WIMEA-ICT Research Component 3

Automated Weather Station (AWS) development and network densification

RC3 Progress report 2014

Björn Pehrson, Robert Olsson

Abstract

This a short summary of our work in 2014 related to the WIMEA-ICT project and some thoughts about the way forward in 2015.

The initial plan was to get the PhD students involved already in 2014. However, since the selection process was delayed, the results discussed in this report have been produced by the supervisors to prepare the ground for the students. The work has been based on working assumptions discussed and agreed upon in the process. All these assumptions are specified in this report. They can be challenged anytime and replaced if there are convincing arguments agreed upon.

Substantial progress has been made, as presented and demonstrated at the workshop in Kampala in November 2014, although the results so far still need to be evaluated by stakeholders that have not been part of the process.

The students were selected by the end of 2014 and should now as soon as possible take the lead in the research and development under our supervision. As soon as their contracts are signed, we expect them to rewrite their research proposals based on the working assumptions agreed and discussed in this report. Since the students will spend time in Bergen and Stockholm in fall 2015, we will prepare for benchmarking of AWS components and sensors during that period and plan for the students to be able to bring prototype stations back home to their own countries for evaluation in their final environment to be tested during 2016 so that a larger number of stations can be procured and deployed.

Introduction

The 2013-2014 work plan included six RC3-activities:

1. Selection and employment of PhD students. The original plan was to recruit two students specializing in RC3 issues. This was in the process changed to three students.

2. Field Survey in Uganda, Tanzania and South Sudan to take stock of existing weather stations, what sensors they use and how the data is transferred to a central repository

3. Reviews to be made by the PhD students regarding needs and requirement analysis, published technical solutions and proposals for sensors to use while balancing between price and performance to fit the budget for 70 weather stations

4. Proposal for the design methodology to be used for systems design, establishing the development environment with tool chains, etc, to be used in the design phase

5. AWS prototyping including a sensor network for each observation station covering data capturing from sensors for the decided set of parameters, power supply, gateway, and uplink to central server.

6. Procurement of servers to receive and store data from AWS stations

We will summarize the progress made in 2014 in these activities and outline the way forward.

1. Selection and employment of PhD students.

The advertisement and selection of students were made for all research components under the leadership of the principal investigator. We provided input regarding the candidates applying for RC3.

The result of the selection process is reported in a separate document. The RC3 students are:

- Maximus Byamukama <maximus.byamukama@gmail.com>, Makerere University
- Mary Nsabagwa <mnsabagwa@cit.ac.ug>, Makerere University
- Emmanuel Kondela <ekkondela@hotmail.com>, DIT

At our first meeting, the annual workshop in Kampala in November 2014, the students gave a brief presentation about their interests. Maximus declared an interest in the power supply issues and how to integrate network management and power management. Mary said she is interested in the embedded systems part of the design of the wireless sensor networks connecting sensors at one observation station and Emmanuel said he wanted to focus on the upstream connectivity including the local observation station gateway and the central repository.

We hope that the contracts with the students are now sorted out so that they can now as soon as possible take the lead in the research and development process under our supervision.

2. Field Survey of existing weather stations

The first tasks for the students include a survey of existing observation stations, what sensors are now in use by the national meteorological agencies and how the data is collected and transferred to a central repository.

This field surveys seem to be in progress and first drafts of reports are expected soon.

The first briefings about conclusions seem not very positive regarding the status of the existing networks. We will review and provide feedback on these reports as soon as they materialize.

We expect these reports to include the positions of existing stations and also an analysis of how the observation station network should be densified, with suggested positions of new stations.

3. Needs and requirement analysis and survey of AWS state of the art

The next steps include to agree with all stakeholders on a needs and requirement analysis for the Automated Weather Stations (AWS) to be developed in the project, to survey the state of the art regarding sensors and sensor systems and to make an implementation plan.

