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SEVENTH FRAMEWORK PROGRAMME

ZEPHYR project – Deliverable D2.6

Technical specification for the communication and control system

Funding scheme: **Collaborative Project**

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ProjectCoordinator: **TUSCIA UNIVERSITY**

Proposal full title: **Zero-impact innovative technology in forest plant production**

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Author: **ADVANTICSYS**

Summary: **This document provides the description of the communication system infrastructure to be developed to collect the information from the stick-sensors and send it to a central point for further processing. Communication infrastructure is based in IEEE 802.15.4 technology**

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1. Scope of the document

1.1 Purpose

Based on the input delivered by D2.3 (Design of the new sensors), this document will describe the communication system to be integrated as part of the new sensors to provide the capability to transfer the information collected to a central point wirelessly.

1.2 Overview of the document

Zephyr project aims to introduce an innovative technology to pre-cultivate forest stock to be used for forestation regeneration materials by means of a zero-impact and cost-friendly growth chamber unit. As part of this work, the project will develop a sensor-stick for detection and measurement of several parameters. This sensor stick will integrate a wireless communication system based on 802.15.4 technology to relay the information obtained from the different built-in sensors to a central unit for further processing of data.

2. Sensor-stick concept

The development of the sensor-stick will be achieved in different phases;During the initial approach the three main modules of the sensor-stick (Communication module, Measurement unit and Electrodes) will be designed, manufactured and tested separately (Fig. 8). After ensuring that the designs satisfy the requirements (D2.2 And D2.3) the integration phase will start.

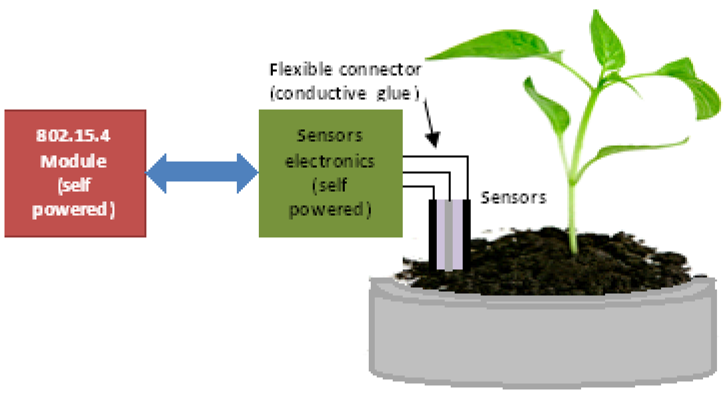


Figure 8. Sensor-stick concept functional blocks (not at scale)

At this stage, the consortium is still working on testing and design validation of the separate modules but some preliminary testing for modules integration has also been carried out, on one side between the Communication module (CM) and the Measurement Unit (MU) and on the other side between the MU and the electrodes (Fig. 9a).

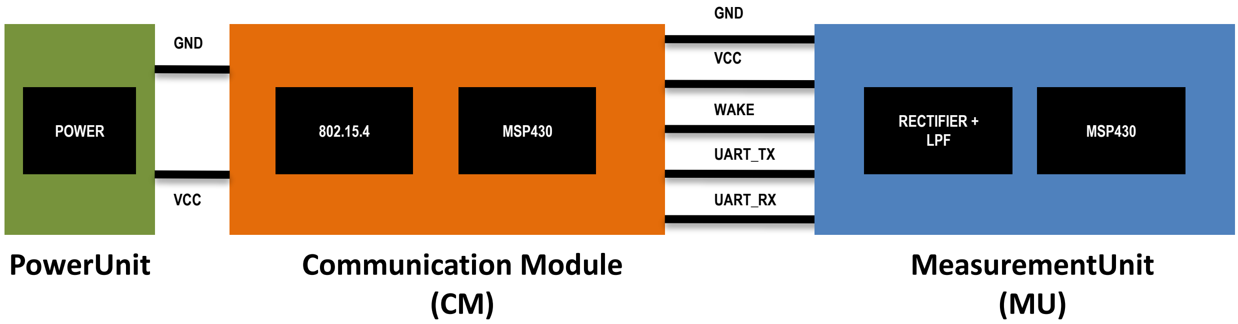


Figure 9a. CM and MU integration

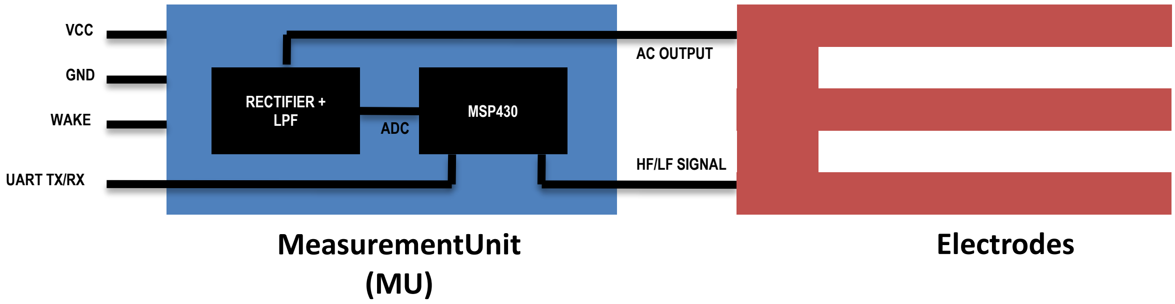


Figure 9. MU and electrodes integration

Ideally, the result of the 3 modules integration should provide a single device with sensing, wireless communication capabilities and a small factor size, allowing this new sensor device to be installed inside the mini-plug tray (small container for plants) and provide readings of the parameters of interest gathered by the electrodes.

