Topology of a network for wireless transmission of data for use in precision agriculture

Alex L. Guedes[1], Maria B. de M. França[1], José A. de França[1], Marcela H. Koyama[1], Marcelo G. Canteri [2]

[1]Departamento de Engenharia Elétrica, [2] Departamento de Agronomia , Universidade Estadual de Londrina, Cx postal 6025, CEP 86051-980, Londrina, PR, Brazil.

Abstract. Weather conditions influences the plant disease progress. Precision agriculture, besides variability of soil, could measure meteorological variables like wetness and temperature for monitoring plant pathogens infection periods. This assessment is carried out in many points of crop area and data set could be sent remotely to a device called "coordinator", using a cable as transmission line. However, a cable network in a crop area has a high cost and presents operational difficulties. The objective of this work was to develop a wireless data communication between meteorological stations. The "coordinator" device has total control over the network. It asks for data to be transmitted and which station will receive the data, creating a communication system type question/answer. The network also incorporates the multi-hop concept, where the data do not need to be transmitted directly, but through routers, increasing the depth of the network. This logic was implemented through the local address of each device. Prototypes of meteorological stations using microcontroller were built to tests the system. The results showed that the network work satisfactorily when the distance between meteorological stations was 1800 meters or less. This enables them to be installed throughout a crop area.

Keywords: wireless communication net, ZigBee, agro-meteorological station, climatic monitoring, precision farming.

Introduction

Climatic parameters like temperature and humidity determine beings' alive development (Sentelhas et al., 2004; Bonde et al., 2007; Vale and Zambolim, 1996). This way, with the knowledge of the climatic variables and of the way how these influence the organisms, can get efficient pests warning systems (Sentelhas et al., 2006). Usually, such systems use agro-meteorological stations to monitor the climate.

An agro-meteorological station can measure environmental greatness like air and soil temperature and humidity, wind speed and direction, solar radiation, precipitation or leaf wetness, among others. The measurement should occur at a constant rate, so that the climatic variations be measured satisfactorily, however, is not viable a monitoring system constant.

Influenced by conditions like the altitude, variables like the temperature and humidity can present great variations, even in small areas cultivation, creating micro-climate (Magarey et al., 2001). Thus, if necessary to improve precision in the data should be increased the numbers of agro-meteorological stations, creating an acquisition system of decentralized data. However, even in this kind of system, to facilitate the analysis, the data should be stored in a centralized form, in devices usually called coordinator, responsible for the measurement processing. That only is possible if the stations are in a network.

The connection of stations in a network is critical. The distance among stations and the working conditions in the field using agricultural machines became unviable the use of wires for communication. This work presents a low cost solution for the wireless communication among stations. A coordinator station has total control on the net, asking data and sending commands. The main characteristic is the use of the data multiple jumps concept, in other words, the coordinator station does not need to send directly one datum for a station, but do use other stations that can act like routers. It is possible to increase the net depth and number of the stations in a property to a relatively low cost.

This work will be integrated to a agro-meteorological station system for monitoring the temperature, leaf wetness, relative humidity, wind direction and intensity. In this system, the reads of every climatic variable will be made in an hour interval and the data will be made available daily for the coordinator station through of this proposed protocol (Koyama, 2009).

Proposed System

The network was developed using the “tree” topology, being formed by two basic components: coordinator and router. A tree configuration or tree topology is a physical characterization of an object (agro-meteorological stations), that by its configuration resembles to a tree, in the sense in which its branches tend to converge for a root or a source (coordinator). By definition, a tree is constituted by knots. A knot of a tree is the unitary element of the tree. It could originate other knots. The Figure 1 presents an example of a tree configuration, where every number is a knot.

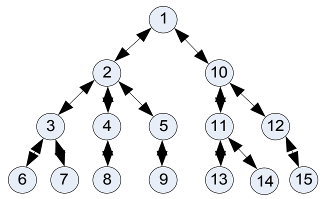

Figure 1: tree topology diagram.

The coordinator is the main knot of the net. Through its, the whole network can be commanded. All the other devices are named routers. They allow to expand the network, serving as a repeater of the received data. When the coordinator chooses a router to ask the data of his station, the same also can be named final device.

