Tyndall National Institute
Instituid Náisiúnta

# GENESI: DELIVERABLE D3.5

# ENHANCED NODES (CLUSTER-HEADS AND GATEWAY) PROTOTYPES

***Public***

The research leading to these results has received funding from the European Union Seventh Framework Programme under grant agreement Infso-ict n°257916.

*Executive Summary:*

*This deliverable documents the development of the GENESI Gateway prototype. The deliverable extracts requirements for a GENESI gateway from deliverables D2.1 and D2.2. These primarily include the ability to connect to the gateway remotely using wired (Ethernet) or wireless (mobile data, e.g. 3G).*

*The state-of-the art is examined to determine the applicability and usefulness of potential off-the-shelf solutions, motivating the need to develop an ad hoc device for GENESI.*

*The deliverable provides an overview of the design methodology, resulting in a hardware prototype that is expected to satisfy the connectivity requirements of GENESI networks. The prototype includes a powerful ARM processor, Ethernet connectivity for wired network access, wireless access achievable via UMTS (in addition to WiFi and Bluetooth), electrical interfacing to a GENESI WSN node, and a range of additional features.*

*Whilst the development of the GENESI Gateway was not a trivial engineering problem, it is expected that, although the device was designed with low-power operation in mind, the most significant challenge will be in ensuring that the GENESI Gateway devices are capable of long-term operation in-line with the nodes that comprise the WSN.*

| | *Name* | *Function* |
|---|---|---|
| *Authors :* | David Boyle, Jonathan Nifenecker, Guillaume Reiniche | Tyndall National Institute, UCC |
| *Approved by:* | Luca Benini | WP Leader, University of Bologna |
| *Approved on 30/05/2012 by* : | Chiara Petrioli | Project Leader, University of Rome Sapienza |

# DELIVERABLE D3.5

# ENHANCED NODES (CLUSTER-HEADS AND GATEWAY) PROTOTYPES

# Table of Contents

## List of Tables



## List of Figures

# 1 Introduction

The purpose of this deliverable is to report the design and assessment of the first enhanced nodes used for backbone connectivity; originally envisaged as Cluster Head and/or Gateway-type devices.

The requirements for a device capable of bridging a GENESI WSN (operating at the 2.4GHz ISM band under the IEEE 802.15.4 standard) with end-user back-end systems are elaborated in deliverable D2.2. For thoroughness, they may be reiterated as:

- Wired connectivity (e.g. Ethernet)
- Mobile wireless connectivity (e.g. UMTS/3G)

The decision not to further pursue any hardware development with respect to cluster-head type devices is explained in Section 1.1, below. Section 1.2 further elaborates the functional requirements for a GENESI Gateway; the realisation of which is of significant importance to the success of the GENESI system. Non-functional requirements are described in Section 1.3. Initial design methodology is presented in Section 1.4.

Section 2 presents an evaluation of the state-of-the-art. This relates to two particular avenues of investigation. The first pertains to the possible selection of off-the-shelf solutions; the second describing the available development boards available to assist in rapid prototyping of such systems.

Section 3 describes the proposed solution for the GENESI Gateway – inclusive of component selection and associated rationale. Section 4 describes the design and implementation of the device, with electrical specifications of the prototype presented in Section 5.

Section 6 presents the results of initial testing, validation and characterisation work, prior to a short conclusion in Section 7.

## 1.1 Rationale

The concept of a Cluster Head (CH) within a wireless sensor network relates to the appointment of a "leader" within a group of nodes; tasked with an additional set of duties. These may include the coordination of tasks within a cluster of nodes, aggregating data for upward transmission, dissemination of broadcast data within the cluster, etc.

From a hardware perspective, only one useful addition is envisaged for existing WSN devices in order to optimise one aspect of CH duties. This would be to provide power amplification to extend the communicable range of the CH device. Such power amplification mechanisms are available.

Considering the additional duties and increased throughput foreseen for CHs, it is widely accepted that there is a significant increase to the power budget required for the CH. In order to normalise the power distribution throughout the WSN, CH duties are usually shared between nodes within the network. Adopting this strategy, which exhibits an additional overhead with respect to CH elections, has been shown to more evenly distribute the energy requirements throughout the WSN.

As a result, the decision to focus on the development of a Gateway device, providing the necessary proxy between the WSN and the Internet, presents a more relevant and challenging problem. Without this device, it is impossible to achieve remote monitoring and/or control over the wireless sensor network.

## 1.2 Functional Requirements

In addition to timely data collection, distributed control in the form of remote programming, and real-time availability of the GENESI WSN are important aspects of the project. Therefore, the user should always, from anywhere, have direct access to the WSN recorded data, the WSN, and the Gateway device.

Depending on the deployment environment, various types of connectivity are required. In settings where no existing wired infrastructure exists (and therefore no local access points for WiFi connectivity, for example), mobile data access is a key enabler. Legacy solutions incorporate GPRS connectivity (from existing wired SHM solutions) that is tightly managed to upload data periodically to back-end systems.

Always available UMTS, or 3G (in addition to emerging and future solutions (4G/LTE)), is desirable to enable the remote management of the network in a timely manner; where wired (Ethernet) connectivity is impossible. Currently, this is an energy-expensive technology, but is desirable nonetheless.

To elaborate the full suite of functional requirements, the GENESI Gateway MUST provide the following:

- Communicability with the GENESI WSN
- Sufficient memory space to store collected data
- Data transfer to back-end systems (bi-directional communicability)
    - via policy based updates to a web server
    - on user request ("pull")
- Interpretation and execution of commands (either locally or for WSN management)
- A rich set of communications interfaces to facilitate a broad spectrum of deployment scenarios. These include:
    - Wireless
        - Bluetooth (IEEE 802.15.1)
        - WiFi (IEEE 802.11)
        - LR-WPAN (IEEE 802.15.4)
    - Wired
        - Ethernet
    - Mobile (wireless) data

    - 2.5/3G (GPRS/UMTS)
- Exhibit minimised energy requirements through low-power component selection, intelligent hardware management and energy policies.

## 1.3 Non-functional Requirements

There exist a number of non-functional requirements for a successful GENESI Gateway. In particular, these relate to energy management and physical enclosures.

Physical enclosures for Gateway devices must provide similar levels of protection to the wireless nodes themselves. These requirements are described in deliverable D2.2.

Maximising the lifetime of the Gateway will be a significant challenge with respect to higher energy consumption of component technologies, particularly related to the processor and the mobile data module. It is envisaged that the Gateway will, in addition to being mains-powered where possible, be powered by the GENESI Smart Power Unit.

## 1.4 Preliminary Design Methodology

To meet the requirements of the functional system, a Linux based solution is preferable. A Linux OS provides the computational power and an easy set-up off all the high level communications by providing software/hardware flexibility and driver availability.

Documentation pertaining to Linux capable boards illustrates that such a solution would be extremely time consuming to develop from the ground up. Therefore, to complete the necessary design without incurring significant development overheads, existing solutions are desirable.

Two different approaches have been evaluated:

1. WSN commercially ready gateway

There are some gateways available on the market which provide subsets of the required functionality. These are discussed in the following section.

2. General Linux “dev-board”, to be modified to the gateway needs.

There are a number of development boards (“dev-boards”) on the market that equally provide subsets of the required functionality for the GENESI gateway. These are also considered in the following section.

# 2 Evaluation of the State-of-the-art

There are several existing WSN systems available on the market with corresponding gateway devices. The following evaluation of the state-of-the-art serves to provide a comprehensive overview of the technologies and the systems used, providing a comparative benchmark for the GENESI system, in addition to providing insight as to optimal approaches to solving the problem within the desing space.

All of the gateways available run a Linux OS, implying the existence of a plethora of software solutions for acquiring, storing and communicating data.

The academic literature includes some limited information regarding the development of gateway devices. In [1], the authors present the design and implementation of a similar type of device that makes use of a GPRS module, with Ethernet connectivity, and USB physical interface to a TinyOS powered WSN node. There is, however, no evidence that the device was actually built and/or tested, with no electrical characteristics of the system reported. In [2] a description of the packaging system (UDP[1], IP and then PPP[2]) for Linux is explained for a similar type of system. Again, no evidence is presented that the system was built or characterised.