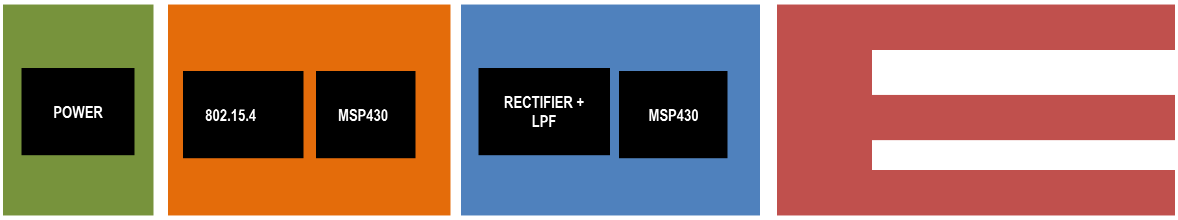


Figure 9. Sensor stick

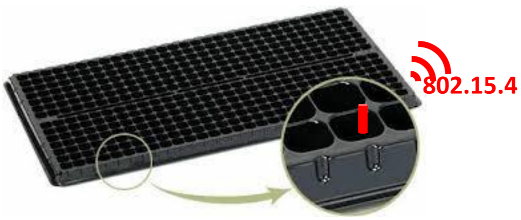


Figure 10. mini-plug tray with sensor-stick

3. Communication infrastructure

3.1 Overview

Technical partners will design and provide a wireless communication infrastructure to communicate with the deployed sensor-sticks network. For a distributed environment such as the one used in the project scenario (growth chamber) with many sensing points over a reduced and constrained area the use of wireless sensor networks to retrieve the information presents many benefits. Indeed, the ease of installation, the network auto configuration and the small form factor are key elements for this application

The whole communication system will be designed to ensure that all the data sent from the networkof sensor-sticks deployed in the growth chamber (each one assigned to a unique mini-plug tray) will be gathered by a gateway that will be integrated as part of the growth chamber control system, allowing a user to access the sensor-sticks data.

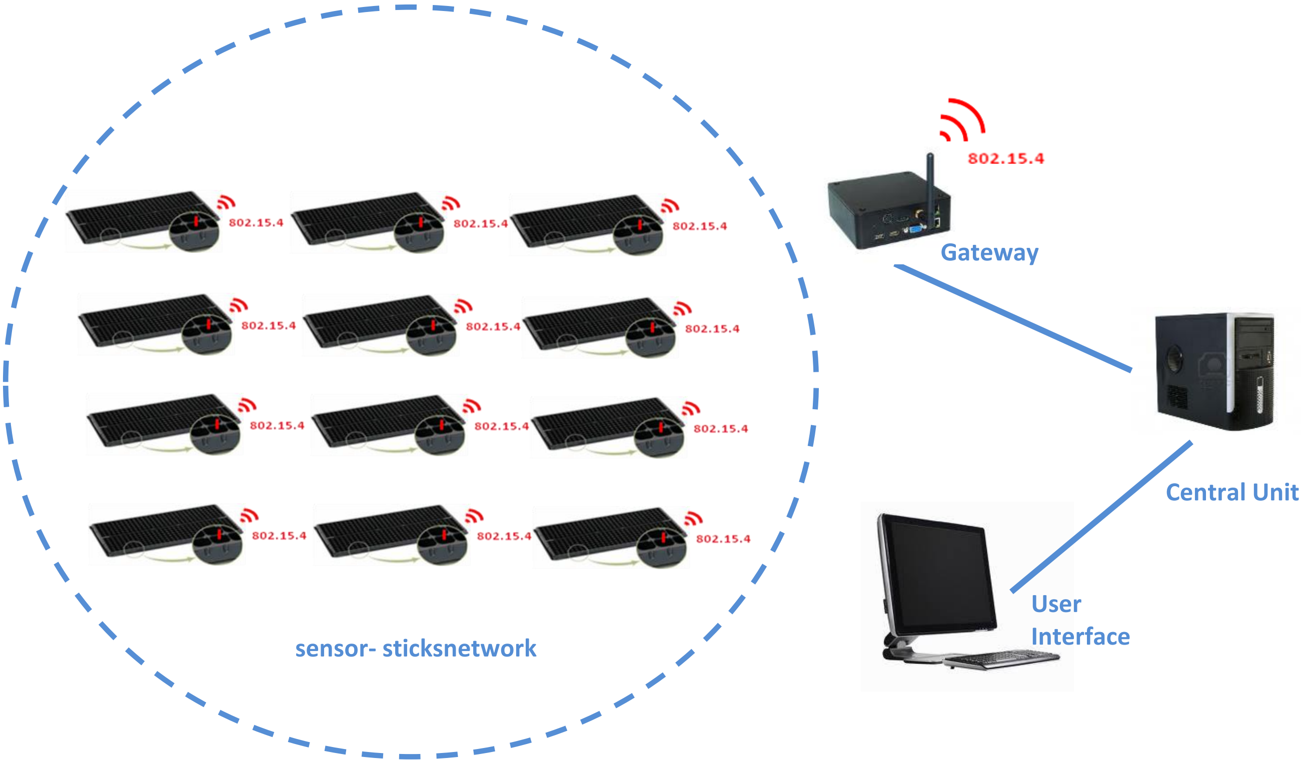


Figure 11.802.15.4 Communication Infrastructure

The sensor-stick device will be programmed to obtain readings from the electrodes periodically, the acquisition time will be set according to the growth protocols defined, data from sensors will be transmitted to the 802.15.4 gateway where some intermediate data processing will be done, (pre-processing, local backup, time stamping), finally those data will be made available to the central unit. The way that these data can be used by the user (growth chamber operator) will be defined in WP4, ensuring the needs identified from requirements and growth protocols definition

3.2 Communication Module (IEEE 802.15.4)

The communication platform chosen is based on IEEE 802.15.4 standard, operating in the 2.4GHz band. This ensures that in a single deployment all of the different devices, no matter the magnitude that is being measured, can communicate with each other, effectively forming cooperating networks of smart objects, where the only difference is the magnitude that is being measured.

