An improved low power wireless sensor network based on ZigBee for agricultural applications

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Abstract: - This paper presents a low power ZigBee sensor network characterized by bidirectional communication and control of inter-node data pack reception designed for use in agricultural fields. The network consists of end devices with sensors, routers that propagate the network over larger distances, and a coordinator that communicates with the computer, which in turns illustrates the data and controls the entire system. The end devices provide data from the sensors to the personal computer, at variable time points determined by the central node, which control the water flow to the plants in a greenhouse. As part of the investigation, extensive studies were performed to reduce the data packets loss. The algorithm developed at the end devices and the coordinator for this purpose is described in detail. Finally, the circuit that drives the humidity sensor, which contributes reducing power consumption and increasing the system's life time, is presented.

Key-Words: - Wireless sensor, Low power, Agriculture management, ZigBee

1 Introduction

The wireless sensor network (WSN) is a wireless network which consists of autonomous devices that utilize sensors for the monitoring of environmental conditions. The use of wireless communication allows placing sensors at distant and potentially difficult to access/wiring-up locations. As well as it makes easy to introduce additional nodes to the existing network. Moreover, each node contains incorporated micro-processors which make data analysis easier. The use of ZigBee technology in wireless sensor networks offers further capabilities such as the non-demanding set-up and extension, the low operation cost and the small size.

Wireless sensor networks are used in many industrial and civilian domains. Lately, there has been significant interest as regards agricultural monitoring and water resources management [1-2]. Additionally, several studies and applications have been carried out in a greenhouse settlement and to monitor the environmental changes during all stages of development of agricultural products [3].

In studies of WSN based on ZigBee technology, the low power consumption has been a major point of focus. Although the ZigBee modules are low power, the sensors being placed in nodes tend to increase consumption dramatically. A lot of work has been done as concerns power consumption focusing on the improvement of circuits and algorithms [4-5]. In this case study a circuit controlling a humidity sensor characterized by very low power consumption is presented. Additionally the validity and data packet loss during wireless communication is investigated [6-7].

2 Problem Formulation

In order to achieve maximum productivity, either inside a greenhouse or in an open field, environmental variables crucial for the development of several different plants, such as the air temperature and the soil humidity, needs to be kept, within predefined values for one of the each plant. The first step in doing so is to establish a flexible system of measurements, which will monitor such variables.

A system like that has to be:

- Wireless, in order to be expandable with minimum cost and capable of covering long distances if necessary
- very low in power for both the sensor-circuit and the transceiver, since it will be battery operated
- reliable
- easily reconfigurable

The second step requires a base station, typically a personal computer. The base station will gather all the measurements from the wireless sensor network and will take action if necessary, in order not only to alter conditions (temperature, humidity, etc) around the sensors but also to reconfigure the sampling rate of specific sensors. A typical example is to activate the irrigation system when the soil humidity is below a given threshold point while at the same time increase the sampling rate of the sensor. That is because soil humidity alters very slowly when the irrigation system is off but much faster when the irrigation system is on. The following paragraphs present a ZigBee wireless network which serves for such applications.

3 Solution and Methods

ZigBee technology is distinguished by its very low power consumption which in combination with low power sensor-circuits comprises a system that can operate for a long period of time. Furthermore a specific algorithm for dummy packets avoidance increases the reliability of the system. The system will be reliable, too, by making use of specific algorithms for packets avoidance. Such a system has been designed, developed, evaluated and described below.

3.1 Hardware

A simple ten-node network was implemented using ZigBee technology. A portable device was designed and developed consisting of a temperature sensor, a humidity sensor and a microcontroller with a ZigBee module, powered by two (1.5V) batteries. The humidity sensor is based on the gypsum block with embedded electrodes, aiming simplicity and low cost [8]. The principle of operation is that the resistance of electrodes embedded in a porous block is proportional to its water content. Thus, the wetter a block is, the lower the resistance measured across two embedded electrodes. The temperature sensor was the STTS75 by ST Microelectronics, which is a precision digital output temperature sensor operating over a -5°C to +125°C temperature range. The entire device in more detail is presented in the following paragraphs.

3.1.1 ZigBee Device

The ZigBee module used in these experiments was the eZ430-RF2480 by Texas Instruments. This is a complete wireless development tool that includes the ultra low power microcontroller MSP430 and the low power transceiver CC2480 at 2.4 GHz.

3.1.2 Low Power Circuit for Humidity Sensor

The circuit for the humidity sensor consists of a Wien-Bridge oscillator followed by a peak detector and a Non-Inverting amplifier with an adjustable gain and dc offset as shown in Fig. 1. The Wien-Bridge oscillator produces a 1V 500Hz signal that is fed to the positive input of the second op-amp.

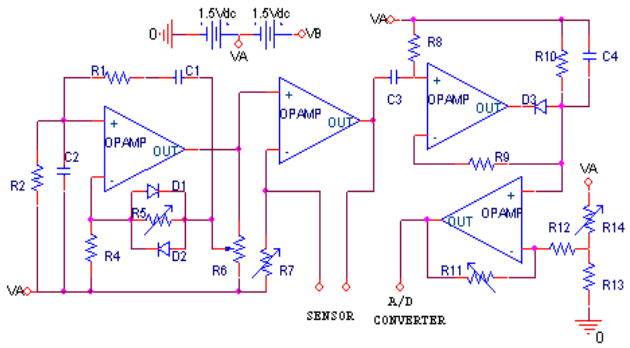

Fig. 1 Circuit for the humidity sensor

The output voltage of the second op-amp depends on both the values of the resistor R7, which controls the current supplied to the sensor and the resistance of the humidity sensor. As the ground humidity increases, the resistance of the sensor decreases, resulting in a lower voltage swing ($V_{P\text{-}P}$) on the output of the amplifier. The peak detector then produces a dc voltage based on the negative peak of the signal while the non-inverting amplifier that follows can be adjusted to give an output of 0-2V for the lowest and the highest humidity level respectively. The implementation of the circuit for the humidity sensor is shown in Fig. 2.

Fig. 2 Sensor's circuit implementation

The design of the circuit was towards simplicity and low power consumption thus CMOS (TLC271) low power op-amps were used throughout the device. Measuring the current drawn out of two AA alkaline batteries (some 70uA) it has been calculated that the circuit will continuant operate for more than a year.

3.1.3 Electric valve driver

Figure 3 shows the circuit used to control the electric valves of the irrigation system. The activation of the electric valves is accomplished via the computer's parallel port which in turns is controlled by the ZigBee coordinator. The coordinator communicates with the PC through serial data transfer.

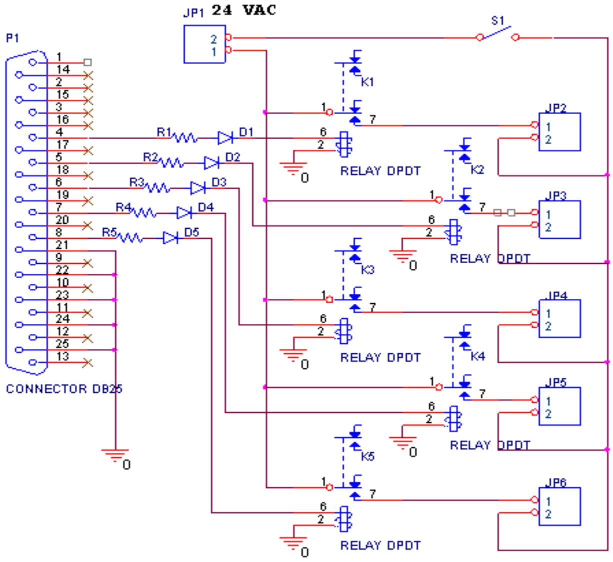

Fig. 3 Circuit controlling electrical valves

The parallel port drives 5 relay switches that, when closed, pass-through to the connected electrical valves the required 24V AC to operate. A typical consumption of a 24V electrical valve is some 250mA thus, the relays selected for the circuit implementation, shown in Fig. 4, allow a maximum current of 1A.