Physically, the data transmission is accomplished by the module X-Bee PRO from MaxStream, a communication device RF who follows the communication standard ZigBee, developed by the ZigBee Alliance close to IEEE (IEEE, 2003). The main characteristics of this standard are the low energy consumption, safety and low cost. It is an ideal standard to be used in systems that demand great energy autonomy, because the devices are able of “hibernate” (sleep) when not used. In Brazil, the nets ZigBee work on frequency of 2,4 GHz in 16 channels, without need a license for operation (IEEE, 2003). The device X-Bee PRO® owns serial communication RS232 and should be configured previously for transmission Broadcast (radial transmission where all the devices within reach of the signal receive the data).

A router is named primary when between him and the coordinator exists only a jump, in other words, occurs direct communication between him and the coordinator. A secondary or tertiary router is relative to the number of data jumps until reach him. The coordinator is the tree root so, the smaller degree routers have larger importance for the net. For example, if there are failure in a router, how much smaller the degree of the same, larger the number of devices that will be inaccessible to the coordinator, determining its importance for the network..

Logic for the local addresses

Thee multiple jumps concept was implemented by a system of local address for the stations. Knowing the local address of a station was possible to determine all the routers that was between it and the coordinator. That enabled to determine the way that the data ran from the coordinator to the destiny, or from itself to the coordinator (question/answer system).

In the logic developed, the most significant number in a local address of a station is determined by the coordinator. There is only a coordinator in a net, so this first digit is common to all the devices. The second more significant digit is determined by the primary router of each tree branch, in other words, in that branch all the devices will have the same digit. The third more significant digit is determined by the secondary router, and so forth. The digit ‘0’ represents the nonexistence, or not importance, of the nearby routers for a specific transmission, in other words, if a destination address of a package of data is “XY00”, it is known that the addressee is a primary router, soon, secondary or tertiary routers are not important for the transmission of that data package.

A system with four hexadecimal digits of address can implement up to three data jumps, and to shelter up to 3616 devices. The biggest advantage of this logic is that this address is done in the microcontroller of the station, not depending on the transmission device. That enables the enlargement of this logic until a net has the depth that was wished or shelter the number of necessary stations. The main disadvantage is the fact of this net to be fixed, in other words, the local address is specific for every station and should be established in microcontroller at the recording moment.

If the destination address of a package is “FFFF” it understands that the package had origin in the coordinator and this message is common to all net. This way, the routers should send again this package before checking which the command was sent by coordinator. This option is important so that all the network can execute determined functions at the same time, such as enter low consumption way or to synchronize clocks.

Implementation

To implement the network with the definitions presented up to now, the routers program was developed starting from a state machine shown in Figure 2 and in the Table 1:

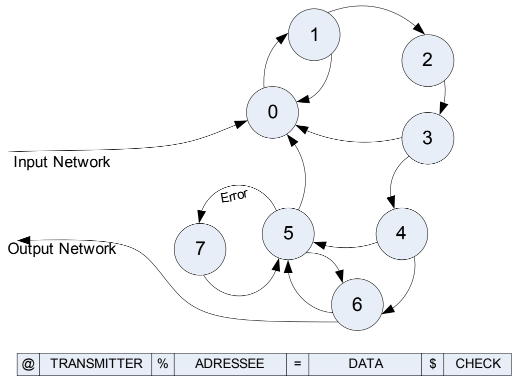

Figure 2: Routers state machine and data frame used at the station network.

Table 1: Description of states of routers machine.

State	Task
Start definitions	Defined local address. XBEE® device configured for Broadcast transmission.
0	It expects receiving the byte at the beginning of the data package.
1	It receives a data package. If the package is correct then it goes to the state 2, else it comes back to the 0.
2	It determines if the received package is addressed to the coordinator.
3	Through the logic of local addresses, it determines if the data should be retransmitted (it goes to the state 4) or not (it comes back to the state 0).
4	It determines if the local station is the data package destination. If it is true, it goes to the state 6, if not, for the state 5.
5	It sends a data package. If the transmission occurs with success, it goes to the state 0, otherwise, to the state 7. If the data is a message for whole network, after the transmission the machine goes to the state 6.
6	If the destination is local station, it determines through the data received, which the answer that the coordinator waits and sends it in response to the state 5. The coordinator can send the net disconnection command, leaving the state machine.
7	It generates a mistake report indicating that the station did not receive a data package with success.