The platform is based on the TelosB open hardware design, which makes it compatible with a wide range of embedded operating systems, the most known of which are probably TinyOS® and ContikiOS®. The IEEE 802.15.4 standard only limits the lower layers of the implemented protocol, and the use of an embedded operating system allows the researcher or integrator to build upon them to find the best solution for his or her application.

Additionally, it also ensures a wide community to support your development, which reduces considerably the development process.

Figure 1 ADV TelosB-based node

3.2.1 Microcontroller and radio

At the heart of wireless modules, is the Texas Instruments® MSP430® family of microcontrollers. This family of microcontrollers uses ultra-low power RISC mixed-signal microprocessors, and is especially adequate for a wide range of low power and portable applications. IEEE 802.15.4 compatibility is granted by the CC2420® RF transceiver, designed for low-power and low-voltage wireless applications. The CC2420 includes a digital direct sequence spread spectrum baseband modem providing a spreading gain of 9 dB and an effective data rate of 250 kbps.

Figure 2.MSP430 Microcontroller

This well-known hardware makes it easy to integrate new sensors. Whenever using embedded operating systems the integration process involves both hardware and software development, in the form of driver implementation which is why in the scope of this project it is envisioned that only reduced modifications of the same hardware design will be done, in orderto keep development times low. By keeping the same hardware core we ensure that.

3.2.2 Interfaces

The Texas Instruments® MSP430® microcontroller has many available interface ports and buses that enable the communication with both analogue and digital sensors and devices. The most relevant of these interfaces are:

- 8 ADC ports to capture analogue signals.
- SPI and I2C buses.
- 2 UART ports.

For the first iteration of the Zephyr project, the initial approach is to interface the sensor electronics with the wireless module using the UART ports. The sensor probe itself has a digital serial interface, which means that simply by sending serial commands via the UART it is possible to retrieve information from the sensors.

3.2.3 IEEE 802.15.4 standard and communication protocol

The IEEE 802.15.4 wireless communication standard was developed to create as a low data rate solution with multi-month to multi-year battery life and very low complexity. It operates in an unlicensed, international frequency band, called ISM as it is reserved for industrial, scientific and medical applications. Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation.

3.2.3.1 IEEE 802.15.4 main features

- Data rates of 250 kbps, 40 kbps, and 20 kbps.
- addressing modes: 16-bit short and 64-bit IEEE addressing.
- Support for critical latency devices, such as joysticks.
- CSMA-CA channel access.
- Automatic network establishment by the coordinator.
- Fully hand-shaked protocol for transfer reliability.
- Power management to ensure low power consumption.
- 16 channels in the 2.4GHz ISM band, 10 channels in the 915MHz and one channel in the 868MHz band.

The 802.15.4 standard only defines the two lower layers of the OSI model: the Medium Access Control layer (MAC) and the Physical (PHY) layer:

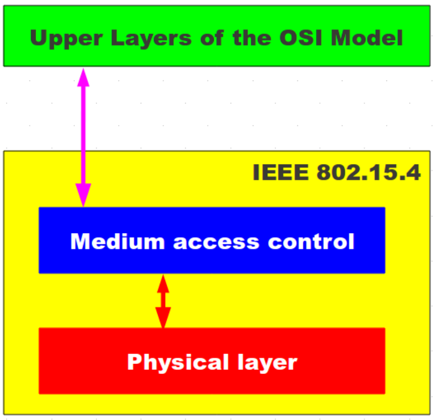


Figure 3.IEEE 802.15.4 OSI layers

The Physical layer is the initial layer in the OSI reference model used worldwide. The physical layer (PHY) ultimately provides the data transmission service, as well as the interface to the physical layer management entity, which offers access to every layer management function and maintains a database of information on related personal area networks. Thus, the PHY manages the physical RF transceiver and performs channel selection and energy and signal management functions. It operates on one of three possible unlicensed frequency bands:

- 868.0-868.6 MHz: Europe, allows one communication channel (2003), extended to three (2006)
- 902-928 MHz: North America, up to ten channels (2003), extended to thirty (2006)
- 2400-2483.5 MHz: worldwide use, up to sixteen channels (2003, 2006)

ADV devices operate in the 2.4GHz band. Of the sixteen channels, channels 15,16,21 and 22 are not shared with the European 802.11b Wi-Fi standard, so one of those will be chosen to avoid any possible interference.

The medium access control (MAC) enables the transmission of MAC frames through the use of the physical channel. Besides the data service, it offers a management interface and itself manages access to the physical channel and network beaconing. It also controls frame validation, guarantees time slots and handles node associations. Finally, it offers hook points for secure services.

Additionally layers can be added to the communication while maintaining compatibility with the standard. Such is the case whenever using the different network protocols inside the TinyOS® and ContikiOS® embedded operating systems distributions. Other commercial solutions, such as proprietary ZigBee® protocol based devices make use of the transport, network and application layers to add several functionalities.

3.2.3.2 Protocol description: Frame structure

The main 802.15.4 frames are transmitted via the RF chip, in this case the CC2420®. Essentially, both an 802.15.4 header and footer are transmitted, and the bytes in between depend on the protocol being used.
For the Zephyr project, the idea is to make use of the TinyOS® operating system together with ADV devices. In the case of TinyOS® the main packet structure is as follows:

```
+-------------------+---------+-----------------------------+--------------+
| 802.15.4 Header   | AM type |            data             | 802.15.4 CRC |
+-------------------+---------+-----------------------------+--------------+
```

Figure 4TinyOS 802.15.4 frame format

The “data” field includes both the protocol and payload frames that will be used. TinyOS® gives freedom to the developer in order to create both single and multi-hop protocols, so the main types (tree, star, mesh and cluster tree) are supported.

