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Drip Irrigation System using Wireless Sensor Networks

I. Bennis*†, H. Fouchal†, O. Zytoune*‡, D. Aboutajdine*
*LRIT, unité associée au CNRST (URAC29), Université Mohammed V - Agdal, Rabat, Maroc
†Université de Reims Champagne-Ardenne, France
‡Université Ibn Tofail, Kénitra, Maroc
Email: ismail.bennis@etudiant.univ-reims.fr, hacene.fouchal@univ-reims.fr,
zytoune@univ-ibntofail.ac.ma, aboutaj@fsr.ac.ma

***Abstract*—Nowadays, adopting an optimized irrigation system has become a necessity due to the lack of the world water resource. Moreover, many researchers have treated this issue to improve the irrigation system by coupling the novel technologies from the information and communication field with the agricultural practices. The Wireless Sensor and Actuators Networks (WSANs) present a great example of this fusion. In this paper, we present a model architecture for a drip irrigation system using the WSANs. Our model includes the soil moisture, temperature and pressure sensors to monitor the irrigation operations. Specifically, we take into account the case where a system malfunction occurs, as when the pipes burst or the emitters block. Also, we differentiate two main traffic levels for the information transmitted by the WSAN, and we use an adequate priority-based routing protocol to achieve high QoS performance. Simulations conducted over the NS-2 simulator show promising results in terms of delay and Packet Delivery Ratio (PDR), mainly for the priority traffic.**

***Index Terms*—WSANs, Drip irrigation, Priority-based Routing.**

I. Introduction

DURING the last decade, the Precision Agriculture (PA) has emerged as novel trend to enhance the agricultural practices. The principal aim of the PA is to monitor the spatio-temporal characteristics of the agricultural parcel [1]. By this way, the crops yield can be optimized while the natural, financial and energetic resources can be preserved. However, since the monitored agricultural regions are generally scattered and suffer from a variable environmental conditions, the need for accurate and real-time collected information is more pronounced. Also, the classical solution as the satellite imagery, aircraft or other systems based on the map cannot be supported by all farmers due to their heavy cost. To overcome this limitation, the Wireless sensor networks (WSNs) were introduced into the agricultural environment context [2].

Technically, the sensor nodes are deployed into the farmland. They start to collect environmental information and monitor soil characteristics. Then, they cooperate according to designed protocols to communicate the collected information to a central node. After that, this information is processed and treated to make an eventual decision.

The WSN have been explored in different ways for the agriculture field. As example, in [3] the authors have used four nodes types: soil, environmental, water and gateway to monitor the water content, temperature and soil salinity at farm located in Spain. Another work presented in [4] where authors have designed a node system for the collection of farmland information at different growth period of wheat, typically: seeding, jointing and heading. The study focuses in the optimal antenna height to use at the different growth period. Further examples presented in [5] and in [6] concern the greenhouse monitoring and the water saving irrigation using the WSN.

The security aspect is another example of how can the WSN improve the agricultural yield. In fact, crops are negatively affected by human or animal intruders. Also, the production process is still insufficiently controlled which lead to a potential product loss. To overcome this point, the video-surveillance nodes can be used to detect and identify intruders as well as to better take care of the production process [7]. In addition, the video-surveillance system allows the farmers to protect their sensors and equipment being installed in the crops from theft or potential damage.

One of the most important application of the WSNs in the PA is the irrigation system control. The interest comes naturally from saving water. For this aim, many researches were conducted to enhance the irrigation control system by coupling novel technologies with the agricultural practices. Among irrigation strategies, the drip irrigation system was considered as the most efficient policy to save water use. Moreover, combining this strategy with the WSNs leads us to have a great benefit from the farmlands. However, the irrigation system reliability need more attention, mainly in the case of general or partial dysfunction. For this aim, we present in this paper a model architecture for a drip irrigation system using the WSANs. Our model includes the soil moisture, temperature and pressure sensors to monitor the irrigation operations. Specially, we take into consideration the case when a system dysfunction occurs, as when the pipes are broken or the emitters are blocked. Also, we differentiate two main traffic levels for the information transmitted by the WSAN. Furthermore, based on our previous work [8], we can achieve a high QoS performance through an adequate priority-based routing protocol. The aim was to ensure an efficient and real-time communication between the different nodes type and the sink.

The remainder of this paper is organized as follows: in section II, we review some related works designed for an efficient irrigation system. In section III, a description of our designed drip irrigation system is given. The priority-based protocol for DIS with simulation results are given in section IV. Finally, in section V, we draw the conclusion and give perspectives.

II. Related work

To the best of our knowledge, monitoring the dysfunction of the drip irrigation system using the WSNs with an adequate priority-based routing protocol was never suggested before in the specialized literature. Therefore, in this section we summarize some related works for the irrigation system control.

In [9], authors propose an energy efficient method for the wireless sensor communication used in an automated irrigation system. This method is based on the Time Division Multiple Accesses (TDMA) scheduling that allows nodes to turn ON/OFF their radio according to scheduled slots. The main advantage of such scheme is saving the node's energy and reducing radio interference. Also, authors give a comparison between two methods to transmit the collected data to the sink node; namely the direct communication method and the data fusion method. For each method, the energy consumed and the data throughput are studied over the NS2 simulator.

To optimize water use in agricultural context, authors propose in [10] an automated irrigation system based in the WSNs technology. The developed system is composed of two kinds of sensors to collect soil-moisture and temperature information. The sensors are placed in the root zone of the plants. Also, a gateway was used to gather sensor information, triggers actuators, and transmits data to a web application. To control the water quantity, authors had programmed into a microcontroller an algorithm with threshold values of temperature and soil moisture. Concerning the energy, photo-voltaic panels are used to power the system. The entire system can be controlled through a web page which help to program an irrigation schedule and performs a data inspection.

In [11], authors present practical irrigation management system using a deployed WSN. This system includes a remote monitoring mechanism through a GPRS module to send SMS message containing land characteristic such as soil temperature and soil moisture, or the network performances such as packet delivery ratio, RSSI or the nodes energy level. The main contribution of this paper is to design and implement a low-cost efficient irrigation management system that combines sensors and actuators in a wireless sensor/actuator network. Authors conclude through this study that the deployment of the sensor nodes in the agricultural field is a critical issue. Furthermore, they suggest that the distance between sensor nodes has to be as short as possible in order to enhance the effectiveness of the system. However, the main weakness of this study is that authors employ only five sensors for the experiment.

We conclude for all referred works, that authors don't take into consideration the case of irrigation system dysfunction. Also they don't use the pressure sensor to monitor the irrigation flow rate. In addition, no priority-based protocol is designed to distinguish the importance of the communicated information. In the following section we present our proposed drip irrigation system that can overtake the dysfunction case.

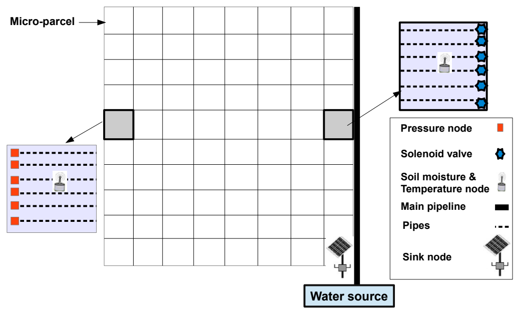

Fig. 1: Drip Irrigation System layout

III. Proposed Drip Irrigation System Model

Recent practices in precision agriculture include two main micro irrigation methods which promote interesting water efficiency. The first method is the drip irrigation. It allows water to be dripped to the plants roots through pipes containing several emitters. This irrigation system is composed of the following components: water source (generally is a tank) which is connected with a main tube called main pipeline. To this line, several pipes are connected using manual or electrical valves that control the water flow. The pipes go through the field and distribute water for each plant.

The second method is the sprinkler irrigation which delivers water through a pressurized pipe network to the nozzles of sprinkler which spray the water into the air [12]. However, this method is less efficient than the drip one, since more water is losing due to evaporation and runoff. Therefore we choose the drip strategy for our design.

Our proposed model is a closed-loop model. As defined in [13], a system can be categorized as a closed-loop model if the response of the system is monitored and used to adjust the control. We note also that our proposed model is designed for a site-specific irrigation where the crops are characterized by a spatio-temporal variation of the irrigation requirements. The variability comes from the soil type, crop type, crop and meteorological conditions [13]. The main purpose of our design is to handle the dysfunctional situation of the drip installation. As discussed in [7], the crops are negatively affected by human or animals intruders. This is more critical in the case of drip irrigation installation. In fact, the pipes can be broken by rangers or by accident which can cause water waste and plants damage. Also the pipe emitters can be blocked due to environmental condition (sludge, sand) which can cause plant stress. To overtake these shortcoming the water flow rate into the drip installation must be monitored. For this aim, our proposed system include the following sensors and actuators:

- Soil moisture sensor: It is used to optimize irrigation and to warn of plant stress by controlling some parameters such as the electrical conductivity of soil or the underground volumetric water content (VWC). Measuring the soil moisture can help the farmers to manage their irrigation systems more efficiently by using less water to grow a crop and increasing quality and yields.

- Temperature sensor: It is used to monitor the ambient temperature. It can be analog or digital and help farmer to adjust their irrigation schedule according the temperature measured to avoid risk of evaporation.
- Pressure sensor: It is used to measure a pressure of gases or liquids and change it into a quantity that can be processed electronically. It generates a signal as a function of the pressure imposed. In irrigation application, this kind of sensor helps to monitor the abnormal pressure of pipe installation. In such case, by means of communication module (Zigbee/802.15.4), a message can be transmitted to the corresponding solenoid valve or the master valve (which control the main pipe) to shut down the system. A very low pressure value can be synonymous of a broken pipe or failure to open valves. Having a high pressure value can indicate that a valve is not closed correctly or some emitters are blocked.
- Solenoid valve: It is an electromechanical valve for use with liquid or gas controlled by running or stopping an electrical current through a solenoid, which is a coil of wire, thus changing the state of the valve [14]. Combined with a Zigbee module, the valve can be controlled trough wireless communication. Concerning the energy issue, the valve can have an external energy sources as solar panel.
- Sink node: It corresponds to the gateway of the system. All sensor nodes in the topology need to forward their gathered information to the sink node to be processed. Also, through this node, a request commands are generated to corresponding actuators or sensors.

An illustration of drip irrigation system with a deployment of the WSANs is shown in Fig .1

A. Deployment strategy

Deploying the sensor nodes to monitor a farmland is crucial issue. In fact, many parameters must be considered to choose the most beneficial deployment, as the crops characteristics, the micro meteorological parameters, the sensors and nodes specification and obviously the farmer's budget. According to a generic guide proposed in [15] the coverage of the sensor nodes in agricultural WSN must be dense. By this way, all the required measurements can be gathered to have reliable knowledge of the monitored area. Authors in this guide argue that for a field with 100 m^2 size, at least 80-90 nodes are needed. They consider roughly 1 sensor node per 1 m^2. Of course, with such density we can reduce the sensors transmission power to the lowest level to save energy. In addition to have an adequate number of nodes, the topology formation must be determined. Among start, tree, or grid topology, the right choice depends to field's size and the plants formation. However, for middle or high surface, the grid topology remains the most suitable.

Based on the above discussion, we choose the grid topology for our drip irrigation design. We divide the field area into several equal micro parcel as suggested in [16]. The size of the parcel must be a trade-off between monitoring quality required, the communication coverage and the deployment cost. In the middle of each parcel we fix a soil moisture and temperature node. We make the assumption that the soil moisture and the temperature remain the same inside the parcel.

B. Communication strategy

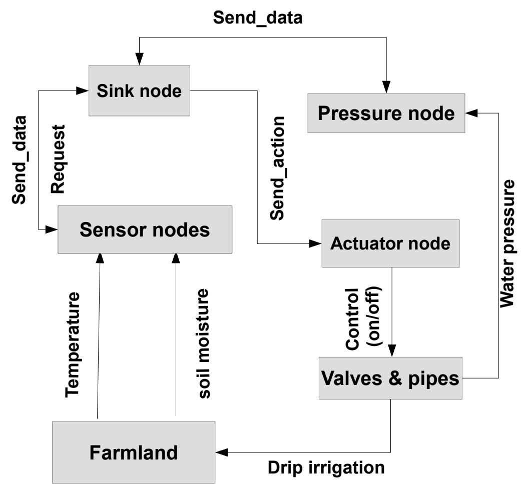

Fig. 2: Drip Irrigation System communication

In Fig. 2 we present a flowchart of the communication between all actors in the designed drip irrigation system. The sensor nodes gather the temperature and the soil moisture from the farmland periodically. According the value obtained, the sensor nodes decide to send the information to the sink or not. At the sink node, the abnormal information is processed and an eventual decision is taken to adjust the irrigation schedule according to the plant requirement. The same irrigation schedule is transmitted to the pressure nodes to be awakened at the same time of irrigation process. Once the actuators receive an action from the sink, they control their corresponding valves to be opened or closed. If the valves are opened, the water flow goes through the pipes and the pressure nodes start sensing. If any abnormal pressure value is gathered, an alert message is transmitted to the sink node to shut down the irrigation process and request an external human verification of the pipe installation.

We make the assumption that the sensor nodes communicate only with the sink node through a multi-hop protocol. Also, the actuators receive only actions from the sink. We assume also that the sink node can request some information from the sensor nodes at any time.

IV. Priority-based DISM

A. Priority-based protocol

As discussed in section III, we have two main traffic type gathered from sensors. The first one related to information gathered from temperature and the soil moisture sensors. We classify this traffic type as normal traffic since no need for an urgent intervention is required. The second traffic type is related to information gathered from pressure sensors. We classify this traffic type as priority traffic due to the need for an emergency resolution of the detected problem (shut off the main valve, require human intervention ... etc). Now, in the case when both traffics are active simultaneously, it is clear that the reliability and the timeliness of the priority traffic is more requested than those of the normal traffic.

However, in the wireless context, there are many troubles that can occur due to the sharing of the same communication medium. Among these problems we cite the interference problem, the exposed and the hidden problem [17]. Another problem that must be considered is the effect of the carrier sense range on communication performances. As discussed in our previous work [8], the carrier sense range is usually more larger than the transmission and the interference range. So carefully routing process must be applied to avoid any trouble between multiple sources and to satisfy the requested QoS for each traffic.

Let us take the example presented in Fig. 3. Two source nodes need to send their data to the sink. The first source node A sends a priority traffic and the source node B sends a normal traffic. We make the assumption that only one path is constructed from each source node. The circle presented around each node represents the transmission range. We avoid adding the carrier sense range in the figure to not overload it. As shown in Fig. 3, the black path refers to the path constructed from the node A to the sink node. After that, the node B needs to find out a valid path to reach the sink. If the red path is chosen, then all the nodes from the black path and the red one will be in concurrence to access to the communication medium which will degrade the final performance. The green lines represent relation between these nodes. To avoid such situation, the node A must construct the blue path. Thus, even if the number of hops is higher the performances at the sink node are better. In what follow we will describe how the two paths can be constructed.

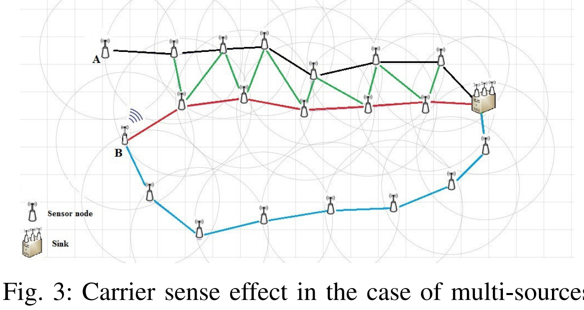

Fig. 3: Carrier sense effect in the case of multi-sources

B. Protocol description

Based on our previous work [8], we design a routing protocol that can allow the priority source node (namely the pressure node) to construct an efficient routing path while avoiding the carrier sense range effect. In this work we make the assumption that nodes are aware of their positions and the position of the sink node. In the following, we give a short description of how the paths are constructed according to our approach.

When a priority source node seeks to communicate with the destination, it sets up a route discovery process by sending a priority forward agent (P-FAGT) to construct a short multi-hop path. The choice of the next hop node is based on the geographic information available at each node. For each selected node i, the node state is changed from free to busy, and a Hello message is broadcasted to all neighbors in the communication range to notify the new state of the node i. Every neighbor node j of the node i becomes a banish node, that means it cannot be selected for any communication. After that, each node j broadcasts in its turn a hello message in their neighborhood. Now, if a normal source node needs to send some information, it constructs the routing path by sending a normal forward agent (N-FAGT) which must respect the following rules: the next hop must not be blocked, and must not be a banish node or having a banish node in its neighborhood. A node is in a blocked state when the destination is unreachable through this node. To avoid a blocking situation when a node cannot reach the destination, we use the same principle as in [18], called the step-back method. The same method is used by the agent when the selected next hop has a banish node in its neighborhood.

Once the destination is reached, the forward agent (either P-FAGT or N-FAGT) becomes a backward agent and an optimized reverse path is travelled. At each intermediate node, the agent records the valid next hop into the routing table, after that, it chooses from the reverse path the nearest neighbor to the current node. The same procedure is repeated until reaching the source node.

In the case where the P-FAGT finds an already constructed path (used by a normal source), it follows this path and changes the state information of all nodes involved in it. After that, the normal source is informed by a special agent to start another discovery phase to take into consideration the current priority source communication.

When the communication is ended, all the nodes altered by the communication process reset their state and become ready for further transmissions. In the remaining of this paper, we denote our approach by Carrier Sense Aware (CSA).

C. Simulation & result analysis

Working environment

Our simulation scenario is based on the topology presented in Fig.1. The topology area is 200*200 m^2, and the total number of nodes is 280 (including pressure, temperature/soil moisture and valve nodes). We make the assumption that the micro parcel size is 20 m^2. Two random source nodes (pressure and temperature/soil moisture) are selected and start transmission at different instance but in the same interval time. To distinguish the two traffic in the simulation in the NS2 simulator [19], we choose for the temperature/soil moisture source node a constant bit rate (CBR) traffic with **X** packets per second, where:

$$X=\{8,16,24,32\}$$

For the pressure source node, we choose an exponential traffic (Exp) with a data rate equals to 20 Kbytes. The duration of communication is 30 s, and no mobility is supported in this scenario. For every value of **X**, 20 scenarios are generated and the average value of results is computed. We present the results with a confidence interval of 95%. According to the characteristic of the MicaZ node [20] and the two-ray-ground propagation model equation, we define the reception and the carrier sense threshold (RXThreshold and CSThreshold). Their respective value was $3.981{*}10^{-13}$ Watt and $3.981{*}10^{-14}$ Watt which represent nearly 20 m for the transmission range and 35 m for the carrier sense range. We compare our work with the Two Phase geographical Greedy Forwarding (TPGF) protocol [18] since it adopts also a geographical approach.

Table I summarizes the parameters used for simulation.

TABLE I: Main configuration parameters

Parameters	value
link layer	LL
MAC layer	IEEE 802.15.4
radio propagation	two ray ground
interface queue	PriQueue
ifqlen	50
antenna	omni-antenna
Antenna height (m)	0.0864
Frequency	2.4 GHz
$CPThreshold$ (dB)	10
$CSThreshold$ (Watt)	$3.981 * 10^{-14}$
$RXThreshold$ (Watt)	$3.981 * 10^{-13}$
Pt (Watts)	0.001
Packet size	100 Bytes

Result analysis

We start our analysis by studying the PDR metrics for both normal and priority traffic. From Fig. 4, which represents the PDR for the normal traffic, we can see that, for both protocols, the PDR decreases as the number of Packet Per Second (PPS) increases. It is quite expected since more the traffic is higher more the collision likelihood is higher too. For the CSA protocol, it has the higher PDR between 8 and 24 PPS, after that, the PDR becomes slightly lower than that of the TPGF. We explain such behavior by the constructed paths of each protocol. In fact, the CSA protocol builds path for the normal traffic while avoiding any banish node as described in subsection IV-B. Concerning the TPGF path, it builds paths according to the greedy forwarding mechanism, so shorter paths are constructed. Therefore, the number of hops in the case of the CSA is higher than that of the TPGF. We can tolerate such performance, since the normal traffic is usually loss-tolerant.

