Research on a Banknote Printing Wastewater Monitoring System based on Wireless Sensor Network

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Abstract. In this paper, a banknote printing wastewater monitoring system based on WSN is presented in line with the system demands and actual condition of the worksite for a banknote printing factory. In Physical Layer, the network node is an nRF9e5-centric embedded instrument, which can realize the multi-function such as data collecting, status monitoring, wireless data transmission and so on. Limited by the computing capability, memory capability, communicating energy and others factors, it is impossible for the node to get every detail information of the network, so the communication protocol on WSN couldn’t be very complicated. The competitive-based MACA (Multiple Access with Collision Avoidance) Protocol is introduced in MAC, which can decide the communication process and working mode of the nodes, avoid the collision of data transmission, hidden and exposed station problem of nodes. On networks layer, the routing protocol in charge of the transmitting path of the data, the networks topology structure is arranged based on address assignation. Accompanied with some redundant nodes, the network performances stable and expandable. The wastewater monitoring system is a tentative practice of WSN theory in engineering. Now, the system has passed test and proved efficiently.

1. Introduction

Wireless sensor network (WSN) are characterized by the dense deployment of smart sensor nodes that are distributed randomly in an environment to sensor data and forward that data to interested users. Each of the smart nodes is equipped with a sensor module (e.g. acoustic, light, temperature, magnetic, image sensor) capable of sensing a parameter or a quantity regarding the environment, a digital processor for processing the signals from the sensors and for performing operating system applications and network functions, radio module for communication and finally a battery to provide energy for operation [1]

In this paper, a banknote printing wastewater monitoring system based on WSN is presented in line with the system demands and actual condition of the worksite for a banknote printing factory. Especially, the paper describes the design of the whole system, Physical Layer, MAC(Medium Access Control), Routing Protocol in Networks Layer in detail.

2. System architecture

According to the actual worksite condition of a banknote printing factory, where have a lot of bump stations distributed randomly, it is limited to layout the wired network. After analysing the working flows among the bump stations, we present the solution for the monitoring system based on the theory of WSN to satisfy the requests of the factory.
The monitoring center consists of an industrial computer and a sink node. Each pump station has a monitoring node, which not only can monitor the status of the equipments, but also can collect, process, transmit concerned data to the monitoring center. The center communicates with the nodes wirelessly. With the help of middle nodes, those nodes that locate out of the radio range of the monitoring center can exchange data through hop-by-hop communication routing. In the monitoring center, workers can get all the equipments status of pump stations. The architecture of the whole wireless monitoring system is shown in Figure 1.

Nowadays, the network software is now highly structured [2]. To reduce the design complexity, most networks are organized as a stack of layers, each one built upon the one below it. The number of layers, the name of each layers, the contents of each layer, and the function of each layer differ from network to network. The purpose of each layer is to offer certain services to the higher layers, shielding those layers from the details of how the offered services are actually implemented. In a sense, each layer is a kind of virtual machine, offering certain services to the layer above it.

Limited by processing speed, memory capability, and battery’s energy of node, traditional network protocols can’t be applied in the WSN directly, until now there are not standard protocols for the layers in WSN. In this paper, the ISO reference model is employed to design the wireless monitoring network. Since many reference books have described the ISO reference model in detail, this paper will emphasize on the characteristic three layers in this network: the Physical Layer, MAC (Media Access Control) sublayer, and Network Layer.

3. Physical Layer

In Physical Layer, the network node is a nRF9e5-centric embedded instrument, which can realize the multi-function such as data collecting, state monitoring, wireless data transmission and so on. The node obtains the wastewater level data in the pool from ultrasonic sensor, and observes state of electromotor or electromagnetic valve through voltaic sensor. Not only has the ability of transmitting the collected data to monitoring center, the node also can realize the data display, parameters setting, automatic controlling of electromotor and electromagnetic valves, warning, and so on.

NRF9E5 is a true single chip system with fully integrated RF transceiver, 8051 compatible microcontroller and a 4 input 10bit 80ksps AD converter. The transceiver of the system supports all the features available in the nRF905 chip including ShockburstTM, which automatically handles preamble, address and CRC [3]. The circuit has embedded voltage regulators, which allows operation on a single 1.9V to 3.6V supply.

Figure 2 is the block diagram of the nodes in the wireless monitoring. From the Figure 2, we can see that all of the four channel of A/D converter in nRF9E5 are used to collect the analog signals such as the wastewater level signal, the current of the electromotors signal and magnetic valves signal. Most of the GPIO pins can be used for multiple purpose under program control. The alternate functions include two external interrupts, UART, RXD and TXD, a SPI master port. The GPIO pins are also used as the input of the buttons and the output of the alarms.
The nRF905 is a radio transceiver for the 433/868/915 MHz ISM bands. The transceiver consists of a fully integrated frequency synthesizer, a power amplifier, a modulator and a receiver unit. For power saving, the transceiver can be turned on/off under software control. In this system, all of the nodes choose the 915 MHz bands for transmission.