For the first prototypes in Zephyr, the most important issue is the interconnection with the sensor-sticks so most probably a basic point to point protocol will be used at the beginning, and this will evolve into a full-fledged multi-hop protocol later on.

3.2.4 Communication module prototype

The design of the initial prototype includes the components described above, microcontroller, radio, interfaces (ADCs, UARTs) but also take into account the antenna and the power unit, as one key objective of the design is to obtain a device with a small form factor, a ceramic antenna has been considered and a button cell battery conceived as main power unit.With regard to the power unit, it is still early to confirm if the button cell option can satisfy the power consumption needs, growth protocols requirements and power consumption from the measurement unit and the electrodes in operating mode need to be tested, so later modification for the power unit may be possible

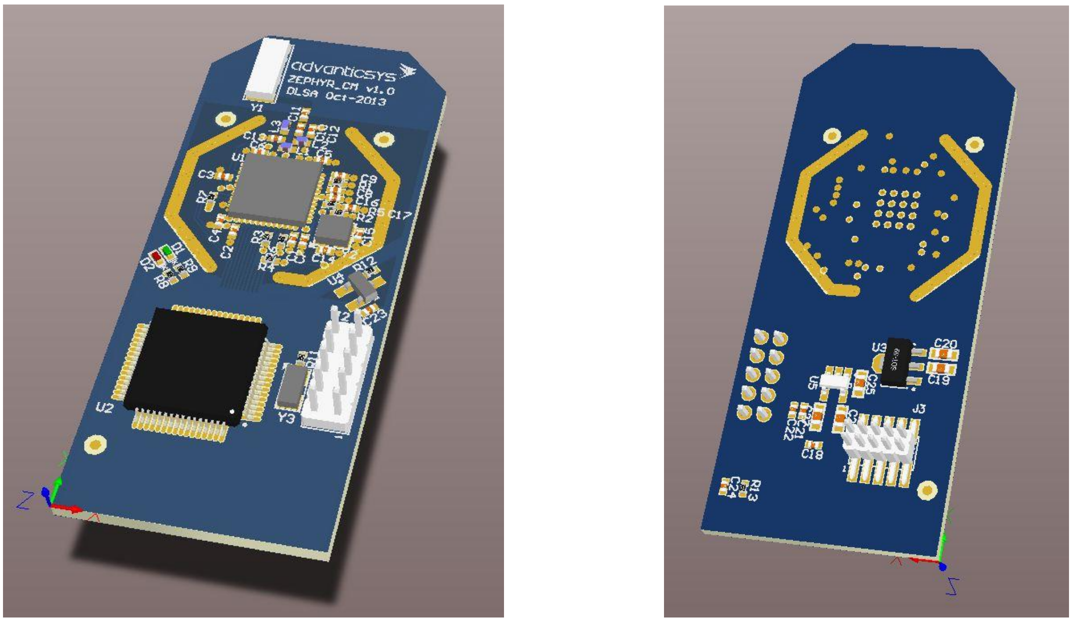


Figure 5. Communication module prototype layout

3.3 SG1000 Gateway

3.3.1 Technicalspecifications

The SG1000 is an 802.15.4-Ethernet gateway device that acts as data concentrator for wireless sensor networks. The device is capable of handling data from a large number of wireless sensor nodes and it's only constrained by its internal memory capacity. Furthermore, the embedded database allows the local storage of this data, enabling the access to these records by external applications thanks to the configurable Ethernet interface.

Figure 5.SG1000

The SG1000 architecture is based around an Intel® Atom®Core. The 2GB of DDR3 RAM and the 160GB of HDD allow very powerful applications, and the small form factor is great for

3.3.1 Network interfaces

Item	Specification	Description
Processor Model	Texas Instruments® MSP430F1611	Texas Instruments® MSP430 family
Memory	48KB 10KB 1MB	Program flash Data RAM External Flash (ST® M25P80)
RF Chip	Texas Instruments® CC2420	IEEE 802.15.4 2.4GHz Wireless Module
Frequency Band	2.4GHz ~ 2.485GHz	IEEE 802.15.4 compliant
Sensitivity	-95dBm typ	Receive Sensitivity
Transfer Rate	250Kbps	IEEE 802.15.4 compliant
RF Power	-25dBm ~ 0dBm	Software Configurable
Range	~40m(outdoor), 15~20m(indoor)	Dongle orientation dependant
Current Draw	RX: 18.8mA TX: 17.4mA Sleep mode: 1uA	Lower RF Power Modes reduce consumption
RF Power Supply	2.1V ~ 3.6V	CC2420 Input Power
Antenna	Ceramic antenna	

The main role of the SG100 is to act as sink node for the wireless sensor network. In the case of Zephyr the SG1000 802.15.4 interface will probably be improved to add an external antenna instead of the ceramic one, to increase overall range.

3.3.1.2 External interfaces

Item	Specification	Description
RS232	1 x Serial port	Serial communication through DB9 connector
USB	4 x USB ports	Serial communication through USB connector
Ethernet	1 x Ethernet port	IP communication through RJ45 connector (LAN 10/100/1000Mbit compatible).

Access to the SG1000 will be done via the Ethernet port using IP communication.

3.3.1.3 Network management tool

The SG1000 has a web interface incorporated, both for configuration of the SG1000 itself and also of the deployed sensor network. A modification of the current interface will have to be done in order to better meet the project's needs.The current configuration is based on PHP an runs on the Apache server installed in the device.

