A Low Power Automatically Warning System Based on Wireless Sensor Network

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Abstract—Aiming at various water storage facilities, the number of which is generally large and whose distribution is not centralized in the industrial and civil buildings, this paper proposed a multi-channel water level telemetry and low power automatically warning system based on wireless sensor network. The sensor nodes of the proposed system could monitor water levels and transmit sensing data to the sink node periodically. The host server analyzed sensing data received from the sink node. Meanwhile, it made decisions according to the multi-grade cycle comparison algorithm proposed in this paper to improve the alarm accuracy. Experiment result indicated that it could not only improve the alarm sensitivity of the system, but also avoid error judgment to a large extent. When a leakage emergency happened, the host server sends an alert message to the alert terminal, through the sink node. In addition, SMS server is added to the system architecture to automatically send emergency messages to related emergency processing offices for dealing with it timely. The design of sensor nodes adopts the sensing data selective transmission mechanism and the node transmission power adaptive mechanism to reduce power consumption. The experiment result indicates that the energy reducing effect is significant. The communication performance of the system network was tested and the experimental results show that the system has good reliability and real-time performance. By testing the system operations, the good performances of alarm accuracy and low power are verified.

Index Terms—wireless sensor network, water level detection, automatically warning, low power

I. Introduction

According to an inquiry by the international Water Supply Association (IWSA), the amount of lost or “unaccounted for” water is typically in the range of 20 to 30% of production. In the case of some systems, mostly older ones, the percentage of lost water could be as high as 50%. Unaccounted for water is usually attributed to several causes including leakage, metering errors, and theft. According to the IWSA survey, leakage is the major cause [1]. For this reason, leakage is a problem which should not be ignored.

There are various water storage facilities in the industrial and civil buildings, such as water storage tanks of solar water heaters, spare tanks in factory workshops, and so on. If these tanks leaked and nobody found it, terrible accidents would occur. In the daily work and life, to maintain the normal water level of water storage facilities, we must always check them, which require a lot of manpower and resources. In addition, if we didn’t check them timely, it would result in the waste of water source. Therefore, unified monitoring and controlling for multiple water storage facilities whose distribution is not centralized is a much-needed technology.

Traditional level detection method is single-channel detection or local detection [2]-[8] and needs artificial periodically check which is not satisfied with the unified monitoring of multiple tanks in a wide range. Most of these research focus on the part of sensing or data detection. For example, Ref. [4] proposed Sensor cable-based tank leak detection system. Ref. [5] presented using multi-sensor data fusion to predict dangerous states of LNG (liquefied natural gas) transport tank. Ref. [6] studied on ultrasound techniques for leak detection in vehicle and pressure vessel production lines. And Ref. [7] showed a smart design of coolant tank leak testing equipment in car manufacture using fault detection and isolation observer based method. The above studies are not aimed at various water storage facilities in industrial and civil buildings and could hardly achieve centralized management for water storage facilities.

Meanwhile, existing level monitoring methods [9] for multiple tanks generally use wired transmission mode which is complex for construction and is not flexible for expansion. Although some research [10], [11] monitored tanks in wireless communication mode, they didn’t consider automatically alarm architecture for notifying leakage situation to users and related offices directly.

WSN (Wireless Sensor Network), to which academia and industry have attached great importance, is one of the most significant technologies of the 21st century [12]. The recent release of the standards in the field, such as ZigBee [13], has characteristics of short-range, low-power, low-rate, low-cost and high-capacity. Especially, the feature of a large number of nodes in the network satisfies the need of centralized monitoring levels of large amount of water storage facilities.

In recent years, ZigBee wireless sensor technology has been widely applied in various fields, and a large number of scientific research results have been achieved. However, most of the achievements focus on the network topology and its applications or the network performance

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analysis [14]-[18]. Even though there have been many researches [19], [20] on implementation of monitoring and alarm system based on ZigBee wireless sensor network, they do not deal with the transmission method of the emergency situation to the users directly. Thus, we propose a multi-channel water level telemetry and low power automatically warning system which can send leakage situation to registered users and related emergency management offices immediately.

II. System Design

Taking aim at the leakage emergency of various water storage facilities of which the water levels generally remain unchanged in the industrial and civil buildings, this paper proposes a low power automatically warning system based on ZigBee wireless sensor network, which can send leakage situation to registered users and related emergency management offices immediately. To achieve automatically warning, the sink node employed a SIM (subscriber identity module) card-type ZigBee module to notify the situation to the corresponding emergency office and registered users who have cellular phones through SMS server of the cellular network. The architecture of the proposed system is shown in Fig. 1.