The working assumptions discussed in Kampala and agreed upon regarding parameters to monitor and measure reasonably accurate include:

1. Temperature and Humidity measured at 2m above ground level, radiation protected and ventilated during daytime
2. Atmospheric pressure
3. Insolation

measured at 10m above ground level in an unobstructed location.,

4. Precipitation
5. Wind speed and direction

measured at 10m above ground level in an unobstructed location.

6. Soil temperature and moisture
7. Outward long wave radiation (IR) measured at 2m above ground level (optional)

The following requirements on the stations were agreed:

1. Each station should be autonomous with respect to power supply and communication capabilities
2. The stations should be affordable. As a working assumption, the indicative cost per stations has been estimated to 2000 USD per observation station for 70 stations. The final number will depend on if the final cost will be lower or higher than the estimated cost.

Another requirement that has not yet been discussed, but which we find important, is that all sensors should be pre-calibrated. We will include this requirement as a working assumption.

4. Design Methodology

We start by listing the working assumptions with respect to design decisions regarding the systems topology agreed on at the Kampala workshop and then continue to discuss the design environment , methods and tools. As pointed out in the introduction, these assumptions can, and should, be challenged anytime and replaced if there are convincing arguments agreed upon.

System topology

These are the working assumptions regarding the topology of each observation station:

- Each station will typically have 7-9 sensors connected via a set of sensor nodes (motes) typically 3-5 per station depending on the number of sensors and rules regarding how to place the sensors.
- The motes form a local wireless sensor network (WSN) communicating with a sink node connected to the observation station gateway.
- The gateway has two functions: it has a sink node connected to read and buffer sensor data from the local wireless sensor network and it has one or several redundant up-links to transfer the data to a central repository.
- Upstream links of one sort or another will connect the observation station gateways to Internet so that captured data can be made available via regional and national repositories for research and analysis purposes.
- The power supply system will be using solar energy as a primary source and adequate types and sizes of batteries for storage of energy.
- The power management tools will be integrated with the systems and network management tools.

Design environment

The design environment will use the Africa-grid Science Gateway as an overarching portal (http://sgw.africa-grid.org/). This provides access to WRF and data repositories as TRODAN. It is also a very good channel to make the WIMEA-ICT weather data repositories available for users in a controlled way.

The main operating systems platform for research and development in RC3 activities is Linux, the main programming language is C the main software repository github (https://github.com/). In the combined environment there is a large number of tools available that the students will learn to master.

5 AWS prototyping

We will now discuss the preliminary design decisions made to implement the AWS prototype demonstrated in Kampala last November. These tentative decisions are made based on our earlier experience and discussions with the other RC-leaders in this project. The implementation of the prototype was made during 2014. The decisions include the hardware and software used to implement the motes including the power supply system, connect the sensors to the motes, connect the local wireless sensor network to the gateway and the upstream connections.

Our short term objective for is now to design and deploy a refined prototype for benchmarking together with other weather stations deployed at University of Bergen.

5.1 Selection of sensors

We have discussed the choice of sensors within the WIMEA-ICT-project and also with other specialists. Our working assumptions about what sensors to use to measure the parameters agreed on in section 3 above include:

1. Temperature and Humidity: Sensirion SHT25 www.sensirion.com/en/products/humidity-temperature/humidity-temperature-sensor-sht2x/
2. Atmospheric pressure: MS5611 www.meas-spec.com/downloads/MS5611-01BA03.pdf
3. Insolation: We have tested two alternative photo-diode sensors and need feedback: Two units have been built, but still needs testing and calibration. We also need input about any potential filter that should be included.

   - Hamamatsu S1223 www.farnell.com/datasheets/8765.pdf

   - Vishay BPW20RF www.vishay.com/docs/81570/bpw20rf.pdf

   We will include both these sensors in the prototype to be installed at UiB for benchmarking.
4. Precipitation: We have tested several different tipping bucket alternatives but have not yet found an affordable equipment with the required resolution of 0.3 mm or less. Suggestions would be appreciated.
5. Wind: We have tested one alternative from Inspeed http://inspeed.com/anemometers

- Direction: The Hall element based vane seems promising

- Speed: Needs more investigation. We are looking at Hall element-based anemometers. Inspeed provides one that has not yet been evaluated. Voltage, power consumption and bearings are key parameters.

