Regular Article

A Low Cost and Low Power Consumption Automatic Water Meter Reading System: Hardware Investigation and Network Design

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Abstract– **This paper presents a low power consumption and low cost automatic data collection network for water meter application. Based on transmission performance and power consumption, several low cost sub-GHz wireless transceivers are analyzed and compared, and consequently a suitable hardware is chosen. The associated network protocol stack is also examined. To construct the automatic collecting data mechanism, we consider a cluster based wireless sensor network (WSN) where routers and a GPRS gateway are used to link each cluster to a data collection center. Advantages of this proposed configuration are the simple implementation, low cost and low power consumption. By using the Monte Carlo simulation technique, packet delivery ratio and power consumption for different topologies are investigated. Based on obtained results, the optimum network topology for automatic water meter reading in a typical urban environment is finally proposed.**

Keywords– **Wireless sensor network, low cost and low power consumption network, automatic water meter reading.**

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1 Introduction

Due to obsolete infrastructures and with rapidly growing population and households, present data collection methods occasionally lead to system unreliability or data loss; the water supplying problem has become more difficult to solve in rapidly growing countries like Vietnam [1]. In this context, automatic and continuous reliable water metering is an important requirement.

There are several solutions for automatic water meter reading. First, transmitting water data using M-bus [2] or power line link structure [3–5]; but it has some disadvantages such as system vulnerability and heavy workload of wiring. It is therefore difficult to be deployed in urban situation of developing countries. Wireless technology using radio frequency communication such as fixed base station [6] or mobile radio station methods [7, 8] recently becomes popular, due to the fact that it is easier to deploy and at a cheaper price than cable. Hence, building a wireless collecting data system for water metering application is more practical than building a wired system. Many research studies on water monitoring based on GPRS have been proposed in the last few years [9]. However, the price of GPRS modems and GPRS services is quite expensive; henceforth, the application of GPRS technology to every household is not practical [10, 11].

In recent years, the wireless sensor network (WSN) technology has been applied to automatic meter reading domain for many reasons. Besides its low cost and low energy consumption, WSNs can be easily deployed with the coverage area easily expanded. It has been implemented for automatic water meter reading in a whole city as an experimental system [12]. With low power consumption, WSNs can last up to more than 5 years on normal battery [13]. ZigBee, a wireless networking standard that is aimed for remote control and sensor applications (working at 2.4 GHz frequency band), is usually chosen for some automatic wireless applications [13, 14].

In practice, besides its advantages previously mentioned, there is a concern about the standard frequency which is reserved for wireless metering application. Many important semiconductor companies have introduced to the consumer market some new transceivers to be used in automatic meter reading application, working at the frequency band 433-868 MHz instead of 2.4 GHz [15, 16]. These transceivers with this frequency band standard will be developed and maintained everywhere around the world.

This paper proposes a new design of an automatic water meter reading network based on the WSN technology. By using simulation tools, an optimized topology with appropriate hardware is suggested. In order to confirm the validity of this new design, we compare the proposed network performance, including the power consumption, with some other known solutions. This comparison shows that our proposed solution is effective. In fact, by constructing a network with low cost, low power consumption, with good performance using the world's common standard would offer people an opportunity to apply it in practice.

This paper is organized as follows. Section 2 discusses elements that influence the design and then

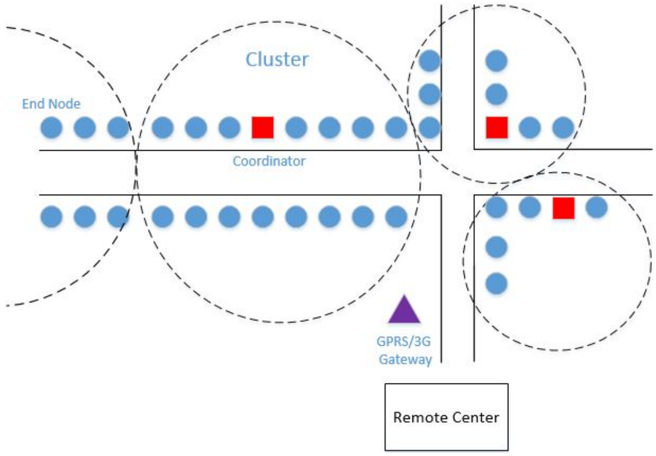

Figure 1. Simple network topology design for distribution metering.

comes up with the proposed topology. In Section 3, water metering circuits are designed and a suitable wireless transceiver is investigated. In order to find out the optimized topology, network performance and network energy efficiency based on simulation are presented in Section 4. The conclusion is finally given in Section 5.