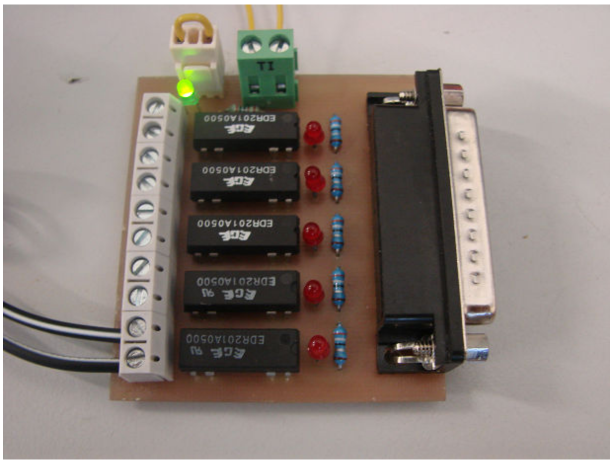

Fig. 4 Parallel port circuit implementation

The led diodes in the circuit protect the computer's parallel port from a potential relay inverted current while providing a visual identification of the activated valves.

3.2 Network Architecture

Figure 5 shows the basic topology used for the implementation. The coordinator corresponds with the base computer through serial communication RS232. The computer in turn illustrates and stores the incoming from the nodes data. It also manages the control signals that regulate the sensors' sampling rate. The coordinator and the end-devices do not use clock units since a real time clock is incorporated in the system. Knowledge of the precise time is important so as the computer to be able to check for the on-time arrival of all the packets, through the coordinator.

The rooter is placed to extend the range of the wireless network while end-devices can be connected directly to the coordinator or to a rooter. The end devices, which are scattered in the field, contain the temperature and humidity sensors. Note that security of data transmission was not taken into account in the present investigation, to maintain simplicity of the application.

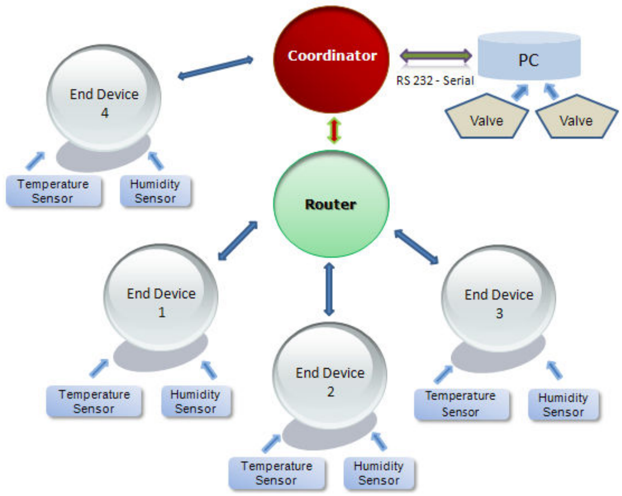

Fig. 5 Application's topology

The most important characteristic of the network is the bidirectional communication as illustrated in Fig. 5, achieving two goals simultaneously. The first one is the control of the sensors' sampling rate. The second one is the validation of measurements taken. When two or more data packets arrive simultaneously to the coordinator, there is a chance only one of them to be received or some of the packets to be incomplete. To avoid that special algorithms have been developed for the communication among the end devices, the coordinator and the computer.