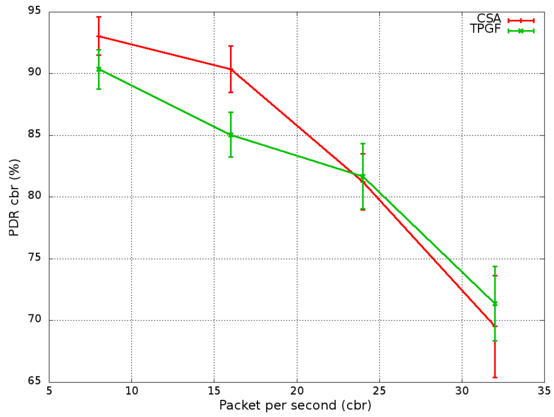

Fig. 4: Average PDR of normal traffic vs packet per second

For Fig. 5, which represents the PDR for the priority traffic, we can see also that, for both protocols, the PDR decreases as the number of PPS increases. However, it is clear that the CSA protocol achieves higher PDR than the TPGF. The PDR gain can reach 20%. For the TPGF, it provides a poor PDR value mainly when the traffic rate increases. Such performance cannot be acceptable for the priority traffic, which is almost loss-intolerant. In fact, as discussed in subsection IV-A, the carrier sense range effect occurs when a node cannot transmit when another node in its carrier sense range is already in transmitting phase. Therefore, when the number of PPS is higher, the nodes of all paths deprive mutually the channel access since there is a competition between them. Thus, the likelihood of loss packet is more pronounced.

In Fig. 6, the delay for both protocols in the case of priority traffic is depicted. As first observation, we can see that the delay increases as the number of PPS increases. We can see also that the CSA protocol provides a lower delay compared to the TPGF protocol. It is quite expected since the construction path process in the CSA protocol, ensures that the priority traffic will not be disturbed by any communication in the neighborhood. Such performance is suitable for the priority traffic which is usually delay sensitive.

V. Conclusion and Future Work

In this paper, we have presented a model architecture for a drip irrigation system using the WSANs. Our model includes the soil moisture, temperature and pressure sensors to monitor the irrigation operations. Specially, we take into account the case where a system malfunction occurs, as when the pipes are broken or the emitters are blocked. Also, we differentiate two main traffic levels for the information transmitted by the WSAN, and based on our previous work, we achieve a high

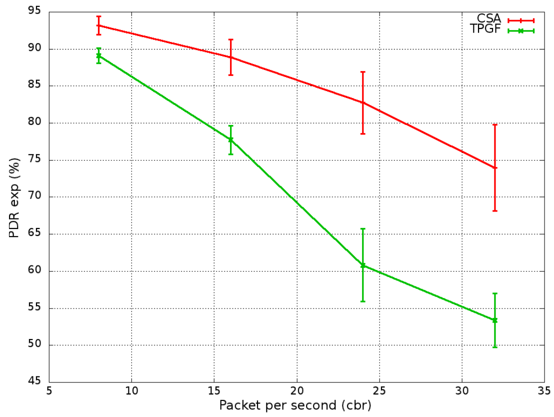

Fig. 5: Average PDR of priority traffic vs packet per second

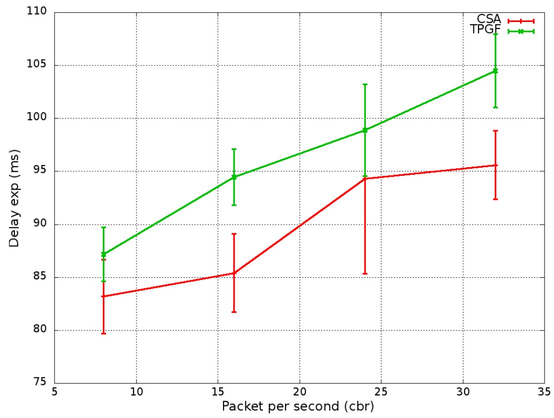

Fig. 6: Average delay of priority traffic vs packet per second

QoS performance through an adequate priority-based routing protocol.

We have performed extensive simulations. The results prove that our solution gives better performances in terms of delay, PDR for the priority traffic. As a future work, we intend to realize a real test-bed to investigate the effectiveness of our approach.

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