3.3.1.4 Database

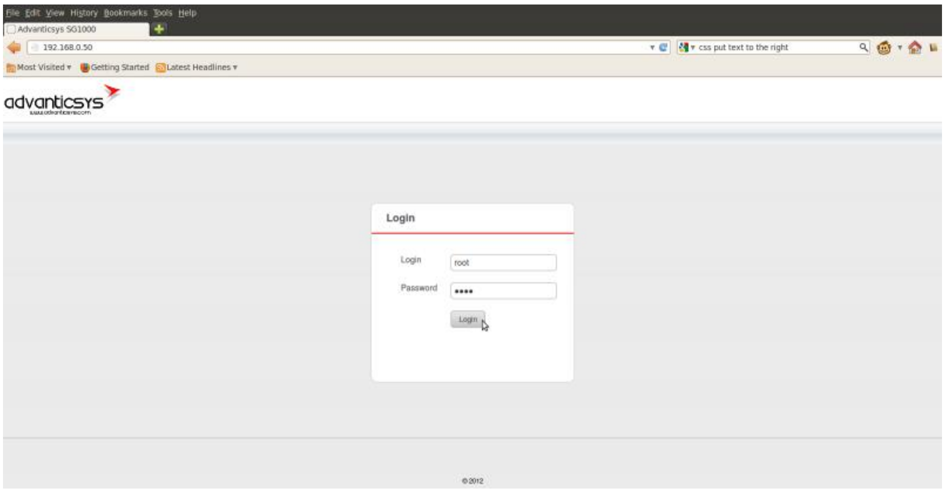
The SG1000 runs a full Linux server distribution. Right now, a MySQL database server is installed. The basic database table that is shipped with the device only allows storage of the raw packets received by the sink node. It seems plausible that a more complex table design will have to be added for this project.

4. SG1000 User Interface

4.1 Accessing the SG1000 web interface

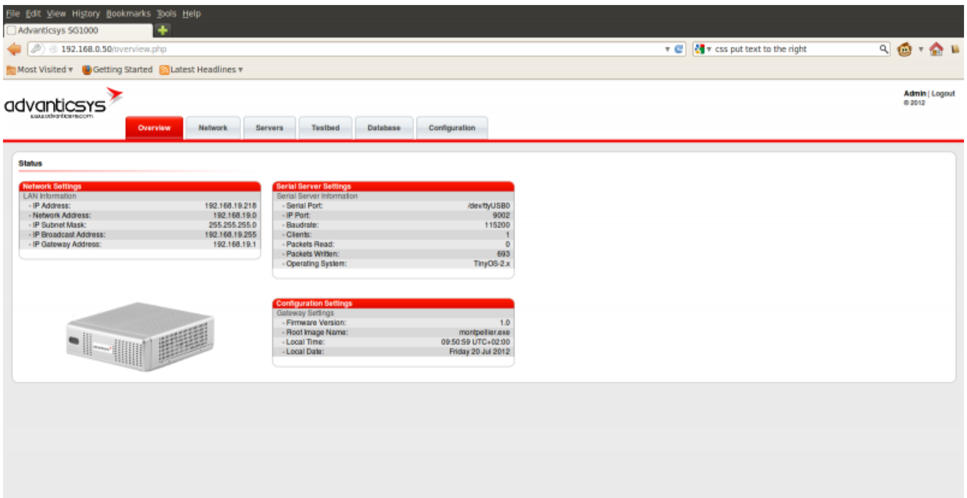
Accessing the **SG1000** web interface is as simple as opening your favourite browser and introducing the gateway's IP address in the address bar. By default, the IP address of the device is **192.168.0.50**. Once we navigate to this address, a login screen appears. This security access prevents unwanted access to your system.

To login in to the SG1000, introduce your username and password. The default access to the SG1000 is: **Username:***root***Password:***1234*



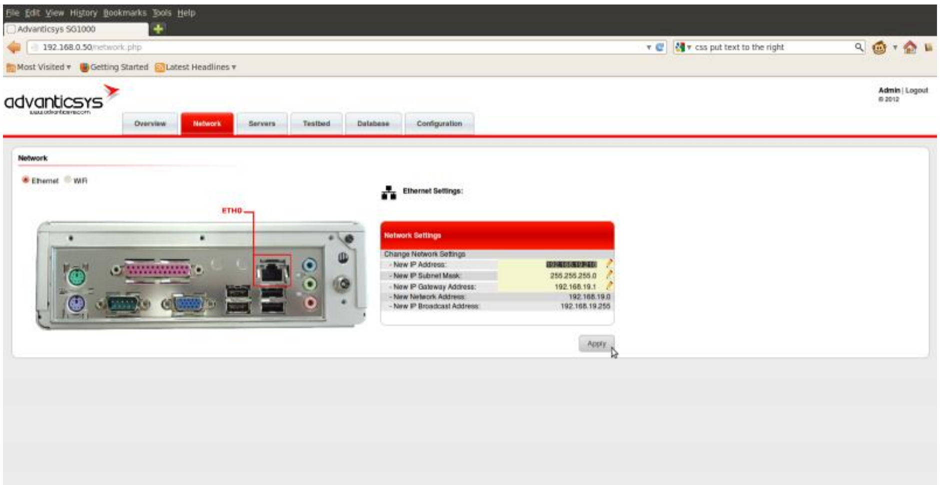
4.2 Overview Tab

The **Overview** tab shows current settings for the SG1000. In a single glance we can see information about the systems settings, including network, serial servers and general configuration status.