2 Network Design for Automatic Meter Reading

Model of one residential area of an urban city in developing countries that has a crossroad with many houses along two sides of streets is illustrated in Figure 1. With the goal of building an automatic and ubiquitous water metering collection data network, the automatic data collection network topology is proposed based on clusters, as also shown in Figure 1.

Consider a situation where in a water meter hardware of every household is integrated with a wireless transceiver node (End Node in Figure 1). The water meter network is divided into several clusters for a simple management and a practical deployment. Each cluster has one Coordinator node that manages many End Nodes. The role of every End Node is to get water metering data from the water meter, then to transmit these data to the coordinating node. After receiving data from end nodes, the coordinating node will transfer the data to the GPRS/3G Gateway (for inter-networking by using GPRS/3G cellular network) in order to forward these data to the Remote center.

3 Water Meter and Automatic Data Collection Network

3.1 Water Metering Circuit

The water metering circuit is designed to record the amount of used water at every household, by converting the water metering data from analog to digital data. All of current water meters consist of a wheel where one or more magnets are attached to that wheel. When an amount of water goes through a water meter, this wheel will spin in order to show how many litres of water were used by this household. This water metering circuit will be integrated with a current water meter for record used water data by calculating the number of wheel rotations.

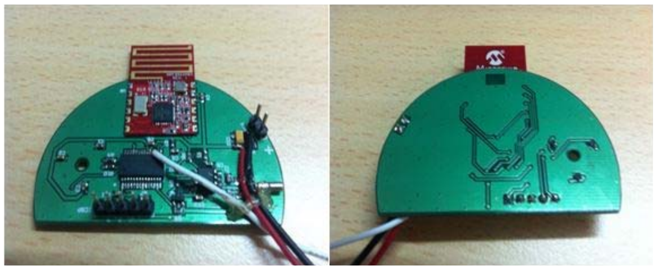

Figure 2. Water metering designed circuit.

Table I
Hardware Comparison of WSN Nodes

	MC13224V (Microchip ZigBee)	CC1120 (Texas Instrument)	CC1110 (Texas Instrument)
Standard	IEEE 802.15.4	IEEE 802.15.4g systems Ghz	TI Proprietary 868/915/433 MHz
Data rate	250 Kbps	0 to 200 kbps	up to 500 kbps
Output power	-30 dBm to +4 dBm	-40 dBm to 16 dBm	-6 dBm to 10 dBm
Received Sensitivity	-96 dBm for DCD mode -100 dBm for NDC mode	-123 dBm for 1.2 kbps -110 dBm for 50 kbps	-110 dBm for 1.2 kbps
Frequency band	2.4 GHz ISM Band	170/315/433 868/915/950 MHz ISM/SRD	315/433/868 and 915 MHz ISM/SRD
Indoor transmission test	Can go through 2 walls	Long range for maximum indoor penetration	Can go through 7 walls
Outdoor transmission test	200m	Beyond 10Km	550m with some obstacles Up to 1Km in free space
Power Consumption	RX: 22 mA TX: 29 mA Sleep: 0.85 μA	RX: 17 mA TX: 45 mA Sleep: 0.3 μA	RX: 18.7 mA TX: 21 mA Sleep: 0.5 μA
MCU	32 bit ARM7	No MCU	Integrated 8051 MCU

A designed circuit (as shown in Figure 2) includes three hall sensors to detect the spins of the magnetic wheel, an MCU (PIC18F26K22) to process data and a low cost, low power consumption transceiver module (which is described in the next section). The schematic diagram of this designed circuit is illustrated in Figure 3.

3.2 Wireless Hardware Selection

This section focuses on the study of an appropriate wireless sensor network hardware which satisfies the following goals: low cost, low power consumption, reliable transmission in urban environments. With a comparison of some latest transceiver hardware on the market in Table I, a suitable transceiver will be chosen based on these criteria.

According to Table I, Texas Instrument CC1110 and Microchip MC133224V have the advantage of an inte-