6. Soil temperature and moisture: Our choice needs to be reviewed by users

- Temperature: A waterproof DS18B20 has been tested

- Moisture: Vegetronix VH400 has been tested http://www.vegetronix.com/Products/VH400/ A VH400 Calibration function between measured voltage and soil moisture is available at https://github.com/herjulf/vh400

7. Outward long-wave radiation (IR): We plan to include the IR-filtered photo diode

VTB8440B in the prototype to be benchmarked at UiB
http://www.farnell.com/datasheets/57158.pdf

8. Examples of other optional sensors tested so far include radioactivity:

- Semiconductor sensor Teviso RD3024 http://www.teviso.com/en/products/radiation-sensor-rd3024.htm
- Netio GC10 Geiger counter https://www.youtube.com/watch?v=sgkhbtO2FrY

Protection of sensors

Some of the sensors need a controlled environment to provide correct measurements. The temperature and humidity sensors are expected to measure the air temperature and humidity by conduction only, not radiation, and need some sort of radiation shield. The standard way of doing this is to place the sensors in a shielding cage or pagoda, possibly ventilated during daytime.

Some sensors may need heating to avoid condensation of water or ice that can destroy the reading, such as photo diodes and precipitation gauges. We expect this to be a minor problem in the African context and will not discuss this further here.

What radiation shield to use requires more evaluation and experimentation. We have tested a very cheap weather station shield in the shape of a pagoda. Via another project we have had the opportunity to use a Vaisala radiation shield at the SMHI main campus in Norrköping. The Vaisala in combination with SHT25 gave very accurate results when benchmarked with the SMHI regular measurements as illustrated at:: http://radio-sensors.com/projects/SMHI-test/installation/both-radiation-shiels.jpg

5.2 Mechanical design of the weather station

Another issue to deal with is the mechanical design of the weather station. We see the standard observation station to consist of the following subsystems, potentially one mote each although some of them may be combined.

- 10m mast located in an unobstructed field, including a mote for the wind and insolation sensors. The mast should be
- 2m mast located in a well-ventilated but preferable shaded location, including a mote for the sensors for air temperature, humidity, and outgoing long wave radiation
- A sink mote connected to the gateway, which also connects to one or more uplinks.

The atmospheric pressure sensor can in principle be integrated with any of the other motes.

We would like to see the PhD students taking the responsibility for this work together with their national meteorological agencies.

EMC-protection

Lightning protection for direct hits in the mast needs to be considered using a lightning rod in the top and proper grounding of the mast.

The need for protection from transients generated by conductors working as antennas in thunderstorms , e.g. by using transient voltage suppression (TVS) diodes.

Protection against vandalism and theft

5.3 Motes

Software

We have earlier made a comparison between the Contiki and TinyOS operating systems for embedded systems. We found Contiki having a smaller memory footprint and to be more “C-like”, which facilitates learning for students with a computer science background. There is a new interesting candidate, mbed, announced by the ARM consortium but not yet available, that the students should evaluate when it becomes available.

Hardware

On the CPU side, we considered different Arduino based systems, Texas Instrument MSP430F1/2xxx, Libellium, ARM-Cortex M STM32 (www.st.com), and Atmel ATMega128RF.

At the time of our evaluation, the ATMega128RF came out on top due to the combination of the fact that the circuit itself integrates an MCU, an 8 channel10-bit ADC and an IEEE 802.15.2 transceiver, and that this MCU has support in Contiki.

We have evaluated a few different commercially available mote cards based on the ATMega128RF component. We chose to work with a card manufactured by www.radio-systems.com for several reasons. There is a Contiki-based proprietary software available, focused on data acquisition and monitoring of sensor data, with support for several of the sensors being considered in WIMEA-ICT. This facilitates a quick start of actual usage in parallel with the development of an open version that can serve as a platform for further academic research on wireless sensor networks. We also have close relations to this manufacturer, which has made it possible to contribute to the design, shorten the development cycle and in return get a developers discount. We will call this mote the RS-mote. The choice of this hardware can, and should, be challenged at any time.