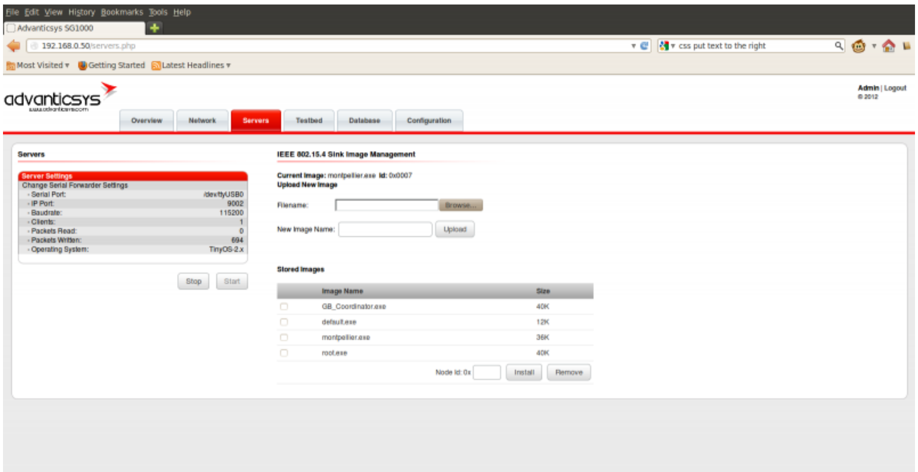
4.3 Network Tab

The **Network** tab allows the user to change the device's network settings, so as to make it accessible in the local network. In order to change the device's address it is necessary to type it inside the corresponding boxes, and then press the Apply button. Bear in mind that once you apply the new settings you will have to type the new address in the browser's address bar to continue browsing the web interface.



4.4 Servers Tab

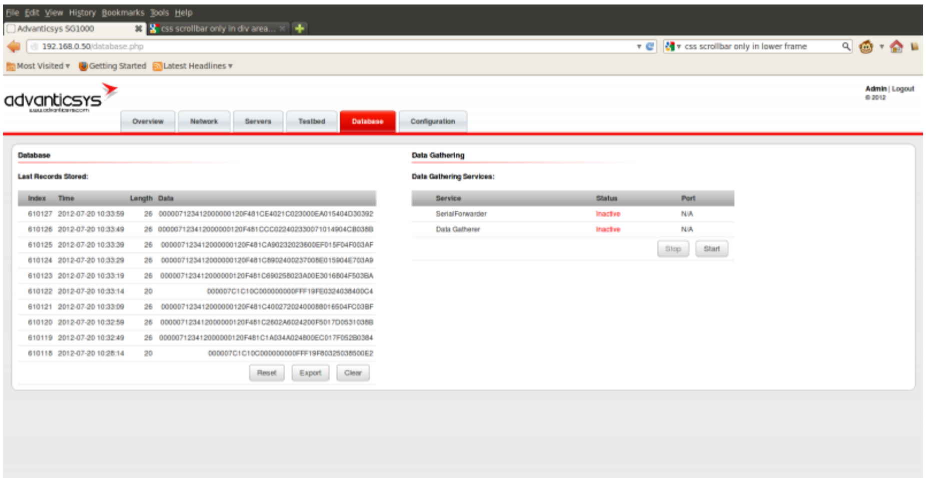
The SG1000 includes a IEEE 802.15.4 compliant interface, acting as **sink** for the deployed wireless sensor nodes and enabling bidirectional communication with the wireless network. The **Servers** tab permits the modification of the image installed in the 802.15.4 interface, and also the launch of a serial to IP translator that enables access to the recovered data through an IP connection.



It is possible to start a serial server that forwards incoming packets from the wireless network to an external IP client connection. This server is based on the well knownTinyOS Serial Forwarder. It is possible to launch the server by indicating a *port* and then pressing the **Start** button. To Stop the server simply press the **Stop** button. The Server settings table also provides useful information about the current connection, including number of clients and packets sent and received.

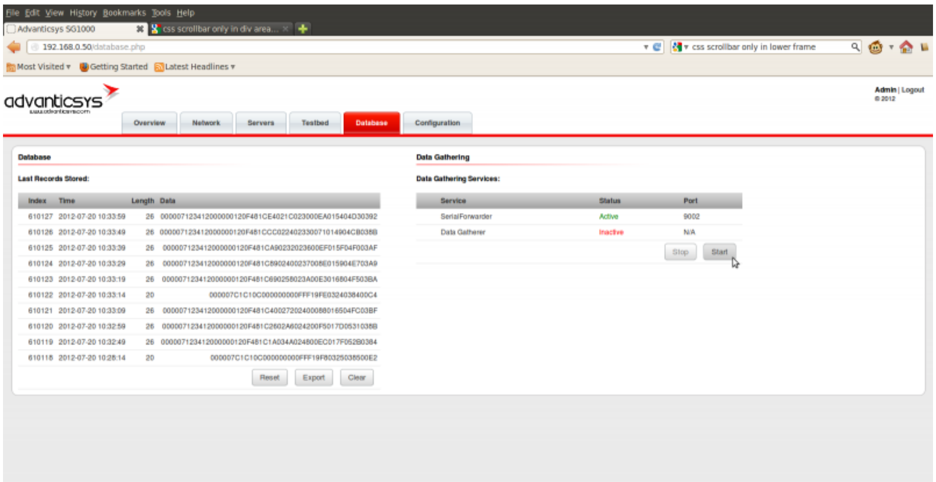
4.5 Database Tab

The SG1000 has as one of its main characteristics an internal database that can be used to store raw data from the sensors. This mechanism prevents data loss in the event of sudden loss of remote connectivity to the SG1000, specially when the deployment takes place in a far away location. The **Database tab** gives the user control over the data gathering services in the system:

