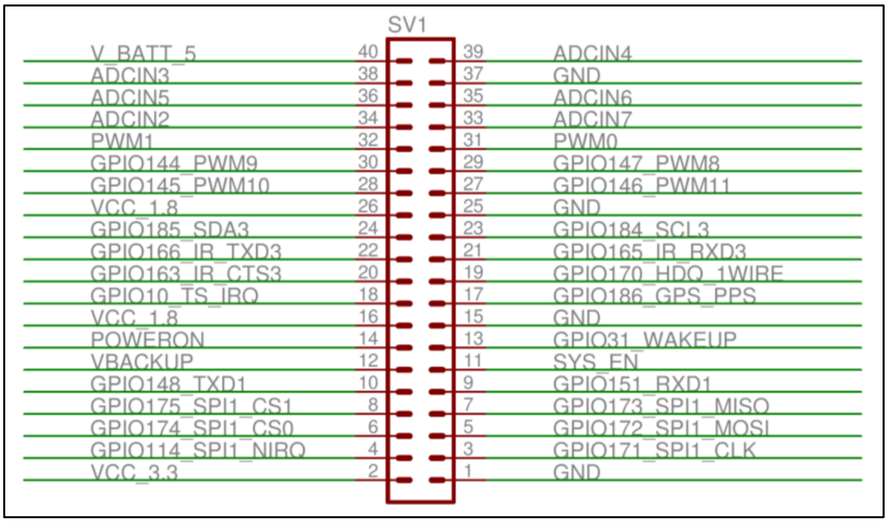
** Estimating 15% of average loses in voltage conversion

Appendix D. Gumstix's GPIO

Usable GPIO Pins in Tobi expansion board:

- Pin 27 –> GPIO146_PWM11
- Pin 29 –> GPIO147_PWM8
- Pin 19 –> GPIO170_HDQ_1WIRE
- Pin 28 –> GPIO145_PWM10
- Pin 30 –> GPIO144_PWM9

Schematic of Tobi's SV1 connector:

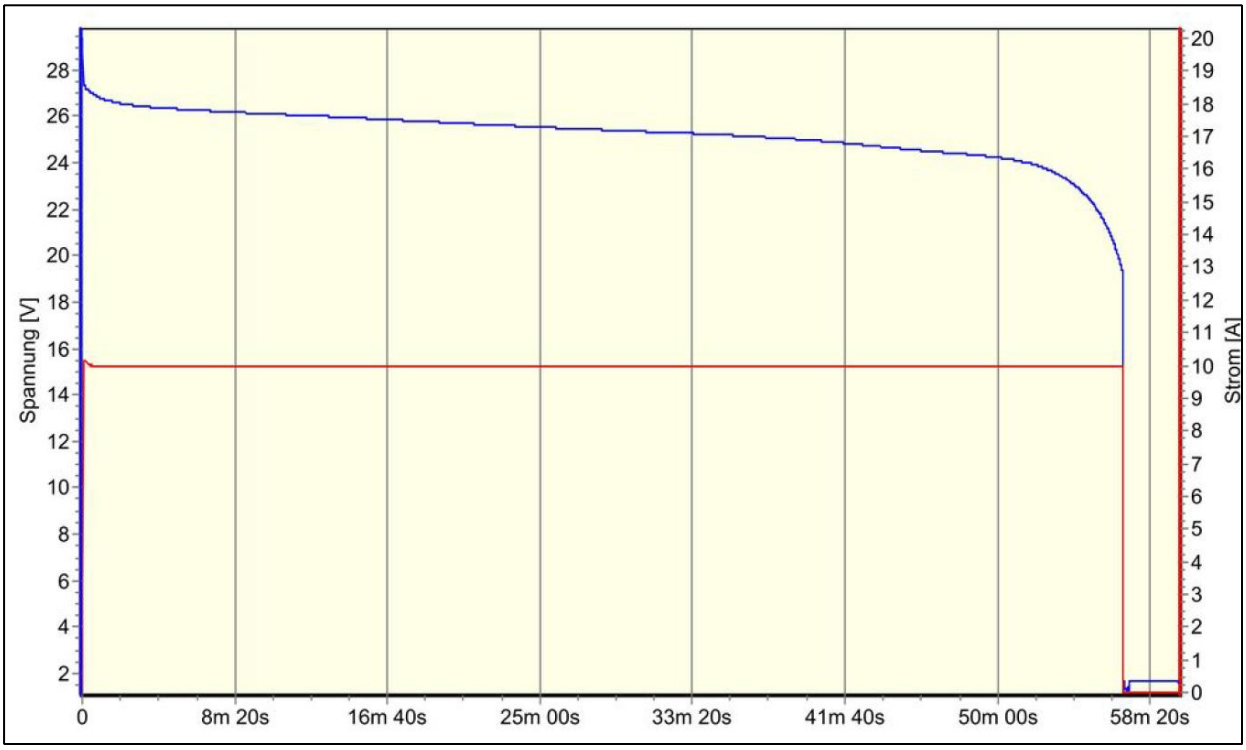


Example of the command lines to control a GPIO port in Tobi board:

```
root@overo# echo 146 > /sys/class/gpio/export
root@overo:/sys/class/gpio# cat gpio146/direction
in
root@overo# echo out > /sys/class/gpio/gpio146/direction
root@overo:/sys/class/gpio# cat gpio146/direction
out
root@overo# cat /sys/class/gpio/gpio146/value
0
root@overo# echo 1 > /sys/class/gpio/gpio146/value
root@overo# cat /sys/class/gpio/gpio146/value
1
```

Appendix E. Charge and Discharge Battery Profiles

Discharge HE-MP-12V-150Ah-P1450battery profile:



Charge HE-MP-12V-150Ah-P1450 battery profile: