Sensors and Wireless Sensor Networks for Irrigation Management under Deficit Conditions (FLOW-AID)

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Abstract

FLOW-AID has the objective to develop and test an irrigation management system that can be used under deficit, when water availability and quality are limited. It intends to use innovative, but simple and affordable concepts usable for a variety of irrigation set-ups and constraints. Amongst others, it focuses on development of low-power wireless sensor networks for soil water monitoring. Six sensor nodes equipped with SM200 soil moisture probes and 3 repeaters were built and evaluated during 5 months under practical Mediterranean conditions for a container grown crop. The work is still on-going and only intermediate results are reported.

The nodes were capable of relaying data to a repeater over a distance up to 20 m, but the requirement of a maximum of 5% data loss could not be fulfilled. The battery lifetime of the sensor nodes was adequate providing that the nodes were configured correctly. Remote access and data transport over the internet worked very stable and fluently. Weak points of the system were identified for packaging, signal losses, high cost and sensor performance. Enhancement recommendations are reported and form the basis for the next generation WSN, currently being developed and to be used during the two upcoming growing seasons.

INTRODUCTION

In the developing world, water allocated to irrigation is about (or exceeds) 69% of water resources (Fry, 2005). In view of increased domestic competition for resources and the need for larger agricultural production to ensure food security, such a fraction is unsustainable. Therefore, future water security can only be warranted by a considerable increase of the water use efficiency. As a consequence, the demand for new water saving irrigation techniques is growing rapidly. To produce “more crop per drop”, growers in (semi) arid regions currently explore irrigation techniques in the range from using less fresh water to using marginal water resources like recycled household water. Doing so, they enter the domain of producing crop under sub-optimal or even stressed conditions for the crop, commonly referred to as deficit irrigation (Lamaddalena, 2007). As such, the margin the grower has to control his crop becomes smaller, and information about actual crop status plays a crucial role. Especially soil water content or soil water tension as well as electrical conductivity (EC) are important parameters to monitor, since highly saline soils invoke crop stress and yield reduction. Current research focuses on monitoring systems that regularly supply information to growers about growing conditions (soil, climate and crop status) and decision support systems (DSS) with automated control that take adequate and timely irrigation or fertigation actions based upon water availability and crop needs.

The concept of using soil water sensors to activate irrigation scheduling is a well-known concept and has become a common practice since the introduction of dielectric (TDR, FDR) soil water sensors (Balendonck et al., 1998). A large number of soil moisture sensors have become available over the past decade, however only the WET-sensor (Hilhorst, 2000) and the new ECHO-EC5 probe (Decagon, US) are capable op monitoring both EC and soil water content. For precision real-time irrigation control, controllers and sensors are installed at each plot or at least at every group of sprinklers or drippers in the field. Each controller performs an individual irrigation schedule which is set and reprogrammed on a regular basis. Due to soil spatial variability, a large number of sensors are needed in each irrigation zone to obtain a reliable mean soil moisture reading. Since many controllers and sensors are involved, the high cost for investment, installing wiring, maintenance, data-handling and use is becoming a large bottleneck, which forces growers to look for new improved and cost-effective monitoring and control systems.

The use of wireless sensor networks (WSN) saves a lot of installation and management cost (Panchard, 2006; Ning Wang et al., 2006; Kim et al., 2006; Baggio, 2005), and companies like Delta-T Devices (UK), Netafim (IS), Decagon (US) and Crossbow (US) start offering systems or components of wireless sensor systems for irrigation management. However, equipment is still expensive and uses a lot of energy to overcome the variable damping of electro-magnetic waves in crops under fluctuating weather conditions (Thelen et al., 2005).

Numerous publications can be found on all the different aspects of WSN and the protocols for ubiquitous communication. Especially in the last 3 years the number of publications has increased rapidly. For a comprehensive survey and state of the art on wireless sensor networks with special attention to the ZigBee standard we refer to Baronti et al. (2007). Most research about the use of WSN in the field of agriculture and horticulture are so far carried out in Australia and North America. Quite often the applications are related to irrigation and water management issues. A number of publications confirm that at the current development stage WSNs are not reliable enough, can't withstand outdoor climate conditions, lose communication, are not fault tolerant, use too much power, are damaged too quickly and are riddled with new problems not foreseen by manufacturers or end users. Tuijl et al. (2007) published a review on WSNs with focus on agricultural and horticultural applications and confirm that short communication distances (10 – 30 m), maintenance cost for frequent replacement of batteries, and above all price, are still the biggest hurdles for implementing dense WSNs. Currently we see that the end-user price of wireless nodes lies between €100 and €350 and for soil moisture sensors between €50 and €800. The use of solar power instead of batteries is sometimes not possible due to sun-blocking by crop foliage. Battery operated equipment is more reliable and still favorable, which makes it needed to improve both equipment and communication protocols in such a way that they become low-power and work reliably under outdoor agricultural conditions.

This work, performed within the framework of an EC project called FLOW-AID, focuses on the development of a prototype low-power sensor/communication device (receiver/transmitter pair called a MOTE), incorporating a robust multi-node communication protocol (MESH-network) for transmission of data-signals from monitoring and control devices for irrigation management. With multiple prototypes of these MOTES, during 3 years, tests will be performed under practical conditions for a container grown crop in Pistoia, in the Tuscany region in Italy. The objectives of the 1st year experiment were to assess the long term robustness and reliability of a WSN with focus on:

1. Communication robustness (failure of nodes/repeaters),
2. Maximum range of wireless communication between nodes,
3. Battery life time / power consumption,
4. Suitability for outdoor usage (packaging as well as radio communication),
5. Connectivity to other interfaces,
6. Sensor performance, and
7. Cost price.

This paper describes the FLOW-AID concept and the progress of the work on the wireless sensor network during the growing season of 2007.

FLOW-AID system

FLOW-AID (Farm Level Optimal Water management, Assistant for Irrigation under Deficit) is an on-going European project that aims to make irrigation sustainable by improving deficit irrigation practices, and by helping growers to safely, more efficiently and cost-effective manage irrigation. It aims at integrating innovative, but simple and affordable, monitoring and control technologies within an appropriate DSS (Balendonck et al., 2007; Balendonck, 2008). It focuses on the various and typical (protected as well as non-protected) growing systems found in the semi-arid regions of the Mediterranean. Testing and calibrating the system under the various local constraints of farm and basin management, helps to ensure that the technical, environmental and economical performance of irrigation systems is improved.

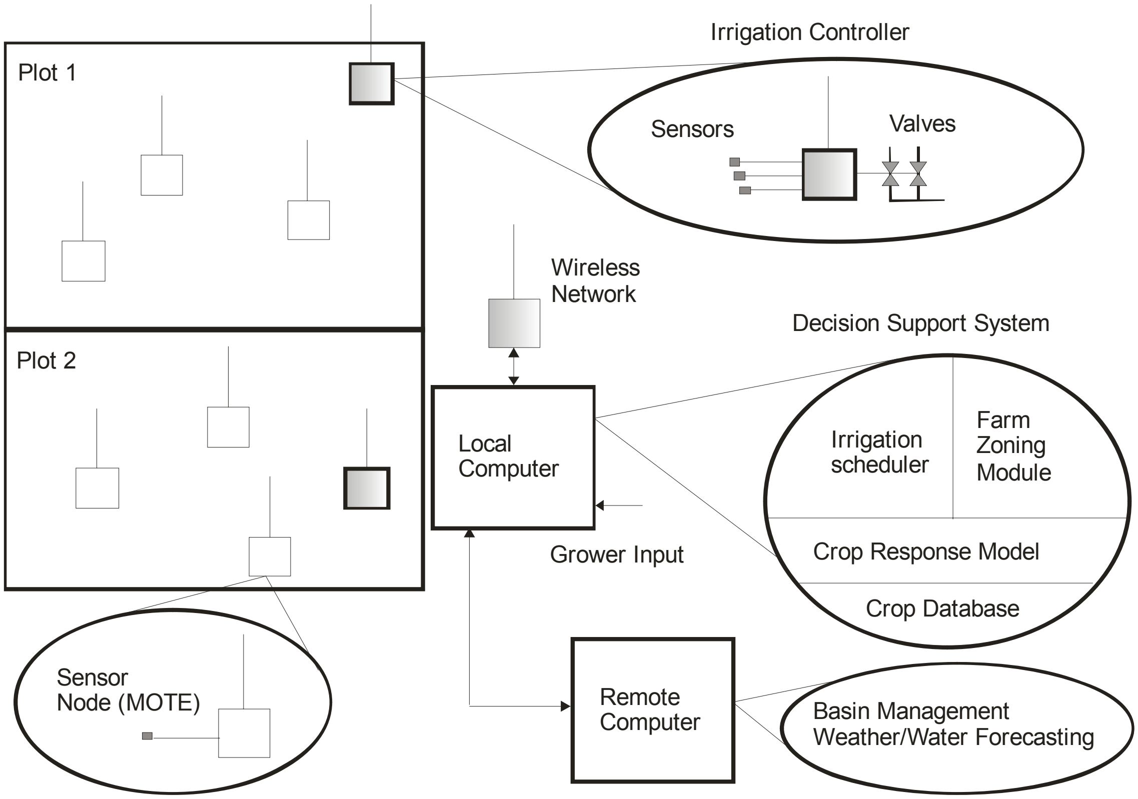

Figure 1 Water management system for farm level irrigation under deficit irrigation.

The FLOW-AID system consists of several irrigation controllers, distributed over the farm zones that need to be irrigated. The controllers are connected via a wireless communication link to a local computer, which has the task to regularly readout sensor data from the irrigation controllers and to update the irrigation scheduling programs running autonomously in the controllers. A Decision Support System (DSS), running on the local computer and partly on a remote computer — connected via internet — is an expert system that helps the grower to optimize the scheduler programs for the irrigation controllers on a long-term as well as on a short-term basis. Figure 1 gives an overview of the system components.

Decision Support System

With respect to the long term (months or years) forecast of water availability in terms of amount, quality and timing, a DSS Farm Zoning Module (Ortega et al., 2004) assists the grower to divide his farm into manageable zones and plots and to make crop planting plans. To evaluate the potential crop yield under deficit conditions this DSS makes use of a crop response model incorporating a library containing all relevant data of crops and soil types the grower uses. It is fed by the grower with relevant data like f.i. plot areas, availability of machinery, water availability, production cost, yield response to soil water matrix potential and salinity as well as data about water availability in the region. Regional data may come over the internet from a central authority. The DSS helps the grower to obtain an optimized crop planting plan, a set of irrigation scheduling tasks and estimates of annual water use per plot.