The evaluation in [3] shows the importance of the power mode (deep-sleep versus power off), and compares the overall impact on the energy consumption for different file size transfers over 3G and WiFi. The authors present guidelines for the system design of a gateway that meets the demands (hardware and software) of data gathering applications; with similar requirements to those of GENESI. The authors conclude by presenting a number of viable solutions (named Single Board Computers (SBCs)) – none of which are as powerful as the Stargate platform upon which the authors based their evaluation; highlighting the lack of availability of schematics and high power consumption as limiting factors to the selection of the Stargate (Crossbow) as a viable long-term solution.

For the GENESI gateway, existing commercial solutions, as well as Linux motherboards ("dev-boards"or"SBCs") were investigated. Indeed, the increasing numbers of Linux running on ARM dev-boards over recent years demonstrates that it would be possible to have a good solution by incorporating and/or tweaking something already available.

The following subsection considers commercially available "off-the-shelf" solutions. The advantages and disadvantages of each are highlighted, with a view to determining suitability for GENESI applications.

[1] User Datagram Protocol (UDP) allow sending message without requiring prior communications to set up special transmission channels or data paths.
[2] Point-to-Point Protocol (PPP) is a data link protocol commonly used in establishing a direct connection between two networking nodes.

## 2.1 Commercial Gateways

### 2.1.1 Meshlium from Libelium [4]

The Meshlium Xtreme device combines a number of wireless communications technologies (including WiFi, Bluetooth, GPRS, and IEEE 802.15.4), in addition to wired Ethernet, and may act as a gateway for wireless sensor networks built upon ZigBee technology. There are a number of configurations that may be selected prior to purchase.

**Figure 1 Meshlium Gateway**

**Pros**: Meshlium may contain different radio interfaces: WiFi (2.4GHz/5GHz), GPRS, Bluetooth and ZigBee. Various database options (file system, MySQL, external MySQL) are provided and numerous interfaces to the Internet possible (WiFi, GPRS, Ethernet).

**Cons**: The underlying processor is unknown. There are no options for extensibility, such as adding USB connections or additional memory. This gateway seems to provide limited programming possibilities trough an API system that only uses ZigBee the protocol.

Selecting the Meshlium solution would have the following implications:

1. Complete hacking for a new Linux installation.
2. No possibility to use SD card storage.
3. Limitation to wireless access.
4. Port the WSN protocol communication, using the Bluetooth antenna, instead of using a mote.

The Meshlium is clearly a powerful device, providing many of the features of a suitable GENESI Gateway; but there remain too many limitations to its adoption within a reasonable timeframe.

### 2.1.2 Sensinode Nanorouter [5]

This gateway resource provides only a software stack, for both the motes and the gateway. It is particularly focused on Sensinode’s implementation of IP over wireless sensor networks.

**Pros**: Give complete mote/gateway matching software. Use the latest standard 6LoWPAN.

**Cons**: Only support Texas Instruments CC2430, CC2530, CC1110, CC1180, CC430 for the mote.

It would not be possible to easily interface with GENESI motes. This solution is not suitable for GENESI.

### 2.1.3 Monitlink Gateway from Monnit [6]

A complete WSN implementation: gateway/sensors/server.

**Figure 2 Monitlink gateway**

**Cons**: This is an out of the box WSN system. The gateway is meant to communicate with the corresponding sensor. No hardware or software specifications are provided. The gateway will only connect to the company server, and there is no hardware adaptability.

### 2.1.4 National instrument WSN9792 [7]

The WSN9792 is a programmable gateway based on labview.

**Figure 3 WSN9792 gateway**

**Pros**: Embedded labview provide intensive computation of the data (model generation).

**Cons**: Cost 1500€ (750€ if labview is executed in a remote PC).

This would represent an extremely costly approach to implementing a gateway for GENESI.

### 2.1.5 Open WRT software [8]

This is an open source project, aimed to take full control of home ARM-based router by upgrading the firmware to a custom Linux OS.

**Pros**: A lot of Ethernet and communication resources are available. Open source.

**Cons**: Software only. A list of supported hardware is given, but most of the router will require modification to add the missing features.

This is not a good solution for the GENESI gateway; although some useful information and software may be taken from the website.

## 2.2 Linux “dev’ board”

There are several Linux dev boards available (otherwise known as SBCs). Only the ones approaching the communications requirements of a gateway are considered. Most of them share the use one of the latest ARM processors: ARM Cortex A8.

### 2.2.1 Gumstix Overo Air [9]

The Gumstix OveroAir COM is a tiny, ARM Cortex-A8 OMAP3503 based computer-on-module that communicates via 802.11g and Bluetooth. It is high-performance and production ready.

**Figure 4 Gumstix compared to a battery**

**Pros:**

- It has a small motherboard, with no unnecessary hardware with respect to GENESI project.
- Software completely accessible.
- Easy connection to another board with missing hardware.
- Very small with a fine pitch smd connector.

**Cons**: Processor range is maybe overkill for GENESI requirement. An extension board must be constructed to allow for the full requirements of GENESI to be met.

Through selecting a Gumstix, it would be necessary to design a custom extension board instead of a complete Linux board. This can *speed the design process, and the available source will* ease software development.

### 2.2.2 IGEPv2 board [10]

IGEPv2 BOARD platform is a low-cost, fanless single board computer.

**Figure 5 IGEPv2 board**

**Pros**: This device has all the needed hardware except 3G and mote connector.

**Cons**: This SCB has many redundant components in the context of GENESI (e.g. HDMI, audio).The connectors are not suitable for board-to-board connections.

### 2.2.3 Atmel's NGW100 mkII [11]

This network gateway kit uses an AVR 32-bit digital signal processor CPU with a selection of communications interfaces.

**Figure 6 NGW100 board**

**Pros**: Lot of support by both Atmel and the AVRfreak community.

**Cons**: No wireless communication. Less powerfull than an ARM processor. Mature design

### 2.2.4 Panda board [12]

The panda board is a development platform for the last OMAP 4 processor series (dual core Cortex A9). It is the new processor and low power version of the widely used "Beagleboard".

**Figure 7 View of a Pandaboard**

**Pros**: Current generation processor. Designed to be low power.

**Cons:** Connector not suitable for board-to-board connection.

Note: The ARM cortex A9 is here considered as the latest ARM processor generation as the Cortex a5 is available, but not much manufactured and developed as it is not attractive to new designs:

- Meant to replace ARM11, but with a need to rewrite software.
- Software compatible with A8 and A9 but much less powerful for small power savings.

Also, the cortex A15 (next most powerful ARM processor) is still not mass produced [34].

### 2.2.5 Lpcxpresso1769 [13]

Lpcxpresso is a small dev board for NXP's Cortex-M3. This is a very basic design aimed at those wishing to become familiar with Cortex-M3.

**Figure 8 Lpcxpresso board**

**Pros**: Easily plugged into another board. There is an embedded JTAG debugger on the board.

**Cons**: Cortex M3 cannot properly run linux; there is limited availability and limited communications hardware provided. The base boards available do not support the required communications suite; lacking 3G, specifically.

### 2.2.6 Armadeus AFP27 [14]

Armadeus provide a small size motherboard based on the I.mx27 (arm926) processor. The motherboard is meant to be plug into extension board.

**Figure 9 APF27 board**

**Pros**: small size, fine pitch smd connector.

**Cons**: useless Xilinx Spartan 3A FPGA. Not much documentation/examples availability due to a small community.

### 2.2.7 Linux stamp [15]

**Pros**: Lowest cost linux dev board.

**Cons**: Uses an old ARM 9. The design has been deprecated. Few software resources are available. Environment must be built from scratch.

### 2.2.8 Friendly ARM [16]

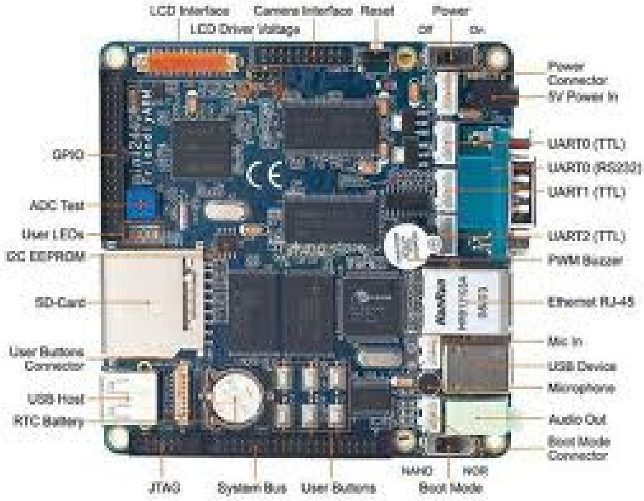


**Figure 10: FriendlyARM mini 6410**

**Pros**: Simple connection with other boards (using large connectors).

**Cons**: Uses ARM11 processor.

### 2.2.9 Chumby one [17]

This is an open source Linux devellopement board, meant to be a small standalone multiple-use touchscreen device (photo display, RSS reader, etc). An application store is available.