3.3 Software

3.3.1 Coordinator Approach

This section presents the analysis of the algorithms applied to the end devices and the coordinator, emphasizing to the avoidance of dummy packets as mentioned above. Figure 6 describes the algorithm applied by the coordinator. Firstly, varying parameters are initialized including the communication of the microprocessor with CC2480, the adjustment of serial communication parameters and the offset of A/D converter. Subsequently, the coordinator seeks for end-devices or rooters to be added to the network. For the addition to take place the end-devices need to have the same (identical) key that has been defined to each one of them during their programming. This key may be changed by the coordinator and is not a matter of ultimate security. Instead it is a way to avoid conflict between two identical devices within the same space (two or more networks) or in adjacent greenhouse establishments. The coordinator can recognize all end-devices of the network using their personal ID and their network key, both given during the programming process. Subsequently, it will check whether all nodes have sent their data packets at the pre-set time points.

The set-up is controlled by the computer to which the coordinator is connected. Since the system is aware of the nodal sampling rate, it is also aware of when each node should be transmitting data. Moreover, when each node starts functioning, an increasing number (1-65535) is provided by the coordinator, corresponding to the packet ID. In this way, if a packet is lost its ID can be traced identifying the time point when sampling should have occurred. The coordinator records which node was the one that has failed to transmit a data packet and asks the node to re-send it, assuming that the packet had not been sent in the expected allocated time slot. The node that had failed to transmit the packet receives the coordinator's message and transmits the data packet again. This happens in every cycle and the coordinator expects from the failing node to re-send the missing packet. If for some reason the node fails to send the specific packet over a relatively long period of time, it would mean that the system is facing a problem and water resource is terminated for the particular node.

The user may set the time window for the data to arrive after sampling reducing this way the dummy packets for each node. After all nodes have been checked, the coordinator transmits all data from all nodes that have sent data packets. The coordinator is aware of the latter through special flags that have been activated during interrupt procedure. The interrupt procedure is being activated when it receives data and anchors the channel for the particular node that is sending at that specific moment. If the entire packet has been received a confirmation note is sent to the node.

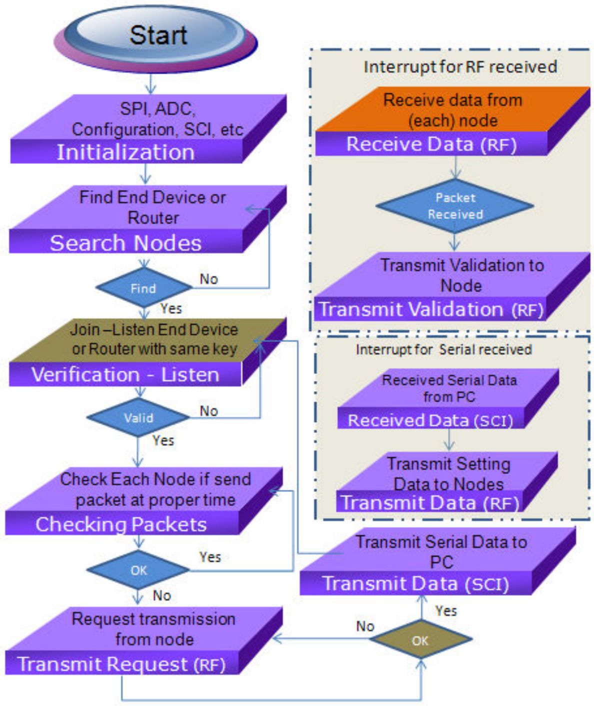

Fig. 6 Block diagram of coordinator algorithm

The sensors at the nodes get activated at regular time points. Thus, humidity levels can be monitored so that a threshold is not overcome. If the threshold is overcome, in combination with other parameters, the appropriate electric valve will be activated. Subsequently, the coordinator will signal the appropriate node to increase its sampling rate so that the environmental conditions can be monitored more closely.