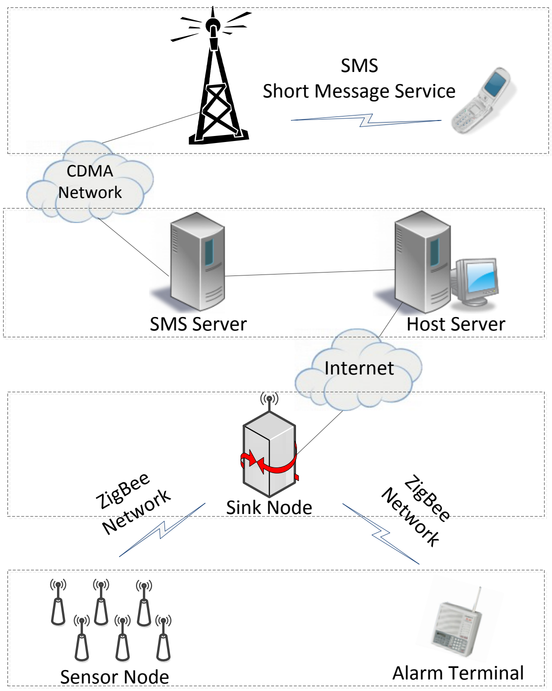

Figure 1. The system schematic diagram

The service flow of the proposed system is as follows: The sensor nodes of the proposed system can monitor water levels periodically and transmit the sensing data, to the sink node immediately. The host server analyses the sensing data received from the sink node and makes decision. If a leakage emergency happened, the sink node transmitted the alert message received from the host server to the alert terminal. At the same time, the emergency situation message is sent to the corresponding emergency offices and registered users who have cellular phones through SMS server of the cellular network.

A. Sensor Node

The sensor node performs periodic sensing data collection and transmits it to the sink node. It is composed of the sensor module and the sensor management module, as shown in Fig. 2. In the system, the ultrasonic measurement sensor is employed to measure water levels according to the distance between water levels and ultrasonic sensors which are placed on the top of water storage facilities. The sensor management module includes: sensing data scheduler, sensing data collector and sensing data communicator.

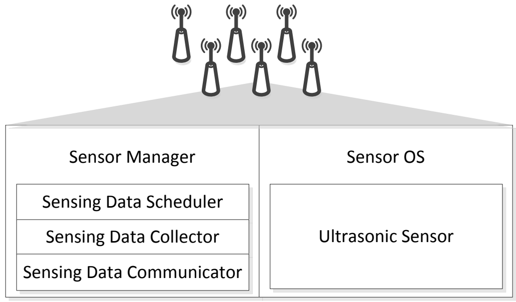

Figure 2. The sensor node

B. Routing node

Since the single-hop transmission distance of ZigBee is short, routing nodes are joined in the wireless network to expand the network coverage. Routing nodes are core nodes of partial sensor nodes groups. In the system, they play a role of routing between sensor nodes and the sink node. They can also get rid of the entire central monitoring system and form dependent partial monitoring system [21]. The hardware structure of routing nodes is similar with sensor nodes.

C. Sink Node

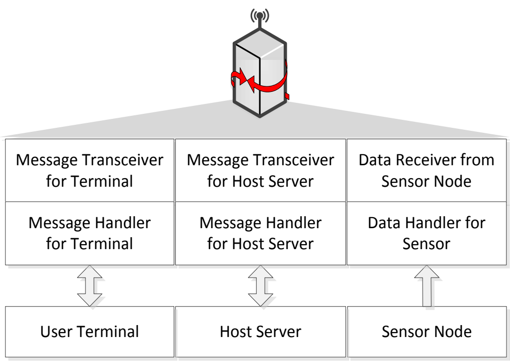

Figure 3. The sink node

The sink node is the communication core of the whole monitor system, as all sensor nodes transmit data to it. Fig. 3 shows the sink node function structure according to which the host server can monitor and control all sensor nodes and terminals. The sink node sends the sensing data received from sensor nodes to the host server immediately. In a leakage emergency, the sink node processes the alert message decided by the host server and transmits it to the alert terminal.