The RS-mote

The RS-mote has a few on-board sensors and a number of interfaces facilitating the use of other sensors, including connectors for pulse counters, two analog inputs as well as the one-wire and i2c-buses to connect sensors directly or via break-out boards.

A meteorological breakout board

An I2C break-out board has been designed and manufactured in a small series (30pcs) especially for the WIMEA-ICT-project to use the meteorological grade sensors agreed upon. This break-out board includes the SHT21 or SHT25 sensor for temperature and humidity, the MS5611 for barometric pressure and a 4-channel 16-bit AD-converter, MCP3424 for digitalization of analog sensor signals requiring a high resolution, such as pyranometers, resistance based temperature sensors (e.g. PT1000) etc.

The breakout board and can be used separately on different platforms , such as Arduino, Raspberry Pi and different motes. The board will be made available as open-hardware to be used freely with other projects and applications.

Schematics: http://www.radio-sensors.com/projects/daughterboard/dboard-1-schematics.png

View: http://www.radio-sensors.com/pictures/bboard-1.1-back.png

Power supply for sensor motes

If the RS-sensor motes are awake all the time, a typical power consumption is around 50-100mW, depending on what sensors are connected. The motes can also be made to enter a deep sleep between measurements in which the power consumption is in the order of 16 microwatts.

The measurement interval requiring the mote to wake up is normally short, in the order of 20 ms, depending on how long time is needed for the sensor to stabilize. If the sampling period is 1 minute, 60s, this is less than 0.1% of the time. We are in the process of measuring average power consumption for motes with different sensors attached. Preliminary results point to ~100 μA currents at about 3V.

At such low power requirement levels, it is possible to use a combination of a small solar panel and a 40F Lithium-Ion-Capacitor (LIC) battery with a simple charge regulator as an autonomous power supply that will in principle keep the sensor mote going for ever. [] .

5.4 Gateways

As pointed out already, the gateway has two main functions:

- To read and buffer sensor data from the local wireless sensor network. This is accomplished by having a sink node in the wireless sensor network connected to the gateway. The sink node is just another RS-mote that automatically becomes a sink node when connected to a host via USB. A gateway daemon, sensd, reads reports from all motes via the USB connection and stores the data in a text file in the gateway.

- To provide one or several redundant uplinks to transfer the data to a central repository. Our design so far relies on the gateway and sink node always being awake and is therefore the single most power consuming unit in the observation station. The power supply solution is discussed more in detail below.

Gateway hardware

On the hardware side, we have tested a number of low-power (3-5W) Linux-based gateways to which an RS-mote can be connected via USB as sink node for the local wireless network, including Alix [], Odroid U3 [], Odroid XU3 [], BeagleBoneBlack [] and the three different versions of Raspberry Pi, version A, B and B+. []

All of them work well. We have so far long term tests only with Alix, which has proven extremely robust. The experience from the others are so far also good. We suggest starting with the Raspberry Pi in the development process since it is probably the cheapest and most easily available gateway. It is also most widely spread and you can find a large number of interesting applications on the network.

Gateway software

On the software side, we have tested several embedded Linux distributions that all work well.

The key software component for transfer of data from the local wireless sensor network to the gateway buffer via USB and via the uplinks is the sensd Linux daemon []. Sensd includes a proxy function facilitating data transfer across a NAT interface.

Sensd is open-source software available via github.com at https://github.com/herjulf/sensd

Power supply for gateways

The power supply system for the gateway is still to be designed as soon as details for specific installations are available. The power requirement is likely to be in the order of 5--20W depending on the uplink arrangements. In general, a solar panel of ~100W and a suitable battery with a capacity of ~100Ah should provide enough margin for periods with less sunshine. We are working on the design of a low-voltage DC-grid concept that might be of interest in this project.