With respect to the short term availability of water, and based upon actual crop status, weather and the weather forecast (f.i. rain, radiation and temperature), a DSS Irrigation Scheduler module assists the grower to predict crop water demand on a day- or weekly basis. It helps him to select an optimal scheduling strategy for each plot including the type of water source in terms of amount and quality. The selected irrigation tasks, including parameter settings, are then down-loaded into the remote irrigation controllers. The irrigation scheduler is run on a day-to-day basis and checks whether new conditions give need to re-programming the individual controllers. The DSS does not need to be installed in full on the local computer, but can be web-based as well or rely on some modules that are web-based.

Irrigation Controller

To ensure that the optimal amount of water per plot is allocated according to the real-time crop status, each plot has an individual irrigation controller node, and local or remote sensors are added to it as needed by the application, either via hard-wire or a wireless link. A typical controller node will monitor relevant soil data such as soil volumetric water content, soil water matric potential, soil temperature and electrical conductivity (water quality) or even weather data like air temperature, wind speed and radiation. It can open and close multiple valves, to make it possible to choose between one or more water sources of distinct water quality (a well, a reservoir, reuse of water, irrigation network etc.). Once programmed by the DSS Irrigation Scheduler, the controller keeps on running its irrigation or fertigation tasks autonomously, until it is re-programmed or stopped by the local computer. This makes the irrigation of individual plots fail safe, in the sense that it does not rely on real-time communication with a remote computer.

To be practically of use, the irrigation controllers must be rugged and affordable, have low maintenance cost, easy installation and reprogramming, no wiring in the field, use little energy, and can accommodate a wide range of sensors. To cover a wide distance (100 m up to several kilometers), controllers communicate with the DSS by using a wireless network (radio transmitters or GSM-modems), serving as repeaters for the single sensor nodes. Within the FLOW-AID project we have chosen to use the GP1-platform (Delta-T Devices, UK). In cases were controllers are used to control directly electric powered valves, in general it is not needed to operate such devices with batteries. However, satellite sensor nodes, placed near the crop in the field at some distance from the controllers, still need to be powered by batteries.

MATERIALS AND METHODS

User demands and WSN specifications

For irrigation management three different areas of application can be identified: open field agriculture, greenhouse horticulture and nurseries with container crops. Based on discussions with irrigation scientists and potential end-users the requirements concerning sensors, measurement frequency, spatial resolution, lifetime, robustness and reliability, costs and packaging were identified. The following table summarizes the main user and system requirements for these applications.

Table 1 System requirement of the WSN

	Open field	*Greenhouse*	*Container crop*
Farm size	10-100 ha	1-10 ha	1-10 ha
Irrigation unit size	3000 m^2	300 m^2	300 m^2
Spatial sensor resolution	10 / ha	100 / ha	1/100 m^2 = 100 / ha
Sample frequency	6h (up to 15 minute)	1h (up to 1 minute)	1 h (up to 1 minute)
Reliability network	max 5% data loss	max 5% data loss	max 5% data loss
Accuracy sensor value (soil VWC and EC)	max 10% deviation	max 10% deviation	max 10% deviation
Maintenance free operation (battery lifetime)	12 months	4 months	8 months

Furthermore, the WSN should be capable of performing irrigation on/off control based on monitoring soil moisture content and electrical conductivity (EC), and should work under wet and arid climatic conditions. Under semi-arid conditions, this means that the ambient temperature might go up to 45 ^{o}C in the shade.

If, during irrigation events, the wetting front can be observed at a higher sampling rate, water can potentially be saved by stopping irrigation well before a pre-set time-out. Therefore, it must be possible to (automatically) adapt the sampling frequency to the process dynamics in a flexible way. To reduce labour cost, the read-out of information and the connectivity to a management system must be simple. To save the environment and to reduce replacement cost, there is a preference of using environmental friendly rechargeable battery types and alternative solar cells for powering the nodes.

Since the WSN would be tested with container grown crops, based upon a spatial resolution of 100 sensors per hectare, the minimum needed range of communication between sensor nodes is 20 m. The preferred sample frequency is 1 to 2 measurements per hour. For good connectivity to the host computer, controller nodes need to cover a minimum distance of 100 m. For this application we estimated that the end-user price for a controller node, including sensors, may range from €200 - €500, and the target price for a single sensor node should not exceed €100, taking into account a life-time of at least 10 years.

Sensor node design and experimental set-up

The user demands and specifications largely determine the design of the WSN. A major design criterion is the choice for the network topology. For our system we made the choice to focus on a MESH-topology, making it possible for nodes to communicate to the host computer via multiple paths and repeaters. However, the design is also limited due to other factors like the availability of the individual components of the system such as the sensors and wireless receiver/transmitter boards. We used a RX/TX-board based upon the CC1000 radio chip from Texas Instruments Incorporated, working in the 866 - 868 MHz frequency band. This system consists out of 8 sensor nodes, 3 repeater nodes and a gateway/base station connected to a PC, which was supplied by SOWNet Technologies B.V. (www.sownet.nl). The sensor node was housed in a plastic water-tight housing, and we used a simple wire as internal antenna (8 cm), according to the CC1000 reference manual.