The Figure 2 shows the frame for transmission of a data package. For a package be successfully received, the transmitter should send the character ‘@’ to mark the start of the data package and then to send its local address, followed by ‘%’. After it is sent addressee's address, followed by the character ‘=’. After these transmission stages, is sent a data or command, that is concluded by ‘$’. The validation is made through a check byte. This byte corresponds to the least significant of the sum of all the characters sent and received. Thus, if the validation byte is not alike so much in the transmitter as in the receiver, it is known that there was mistake in the transmission and the package is considered disable.

Implementation of a Case

The validation of the proposed system was made by a station network with five micro-stations and a coordinator. The micro-stations used MSP430F2013 microcontrollers from Texas Instruments and measured the temperature through the sensor LM92, from National Semiconductors. The temperature sensor uses the serial communication I2C and read the temperature with resolution of 0.0625 ºC. The blocks diagram of the micro-station is shown in Figure 3. The Figure 4 shows a Picture of the micro-station used in the test.

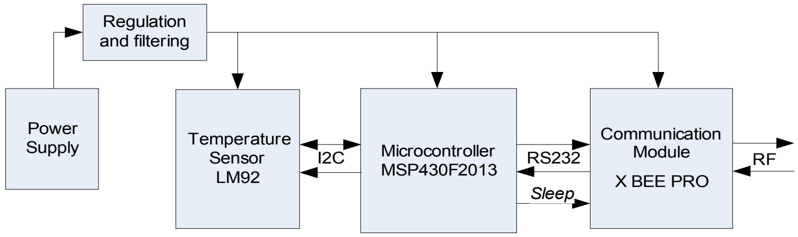

Figure 3: Block diagram of the test micro-stations.

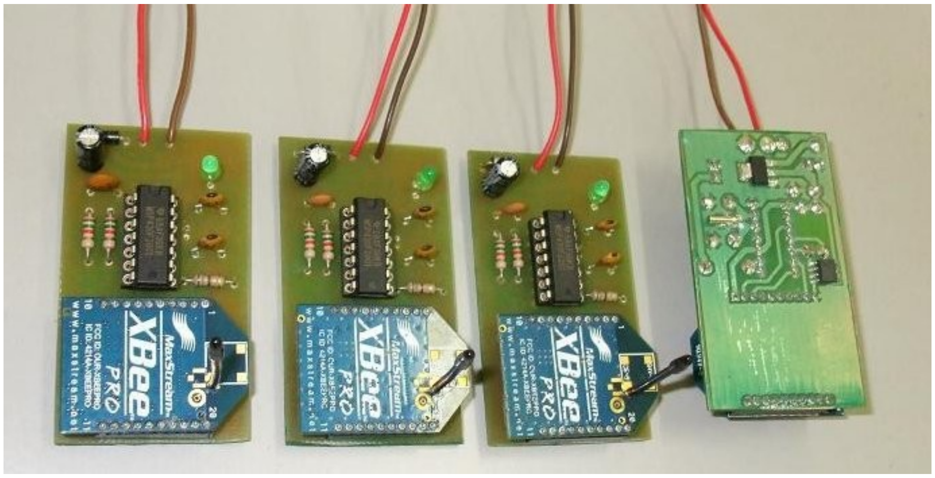

Figure 4: Micro-station used in the test.

The coordinator was implemented with a microcontroller PIC16F877 using language C. It read uninterruptedly all the devices in the net, taking the ambient temperature of every micro-station and showing the measurement in a LCD display for about 2 seconds. This system is able to recognize up to four abnormal situations of operation: Mistake in the temperature sensor of a station, if the station did not recognize the asked data, if any device was turned off or with some mistake and if the data package was lost. It also is possible send commands for all the net devices through the coordinator. These commands will be used for clock synchronization.

In the test network a station can receive two packages of valid data: first one asks for temperature and the second one is a command to go out from the state machine. If it received a data package asking the temperature, the station read the LM92 through communication I2C and answers to the coordinator. If are not possible to do this reading, the station sends the answer that the solicitation was not attended because, or the temperature sensor or the communication I2C, have a mistake. If there is a command to go out from the state machine, the station will light a LED indicating not waiting data and will reboot, being off-line for about two seconds. If the data package contains some different solicitation, the station will answer to the coordinator who the package was not comprehended.

If some net device is damaged or for some reason do not answer when asked, the previous router generates a mistake report and sends it to the coordinator, in such a manner that the coordinator knows if any net knot is not reviewing the data. If the coordinator sent a package with success, but do not receive answer in about 2 seconds, it supposes that there was an unknown mistake and the data was dispersed.