### 4. The MAC Sublayer Protocol

The 802.11 MAC sublayer protocol is quite different from that of Ethernet due to the inherent complexity of the wireless environment compared to that of a wired system. With Ethernet, a station just waits until the ether goes silent and starts transmitting. With wireless, this situation does not hold.

To start with, there is the hidden station problem since not all stations are within radio range of each other, transmissions going on in one part of a cell may not be received elsewhere in the same cell. In addition, there is the inverse problem, the exposed station problem, most radios are half duplex, meaning that they cannot transmit and listen for noise bursts at the same time on a single frequency. As a result of these problems, 802.11 does not use CAMA/CD, as Ethernet does [2].

The competitive-based MACA (Multiple Access with Collision Avoidance) Protocol is introduced in MAC, which can decide the communication process and working mode of the nodes, avoid the collision in data transmission, hidden and exposed station problem of nodes.

Figure 3 shows the principle of the MACA protocol. It uses virtual channel sensing [2]. If A wants to send to B, C is a station within range of A, D is a station within range of B but not within range of A. The protocol starts when A decides it wants to send data to B, and it begins by sending an RTS(Request To Send) frame to B to request permission to send it a frame. When B receives this request, it may decide to grant permission, in which case it sends a CTS(Clear to Send) frame back. Upon receipt of the CTS, A now sends its frame and starts an ACK timer. Upon correct receipt of the data frame, B responds with an ACK frame, terminating the exchange. If A’s ACK timer expires before the ACK gets back to it, the whole protocol is run again.
Now let us consider this exchange from the viewpoints of C and D. C is within the range of A, so it may receive the RTS frame. If it does, it realizes that someone is going to send data soon, so for the good of all it desists from transmitting anything until the exchange is completed. From the information provided in the RTS request, it can estimate how long the sequence will take, including the final ACK. So it asserts a kind of virtual channel busy for itself, indicated by NAV (Network Allocation Vector). D does not hear the RTS, but it does hear the CTS, so it also asserts the NAV signal for itself. Note that the NAV signals are not transmitted; they are just internal reminders to keep quiet for a certain period of time [2].

5. The network layer

The network layer is the lowest layer that deals with end-to-end transmission, and it is concerned with getting packets from the source all the way to the destination. To achieve its goals, the network layer must know about the topology of the whole network and choose appropriate paths through it. Routing algorithm is that part of the network layer software responsible for deciding which output line an incoming packet should be transmitted on.

As networks grow in size, the router routing tables grow proportionally. Not only is router memory consumed by ever-increasing tables, but more CPU time is needed to scan them and more bandwidth is needed to send status reports about them. At a certain point the network may grow to the point where it is no longer feasible for every router to have an entry for every other router, so the routing will have to be done hierarchically, as it is in the telephone network [5].

When hierarchical routing is used, the routers are divided into what we will call regions, with each router knowing all the details about how to internal structure of other regions. When different network are interconnected, it is natural to regard each one as separated region in order to free the routers in one network from having to know the topological structure of the other ones.

According with the distribution of the nodes in the factory, we use the hierarchical routing topology structure for this system. The node in the monitoring center is definition as sink node of WSN, which is the root of the address tree. Those nodes that can communicate with the sink node directly are assigned as first level children address, then, we can assign second level address analogically [7]. Figure 4 is the block diagram of the networks topology structure.

![Figure 4. Block diagram of the networks topology structure.](image)

The data packet is shown in Figure 5, and Preamble is leader of the packet, and Add is address of the receiver, and Payload is valid data of the packet, including identification code of the receiver (Tid), identification code of the aimed node (Aid), identification code of the source transmitter (Sid), marker of the data (Kind )and the data (Data), CRC is checking code.

| Preamble | Add | Payload | CRC |
|----------|-----|---------|-----|
|          |     | Tid     | Aid | Sid | Kind | Data |

![Figure 5. Data packet.](image)

In ShockBurst™ TX, Add and Payload is loaded into nRF905 in sequence through SPI by processor. Then the nRF905 automatically generates preamble and CRC for the data packet. In ShockBurst™ RX, when nRF905 receive a packet, it will verify the correctness Preamble, Add, and CRC, then load the Payload in processor. If Tid in the data packet is equal to identification code of this node, the
processor will accept and process the data packet, otherwise will ignore it. If the Aid in the data packet is equal to identification code of this node, the processor will change the Tid and transmit the packet to the upper level node until the sink node receive the packet.

In Figure 4, we can see there is a three level children address topology structure in the network, all of the identification codes are configured as 12 bits, and the root node (sink node) is 0x000h. The first level identification codes can be differentiated with the high 4 bits. The second level can be differentiated with the middle 4 bits. The third level can be differentiated with the low 4 bits. Through this three level address topology structure, the network can configure more than 4000 nodes and generate a large wireless local network [3].

6. Conclusion
In this paper, a banknote printing wastewater monitoring system based on WSN is presented for a banknote printing factory in line with the system demands and actual condition of the worksite. Especially, the paper describes the design of the general system, Physical Layer, MAC, Routing Protocol in Networks Layer in detail, and then proposes a design method for little-scale wireless sensor networks. The wastewater monitoring system is a tentative practice of WSN theory in engineering. Now, the system has passed test last year and proved efficiently.

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