**Figure 11 Chumby one with its case**

**Pros**: The device was built to encourage hardware modification and experiment. A lot of resources are available.

**Cons**: The project has been running a number of years, and the development community has migrated to newer platforms (such as smartphones and Android).

## 2.3 Summary

The following tables summarise the above criteria, with some additional details.

**Table 1: Comparison of Commercially Available Gateway Devices**

| Gateway | Characteristics/Features | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Architecture** | **10/100 Ethernet** | **WiFi** | **Bluetooth** | **GPRS/3G** | **OS** | **USB** | **SD Card** | **Price** | **Comments** |
| **Gumstix Overo Air** | Omap 3503 (arm cortex a8) | No | Yes | Yes | No | Linux | 1 host, 1 otg | Yes | 200$ | Closest to our needs. Power supply via expansion board: 27$ for simpliest, 79$ for ethernet. No GPRS/3G options available |
| **Meshlium Mesh GPRS AP** | No hardware details | Yes | Yes | Optional | Yes | Linux | No | No | | Very similar to our needs. Does not have SD card, but internal sql database and several connection type (http, ftp, ssh) |
| **Sensinode – "Nanorouter"** | Software stack only | | | | | | | | | NanoRouter™ 2.0 is a border router software solution that enables routing between IP-based 6LoWPAN low-power wireless networks |
| **Monitlink Gateways** | | | | | | | | No | | Out of the box system. To be used with the corresponding sensor node. No configuration possible. WiFi xor USB xor Ethernet |
| **National Instrument WSN9792** | | 2 | Yes | No | No | Labview | 1 host | No | 1500€, 750€ if labview is executed from a remote PC | Gateway to embed labview. For intensive computational needs. |
| **Open WRT Software** | Custom Linux | Yes | Yes | No | No | Custom Linux | Depends on the router, usually 1 | Depends on the router; rare | | Any router may provide a good test basis. Using a router may have license issues, but the software may still be usefull for other boards. |

Text colour key: (indicates compatibility with GENESI requirements). Red: not suitable. Green: very good match. Orange: replacement or easy workaround.

**Table 2: Comparison of Available "dev boards"/single board computers (SBCs)**

| **DEV board** | **Characteristics/Features** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Architecture** | **10/100 Ethernet** | **WiFi** | **Bluetooth** | **GPRS/3G** | **OS** | **USB** | **SD card** | **Memory** | **Price** | **Comments** |
| **IGEPv2 Board** | TI OMAP3530 ( CORTEX A8 + DSP TMS320C6 4x) | 1 (SMSC LAN9221i) | Wifi IEEE 802.11b/g (Marvell 86w8686B1) | Bluetooth 2.0 (CSR BC4ROM/21e) | No | Linux, Android, Win CE, Linaro, QNX | 1 host, 1 otg | Yes | 4Gb NAND/ 4Gb Mobile Low Power DDR SDRAM | 200 € | |
| **NGW100 mkII Network Gateway Kit** | AVR32 bit AT32AP7000 | 2 (DP83848I) | No | No | No | Linux | 1 | Yes | | 200 € | Lot of information on the avrfreaks wiki |
| **Panda board** | Dual-core Cortex-A9 | 1 (+2 usb host via usb hub LAN9514) | 802.11 b/g/n & Bluetooth v2.1 (based on WiLink 6.0) | | No | Android, Linux | 2 host, 1 otg | Yes | 1 GB low power DDR2 RAM | 174$ (125€) | low power succesor to the beagle board |
| **lpcxpresso lpc1769 with base board** | Cortex M3 | No | No | No | No | freeRTOS, No linux possibilities | 1 host | No | No external memory | 102 € | |
| **Armadeus (apf27)** | i.MX27 (ARM926) | An extension board with: 2 ethernet/wifi/usb host/usb otg | | No | GSM extension possible | Linux | | By extension | 256MB ddr flash, 512MB nand | 108€ procesor board + 150€ dev board | Additional 200k gate FPGA. Only one extension can be used (WiFi XOR SD card) |
| **Linuxstamp** | AT91RM9200 (Arm9) | 1 | No | No | No | Linux | | Yes | 32MB SDRAM , 8MB SPI dataflash | | Many broken-out pins |
| **Chumby One** | i.MX233 (arm 926) | No | RT2571 USB WiFi dongle | No | No | Linux | 1 | Yes | 512MB DDR SDRAM | 200 € | |
| **friendly ARM Mini6410** | S3C6410 ARM11 | 1 | No | No | No | Linux | 1 host (1.1), 1 otg (2.0) | Yes | 128MB SDRAM, 256MB NAND Flash | 135 € | |

# 3 Proposed Solution

The preceding investigation of the state-of-the-art concludes that no existing commercially available gateway or dev-board (SBC) meet all of the GENESI project requirements. However, many of them are very close and do not need a lot of additional hardware. It is necessary, however, for a board to be designed in order to have the mote connector and a 3G module.

For a board to be designed, and connected to one of the above solutions, the motherboard / extension-board format of the GUMSTIX and the Armadeus are preferred. This is because they are the only boards with fine pitch SMD connectors. Therefore, they will keep the connection simple and small in size.

The GUMSTIX and the pandaboard are the closest solutions to the project in hardware. They both use a cortex A8 ARM processor, which is one of the latest “application processors”[3] [18].

The GUMSTIX is selected because it is the only solution that provides:

1. A very small size, with fine pitch board to board SMD connector
2. Most of the requirement are met (working Linux, Bluetooth, WiFi, SD card) without any useless hardware (HDMI and LCD controller, FPGA, audio, etc.).

Implementing the minimal hardware set, as dictated by the requirements, will ensure an optimised low-power approach and expedited development timescale.

## 3.1 Gumstix description

The exact gumstix specifications are:

Processor: TI OMAP 3503 (ARM Cortex-A8) 600 MHz

Memory: 512MB RAM & 512MB Flash

Features:

- 802.11b/g wireless communications
- Bluetooth communications
- microSD card slot
- TPS65950 Power Management

70-pin connectors with 140 signals for:

- $I^2C$, PWM lines (6), A/D (6), 1-wire
- UART, SPI, extra MMC lines
- Headset, Microphone
- Backup battery
- High Speed USB Host and USB OTG

[3] Application Processors are defined by the processor's ability to execute complex operating systems.

2 u.fl antenna connectors (WiFi, Bluetooth)

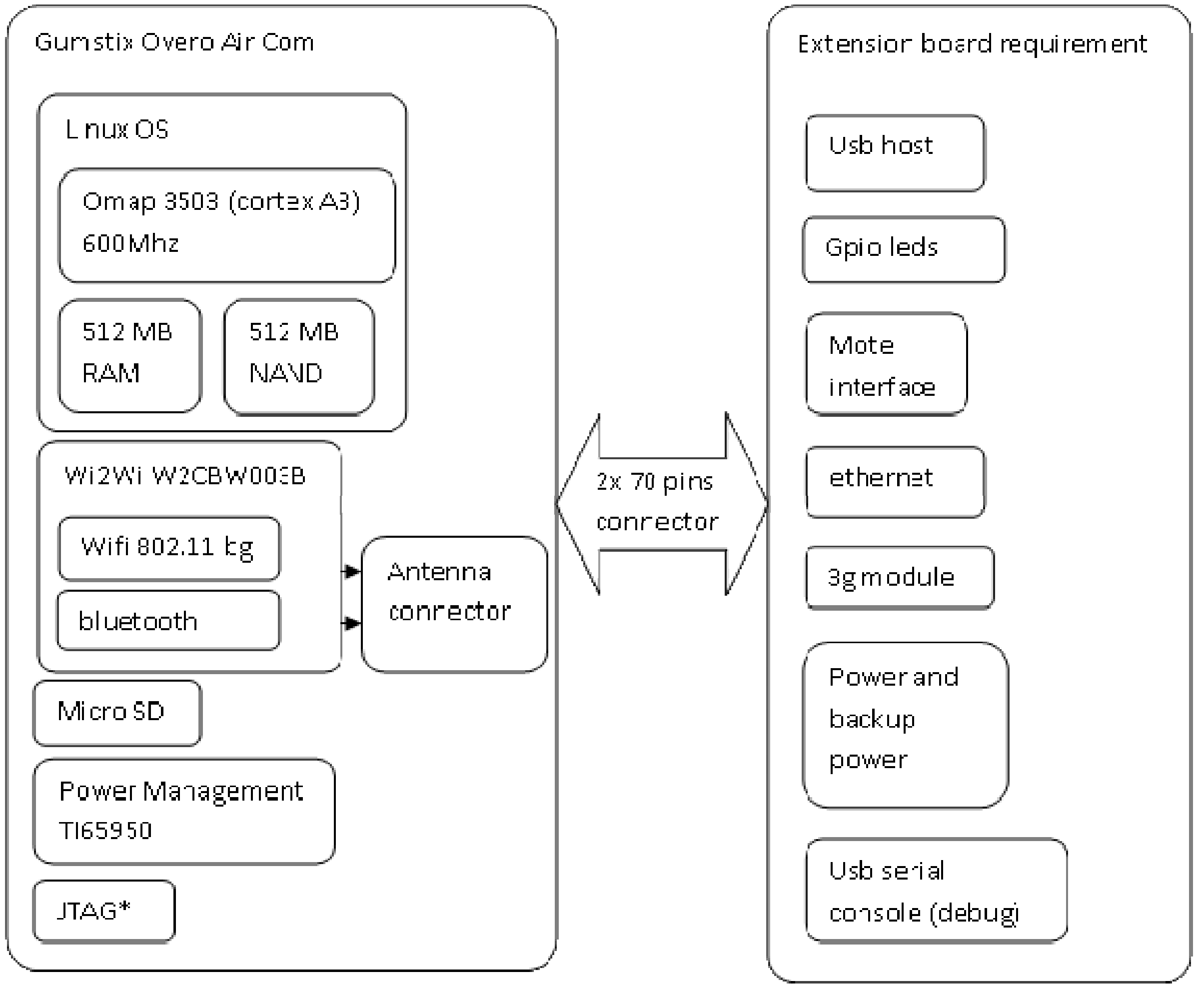


**Figure 12 GENESI gateway block diagram**

The GUMSTIX software provides a full working linux environment, based on OpenEmbedded [19], and the entire configuration files are available to rebuild it from scratch. This may only be needed to reconfigure the kernel; to change the heartbeat led configuration, for example.

The GUMSTIX officially only supports an OpenEmbedded distribution, but several resources show that many other OS can be installed such as Android [20], Windows CE [21], Ubuntu [22], etc.

## 3.2 Expansion board description

The hardware required for inclusion for the GENESI project, currently not provided by the GUMSTIX motherboard, and therefore required to be interfaced via a custom expansion board, include:

- 3G module
- Ethernet
- USB serial console

- USB host and OTG
- Power supply and backup
- Leds on some GPIO
- Mote connector

Note: the official extension board ("Tobi") provides a reference schematic for the Ethernet, USB serial console, the USB OTG and the USB [23].

# 4 Design and Implementation

## 4.1 Schematic design

The schematic design implements reference design layouts corresponding to the relevant documentation:

- The Ethernet and gumstix USB part, taken from the official GUMSTIX expansion documentation [23]
- The mote connection was made with the mote documentation and the mote's programmer documentation [24]
- The 3G part with the module datasheet [25]

These schematic parts do not share many common connections. They are all directly connected to the GUMSTIX. Some voltage shifters were necessary to adapt the voltage (mainly between the GUMSTIX and the mote).

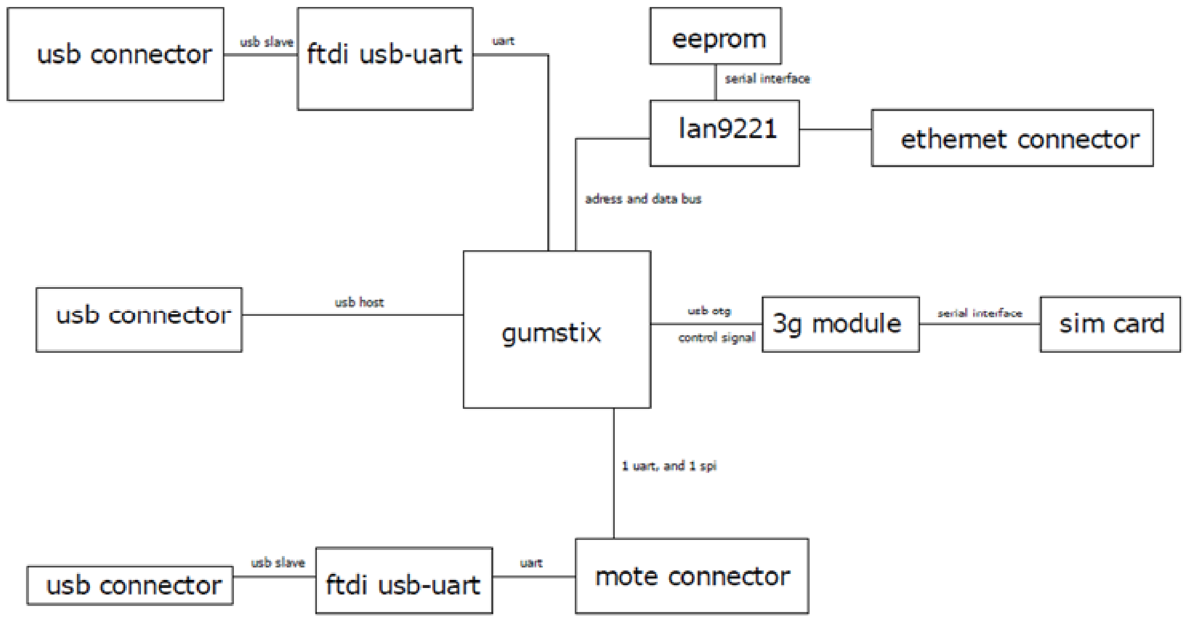


**Figure 13 Main Component Block Diagram**

## 4.2 Ethernet

Several connection options to the GUMSTIX are available to facilitate an Ethernet connection. These are tabulated below, considering the advantages and disadvantages of each.

**Table 3: Ethernet Connection Options**

| <u>Method</u> | pros | cons | Classic example |
|---|---|---|---|
| Use the processor's data/address bus | Assure access to the full 100Mbits/s.<br><br>Efficient use of the processor.<br><br>Commonly used in OS capable boards, which mean drivers easily accessible. | Numerous signals to route. | LAN9221 |
| Use a simple connection (UART or SPI) | Few traces to route | Slower transmission. | W5100 or lan9313 (SPI to Ethernet) |
| Use a USB connection | USB generic driver.<br><br>Few trace to route. | Limited number of USB connection on the processor.<br><br>Depending of the USB device connected, the transfer rate may vary. | Lan9514 (hub to 4 USB and 1 Ethernet) |

The price for these components is typically between 6€ and 8€ for the low power version.

The bus connection was choosen, because a bus connection is what the processor is meant to be using for Ethernet. It will allow more easy and efficient Ethernet data access.

The LAN9221 was specially chosen because it is the one used in the official GUMSTIX board. This will allow code compatibility, and easily establish its connection.

In addition, this chip has reasonable power consumption (380 mW at full speed traffic load). For comparison, a microchip ENC28J60 consume up to 180mA at 3.3v (594mW) when transmitting [26].

## 4.3 USB console

The GUMSTIX offers a console prompt as an UART connection. To use it as a USB connection from any computer, an UART to USB bridge is necessary. A FTDI FT232 family chip has been selected, as FTDI is a leader in those translators. It is therefore highly available, and supported.

Its connection has been made so it will get its power from the computer connected to it, not from the gateway. While no computer is connected, the chip will not draw power.

## 4.4 USB host

The USB host work is entirely done by the GUMSTIX. The hardware need is only:

- A USB power chip, to ensure that 5V (500mA max) is provided to the device.

- A 1.8V (GUMSTIX) to 3.3V (previous USB power chip) logic converter for the USB enable signal.

These components are very common. Once again, they have been chosen according to the one used on the GUMSTIX official expansion.

## 4.5 Power

The board requires a number of voltage levels:

- 5V for USB
- 3.3V for Ethernet (communication), GUMSTIX power supply (and therefore Bluetooth and WiFi) and mote supply
- 1.8V for Ethernet (core), UART to USB bridge
- 3.8V for the 3G module (does not tolerate 3.3V)

The main power input to the gateway has been chosen to be 5V, and to use different voltage regulator for the needed voltage.

The 3.3V regulator will be a TPS62111 and the 3.8V a TPS62110 of the same series, same characteristic chip, but with an adjustable output. This voltage regulator series has been chosen because of their following characteristic [27]:

- High-Efficiency Synchronous Step-Down Converter With up to 95% Efficiency.
- 20-µA Quiescent Current (Typical)

The 1.8V regulator is a mic5247 which powers only a few components. The GUMSTIX processor also works at 1.8V; but the GUMSTIX needs 3.3V for other components, and therefore already has its own 1.8V regulator.

As it is still unclear on how the board will be powered, a standard 5V jack connector has been placed as the main connector; and additional footprint on the input was added, in order to allow prototyping. Power devices such as the GENESI Smart Power Unit could be used to power the gateway via one of the connectors, or by directly soldering a pad to the input power signal.

## 4.6 Mote interface

The gateway will use a mote as an access point to the WSN. The mote attached to the gateway will therefore have dedicated software which will only echo the information it gets from the WSN to the gateway and send command to the WSN from gateway request. For this purpose, two communication lines will connect the mote to the gateway:

- SPI (SPI1 on the GUMSTIX, UCB1 SPI on the mote)
- UART (UART1 on the GUMSTIX, UCA1 UART on the mote)

As the mote’s dedicated software has not been investigated in the context of GENESI Gateway development, these two communications options are expected to provide flexibility with regard to developing solutions.

In addition to the gateway connection, a USB to UART bridge will provide a direct access to the UCA0 UART, and to the UCB0 SPI (via control line CTS, DTR, RTS). This will provide a debug interface, for dedicated mote software programming, as well as a programming interface (via a bootloader).

As the USB console, this chip will get its power from the USB host.

## 4.7 3G module

A comparison of some popular modules is presented in Table 4, below:

**Table 4: Comparison of Commercially Available 3G Modules**

| | Manufacturer: | Anydata | Anydata | Sierra Wireless | simcom | Telit | Criterion |
|---|---|---|---|---|---|---|---|
| | Model: | dtw-600w [28] | dtw-400w [29] | Q26 series [30] | sim5215[31] | uc864-e [25] | eu3-e [32] |
| Characteristics | ETSI Spec’. | | | AT command set ETSI (TS 27.005, TS 27.007) | | UCI (Universal Computer Interface, ETSI DE/PS 3 01-3) | Numerous citations. See datasheet: related documents section |
| | Max. data speed (dl/ul) | 3.6Mbps/ 384Kbps | 384Kbps / 384Kbps | 7.2 Mbps/ 2 Mbps | 384Kbps/ 384Kbps | 7.2Mbps/ 384kbps | 3.6 Mbps/ 384 kbps |
| | Connection | 90 pin connector | 90 pin connector | | 70 pin connector | 80 pin connector | 80 pin connector |
| | Price | | | 197 € | 54 € | 125 € | 106 € |
| | Idle current | | | 2.5mA | | <4.1mA (umts) | 25mA |
| | Sleep current | | | 2.5mA | | | <2mA (umts) |
| | Off current | | | | | 26uA | |
| | HSDPA max current | | | <800mA | | <730mA | |

The Telit UC864 series was selected due to high bandwidth, and popularity. A significant reason for this popularity is the full disclosure of the technical documentation [25] as explained by the HBPD project [32]. As one of the most common 3G modules, it will be simple to obtain, implement and debug.

It is connected to the GUMSTIX by a USB connection, providing several virtual com ports:

- UART serial data
- Modem USB serial port
- Aux USB serial port (serial trace)
- Nmea usb serial port (for version G, with GPS)

As an additional feature, it is simple to add GPS capability to the gateway. It simply required the selection of the UC864-G model rather than the UC864-E.

The Telit UC864 family module is compliant with the applicable 3GPP reference documentation (TS 25.101 Release 2004-03). The AT command set described are referred to the 3GPP TS 27.007. Access to the UC864 antenna is provided by the UFL connector on top of the module.

The 3G module requires only a small amount of current from the USB bus (25mA), as it has its own 3.8V voltage regulator. Therefore the USB OTG port of the GUMSTIX, that only provides 100mA, was originally chosen to be used for the connection. This has proven to be an ineffective approach, and will be rectified in future.

## 4.8 PCB Design

The board is 9x12 cm, and is routed on 2 layers. The antenna connectors are already provided by the GUMSTIX (Bluetooth and WiFi) and the 3G module. Therefore no analogue parts are on the board, and no separate analogue-ground plane is required.

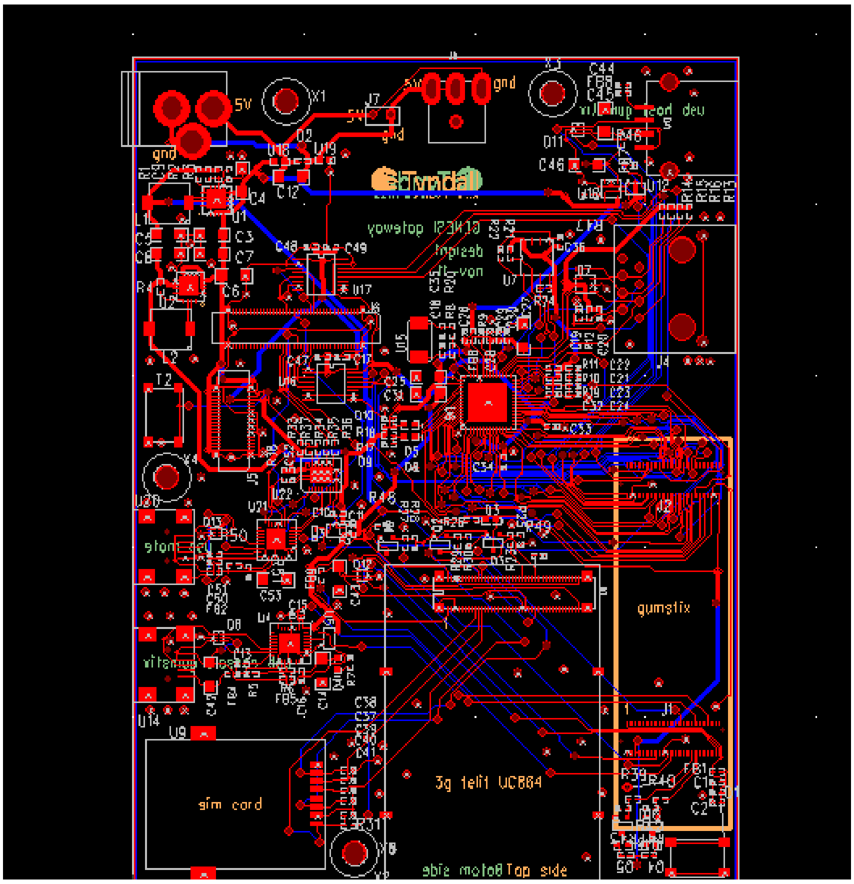


**Figure 14 PCB board design**

A bill of materials give a cost of 375€ for all the components, including the GUMSTIX (150€) and the 3G module (125€).

## 4.9 GENESI Gateway Prototype

The prototype developed is illustrated in Figure 15, below, with important components labelled accordingly.