The sensor nodes were configured to operate in a star network (using the repeaters as a host), and the repeaters were programmed to work in a mesh network (hopping principle). The configuration as such might be called HYBRID. The maximum signal strength for transmitting data from a node can be pre-set in the nodes firmware. For the sensor nodes, this was set to half the maximum output (rated 1.5 mW at 17.8 mA), trying to save as power as much as possible. Each sensor node is equipped with a SM200 soil moisture sensor (Delta-T Devices, UK), which was powered from the same battery as the receiver/transmitter node. Figure 2 shows the internal of the sensor node as well as the sensor node mounted on a PVC-pole placed in a container (1 m height), and the SM200 sensor placed in the soil of an adjacent container plant. The repeater nodes were made according to the same concept, except that they did not contain a sensor and were programmed to operate as a repeater.

The WSN was tested at the Centre Sperimentale Viterbo in Pistoia, situated in Tuscany, the largest Italian region for nursery stock production for garden and ornamental plants. The experimental plot was about 60 m long and 19 m wide with 8 different irrigation sectors. The site was set-up with 24 cm diameter containers with a mixture of four species of shrubs (*Photinia x fraseri, Viburnum tinus, Prunus laurocerasus and Forsithia intermedia*) with similar size and characteristics. The plants were regularly irrigated with an automated irrigation system equipped with drippers, apart from the first period when the containers were observed during a drying-out experiment. The base station and the logging PC of the WSN were placed inside a nearby greenhouse, for better protection. The PC was connected to the Internet by means of an Ethernet wire and an ADSL modem located in the central office (see Figure 3), making it possible to control the system from a remote place (in our case Wageningen, the Netherlands).

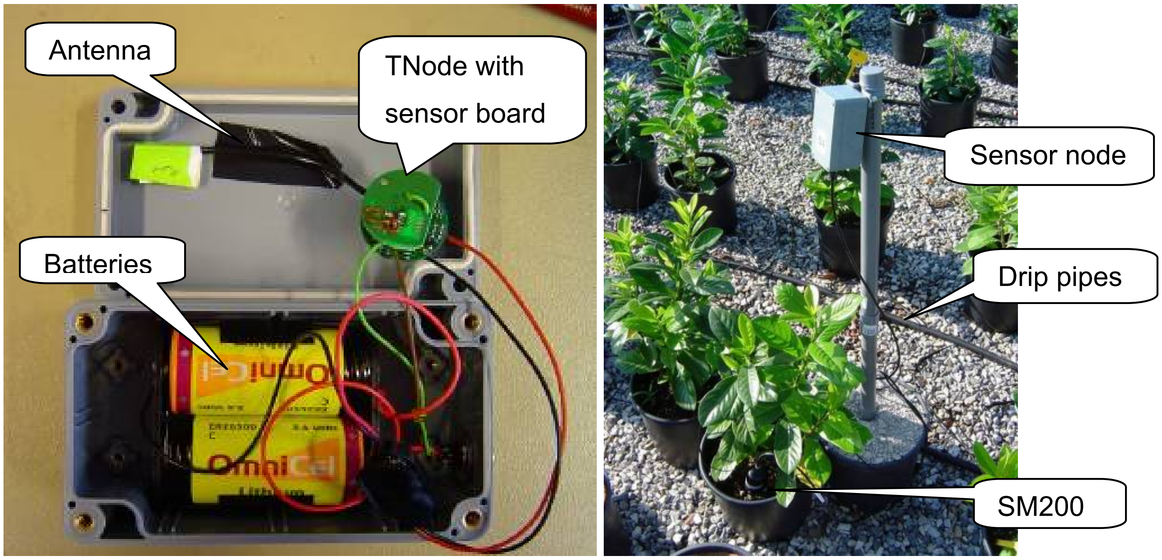

Figure 2 Open housing of one sensor node (left), single sensor node equipped with SM200 sensor in adjacent container (right).