The local addresses were written with four hexadecimal digits using ASCII. The Figure 5 presents the net diagram, being possible to observe the system of multiple jumps, the "tree" topology, the numeration adopted for every station and its respective local address.

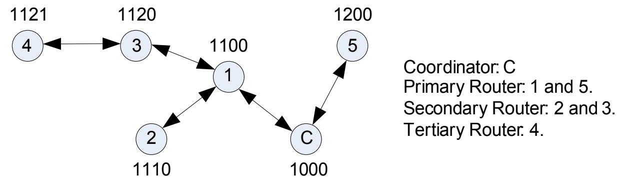

Figure 5: Diagram for the implemented test net.

To validate the algorithm, the net presented in the Figure 5 was tested in the Department of Electric Engineering of the State University of Londrina (UEL). First test was made with about 10 meters distance among stations. This distance allowed communication among stations without data loss caused by device XBEE PRO®, being possible to control the mistake situations. They were followed the next steps to test the net and the possible failures that could occur:

1. Sent an unknown question for every station.
2. Sent a valid data package with the stations turned off.
3. Provoked mistake in the temperature sensor reading of the stations.
4. Simulation of data dispersion. The coordinator sends a valid package, but does not receive answer or some mistake message of the cases 1, 2 or 3.
5. Transmission test of a same message for all the net simultaneously.
6. Normal operation of the net, sending and receiving valid packages contend the ambient temperature for every station.

In the situation 1, when receiving an unknown solicitation, the stations answer with the character scheduled to indicate that the question is disabling. This mistake can be caused by incompatibility between coordinator and routers or some mistake in the coordinator, therefore its minimum probability of occurrence. The situation 2 is common to happen in a real net, because can be caused by any problem that can forbid the station of receiving or to transmit a data, such as failure in the energy circuit or in reception/transmission RF. This way, as verified in this test, the previous router to that presents mistake elaborates a report and answers to the coordinator the local address of the station that failed. This way, it is possible to determine quickly a defective station.

The situation 3 occurs when there is some abnormality in the temperature sensor, or with interlinking with microcontroller. This mistake occurs if the bit acknowledge of the protocol I2C is not received by the master during the temperature reading. If there are any failure in transmission/reception of a data package during the answer of a station to the coordinator, it can describes by the situation 4, in other words, the data is considered lost. This mistake is unlikely of happen, because when sending coordinator's question, also does itself a stations test until the destiny device. Therefore it is unlikely that during the answer some device presents mistake. This failure can be detected or contoured with the transmission of a new question by the coordinator

If a message is common to whole net, there is the option of sending the data for all the stations simultaneously. This was the fifth step of the accomplished test. This option will be used to synchronize the stations clocks and to do the net enter low consumption way, however in this test, a LED was activated to indicate the receipt of this command.

The last accomplished test was a normal situation: all the stations turned on and the coordinator asking the ambient temperature of every one of time to time. In these tests was shown that the coordinator has net total control, recognizing problems and relating the data received with the respective station. The routers work without human intervention, and if the same is necessary, is possible to determine through the coordinator which station presents problems, turning the solution fast and direct.

Conclusion

Agro-meteorological stations are used to climatic record. They are used in extensive areas and its necessary reliability for variable measure, so several stations need to work together and connected to a network. The construction of this net of agro-meteorological stations is critical, because long distance among them avoid using wires. In this work, it presented a solution for the communication using wireless. A coordinating device asks the data to be transmitted and which station will receive it, creating a system question/answer. The data does not need to be transmitted directly, could be reviewed until the destiny, through routers. Thus, the net depth increases and enables the stations installation along all a property for a low cost.

The accomplished tests showed that the proposed protocol is functional and not bolt or stays in loops. The tests used conditions that can occur in the net when installed in a plantation. Thus, it would be possible to determine through the coordinator which the failure and which station presented problem, in other words, the coordinator has total control on the implemented net.

The main advantage of the proposed system is the low cost. The net works directly in the microcontroller, without depending of the device of communication. This way, it can migrate easily for other RF's transmission/reception, and as the system is implemented with the multiple jumps concept, these devices need not necessarily to have a great reach of transmission.

The next step will be to join it to a low cost micro-stations system to be used in soybean plantations. In the future also will be studied a form of turning this protocol even more functional, making the coordinator distributes local addresses for the stations, what will facilitate in the system installation (Koyama, 2009).

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