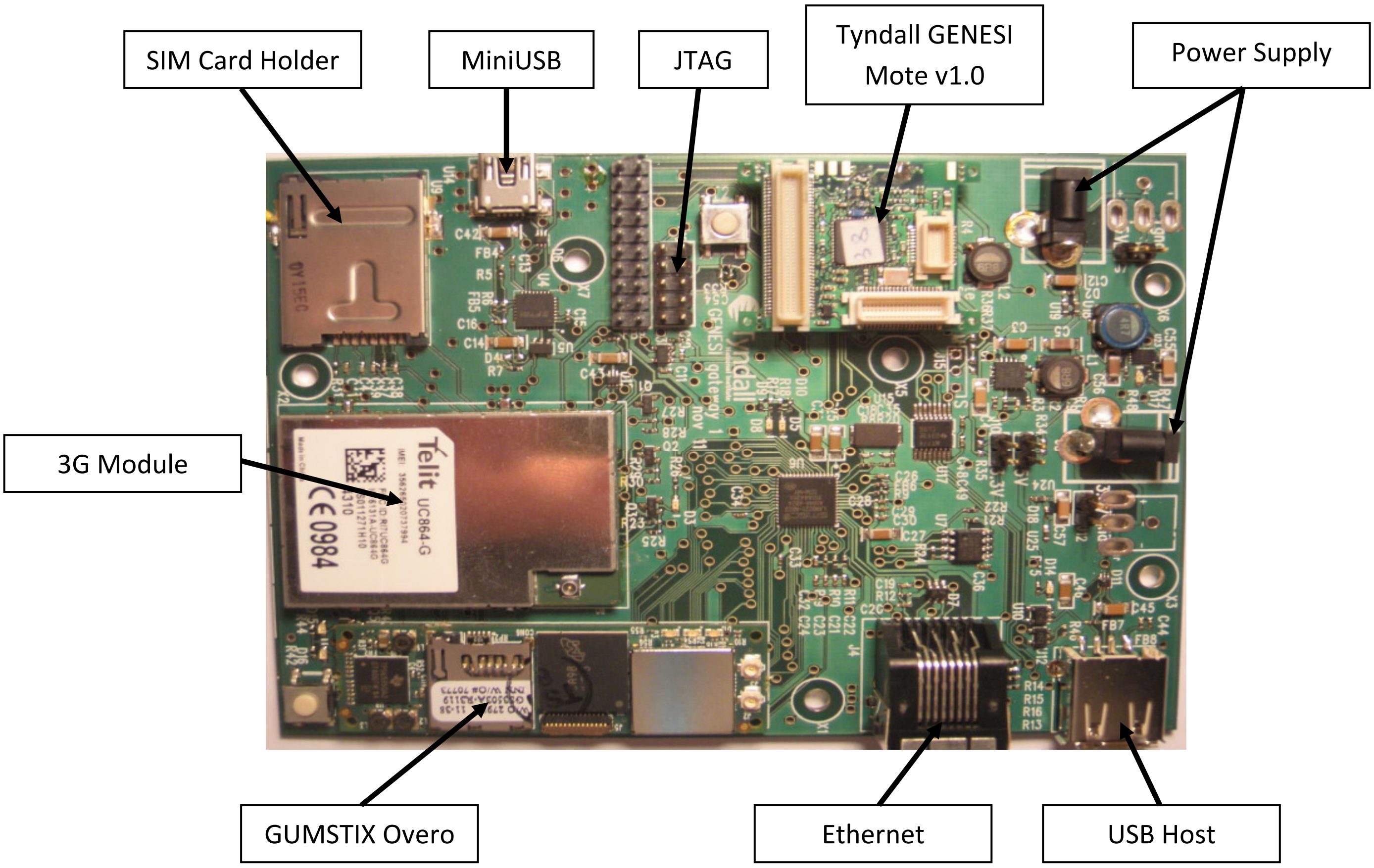


**Figure 15: GENESI Gateway Prototype**

# 5 Device Specification

## 5.1 Electrical Specifications

Given the various datasheet information and tests available, the power consumption of the gateway may be hard to estimate because due to each of the energy consuming components having various modes of operation. The power consumption of the principal components (extracted from the relevant datasheets) is presented in Table 5, below:

**Table 5: Gateway component power consumption**

| | | | **current mA** | **power mW** |
|---|---|---|---|---|
| **GUMSTIX** | Core | | 210 | |
| | WiFi | | 120 | |
| | Bluetooth | | 70 | |
| **Ethernet (device + system components) 100base mode** | Normal mode | Full traffic | | 522 |
| | Normal mode | Idle | | 510 |
| | Wake on lan | Idle | | 416 |
| | Low power energy detect | Energy detect power down | | 64 |
| | Low power energy detect | General power down | | 11 |
| **3G** | Idle | UMTS | <4.1 | |
| | Transmition max level | HSPDA | 730 | |
| | Transmition max level | GPRS | 790 | |
| | Transmition | Usual network cover | 150 | |
| | GPS | | 110 | |
| **Tyndall Mote** | CC2420 off | Idle | 0.7 | |
| | CC2420 off | Active | 4.5 | |
| | CC2420 on | TX | 19 | |
| | CC2420 on | RX | 18.5 | |

The prototype must be fully characterised in various modes of operation with respect to platform level energy specification. It must be optimised for implementation as a Gateway device for the GENESI system.

# 6 Test, Validation, Characterisation and Evaluation

The prototyped GENESI Gateway is to be assessed with respect to functionality and appropriateness for the application scenarios. This gives way to two initial evaluation mechanisms. The first pertains to ensuring that the required functionality has been achieved through the development of the prototype. These aspects are discussed in Section 6.1, below. The second regards the evaluation of real energy consumed by the prototype in operation. This is discsussed in Section 6.2, below.

## 6.1 Functionality Testing

In order to test the developed hardware, a testplan was constructed. The procedure can be summarised as follows: testing electrical correctness of the board, testing the implementation of the hardware components for correctness, and profiling the current consumption of the device in various modes of operation (Section 6.2, below).

Testing the power supply to the device is of primary importance. As the power supplies were unknown for the device prior to design, a number of options are present. From a voltage perspective, 3.3V (the default output supply of the GENESI Smart Power Unit) and 5V (standard mains type supply) were selected. The initial power supply tests were successful, as illustrated in Figures 16 and 17, respectively, below.

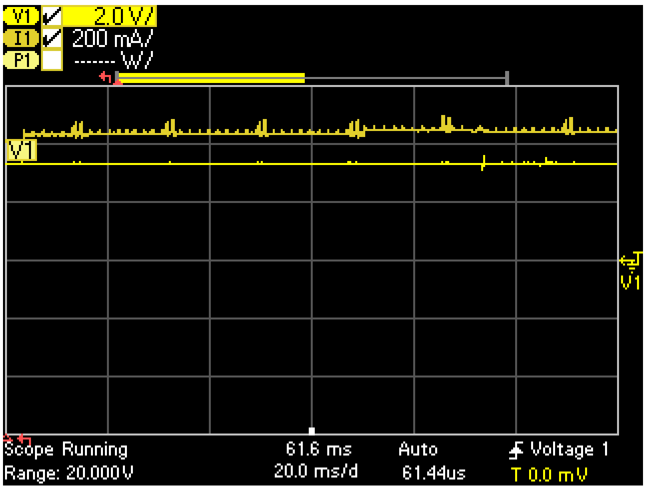


**Figure 16: The GENESI Gateway supplied at 3.3V (taken using Agilent Power Analyser)**

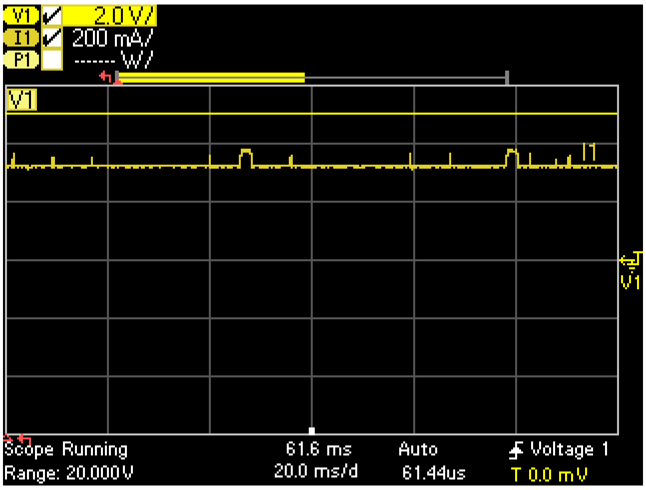


**Figure 17: The GENESI Gateway supplied with 5V (taken using Agilent Power Analyser)**

A functional console with correctly booting CPU (GUMSTIX) and operating system are required to ensure that the device is capable of functioning. The boot sequence is illustrated in Figures 18 and 19, below. It can be seen that the device boots correctly.