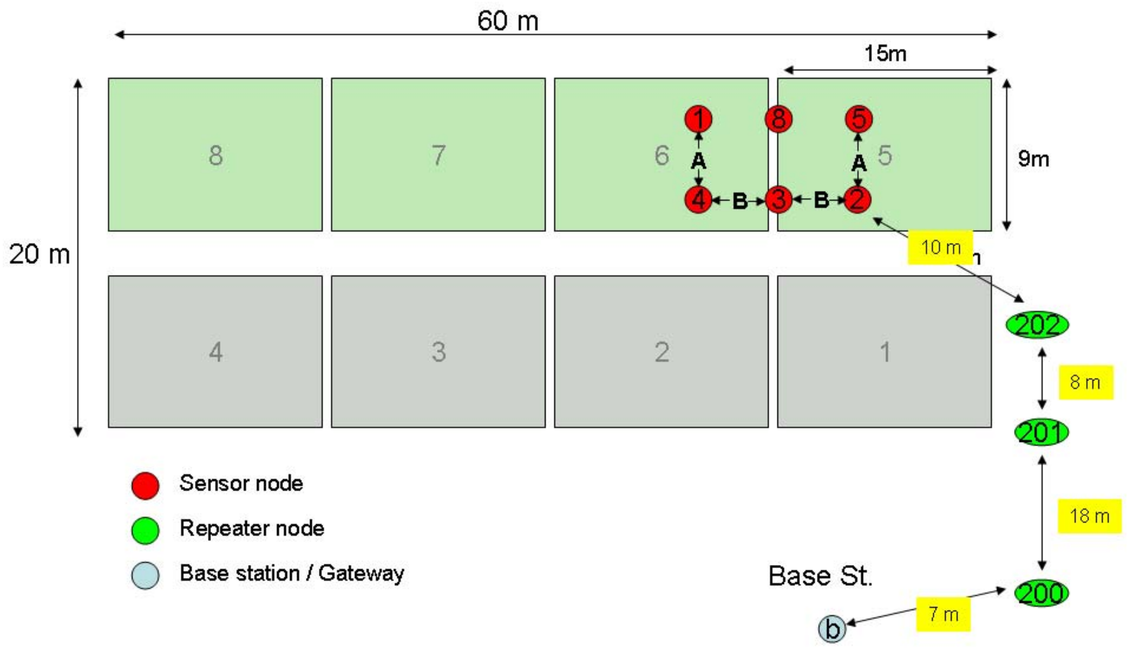

Figure 3 Set-up of the test plot and initial sensor node locations on 11-05-2007. Plots 1, 2, 3 and 4 were not equipped with container plants (A = 1 m, B = 2 m).

Six wireless sensor nodes (1, 2, 3, 4, 5 and 8) were used continuously within the experiment (see Figure 4).

Figure 4 WSN installed in potted plants at test-site in Pistoia (May 2007).

To bridge the distance between the base station/gateway in the greenhouse and the actual sensor network up to three repeaters (200, 201, 202) were used to route the data from the sensor grid to the base station. The distance between the repeater nodes was kept constant with an average spacing of about 10 m. In order to investigate the reliability of the overall system in regard to node-repeater distances, different geometrical positions of the nodes within the test field were realized (different spacing). The expected maximum range per node and/or repeater was 40 – 80 m. The horizontal spacing between the nodes was doubled step by step. The starting point was a rectangular short distance grid of 1 by 2 meters (C1). Due to the limited communication range observed in intermediate results the end configuration was a grid of 5 by 10 m (C3). Thereafter the sensor nodes were placed in a circular grid (C4) with fixed distance (4 m) to the repeater 201, which was replaced into the middle of plot number 5. The experiment started on 11th of May and was finished by 1st October 2007.

Table 2 Sensor node placement patterns (B = 2 × A).

Configuration	*C1*	*C2*	*C3*	*C4*
Pattern	rectangular	rectangular	rectangular	circular
Treatment	drying out	irrigated	irrigated	irrigated
Start date	11th of May	5th of June	13th of July	28th of August
Duration [days]	24	37	39	31
Distance A [m]	1	2	5	4
Distance B [m]	2	4	10	-

RESULTS

Sensor readings, as well as communication performance (missed readings and signal strengths) were monitored during the 5 months period of the experiment. First results of the on-going experimental work were presented in Balendonck et al. (2007).

Sensor readings

Figure 5 gives an overview of all sensor readings for the whole experimental season. Due to lack of a suitable volumetric water content calibration curve for the specific used soil (a peat-pumice mixture) all readings are displayed as permittivity values (ε). There is one major gap in data between 15th of July and 9th of August. In this period the system had a total breakdown which could finally be recovered by replacing the batteries of all repeaters.

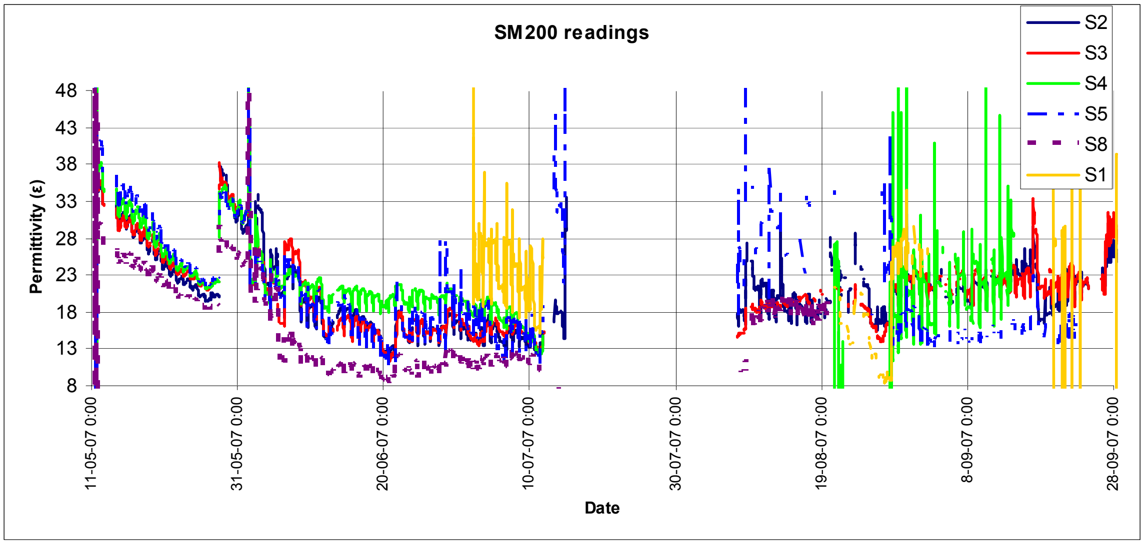

Figure 5. Overview sensor readings

Data reliability and robustness

From the number of missing data, the percentages of signal loss during the 4 periods were calculated and the results are shown in Table 3.