To achieve automatically warning for users, the sink node employs a SIM card-type ZigBee module to identify every sensor node, so that, in the case of leakage emergency, the system can immediately send the situation message to the related emergency processing offices and the corresponding registered users through SMS server of cellular network.

D. Host Server

The host server analyses the sensing data received from the sink node and makes decisions on it. In a leakage emergency, it sends the alert message to the sink node to start the alarm terminal. Simultaneously, the host server sends the situation message to the related emergency processing offices and the corresponding registered users through SMS server of the cellular network. Fig. 4 shows its structure.

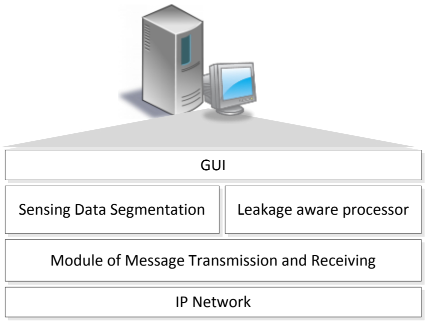

Figure 4. The host server

The host server analyses the situation by comparing the change value of sensing data with a given threshold. Thus, in the case of severe leakage accidents, it can be perceived easily. However, when tanks seep or leak too slowly, the system can hardly detect the change of water levels by comparing two consecutive collected data due to that sensor accuracy is limited. To solve this problem, we propose the method of multi-grade cycle comparison. The theory of this method is that receiving data is compared with not only the previous receiving data but also some data received a longer time ago.

For instance, the time interval between two consecutive collections is 1s. When a tank leaks very slowly, the change of water levels is very slight during 1s. It's difficult to detect the difference of two consecutive receiving data due to that sensor accuracy is limited. In this case, one more grade cycle comparison should be added. For example, the receiving data is compared with not only the previous one but also the one received one minute ago. By accumulating time, change of water levels is easily perceived.

Of course, according to actual needs, more grades comparison could be adopted in the system to detect leakage accurately. In addition, requirements of the sensor accuracy could be reduced by using the method of multi-grades comparison. Thus significant cost saving is brought about.

The mathematical description of the multi-grade cycle comparison algorithm is as follows: firstly, the $\Delta_j(i)$ is defined as the difference of two consecutive comparison samples of the j^{th} grade, and its expression is,

$$\Delta_j(i) = D(i) - D(i + g_j) \tag{1}$$

where $i \in (1, 2, 3, \cdots, n)$, $D(i)$ is i^{th} receiving data and g_j is the interval of j^{th} grade, which satisfies that $g_1 = 1$, and $g_{j+1} > g_j$. It means that in the first grade, two consecutive receiving data are compared; In the j^{th} grade, two data whose interval is g_j is compared. The basis of leakage decision is whether $\Delta_j(i)$ satisfies Eq. 2.

$$\Delta_j(i) = D(i) - D(i + g_j) > \xi \tag{2}$$

where ξ is the given threshold for leakage judgment. Equation 2 means that if the difference of the two consecutive comparison samples of the j^{th} grade was beyond the given threshold, system determines leakage occurred.

As we know, the smaller the value of the given threshold ξ, the higher the alarm sensitivity. However, the alarm error rate is also getting higher and higher. For example, if we set a very small ξ, in the case of water surface fluctuation caused by storage facilities sloshing or sensor error detection, making decision based on Eq. 2, the host server likely make error decisions. So the threshold ξ shouldn't be set too small. In the actual situation, when storage facilities are leaking, water would flow away at a constant speed, in another word, the water levels would decrease at a constant speed. According to this feature, the basis for making decisions is changed to Eq. 3 to improve the alarm sensitivity and reduce the alarm error rate.

$$\begin{cases} \Delta_j(i) > \xi \\ \Delta_j(i+1) > \xi \\ \vdots \\ \Delta_j(i+k) > \xi \\ \Delta_j(i) \approx \Delta_j(i+1) \approx \cdots \approx \Delta_j(i+k) \end{cases} \tag{3}$$

where $k \in (1, 2, 3, \cdots, n)$. Therefore decision-making is kept from interference caused by unexpected situations to a large extent.

Obviously, if the host server detected leakage in the first grade, next grades are not necessary. In another word, one comparison grade needs to be carried out, only when no leakage was detected in the previous grade.