**Figure 18: GENESI Gateway Boot**

The Gateway device is designed to interface a GENESI Node to the Internet. A physical connection for a local base-station node was selected so as to avoid the problem of having to implement the embedded software for an IEEE 802.15.4 (2.4GHz) radio transceiver on the GUMSTIX motherboard. For convenience, a number of interfaces will be defined to allow commands to be passed between the motherboard of the Gateway and the GENESI Node attached (i.e. the sink node of the WSN). Communication between the "mote" and the motherboard is enabled through UART and SPI. Furthermore, it is possible to program the mote using the JTAG connection on the Gateway board. Figure 20, below, illustrates functional serial communication between the mote and the Gateway.

```
Deconfiguring network interfaces... done.
Stopping syslog-ng:.
Sending all processes the TERM signal...
Sending all processes the KILL signal...
Unmounting remote filesystems...
Stopping portmap daemon: portmap.
Deactivating swap...
Unmounting local filesystems...
musb-hdrc musb-hdrc: remove, state 1
usb usb1: USB disconnect, device number 1
musb-hdrc musb-hdrc: USB bus 1 deregistered
Power down.
�`U@ @   @�

Texas Instruments X-Loader 1.5.0 (Aug 29 2011 - 12:52:49)
OMAP3503-GP ES3.1
Board revision: 1
Reading boot sector
Loading u-boot.bin from mmc


U-Boot 2011.09 (Feb 20 2012 - 12:47:46)

OMAP3503-GP ES3.1, CPU-OPP2, L3-165MHz, Max CPU Clock 600 mHz
Gumstix Overo board + LPDDR/NAND
I2C:   ready
DRAM:  512 MiB
NAND:  512 MiB
MMC:   OMAP SD/MMC: 0
*** Warning - bad CRC, using default environment

In:    serial
Out:   serial
Err:   serial
Board revision: 1
Tranceiver detected on mmc2
No EEPROM on expansion board
Die ID #0b9000040000000000403d0a91002101c
Net:   smc911x-0
Hit any key to stop autoboot:  3
```

**Figure 19: GENESI Gateway Boot sequence**

```
Welcome to minicom 2.3

OPTIONS: I18n
Compiled on Feb 20 2012, 12:38:15.
Port /dev/ttyO0

               Press CTRL-A Z for help on special keys

  this is MOTE communication
  this is MOTE communication
```

**Figure 20: GENESI Gateway On-board Serial Communication between GENESI Node and Motherboard (ARM CPU)**

## 6.2 Initial Energy Analysis

Figure 21, below, illustrates the preliminary analysis of the power requirements of the GENESI Gateway. Presented is the current consumption profile for the device during the boot period through to active mode on the GUMSTIX, and driving a 3G connection. For the purposes of this experiment, a 3G USB dongle was used (connected via host USB to the GUMSTIX motherboard). It can be seen that the current consumption of this device is extremely high in comparison to that of a GENESI WSN Node. Figure 22, below, presents the initial setup of the mobile connection between the GENESI Gateway and a remote entity (data, SMS, voice, etc.) using AT commands.

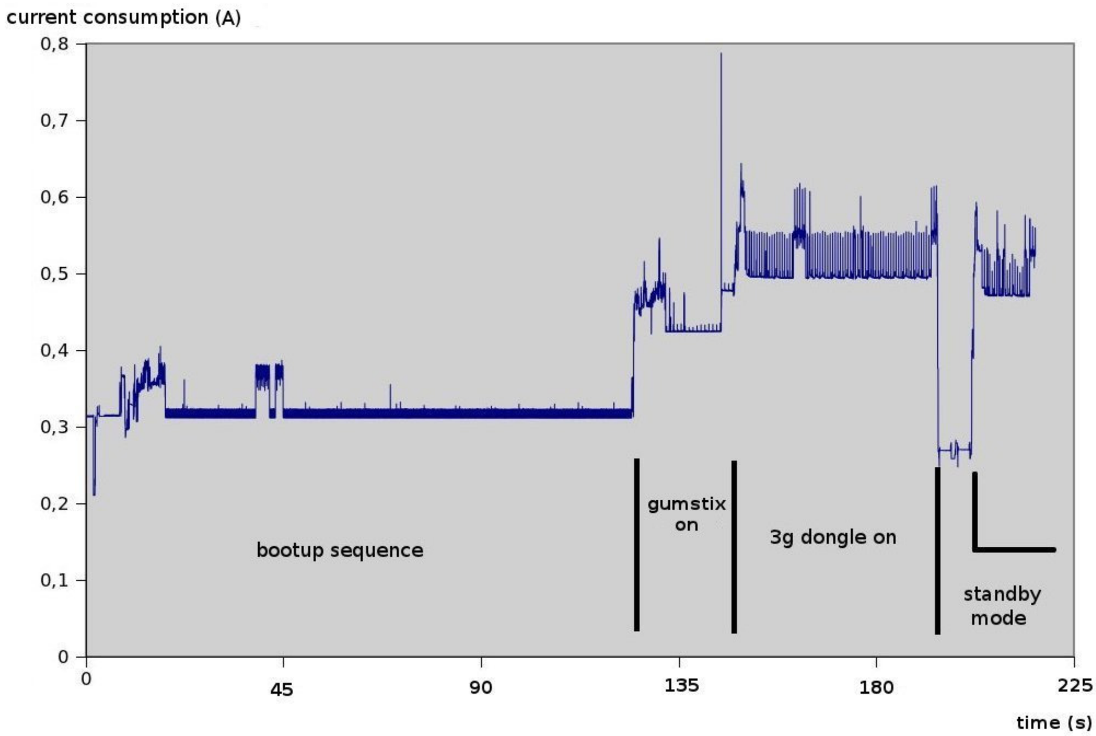


**Figure 21: Preliminary Power Evaluation of the GENESI Gateway (various modes of operation)**

As discussed in Section 4.7, the implementation of the OTG USB connection between the GUMSTIX and the 3G module was ineffective. For this reason, 3G connectivity was achieved for testing by using a USB dongle. This dongle was governed by a similar set of AT commands to those that would normally be used for the 3G module selected for the GENESI Gateway [35]. Figure 22, below, illustrates the command line setup of the device using the AT commands.

```
option 2-2:1.1: GSM modem (1-port) converter detected
usb 2-2: GSM modem (1-port) converter now attached to ttyUSB1
option 2-2:1.2: GSM modem (1-port) converter detected
usb 2-2: GSM modem (1-port) converter now attached to ttyUSB2
option 2-2:1.3: GSM modem (1-port) converter detected
usb 2-2: GSM modem (1-port) converter now attached to ttyUSB3
usbcore: registered new interface driver option
option: v0.7.2:USB Driver for GSM modems
scsi 6:0:0:0: CD-ROM            HUAWEI   Mass Storage     2.31 PQ: 0 ANSI: 2
sr0: scsi-1 drive
sr 6:0:0:0: Attached scsi generic sg0 type 5
scsi 7:0:0:0: Direct-Access     HUAWEI   SD Storage       2.31 PQ: 0 ANSI: 2
sd 7:0:0:0: Attached scsi generic sg1 type 0
sd 7:0:0:0: [sda] Attached SCSI removable disk

root@overo:~# cat /dev/ttyUSB0 &
root@overo:~# echo -en "ATE0\r" > /dev/ttyUSB0
root@overo:~# ATE0


OK



OK


root@overo:~# echo -en "AT+CPIN=7394\r" > /dev/ttyUSB0
root@overo:~#

OK
```

**Figure 22: AT Commands to Configure an Outgoing Mobile Connection from the GENESI Gateway**

# 7 Conclusion

This deliverable presented the research methodology behind the selection and eventual development of a Gateway device suitable for bridging the GENESI WSN to the end-users back-end systems (and eventually, *vice versa* for bi-directional communicability). Requirements for the device were extracted from relevant project deliverables (WP2), and integration considerations (WP2/WP6) relating to the prospective deployment of a network of GENESI Nodes in the field.

The device was prototyped, selecting the most suitable and available technologies to create the required system, having thoroughly evaluated the current state of the art and existing COTS solutions. The prototype created is currently undergoing further assessment and characterisation. Early testing suggests that the functional requirements of the device can be satisfactorily met.

It will be of significant importance to manage the hardware effectively to thereby ensure long-term operation; optimising for low-power modes, where possible, to maintain sustainable and effective integration of widely distributed networks of GENESI sensors and remote stakeholders. This is particularly relevant to network managers who may wish to remotely interact with the deployed nodes, in addition to the performance of regular data collection duties from the GENESI WSN.