5.5 Uplinks

Our general strategy when it comes to Internet connectivity, from a performance point of view, is to 1) first look for wired connectivity, optical fiber or copper wires. 2) If for what ever reason it is not possible to get access to, or deploy, such links, try terrestrial wireless links, such as a data service from a mobile network operator if there is coverage in your area, or dedicated links based on VHF, UHF or WiFi. 3) If this is not possible either, try satellite, if economically feasible. 4) If none of these alternatives are feasible, there is always physical transport of data as a last resort, via a USB stick or a mobile device supporting delay tolerant links.

Optical fiber

Optical fiber as such is cheap and so is the optical transceivers and the electronic equipment required to use them. The main cost for deployment of fiber is in right of way and the civil works involved. We have experience in this area from our involvement in the deployment of the Serengeti Broadband Network [10].

Commercial mobile services

Using commercial mobile network data services for data transfer is straight forward if there is connectivity in the area of the observation station. The cost varies between operators. The GSM/3G configuration for the Raspberry Pi is available, e.g. via http://www.radio-sensors.com/docs/S2/HOWTO/HOWTO.3g-sensd-WSN-GW

Dedicated VHF/UHF links

We have also tested different dedicated VHF, UHF and WiFi links that can be used in areas where there is no commercial coverage or where a dedicated solution is cheaper than a commercial service. In the Kampala demonstration, a WiFi connection was used.

Satellite and delay tolerant networks

We also have earlier experience from using satellite links and delay tolerant network technology.

5.6 Data transfer

The sensd daemon running in the gateway uses TCP for uplink communication. Sensor reports can be subscribed to and delivered in real time, as long as at least one uplink is up, by connecting to specific TCP port using simple utilities, like telnet or net cat. This was demonstrated in Kampala.

5.7 Visualization of data

A mobile app has been developed to visualize sensor data directly in real time over Internet. This was demonstrated in Kampala.

For Android, the app is available via Google Play under the name “Read-Sensors”. It includes a commercial grade plotting function. The code is open source that is available at github.com at https://github.com/herjulf/Read-Sensors. The todo-list includes a more intuitive user interface and customized screens for specific user groups.

There is a version also for Apple iPhone but due to Apple's licensing requirements, the cost is much higher and so far funding has been a problem. Also more testing and development is needed for this version.

6. Lab equipment

There are three different needs for lab equipment: 1) Evaluation of new sensor candidates in the cases for which we have not yet made a final decision. 2) For the students to learn via experiments and take the responsibility for further development and 3) To produce prototypes that can be evaluated by all stakeholders

6.1 Evaluation of new sensor candidates and power supply system

There is a need for a budget to buy sensors in not yet frozen design decisions for testing. Examples include sensor candidates for wind speed (anemometer) and precipitation.

There is also a need for experimentation regarding the power supply for the observation station gateway, including sink node and uplink arrangements.

6.2 Individual lab equipment for the learning of RC3 students

The students need as soon as possible some equipment to able to do experiments for learning and to do their research work.

We suggest the following equipment to be procured and given to the RC3-students as son as possible

- Emmanuel: 2 RS-motes, 1 Raspberry Pi, 3G-modem with refillable sim-card for data services, 2 wifi back-haul links units, components for experiments with UHF/VHF-links, including TVWS
- Mary: 3 RS-motes, 1 Raspberry Pi
- Max: 2 RS-motes, 1 Raspberry Pi, components to ultra-cap batteries and micro-grid controllers,

instruments for measuring and recording power consumption parameters

6.3 Prototype AWS for benchmarking

We have discussed establishing a prototype AWS in Bergen in March 2015 to be benchmarked against other AWS's already deployed there.

This station can be studied by the students visiting Bergen in fall 2015 and then be multiplied with one prototype each at DIT, Makerere University and UoJ when the students return back home in the end of 2015. They will then be deployed and tested by all local stakeholders to arrive at a final requirement specification for the 70 stations that will be procured, assembled and deployed later in 2016.