Table 3. Data reliability results: total number of readings, number of missed data packets and percentage signal loss for the 4 configurations during the experiment.

Configuration / Node	*1*	*2*	*3*	*4*	*5*	*8*	*Average*
Total measurements							
C1 (2×4 m)	n.a.	624	624	624	624	624	624
C2 (2×4 m)	528*	1728	1728	1728	1728	1728	1528
C3 (5×10 m)	n.a.	816	816	816	816	816	816
C4 (circular 4 m)	1488	1488	1488	1488	1488	1488	1488
Missed data packets							
C1	n.a.	45	46	31	31	31	37
C2	56	179	213	152	204	273	180
C3	n.a.	212	467	80	689	167	323
C4	797	270	310	292	678	1224	595
% Signal loss							
C1	n.a.	7.21	7.37	4.97	4.97	4.97	5.90
C2	10.61	10.36	12.33	8.80	11.81	15.80	11.62
C3	n.a.	25.98	57.23	9.80	84.44	20.47	39.58
C4	53.56	18.15	20.83	19.62	45.56	82.26	40.00

* node 1 available from 2-7 online

To evaluate whether the signal loss has a correlation with the distance between sensor and repeater, signal loss values versus distances were plotted in a graph (Figure 6). Only the sensors 4, 5 and 8 showed a data loss not more than 5%, but only for configuration C1. Data loss can go up to 100% and there is no correlation seen with the distance. Data from the circular experiment (C4) showed high signal losses even up to 80%. Since this experiment was at the end of the season, it might well be that the batteries tended to run out.

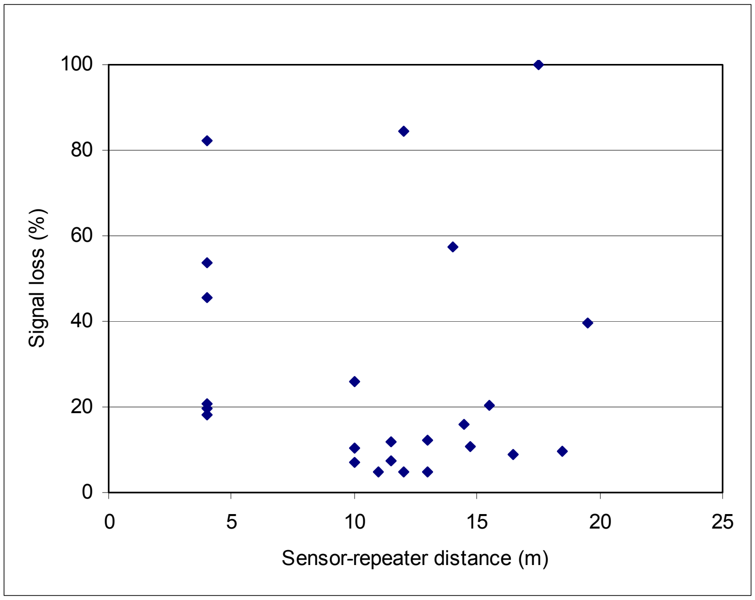

Figure 6. Data reliability in relation to the distance between sensor nodes and repeater. Distances were calculated based upon the distance between the sensor node and the nearest repeater.

Communication signal strength

The CC1000 radio chip has a built-in Received Signal Strength Indicator (RSSI) which can be used to obtain the power ratio in decibel (dBm). A low RSSI value represents a bad radio link, a high value a good radio link. The typical range is −60 to −80 dBm. Figure 7 shows the relation of RSSI from sensor node 8 with the measured relative air humidity for a period of two days. There is a correlation between relative humidity and measured signal strength. The received signal quality seems to be a few dBm better at high humidity values (60 – 90%) compared to lower humidity values (30 – 60%). Nevertheless the variation is within a very small band. For the two days showed here, there is a little higher signal strength around the peak values of relative humidity, in the early morning hours around 4:00h to 5:00h. At this time of the day condensation of water on the outside of the housing was observed which might have caused this behavior. This behavior was also observed by Thelen (2004) in a study on radio wave propagation in potato fields.