Against the problem of difficult to detect water level changing when storage facilities seeping or leaking slowly, the multi-grade cycle comparison algorithm accumulates the water level changing value through increasing comparison interval. In the same sensor accuracy condition, it significantly improves the detection accuracy of the system.

III. Network Structure

According to the actual application environment, since the number of nodes in the system is not too large and the communication distance is relatively short, the system adopts the star topology for the wireless network. It cannot only satisfy the need for system monitoring and alarming, but also reduce the complexity of the algorithm. Meanwhile, as sensor nodes are battery-powered, it can reduce energy consumption by using the star topology. It comes to that sensor nodes can work for a longer time and the network lifetime is prolonged [22].

IV. Low Power Consumption Design for Sensor Node

Since the power of sensor nodes in the ZigBee wireless network generally is provided by batteries which could not be charged at any time, sensor nodes will lose effectiveness with batteries being used up. So power consumption is a key index for ZigBee network. Therefore, design of low power nodes is particularly important for reducing power consumption of nodes and prolonging the lifetime of nodes and network.

The power consumption model of sensor nodes [23] has been proposed by Professor Deborah Estrin, as shown in Fig. 5. As can be seen in the figure, the power consumption of sensors and processors is much lower than that of communicators. In other words, most power of sensor nodes is consumed by communicators. Thus, it can significantly reduce node power consumption by decreasing data transceiving of nodes and reducing transmission power of antennas. In view of the above, the following two methods are employed to reduce node power consumption.

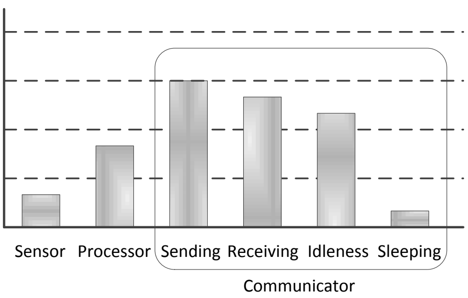

Figure 5. The power consumption model of sensor nodes

A. Sensing Data Selective Transmission Mechanism

In the system, the host server needs to monitor water levels in real time, so sensor nodes must transmit sensing data at a high frequency. Generally, there is no change in water levels, and in this case, the host server does not need to make decisions. It causes a large number of repeated redundant data transmitted, and also wastes of lots of power.

To solve the above problem, we adopt the sensing data selective transmission mechanism [24]. T_{sensor} and T_{sen} respectively represent the sensing data collection period and the transmission period, and the relation of them is as follows:

$$T_{\text{sen}} = m \times T_{\text{sensor}} \tag{4}$$

where $m \in (1, 2, 3, \cdots, n)$. Equation (4) shows that sensor nodes transmit data one time after m samples being collected. During a transmission period T_{sen}, the m sensing data are analyzed by sensor nodes, and the differences τ_l are as follows:

$$\tau_l = |X(l+1) - X(l)| \tag{5}$$

where $l \in (1, 2, 3, \cdots, m)$, $X(l)$ represents the l^{th} collected sample during a transmission period T_{sen}. If $\tau_l < \omega$, where ω is the given threshold, sensor nodes transmit sensing data at transmission period T_{sen} regularly. Namely, only $X(m)$ of the m samples is transmitted, but $\{X(1), X(2), X(3), \cdots, X(m-1)\}$ are all abandoned. Consequently, much repeated redundancy data is decreased to be transmitted. On the contrary, when $\tau_l > \omega$, it means that a leakage emergency may be happened. In this case, the sensing data is immediately transmitted to the sink node without waiting for the transmission time.

According to the above analysis, employing the sensing data selective transmission mechanism can reduce node power consumption significantly without sacrificing the system warning reliability. In this mechanism, the threshold ω, the periods T_{sensor} and T_{sen} should be set according to the actual situation.

B. Node Transmission Power Adaptive Mechanism

In this system, the distances between every sensor node and the sink node are not equal to each other, and different kinds of obstacle obstruct communication of them. Thence, it is not reasonable and wastes much power that every sensor node communicates with the sink node at a same transmission power.

