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Wireless monitoring of the pH, NH_4^+ and temperature in a fish farm

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Abstract

In this paper, we present a practical application for wireless sensor networks (WSN): The sensing of the pH, NH_4^+ and temperature for a fish farm. Two different kinds of modules were designed: Te sensor and the wireless module. The sensor module includes pH and NH_4^+ sensors based on a specially designed ISFET. The sensor module collects and transmits the information to the wireless module by means of a 9600 b/s asynchronous wired communication. The wireless node, retransmit it to the central unit via RF. The WSN follows the standard IEEE 802.15.4 and implements a routing protocol based on Zigbee. The aims of this work are (1) show the ISFET developed to monitor pH and NH_4, (2) show the design of the whole sensor module and (3) show the implementation of the WSN.

Keywords: Wireless Sensor Networks, pH Sensor ISFET.based

1. Introduction

Wireless sensor networks have had a large increase in real applications during the recent years. Its main advantage over the rest of technologies is the actual economic development of its installation. Wireless sensor applications are not a real technology as a concept. The idea to implement an ad-hoc wireless network started at the beginning of the 70s [1]. The typical scenario was to set up a communication network in a battlefield, where no infrastructure is available. Since then, there have carried out a great quantity of theoretical studies regarding the implementation, power consumption, routing algorithms, but it was difficult to find real applications that solve a specifically case due to the high cost of the devices. Nowadays the reduction of prices has increased the usage of wireless for consumer applications. Wireless devices are omnipresent: cell phones, PDA's, WLAN (Wireless LAN) access points at home or even in public places, while in industrial environments, wireless communications are in the focus in the field of control and specially sensing. Autonomous wireless sensor devices have the possibility to communicate with others of the same type and build larger ad hoc networks without the need of human intervention. Wired and wireless computer networks are composed of computers (data sources / sinks) and infrastructure (routers / repeaters) that forwards and delivers the information when there is not a direct link (physical or logical) between two communication peers. In case of wireless sensor networks (WSN) this division is fuzzier, because of routers can work as data sources and/or sinks. This work shows a direct application: the monitoring of a fish farm using pH, NH_4^+ and temperature sensors. Usually, these kind of measurements require a very specialized staff, who have to measure periodically the living conditions of the farm (pH, temperature, NH_4^+,...) with a high accuracy. However, this periodically test of the farm can not detect immediate changes or predict when it will produce a possible event. Other cons that are detected are the high maintenance conditions, and the high cost. The answer to improve these

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conditions is the implementation of an ambient intelligence WSN. This sensor network is based on an open communication protocol to be compatible with other manufacturer nodes. Although there are a lot of proprietary protocols studied, designed and developed at the literature, the current trend is to use standard protocols as IEEE 1451.5 or IEEE 802.15.4 [2, 3]. The last one is the protocol used to develop this study. IEEE 802.15.4 defines three types of nodes: (i) the end devices, also known as reduced functional devices, nodes which does not implement the whole standard, but who are responsible for acquiring the information from the sensor, pre-process and transmit it to the nearest routing node; (ii) the routing nodes or fully functional devices, nodes with the same functionality that end devices plus the software necessary to be connected to the network and responsible of transmitting and receiving the information to/from the coordinator. Finally, (iii) the coordinator node is the responsible of the establishment and management of the network. From a general point of view, the communication goes from the end devices to the coordinator, which acts as a information collector, whereas the control frames goes from the coordinator to the end devices. Finally, it is important to remark that the difference among all these three different nodes does not depend on the hardware but on the software implemented on the wireless boards.

2. Scenario and experimental design

The network implemented is composed by two different types of modules. The first one is the instrumentation module itself. This module is directly connected to the sensing system. It will be introduced into the pool to make the required measures of the pH, the temperature and other relevant parameters. Due to the size of the pool, several nodes must be distributed in order to have a real knowledge of those substances that may be critical for the live of the different fish species. The second one is the wireless communication module. The wireless nodes will transmit the information to the central computer, where data will be presented and analyzed, and actions will be realized in case that was necessary. The communication among the different instrumentation modules and the wireless collecting data module will be done using a polling serial wire connection.

The wireless nodes used in this work are the well known Tmote Sky [4], a compliant device for IEEE802.15.4 wireless communications. The microcontroller used is a 8 MHz Texas instrument 16 bit MSP430F1611. Tmote Sky includes a real time embedded operating system: TinyOS [6]. TinyOS is an operating system specifically designed for wireless sensor communications. Its component-based architecture permits the abstraction between hardware and software. The information between the instrumentation module and the wireless node is transmitted and received through the USART port. It is configured as a serial asynchronous polling communication system. The information is processed and packed in an IEEE 802.15.4 frame format and sent to the medium from the wireless communication facility (WCF). The WCF is based on a CC2420 transceiver from Chipcon. The CC2420 is a low-cost transceiver specifically designed for low-power, low-voltage RF application in the 2.4 GHz unlicensed ISM band. This RF transceiver is compliant with the IEEE802.15.4 standard. For our experimental result, we use two 1.5V batteries serial connected. The current consumed to transmit and receive a typical frame of around 40 bytes (mean frame size for our experiment) is 20.85 mA. Consequently, since the voltage supply is 3V, the power consumed during the transmission is around 60 mW for a 0dBm wireless power transmission. Moreover, from our experimental results, we detect that the power consumption for transmission and reception is the same for the particular case of Tmote Sky. This 60 mW can be decreased up to 45 mW programming directly the communication between MSP430 and CC2420 without consider TinyOS, but indeed, the advantages of using this operative system outweigh the disadvantage of the increase in power consumption.