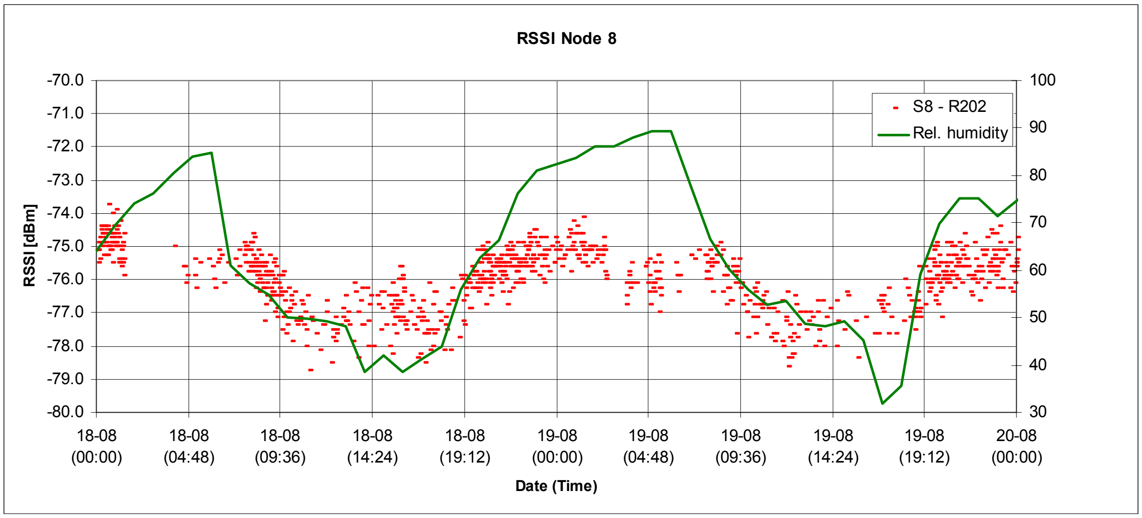

Figure 7 Relation of RSSI and measured relative humidity from sensor node 8 in the period 18-08 to 20-08.

DISCUSSION

The obtained data was analyzed with respect to the following seven design objectives.

1. Communication robustness (failure of nodes/repeaters)

Looking at Table 3 it can be seen that the WSN already has an average data loss of more than 5 % for nearly all configurations and sensor nodes. The defined requirement of a maximum of 5% data loss could not be fulfilled in this experiment. However, most of the results show a maximum data loss of 50% for a maximum distance of 20 m. Although we can not meet the initial requirement, it is likely that after tuning the system (f.i. a higher transmission power, or the use of an external and tuned antenna) we might succeed in a next experiment.

2. Maximum range of wireless communication between nodes

In general we observed a clear correlation between RSSI value and the distance node – repeater. By looking at Figure 6 however, we can only find a weak correlation for data losses in relation with distance, and only by discarding data from configuration C4. Looking in detail at data about the pathways data-packets generally use, we observed that in a significant amount of the cases (over 15%), data-packets were not sent to the nearest repeater, but to another repeater even double the distance away. This implies that signal propagation is sometimes hampered by more factors than only the distance between transmitter and receivers.

Signal strength is known to be dependant on the 3D-positioning of transmitter-receiver combinations. The internal wire antennas of sensor nodes as well as repeaters were all kept up-right in the same direction, to be sure that the maximum signal strengths could be obtained. No investigations were however performed for check the alignment of the nodes. It might be valuable to check the sensitivity of the signal performance due to this effect in future experiments.

3. Battery life time / power consumption

At 15th of July the whole system went off-line due to failure of the repeaters invoked by high temperatures. At 9th of August the batteries of all repeaters were replaced. From this day on the expected behavior of slowly reducing voltage was recorded. All this makes it difficult to interpret and discuss the results of the supply voltage measurement for the repeaters.

The sensor nodes were equipped with different type of batteries. The battery level of all the sensor nodes stayed very stable in the range of approximately 3.5 to 3.8 V in the first months of the experiment. Some sensor nodes showed a stable high battery voltage over the whole period of the experiment. Battery operation is shortened extremely (to maybe 1 - 2 months) when the sensor operates at high frequencies (f.i. 5 minutes sample interval). Part of the power is consumed by the SM200. The SM200 needs at least a power-up time of 1 s before readings are stable. The node concept could not cope with such small numbers, and instead a power-up time of 1 minute prior to a measurement was chosen. Probably this has lead to an excessive power use.

4. Suitability for outdoor usage (packaging as well as radio communication)

Weak point was the packaging. In some cases condensation was found inside the housing. The propagation conditions (f.i. humidity) have influence on the failure rate, but no statistically significant relation has been observed. The labeling (identification) was bad, and readability was influenced by the sun-radiation over time. The repeaters were exposed to direct sunlight. Probably the maximum temperature inside these nodes was exceeded what finally may have killed the batteries one time during the experiment.

The packaging concept should be re-designed in order to be able to cope with the high outside temperatures (e.g. integrate ventilation openings for cooling of the electronics/batteries). Beside this the antenna should be repositioned in order to enhance the signal quality of the wireless nodes.

5. Connectivity to other interfaces

The graphical user interface (GUI) of the WSN worked fine and sensor data and information about the network was logged continuously. Remote access to the PC using internet worked very stable and data transport from Italy to The Netherlands for further analysis worked fine.