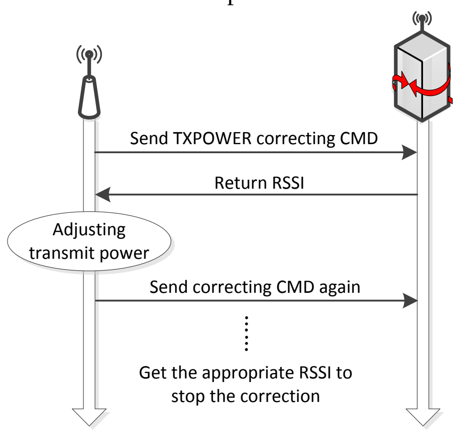

Figure 6. Power correction process

Against the above problem, the node transmission power adaptive mechanism [25] is employed in this paper, and the working flow is shown in Fig. 6. In the beginning, every sensor node joins in the network at the highest transmitted power and sends a TXPOWER correcting CMD to the sink node. Then the sink node returns RSSI (Receiving Signal Strength Indication) according to which sensor nodes adjust their own transmission power to sensor nodes. After adjusting, sensor nodes send correcting CMD again and wait for the next RSSI. The power correcting process will not be end until sensor nodes can exactly communicate with the sink node at the lowest transmission power.

By using the node transmission power adaptive mechanism, sensor nodes can adaptively select transmission power according to their own actual quality of the communication channel with the sink node. Upon this, the system gets rid of the power waste due to all sensor nodes transmit data at a unified power.

V. Experiment and Analysis

A. Communication Performance

For monitoring system, the accuracy and real-time performance are two of the most important indexes. In wireless sensor network, the end-to-end transmission is generally as a key index to evaluate the communication performance, due to the end-to-end delay and the packet loss rate respectively influence the accuracy and real-time performance of the network directly.

Therefore, in the paper, we test the end-to-end delay and the packet loss rate to verify the accuracy and real-time performance of the system.

The average end-to-end delay [26] $\overline{t_{delay}}$ is:

$$\overline{t_{delay}} = \frac{1}{N}\sum_{i=1}^{N}(rt_i - st_i) \tag{6}$$

where N is the times of successfully transmitting packets, rt_i represents the time when the i^{th} packet arrives the destination node, and st_i is the time when the i^{th} packet is sent.

In a wired network, the packet loss rate can be ignored generally. However, in a wireless network, it is an important factor for communication performance. It can be influenced by environmental condition, distance, relative height between transceiver and receiver, transmission power, data rate and packet size [27].

Experiments are carried out in open space. In the experiments, height of network nodes is about one meter. We deploy network nodes apart from 30 m. Antennas perpendicular to the ground plane and their transmission power is 1 mW. And the packet is 30 bytes. Based on a large number of experimental data, the statistical values of the average delay and the packet loss rate are shown in Fig. 7 and Fig. 8.

In the experiment result, as shown in Fig. 7, all of the delays are shorter than 0.01 s. It is so short that the system could monitor water levels in real time. The packet loss rate is shown in Fig. 8. The experimental result indicates the packet loss rate is less than 1.2% under 50 m. It means that the accuracy of the system is relatively high. As a warning system, this performance is critical. This experiment reveals that ZigBee wireless network can satisfy the warning system.

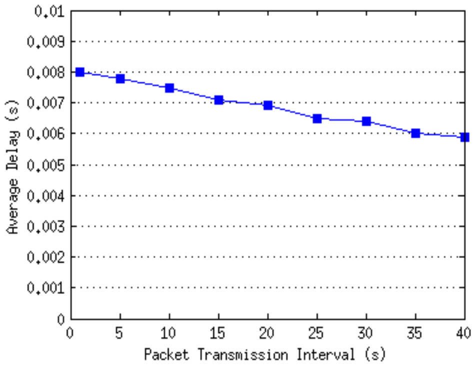

Figure 7. The average delay

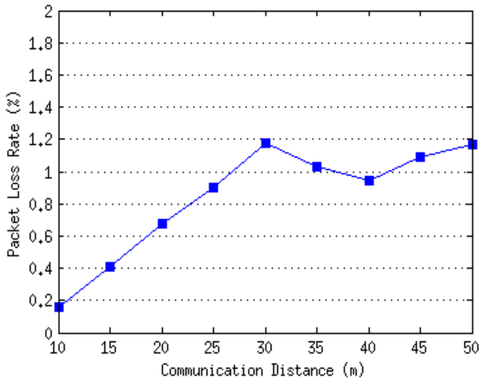

Figure 8. The packet loss rate

B. Multi-grade cycle comparison algorithm

To test the multi-grade cycle comparison algorithm, three water tanks (Tank 1, Tank 2 and Tank 3) of the same size were detected. In this experiment, every tank was monitored and judged by two detection rules: the one who making decisions with the multi-grade cycle comparison algorithm (hereinafter referred to as rule 1); the other one who making decisions without the algorithm (hereinafter referred to as rule 2). According to Eq. 3, the parameters of rule 1 are as follows: $j=2$, $k=3$, $g_1=1$, $g_2=10$, $\xi=5mm$; In rule 2, the given threshold is also 5 mm. Both in rule 1 and in rule 2, the data receiving periods are 5 s.