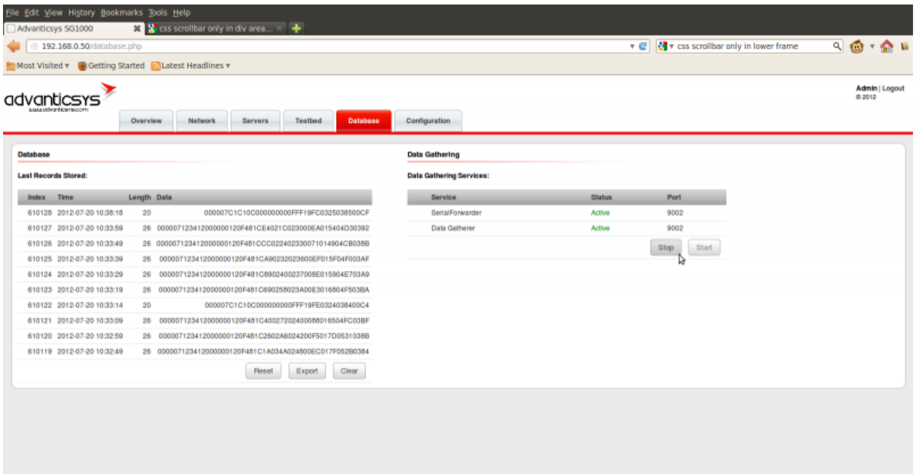


4.6 Data Gathering

The **Data Gatherer** Service is in charge of storing the raw data in the internal database. Before starting it, it is first of all needed that an active **Serial Forwarder server** is running. To start it, go to the **Servers tab** and follow the instructions.
Once the Serial Forwarder has been started, return to the Database tab. The Serial Forwarder service should be up and running:

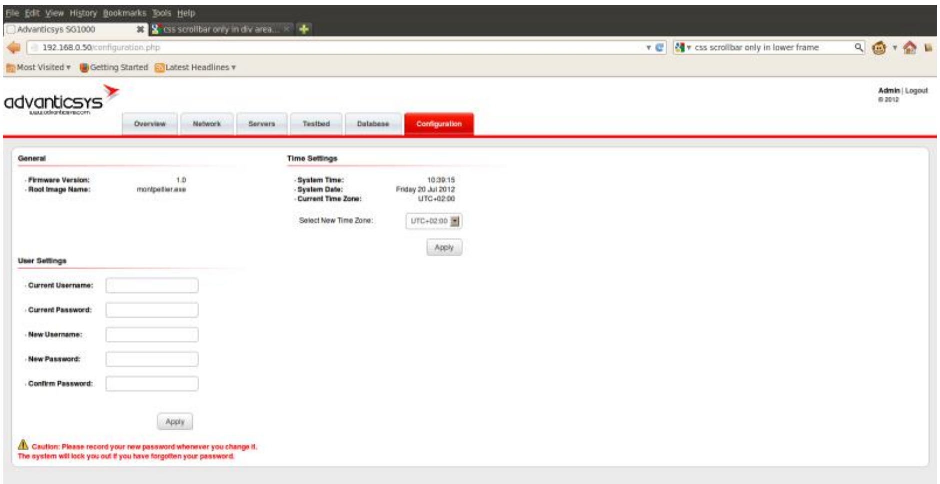


To start gathering incoming data, press the **Start** button. To see an overview of the last messages received, you can take a look at the left side of the screen where the last ten records are shown after an update of your browser.



4.7 Configuration Tab

The SG1000's **Configuration** tab is used to change the system's *username* and *password* access, as well as the *time zone* settings.



5. Control system

5.1 Overview

As described above, the sensing system has three main components: the communication module (CM), the measurement unit (MU), and the electrodes. The MU electronics generate the excitation signals for the sensing electrodes and also contains detection circuitry. The CM controls will supply power to the MU, and at MU power-on, the MU performs a measurement sequence. The raw experimental data resulting from the measurement is sent to the CM, which in turn relays the data to the central unit. In the central unit the raw experimental data is converted into the physical soil characteristics of interest.

The first generation of the MU comprises MU and electrodes on one single PCB, as can be seen in Figure 6 below.

In the second generation MU, the electrodes will be separated from the MU and the design will be done with later integration into the 'sensor-stick' in mind.

Soil water content and soil conductivity will be determined by analyzing the electrical impedance of the soil of a frequency spectrum. In short, information about soil conductivities obtained from low frequency electrical conductivity (resistance) and information of soil water content can be obtained from the capacitive response at high frequencies.

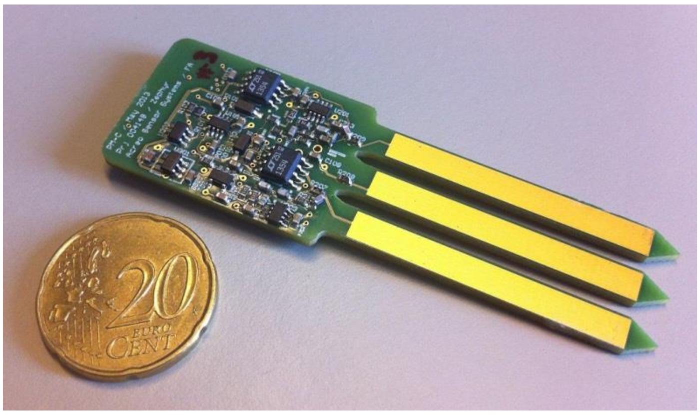


Figure 6.The first generation of the Measurement Unit with sensing electrodes and sensor electronics integrated on one single PCB

5.2 Block description

The electronic circuit measures soil properties at two fixed frequencies, low frequency (LF) and high frequency (HF).The conductivity is determined at LF, and the capacitance is measured at HF. In order to keep the electronic circuitry as simple as possible (thereby energy efficient), the excitation frequencies are created by filtering square-wave signals directly generated by the processor and an oscillator.