Novel protocols for Gateway-type device management must be developed. The “always-on” concept of currently available and emerging mobile data access technologies is to-date, too power-intensive to match the lifetime of the underlying wireless sensor networks. Novel protocols that effectively manage access (via availability windows, for example) could be used to enhance lifetime of the Gateway devices, with minimal trade-offs.

# 8 Ongoing and Future Work

There are a number of refinements to the first prototype to be made in order to complete the design to fully meet the requirements of the GENESI Gateway. These are summarised as follows:

- Reimplementation of the Ethernet connection
- Switch 3G module USB connection to host rather than “on-the-go”

Additionally, a number of other minor wiring flaws need to be fixed in the design. Such errors are commonplace in the design of complex devices. The goal will be to ensure that every flaw is detected and fixed prior to building and testing a second revision.

It will be necessary to implement the data connection between the Gateway and the backend systems of the endusers. This will require extracting the WSN data from the sink node attached to the Gateway and formatting it correctly for upward transmission to the server. The format is given in deliverable D2.1. The protocol for information exchange must be agreed. A number of protocols are supported by the gateway, thereby providing flexibility to the end user.

Finally, it will be necessary to develop operational policies for the device that complement the requirements of the project and/or the intended application; ensuring that the lowest possible power is consumed whilst maintaing the required levels of functionality.

# 9 Bibliography

[1] Ye Dun-fan, Min Liang-liang, Wang Wei (2009) 'Design and Implementation of Wireless Sensor Network Gateway Based on Environmental Monitoring', *International Conference on Environmental Science and Information Application Technology*, 2009.

[2] Hong-jiang He, Zhu-qiang Yue, Xiao-jie Wang (2009)'Design and Realization of Wireless Sensor Network Gateway Based on ZigBee and GPRS', *Second International Conference on Information and Computing Science*, 2009.

[3] Raluca Musaloiu-E, Razvan Musaloiu-E, Andreas Terzis, *Gateway Design for Data Gathering Sensor Networks, 5th Annual IEEE Communications Society Conference on Sensor*, Mesh *and Ad Hoc Communications and Networks,* 2008.

[4] Libelium Comunicaciones Distribuidas S.L. (2012) "Meshlium description."[Online]. Available: http://www.libelium.com/products/meshlium [Accessed: 23/03/12].

[5] Sensinode Ltd. (2008) "Building the Embedded Web." [Online]. Available: http://www.sensinode.com/EN/products/software.html [Accessed: 27/03/12].

[6] Monnit Corp. (2012) "MonnitLink™ Wireless Sensor Network Gateways." [Online]. Available: http://www.monnit.com/products/wireless-gateways.php [Accessed: 27/03/12].

[7] National Instruments Corporation (2012) "NI 9792 Programmable WSN Gateway." [Online]. Available: http://sine.ni.com/nips/cds/view/p/lang/en/nid/208440 [Accessed: 27/03/12].

[8] OpenWRT (2012) "About this project." [Online]. Available: http://wiki.openwrt.org/ [Accessed: 27/03/12].

[9] Gumstix Inc. (2011) "Overo Air COM Product Overview." [Online]. Available: https://www.gumstix.com/store/product_info.php?products_id=226 [Accessed: 27/03/12].

[10] ISEE (www.igep.es) (2012) "IGEPv2 board." [Online]. Available: http://www.igep-platform.com/index.php?option=com_content&view=article&id=46&Itemid=55 [Accessed: 27/03/12].

[11] Atmel Corporation (2012) "NGW100 mkII Network Gateway Kit." [Online]. Available: http://www.atmel.com/dyn/products/tools_card.asp?tool_id=17351 [Accessed: 27/03/12].

[12] Pandaboard.org (2012) "PandaBoard Platform Specifications" [Online]. Available: http://pandaboard.org/content/platform [Accessed: 27/03/12].

[13] Embedded Artists AB (2012) "LCP1769 LCPxpresso Board." [Online]. Available: http://www.embeddedartists.com/products/lpcxpresso/lpc1769_xpr.php [Accessed: 27/03/12].

[14] Armadeus systems (2008) "APF27." [Online]. Available: http://www.armadeus.com/english/products-processor_boards-apf27.html [Accessed: 27/03/12].

[15] Open Circuits (2011) "Linuxstamp." [Online]. Available: http://www.opencircuits.com/Linuxstamp [Accessed: 27/03/12].

[16] FriendlyARM (2012) "Mini6410 S3C6410 ARM11 Board." [Online]. Available: http://www.friendlyarm.net/products/mini6410 [Accessed: 27/03/12].

[17] Chumby Industries (2011) "Main Page: Welcome to the Chumby Wiki." [Online]. Available: http://wiki.chumby.com/index.php/Main_Page [Accessed: 27/03/12].

[18] ARM Ltd. (2012) “Processors.” [Online]. Available: http://www.arm.com/products/processors/index.php [Accessed: 27/03/12].

[19] Gumstix inc. “Pre-Built Images.” Internet: http://gumstix.org/software-development/pre-built-images.html [Accessed: 31/11/11].

[20] Gumstix User Wiki (2011) “Android Gingerbread.” [Online]. Available: http://wiki.gumstix.org/index.php?title=Android_Gingerbread [Accessed: 27/03/12].

[21] Gumstix User Wiki (2011) “Windows CE solution.” [Online]. Available: http://wiki.gumstix.org/index.php?title=Windows_CE_solution [Accessed: 27/03/12].

[22] Gumstix User Wiki (2012) “Installing Ubuntu 10.04 on Gumstix Overo.” [Online]. Available: http://wiki.gumstix.org/index.php?title=Installing_Ubuntu_10.04_on_Gumstix_Overo [Accessed: 27/03/12].

[23] Gumstix inc. (2011) “Boards.” [Online]. Available: http://pubs.gumstix.com/boards/ [Accessed: 27/03/12].

[24] GENESI: Deliverable D3.1.

[25] Telit (2011) “UC864-G.” [Online]. Available: http://www.telit.com/en/products/umts-hsdpa.php?p_id=14&p_ac=show&p=14 [Accessed: 27/03/12].

[26] Microchip. ENC28J60 datasheet. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/39662c.pdf [Accessed: 27/03/12].

[27] Texas Instruments. TPS6211x datasheet. [Online]. Available: http://www.ti.com/lit/ds/symlink/tps62110.pdf [Accessed: 27/03/12].

[28] AnyDATA Corporation. TDW-600w datasheet. [Online]. Available: http://www.anydata.com/pdf/dtw-600w.pdf [Accessed: 27/03/12].

[29] AnyDATA Corporation (2009) TDW-400w datasheet. [Online]. Available: http://www.anydata.com/pdf/dtw-400w.pdf [Accessed: 27/03/12].

[30] Sierra Wireless (2012) “AirPrime Q26 Extreme HSPA module.” [Online]. Available: http://www.sierrawireless.com/productsandservices/AirPrime/Wireless_Modules/Smart/Connectorized/Q26_Extreme.aspx [Accessed: 27/03/12].

[31] SIMCom Wireless Solutions Co., Ltd. (2008) “SIM5215.” [Online]. Available: http://wm.sim.com/Sim/wm/html/en/WMS/EDGE%20Module/ProductDetail.aspx?id=795 [Accessed: 27/03/12].

[32] Cinterion Wireless Modules GmbH (2012) “EU3 Overview.” [Online]. Available: http://www.cinterion.com/products/m2m-advanced/broadband/eu3.html [Accessed: 27/03/12].

[33] HBPD (Home-brew Phone and Desktop PC). “TelitUc864g.” [Online]. Available: http://code.google.com/p/hbpd/wiki/TelitUc864g [Accessed: 27/03/12].

[34] AnandTech, Inc. (2011) “TI Reveals OMAP 5: The First ARM Cortex A15 SoC.” [Online]. Available: http://www.anandtech.com/show/4153/ti-reveals-omap-5-the-first-arm-cortex-a15-soc [Accessed: 27/03/12].

[35] Telit Communications S.p.A (2011) ‘uc864-E/G/WD/E-Dual AT Commands Reference Guide’. Rev 8 – 2011-07-19. [Online]. Available: http://www.telit.com/en/products/umts-hsdpa.php?p_id=14&p_ac=show&p=14 (Downloads/User Guides/ Telit_UC864_AT_Reference_Guide_r8) [Accessed: 11/04/12].