The initial water levels of the three tanks are 200 mm, and then different changes happened to them, shown in Fig. 9. Tank 1 and Tank 2 leaked at 1.2 mm/s and 0.6 mm/s respectively. Instead of leaking, Tank 3 sloshed.

In this experiment, leakage of Tank 1 and Tank 2 were determined by rule 1. However, by rule 2, Tank 1 and Tank 3 were determined leaking. Tank 1 leaked at a relatively fast loss speed, so it can be detected by both rule 1 and rule 2. But the change of water level of Tank 2 during a receiving period is smaller than the given threshold. Thus rule 2 cannot detect it. For Tank 3, it was not leaking, but the water surface just fluctuated. However, rule 2 misjudged it.

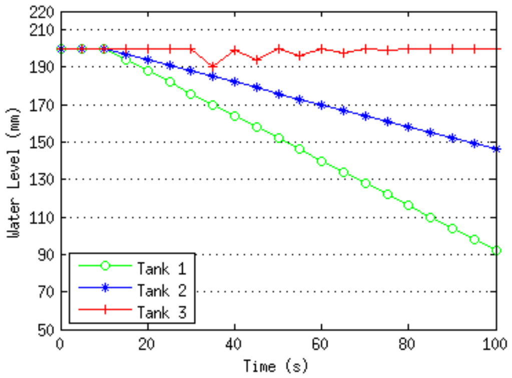

Figure 9. The change of water levels

The experiment result indicates that by comparing with conventional leakage judgment method, the multi-grade cycle comparison algorithm can not only improve the alarm sensitivity of the system, but also avoid error judgment to a large extent.

C. Low Power Mechanism

To test the performance of the low power mechanism of sensor nodes proposed in this paper, we simulate their power consumption according to a node power consumption model. Thus, the model of energy consumption based on characteristic analysis of wireless communication and computation [28] is referred. Its mathematical model is as follows:

(1) Energy consumption of application-oriented node:

$$E_{depletion} = E_{rf} + E_{cal} + E_{sensor} \tag{7}$$

(2) Energy consumption of communication module:

$$\begin{aligned} E_{rf} &= \int_0^t p_{sen} \cdot t_{sen} / T_{sen} dt + \int_0^t p_{rec} \cdot t_{rec} / T_{rec} dt \\ &+ \int_0^t p_{idle} \cdot t_{idle} / T_{idle} dt + \int_0^t p_{sleep} \cdot t_{sleep} / T_{sleep} dt \end{aligned} \tag{8}$$

(3) Energy consumption of computing module:

$$E_{atom} = \int_0^t p_{atom} \cdot t_{atom} / T_{atom} dt \tag{9}$$

(4) Energy consumption of sensor:

$$E_{sensor} = \int_0^t p_{sensor} \cdot t_{sensor} / T_{sensor} dt \tag{10}$$

where p_{sen} is the average transmission power of the RF, t_{sen} is the average time of that the RF sends one frame and T_{sen} is the transmission period of the RF. Similarly, p_{rec} , t_{rec} and T_{rec} respectively are the average receiving power, the average receiving time and the receiving period. p_{idle} , t_{idle} , T_{idle} , p_{sleep} , t_{sleep} and T_{sleep} are the average power, the average time and the period of the RF when it is at idleness mode and sleep mode respectively. p_{atom} , t_{atom} and T_{atom} are the average power, the average time and the period of atomistic computing. Likewise, p_{sensor} , t_{sensor} and T_{sensor} are the average power, the average time and the period of sensor node sampling.