The principle of the detecting circuitry is that of a precision rectifier, which after a low pass filtering produces a DC equal to the amplitude of the signal response from the soil electrodes. The DC voltage is measured by the ADC of the processor. A block description is shown in Figure 7 below.

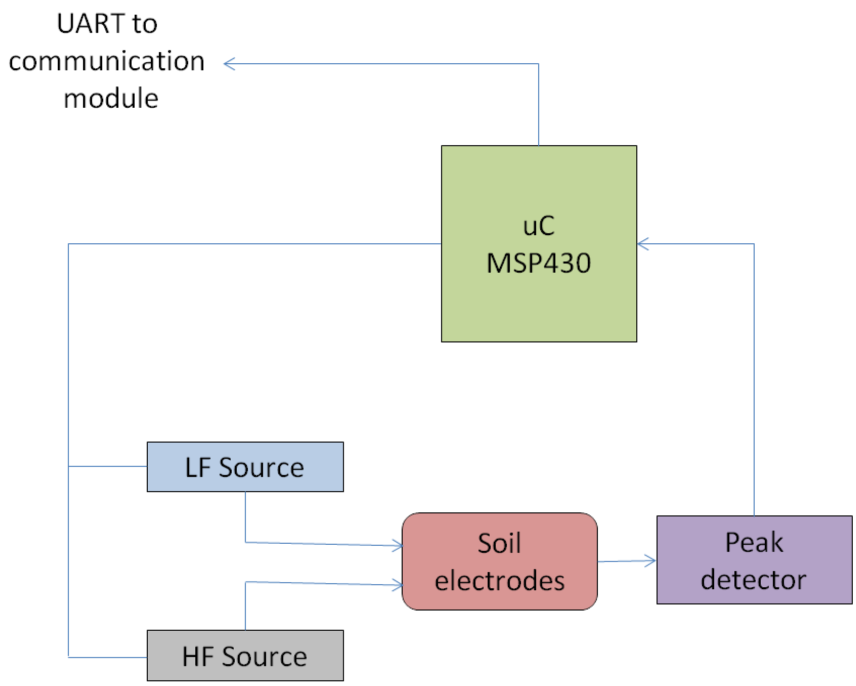


Figure 7 . Block description of the MU electronics. Two excitation signals (HF, LF) are generated and fed to the soil electrodes. A peak detector then creates a DC signal proportional to the amplitude of the AC response of the soil electrodes. The microprocessor digitalizes the response and transfers via UART interface to the communication module.

The MSP430 family was chosen as microprocessor due to its low current consumption. It is foreseen that the number of measurements per day will be low enough for the electronics to be powered from the communication module battery without much affecting its lifetime.

The sensor electronics will be in a deep sleep mode most of the time to reduce power consumption. We propose that the communication module wakes the sensor electronics when it is time for a measurement. This trigger could come either from a timer in the communication module or as a result of radio communication with an external system.

In order to further save valuable battery energy, the MU can also be completely powered off. A measurement sequence is performed at power-on and data passed on to the CM, after which the MU can be powered off.

5.3 Technical specification

Power will be taken from the communication module battery. Most of the time will be in deep sleep mode with very low consumption. A measurement will only be made on request from the communication module. This procedure will take a few seconds and the electronics will return to sleep mode after sending the data.

Voltage:	*3.3V (Could be changed to +3.0V if more suitable with communication battery)*
approximate power consumption:	
Sleep mode:	*< 5 µA*
Active mode:	*57 mA (measurement sequence duration: 5 s)*

The interface of the sensor electronics towards the communication module will consist of:

- Power input
- Ground
- Wake up logic input (wake)
- UART Tx(data output)
- UART Rx (data input)

5.4 Communication interface

The interface to the communication module will be UART with following parameters:

Baud rate: **115200**
Parity: **None**
Data bits: **8**
Stop bits: **1**
Flow control: **None**

The voltage level for the UART-communication should be the same as systems voltage (see above).

5.5 Protocol and Data format

The sensor electronics will take measurements from sensor channels, and attach a channel ID to it.There will also be a separate logic signal to wake the sensor electronics from sleep. This signal (wake) will be active low.

During the course of the project, the amount of sensor channels to measure may vary. Some flexibility is therefore needed in the protocol.

One byte will be more than enough to hold the channel ID. Channel value could fit into two bytes if conversion to real units is performed in the central system. To facilitate debugging and integration the channel value is printed out as an ASCII string over the UART interface, and is then compressed in the communication module.

The following data will be sent from the MU upon wake up signal “wake” goes low or at power-on:

UART Protocol:

The device is at present programmed to output 3 channels: A, B, and C.

Channel	Data
A	LF Measurement
B	HF Measurement
C	Temperature Measurement

Data Format		
[1 byte] **“<”**	Transmission start	
[1 byte] **“A”**	[5 bytes] **LF measurement** (value ranging from 0 to 65535)	**LF** [1byte]
[1 byte] **“B”**	[5 bytes] **HF measurement** (value ranging from 0 to 65535)	**LF** [1byte]
[1 byte] **“C”**	[5 bytes] **Temp measurement** (value ranging from 0 to 65535)	**LF** [1byte]
[1 byte] **“>”**	Transmission stop	

Example (ASCII transmission - 23 bytes):

A00001
B12345
C65535
>

6. Conclusions

The document describes the technology selected (IEEE 802.15.4), the communication infrastructure and the control system that will be developed for the sensor-stick component. The focus is set on the two main components of the sensor stick, the communication module and the measurement unit. The approach proposed here will evaluated in T4.3 where the components and firmware will be developed, implemented and the whole system tested to evaluate the performance and make sure the capabilities cover the requirements defined in T2.3.