3.3.2 End Device Approach

In this section the algorithm used by each node/ end-device will be analyzed, as illustrated in Fig. 7. At the beginning, the appropriate initializations is performed. The key points during this process is the initialization of the analog to digital converter and the setting of the appropriate Vref as well as the activation of all channels that have sensors. Afterwards, each node seeks a coordinator or a rooter, depending on the way they have been designed to get connected. Following confirmation, the node may join the network using the identical key. Afterwards, the temperature and humidity sensors are being "read". Finally, the data is being send through wireless transmission to the coordinator (or the rooter accordingly).

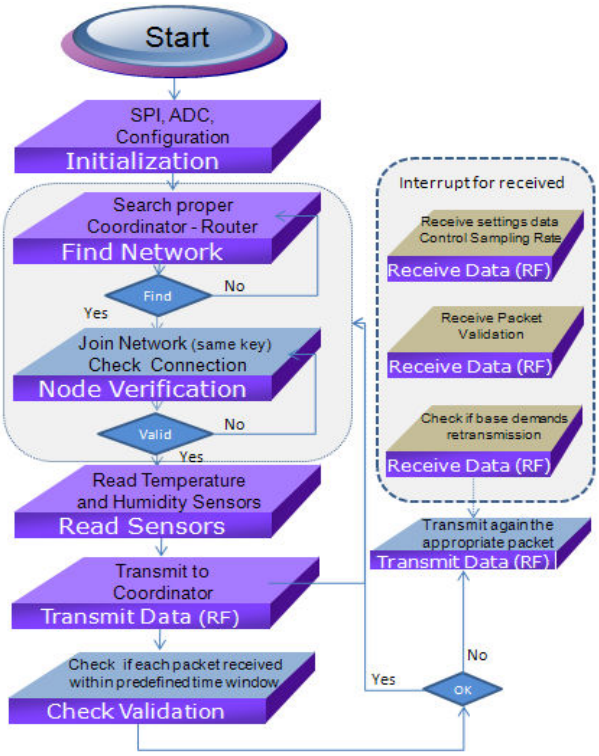

Fig. 7 Block diagram of end-device algorithm

As mentioned above, in the algorithm of the coordinator, the end-device is awaiting for the coordinator to confirm receipt of the packets, within a certain time frame. In case no confirmation is received, the end-device re-sends the packet that has been placed in a stack. Each node uses interrupt for the receipt of data from the coordinator without continuously occupying the processor. Upon receipt of a data packet it checks which process the packet is referred to. One of these processes is the parameter adjustment, such as controlling the sampling rate. Moreover, it checks whether the packets awaiting confirmation in the stack have received their confirmation. Finally, it checks whether the coordinator asks for re-transmission. Subsequently it completes the circle by checking once again its status within the network and proceeds repeating the above process.

3.3.3 Computer Algorithm Approach

Figure 8 illustrates the algorithm of the program running on the PC. At the beginning, the graphical user interface window, where all measurements will be illustrated, is initialized. Following that, the serial communication with the coordinator is initialized, too.

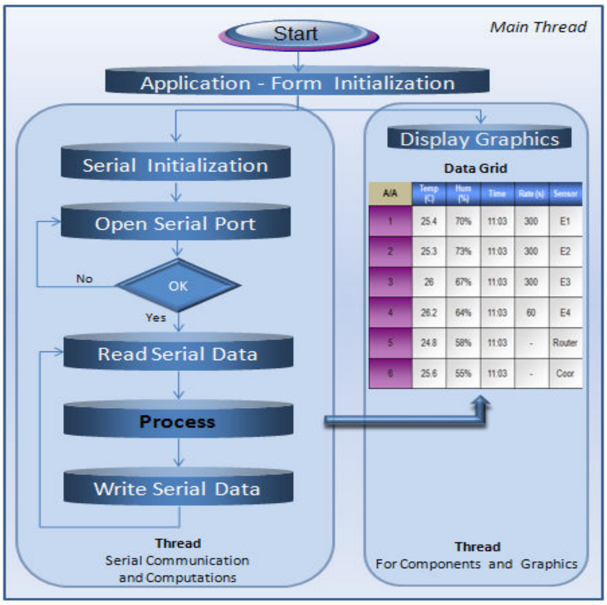

Fig. 8 Block diagram of PC-running algorithm

As shown in Fig. 8 data processing is taking place right after the data reading through serial communication and before sending the data to the coordinator. The main advantage of the programme is the use of multithreading technique [9]. One thread is being used for graphic display and another thread for processing of data and serial communication. Both threads are getting coordinated by the central thread and communicate each other. In this way, the graphic illustration processes do not engage the flow of main algorithm utilizing properly the remaining computer power.