In this experiment, node hardware employs the CC2530 SoC [29] of TEXAS INSTRUMENTS Company and the DYP-ME007 ultrasonic sensor [30]. Thus the physical parameters provided by their companies are as follows:

$$p_{sen} = u \cdot i_{sen} = 3.3\text{V} \times 29\text{mA} = 95.7\text{mW}$$

$$p_{rec} = u \cdot i_{rec} = 3.3\text{V} \times 24\text{mA} = 79.2\text{mW}$$

$$p_{idle} = u \cdot i_{idle} = 3.3\text{V} \times 0.2\text{mA} = 0.66\text{mW}$$

$$p_{sleep} = u \cdot i_{sleep} = 3.3\text{V} \times 1\mu\text{A} = 3.3 \times 10^{-3}\text{mW}$$

$$p_{sensor} = u \cdot i_{sensor} = 5\text{V} \times 15\text{mA} = 75\text{mW}$$

$$p_{atom} = 5/4 = 1.25\text{mW}$$

$$t_{sensor} = 1\text{ms}$$

According to the above energy model and physical parameters, the energy consumption of both the sensor nodes which adopt low power mechanisms and the sensor nodes that do not adopt them is simulated to analyze the performance of the low power design. To facilitate the analysis, the network in this experiment is only composed of a sink node and three sensor nodes (node A, B and C) and utilizes the star topology. Table I shows some parameters of the sensor nodes in the two situations.

TABLE I: PARAMETERS OF SENSOR NODES

		With the low power mechanisms	Without the low power mechanisms
Transmission power p_{sen} /mW	Node A	95.7	95.7
	Node B	75.9	95.7
	Node C	82.5	95.7
Sampling period T_{sensor} /s		1	1
Transmit period T_{sen} /s		10	1

In addition, in the ZigBee network, during one communication period the average time of node in every mode is as follows [28]:

$$t_{sen} = 3.291\text{ms}$$

$$t_{rec} = 0.842\text{ms}$$

$$t_{atom} = 1.033\text{ms}$$

$$t_{sleep} = \begin{cases} 950\text{ms}, & T_{sen} = 1\text{s} \\ 9950\text{ms}, & T_{sen} = 10\text{s} \end{cases}$$

$$t_{idle} = T_{sen} - t_{sen} - t_{rec} - t_{sleep} = 45.867\text{ms}$$

Combining with all the above parameters and the energy consumption model, we simulate the energy consumption of the sensor nodes which employ the low power design proposed in this paper and the sensor nodes which do not employ it. Moreover, the low power nodes are simulated in two situations: one is that the sensing data has remained stable states; the other one is that the sensing data has drastic changes within a certain time. The simulation result is shown in Fig. 10.

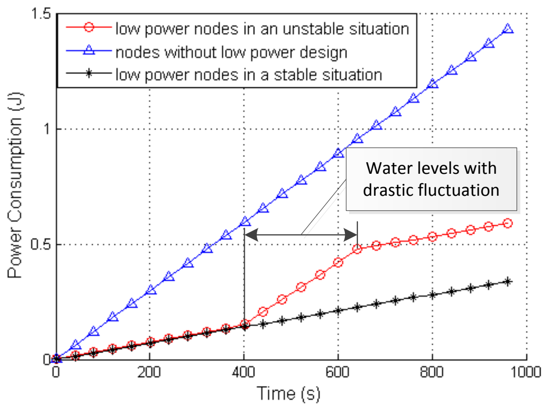

Figure 10. Energy consumption

As can be seen from the simulation result, the power consumption of the sensor nodes adopting the low power design proposed in this paper is much lower than those which do not adopt the low power design. In addition, when the water levels drastically fluctuated, the power consumption of the low power sensor nodes increased significantly. It is due to adopting the node data selective transmission mechanism. Being obtained by the simulation data, the power consumption of sensor nodes employing the low power design reduces 76.37% compared to that of sensor nodes which do not use the low power design.

D. System Test

To test the system operations, we compare the performance of the lower power automatically warning system with that of a conventional warning system, without automatic SMS alarm architecture, the multi-grade cycle comparison algorithm and low power design of sensor nodes. In this experiment, we assume that 50 tanks are randomly located in a 20 m×20 m area. Scale of all the tanks is $200\times200\times500$ mm^3. Every tank is equipped with two sensor nodes: one is sensor node of the lower power automatically warning system; the other one is that of the conventional system. The hardware of the two sensor nodes is exactly the same, and only programs of them are different.