The instrumentation module includes a low-cost low-power 16 bit texas MSP430F2013 microcontroller as a processing unit . The sensor used is an ion sensitive field effect transistor (ISFET), necessary to extract the pH and NH_4^+ level of the pool. Information about this device can be found at [6, 7]. Figure 1 shows the image of the Lab-on-chip sensor. Due to the basic characteristics of ISFET, the potentiometric method has been used to measure the change in pH through a corresponding shift in the device threshold voltage [7]. In order to extract the relevant signal from the electrical behavior of the sensor, it is necessary for the ISFET to be accompanied by an analog readout interface. The signal amplification circuitry is shown at figure 2. The source I1 and I2 supplies to the circuit a current of 100 uA. The selected component used to generate this supply current is the Texas REF200 integrated circuit [5]. The voltage drop at the resistor R (figure 2) is the same that the voltage drop at the ISFET. So, in the hypothetical case that R_{DS} was 5kohms, the operational amplifier OPAMP2 will not supply any current and the output voltage of OPAMP2 will be 0V. For real R_{DS} values, the output voltage varies from -0.5 to -1.5V. The source

I2 force the ISFET to supplies 100 uA, moreover, taking into account that the V_{DS} is fixed to 0.5V, changes at the Gate of the ISFET implies changes at V_D and V_S. These changes fix the output voltage of the OPAMP2 and also fix the input signal of the OPAMP1 to maintain the system in equilibrium. The temperature sensor is a thermistor due to the fact that the associated electronics is easily implemented. The thermistor used is a B59801 from Epcos.

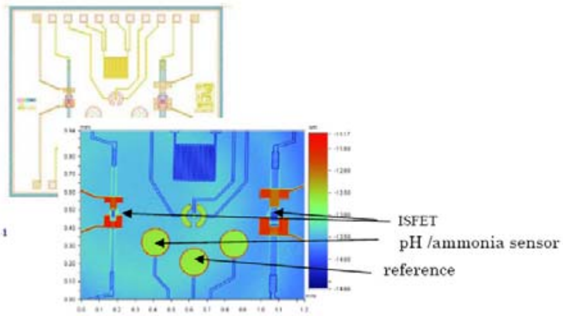

Figure 1. Interferometric image of the Lab-on-Chip fabricated by silicon microelectronics technology

The supply system uses a rechargeable Litium-Ion battery from Varta that gives an output voltage of 4V. The National Semiconductor inverting switching LM2611A is the component selected to generate the -4V negative voltage. Both, the direct output of the battery plus the negative voltage generated from the LM2611A are used to supply the analog circuitry of the instrumentation module. Finally, a Texas Instruments LDO voltage regulator is used to generate the 3.3V output voltage to supply the digital part. The output voltage is shifted to positive values and sent to the microcontroller's analog-to-digital converter (ADC), a 16 bit sigma-delta precision converter with a resolution of 0.045 mV/bit.

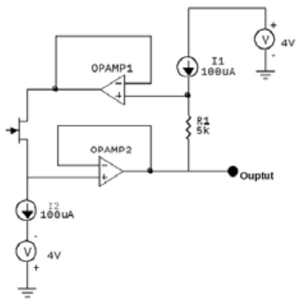

Figure 2. ISFET adaptation and amplification circuitry. The output of this circuitry is connected to one of the MSP430F2013 16 bit-Sigma-Delta ADC channels.

3. Network performance

TinyOS includes some libraries that implement the IEEE 802.15.4 standard. So, it is relatively easy to implement the network layer based on the specifications of Zigbee, the protocol that includes in its low level layers the IEEE 802.15.4. The zigbee routing protocol used by the Network layer is an AODV distance vector based routing algorithm [8]. This protocol works as a reactive routing algorithm. Neither complicated routing tables are needed nor a manage of this routing table is considered, only a simple list of neighbors and some destinations previously located. In order to find any destination device, the source node searches the destination address in its routing table. If it is found, the datagram will be sent to the address specified by the routing table. On the contrary, the source node broadcasts out a route request to all its neighbors. This process is repeated until the broadcasts datagram arrives to the destination. Once the destination is reached, it sends its route reply via unicast transmission following the lowest cost path back to the source. When the source receives the reply, it will update its routing table for the destination address with the next hop in the path and the path cost. In our particular case, there exists a drain node that collects all the information datagram: The coordinator. This node is located at the office of the fish farm and is directly attached to the mains supply. This network configuration implies that all the data will be sent to this node. So, once the route has been established, the rest of the transmissions for a given source node will follow the same path, and then, the discovery route should only be done when the network wakes up for the first time and in exceptional circumstances when a node falls due to battery problems. Figure 3 shows the wireless transmission among three nodes of the network. The wireless node collects the information from the different instrumentation boards, preprocesses the data and transmits the datagram (capture 1 at figure 3) to router 1. Due to the proximity among all the nodes, necessary to capture the image, the datagram is received by both nodes: router 1 and coordinator (captures 2 and 3). When the coordinator decodes the frame, discard it when detects that it is not for him. Router 1 decodes the frame and detects that the message must be re-send to the coordinator. Capture 4 shows the transmission from router 1 to the coordinator. This transmission is again detected by all the nodes; again, the initial wireless node discards the frame and coordinator process the data.

Figure 3. Wireless communication performance for three nodes of the network. Node 1 transmit the frame (1). Nodes 2 and 3 receive the frame. As the next hop is node 3, node 2 discards the frame. Finally, node 3 re-transmit the frame to node 2.

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