4 Results

Table 1 presents the characteristics of the network constructed.

TABLE I
Network characteristics

Feature	ZigBee Sensor Network
Re-connection latency	30ms
Network Establish	0.5s
Nodes per Master	10
Connection : PC - Coordinator	every 100ms
Connection : Router - Coordinator	every 10ms
Range in free area	100m
Extended Range with one router	170m
Data Transmission to base	1s – 65535s

It should be noted that the rooter communicates with the coordinator more often compared to the end-devices, since it has more data to process.

Figure 9 illustrates the percentage of data packets loss in correlation with the sampling/transmitting time intervals for one node and ten nodes, directly connected to the coordinator, respectively. The larger the sampling time interval, the smaller the percentage of data packets lost.

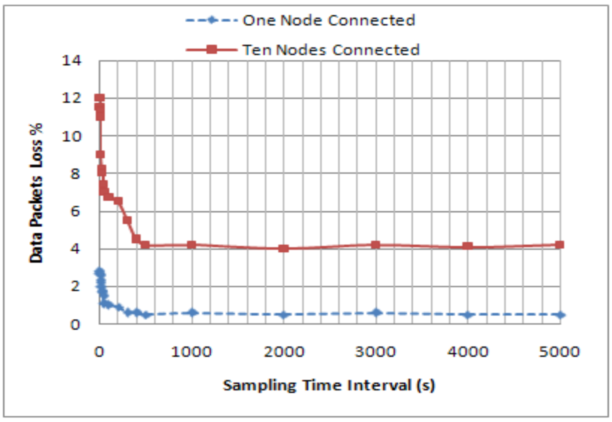

Fig. 9 Percentage of data packets loss

Figure 10 shows the variation of the soil humidity when the system is active. The margins are set to be between 35% and 45% and the graph depends heavily on the texture and the quality of the soil as well as the climate conditions. It can be seen that although the upper limit is set to be 45% this can be exceeded making more obvious the need for increased sampling rate during irrigation.

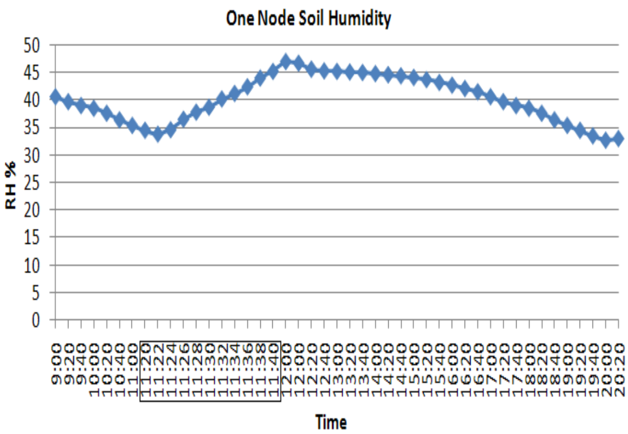

Fig. 10 Soil humidity during cycle of irrigation

5 Conclusion

A wireless sensor network that includes confirmation of valid data transmission from the base computer is presented. Using low power designs for the sensors circuitry in combination with the low power operation of ZigBee, increases the device's life time. The evaluation of the system have shown that the data packets loss appears to be larger for more frequent sampling time intervals and large node numbers while it tends to get stabilized for high sampling time intervals.

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