In the low power automatically warning system, the test conditions are as follows: the sensors detect water levels every second and the sensor nodes transmit the sampling data to the sink node every 10 s according to the sensing data selective transmission mechanism, since the leakage is a very urgent situation. In the making decisions part, the host server using the multi-grade cycle comparison algorithm, and the parameters of Eq. 3 are as follows: $j=2$, $k=3$, $g_1=1$, $g_2=6$, $\xi=5mm$. In the conventional system, the sensors detect water levels every second and the sensor nodes transmit the sampling data to the sink node immediately.

In this experiment, the two systems work for 10 days. To test the system operation under leakage situations, we artificially generate water leakage and shake water tanks occasionally. During this experiment, we have created 500 times leaking accidents. Water level data, leakage times, alarm times, alarm error times and system power consumption were recorded for analyzing the experiment result. Table II shows the alarm performance of the two systems. And Table III shows the two systems' power consumption in every day. In the low power automatically warning systems, the sink node, the host server and the SMS server are not supplied with power from battery, so considering power consumption of them is meaningless. Thus, the power consumption, shown in Table III, only includes that of sensor nodes. Moreover, the low power mechanisms are also designed for sensor nodes.

TABLE II: ALARM PERFORMANCE

Different system	Accurate alarming times	Missed alarming times	False alarming times
Low power automatically warning system	500	0	1
The conventional system	457	43	12

TABLE III: ENERGY CONSUMPTION COMPARISON

Day	The low power automatically warning system	The conventional system
1	634.3J	2103.7J
2	612.8J	2098.9J
3	609.6J	2096.6J
4	619.0J	2097.5J
5	621.4J	2093.9J
6	622.5J	2097.1J
7	613.8J	2097.3J
8	624.2J	2095.8J
9	625.9J	2099.7J
10	620.1J	2096.6J

In Table II, the accurate alarm times, the missed alarm times and the false alarm times are shown to explain the accuracy of systems. During 500 leaking situations created artificially, the low power automatically warning system accurately alarmed 500 times. However, the conventional system missed alarmed 43 times. In this experiment, we also created tank sloshing 50 times. Then, for the conventional system, false alarm occurred 12 times. In contrast, the low power automatically warning system false alarmed only one time. This experimental data indicates that the alarm accuracy of the system proposed in this paper is higher than that of the conventional one.

Meanwhile, in these test situations, warning messages about corresponding leakage emergency were received in less than three seconds after alarming by the low power automatically warning system. Compared to calling related offices and users by person, this performance is meaningful.

As can be seen from Table III, for the low power automatically warning system, the fluctuation of the power consumption is related greater compared to that of the conventional system. It is because of the sensing data selective transmission mechanism. That is, during leaking, the power consumption is more than that during normal condition. Furthermore, the average power consumption of the low power automatically warning system is reduced 70.43% compared to the conventional system. The energy reducing effect is significant.

VI. Conclusions

Considering the problem of monitoring a large number of water storage facilities in the industrial and civil buildings, this paper has proposed a lower power automatically warning system for ZigBee wireless sensor network. It could achieve centralized monitoring for large amount of water storage facilities and alarming for leakage emergency. Moreover, the SMS server was added to the system architecture, so as to send the emergency message directly to related emergency management offices and the corresponding registered users. Thereby, the system achieved the automatically warning function comparing with calling the police by people after that he or she becomes aware of the leakage emergency through the alarm terminal.

Meanwhile, this article proposed the multi-grade cycle comparison algorithm, with the purpose of improving the sensitivity in the case of water storage seeping or leaking slowly. Through testing the algorithm, the experiment result showed that it cannot only improve the sensitivity of alarm, but also decrease the misjudgment rate.

Simultaneously, to reduce power consumption of the sensor nodes, the sensor node design employed the sensing data selective transmission mechanism and the node transmission power adaptive mechanism. By building a mathematical model for energy consumption of sensor nodes, the energy consumption has been simulated. The simulation result showed that the energy reducing effect is significant. This could satisfy the need for sensor nodes to monitor water levels long-term, and could effectively prolong system lifetime.

Then, we verified the system communication performance in the testbed. Through testing the end-to-end average delay and packet loss rate of the system network, it was verified that the system wireless network has a good performance.

After designing the system, we tested the system operations. In the experiment, for the low power automatically warning system, it is verified that the accuracy is improved and the power consumption of the sensor nodes is reduced significantly compared to the conventional system.

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