The Bergen benchmarking prototype

We suggest it to include four sensor nodes

1. Wind direction and speed (Inspeed) and insolation (Hamamatsu) in a 10m mast with lightning and TVS protection , an RS-mote with an MCP3424 16-bit ADC on a breakout card a 40F LIC battery with 2.2 V LVD and a 10W solar panel with fixture.
2. Air temperature and humidity sensor (SHT25) in a ventilated cage/pagoda and outward IR radiation sensors (four VTB8440B, two up and two down on a horizontal arm) in a 2m mast, a 40F LIC battery with 2.2 V LVD and a 10W solar panel with fixture.
3. An RS-mote in a box at ground level with precipitation and Soil sensors, TI DS18B20 for Soil temperature and Vegetronix VH400 for soil moisture, a 270F LIC capacitor battery with 3.3V LVD, and a 10W solar panel with fixture.
4. An RS-mote indoors as sink node attached to Raspberry Pi gateway with one wired and one fail-over wireless uplink connection. Powered via 12 or 6V lead-acid battery charge controller and AC-adapter. alternatively an experimental 7.5V LIC battery.

The LIC batteries include one or two LIC capacitors (40 or 270F), a voltage regulator, a diode, all mounted in a small box

7. Way forward

We summarize a semiannual plan below. More detailed in the beginning.

7.1 First half of 2015

1. Feedback on surveys of existing observation stations in South Sudan, Tanzania and Uganda,
2. A visit to Bergen in the first week of March (4-6 March) in order to

- Present this report at a seminar and discuss the issues with those involved in the WIMEA-ICT project, including the UiB PhD students in applied meteorology,
- Installation of an AWS prototype for benchmarking with other systems at UiB
- Discuss the work program for the students visiting Bergen and Stockholm fall 2015.

3. Feedback to the RC3 students in their work on writing

- Their research proposals and publication plans
- The Needs and requirements analysis, including locations for new observation stations
- The Survey of state of the art of weather observation stations

4. Prepare for the student visits in he fall 2015

7.2 Second half of 2015

1. Supervise the PhD students when in Bergen and Stockholm, especially work with them on their first research paper.

2. prepare the students for brining home a prototype AWS to be installed at their home campus when they go back home after the visits in Bergen and Stockholm.

7.3 First half of 2016

Support the students when setting up their prototypes at their home campus and organizing the interaction with local stakeholders.

Supervision of the students' research work and work with them on their second research paper.

7.4 Second half of 2016

Supervision of the students' research work and work with them on their third research paper.

Conclusion of the tests of the prototype AWS units.

7.5 First half of 2017

Supervision of the students' research work and work with them on their fourth research paper.

Supervision of the procurement and assembly of 70 AWS units

7.6 Second half of 2017

Supervision of the students' research work and work with them on their fifth research paper.

Supervision of the deployment and tests of the 70 AWS units so that they start producing data.

7.7 Final year 2018

Supervision of the students' final thesis writing

8. References

[1] Nungu, A., Olsson, R., Pehrson, B., 'Design and Implementation of an Inclusive Ubiquitous Access', Int. Journal. of Wireless Personal Communications, Springer, November 2012

[2] Nungu, A., Olsson, R., Guo, J., Pehrson, B., Towards single Watt and nJoule/bit routing, UbuntunetConnect, Lusaka, November 2014

[3] Olsson, R., Pehrson, B., Powering of electronic devices using ultra capacitor batteries, submitted for publication.

[4] LIC technology http://en.wikipedia.org/wiki/Lithium-ion_capacitor

[5] Alix http://www.pcengines.ch/alix.htm

[6] Raspberry Pi http://www.raspberrypi.org/

[7] BeagleBone Black http://beagleboard.org/black

[8] Odroid U3/XU3 http://hardkernel.com/main/products/prdt_info.php

Appendix Cost estimates of AWS components

See attached spreadsheet