6. Sensor performance

For the SM200 sensors, no soil specific calibration curves were available, since the standard curves from Delta-T were not suited for the peat-pumice mixtures used in the containers. A separate experiment with WET-sensors was performed to obtain these calibration curves as well as a good calibration for pore water EC (Incrocci, 2008). The readings of the SM200 sensors are very dependant on the way how they are inserted and have contact with the growing substrate. This is a commonly known aspect of dielectric soil moisture sensors. The inter-pot variability of sensor readings is very high, which can be expected for the highly porous growing media mixtures used, and their intrinsic high density variability. This makes it difficult to use an SM200 – or any other dielectric soil moisture sensor – for irrigation control in container crops without an in-situ calibration of the sensor. It might be worth-while to explore the use of dielectric soil matric potential sensors like proposed by Whalley et al. (2007).

There is a temperature influence on the sensor readings, and the effect has clearly a daily repetitive pattern. However, no correlation between the sensor deviation and the ambient temperature was found looking at data at the same time instances. Therefore we expect that this effect comes from a combination of effects like heating of the top soil and the sensor by direct radiation from the sun, as well as heating by the ambient air. To be able to compensate for this effect it is advisable to sensor companies to embed temperature sensors into their sensors so to be able to compensate for these effects. However, little references are found in literature about the nature of this effect. We expect that these effects are different for each available sensor type, so research on this is still needed.

An SM200 sensor measures only soil moisture content. It was chosen for convenience purposes since it has an analogue output which fits well to the analogue input of the transmitter/receiver boards. For future experiments it is desirable to measure EC as well. But, there are little sensors available that can measure soil moisture and EC based on a single sensor concept. For this purpose the Delta-T WET-sensor could be used, as well as the cheaper ECHO- EC5 probe with embedded EC-sensor (Decagon). However, the WET-sensor and ECHO-probe have digital interfaces and exhibit a higher price.

7. Cost price

No special attention was paid to the end-user cost-price of the sensor node in this phase of the research. The end-user price of the setup was estimated to be €200 for a single node and €250 for the SM200. In this estimation the cost for software, the host PC and development were not taken into account. The total price is high compared to the target price of €100. It could be reduced when sensor and WSN-node would be integrated into a single housing, but wave propagation works better above the canopy and a soil sensor must be in contact with the root zone. We might expect that as WSNs become more popular, prices for components will drop, but the cost for a good soil moisture and EC sensor is still high, and is not likely to drop within a short time. Most applications therefore still use the cheap Watermark sensor (Holler, 2007).

Recommendation for enhancements

The experiments in Pistoia to evaluate the long term robustness and reliability of the system under practical circumstances will continue over another 2 growing seasons. Every year the system will be enhanced according to the findings in the previous year. For the 2nd growing season we plan to use the existing WSN by adapting the transmitter power and changing the housing of the nodes. Recently, Holler (2007) reported on the successful use of the Crossbow Eko-Pro series self organizing WSN, in which Watermarks granular matrix soil moisture sensors were used. We intend to build another WSN based upon a new version receiver/transmitter node which has become available recently as a β-test version from Crossbow (US), using a full MESH topology. Based upon last year results, discussion with experts and looking for possibilities to update the system, the following enhancement are foreseen:

Signal strength

We will use a new antenna design, instead of using a “simple wire”. Either we use new small high gain antennas for PCB-mount (internal) or large high gain standard antennas for external mounting. To boost the antenna gain, we will look for ways to implement a ground-plane antenna configuration for the housing. Antenna gain and received signal strengths should be optimized in a new design by matching antenna and receiver/transmitter. Batteries form a large (metal) body that can influence the signal strength. Special attention must be paid to placement of batteries in the housing in relation to the antenna placement. We will enlarge the transmitter power for the current system, but we need to be aware that this will reduce the battery lifetime.

Housing

The housing should be adapted so that under Mediterranean practical conditions an under direct radiation, the internal content of the housing will never reach a higher temperature than the lithium batteries can withstand. The use of a double wall construction is recommended. Furthermore we look for ways to monitor internal temperature during next experiments.

Power supply

To save costs we want to use a single battery instead of two. The use of a solar power supply will be explored together with the Crossbow set. “Intelligent power management of nodes”, is highly recommended. Minami et al. (2005) report on a system in which the measurement frequency is changed according to actual needs from an irrigation operation point of view, as well as according to available power inside the WSN. We will explore ways whether we could implement such an approach into our WSN.

Sensors

We intend to build for the Crossbow system a hard- and software interface for a combined moisture and EC-sensor. Development and implementation of an in-situ calibration procedure to make readings per pot comparable is advisable.

CONCLUSIONS

This paper described the research goals of a specific targeted European 6th Framework project (FLOW-AID) aiming at optimal water management at farm level under deficit conditions. Focus of this paper was on the development and test of a low-power wireless sensor network capable of monitoring soil moisture content. Only intermediate results were reported, since the work started in October 2006 and is still on-going.

Six sensor nodes equipped with SM200 soil moisture probes and 3 repeaters were built and evaluated under practical Mediterranean conditions in Italy for container grown crops for a period of 5 months. The nodes were capable of relaying data to a repeater over a distance up to 20 m. However, the defined requirement of a maximum of 5% data loss could not be fulfilled. The battery lifetime of the sensor nodes was adequate providing that the nodes were configured correctly. Remote access to the WSN using Internet worked very stable and data transport from Italy to The Netherlands for further analysis worked fluently. Weak points of the overall system, including the packaging, were identified and form the fundamentals of the next generation WSN which is currently designed for the next season.

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