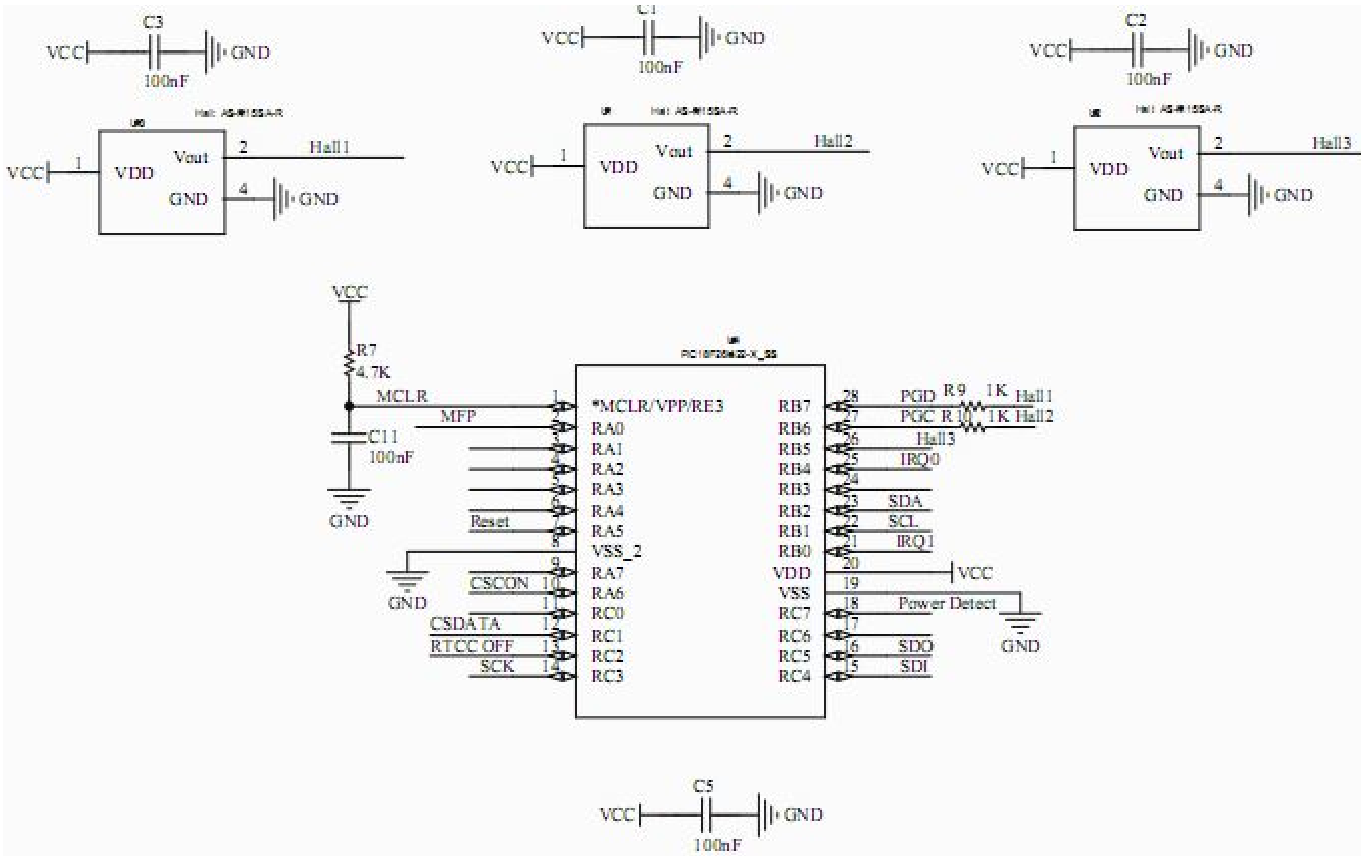

Figure 3. Water metering designed circuit schematic.

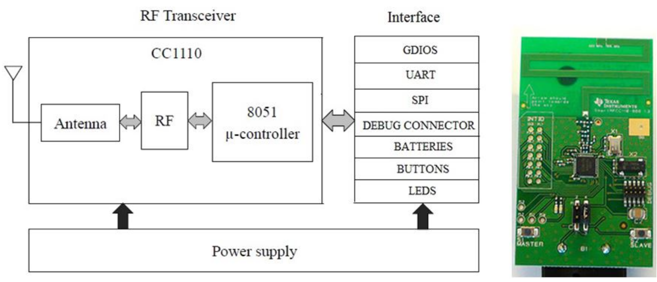

Figure 4. CC1110 mini development kit and its block diagram.

grated MCU (Micro-controller unit), yielding a lower cost of a wireless module. The power consumption of CC1110 and MC13224V SoCs (including the MCU) are equal, but CC1110 has the advantage of a reliable transmission distance due to the lower received sensitivity and the higher transmission out-put power. In case of transmission range, CC1120 has the longest transmission (up to 10 Km in datasheet), but with higher cost and power consumption than CC1110.

In Figure 5, we perform a practical range testing of the CC1110 module in a real case of semi-urban, city and indoor environments. Results of transmission distance test in Table II prove that the CC1110 transmission range is very appropriate and suitable for the proposed Automatic Water Meter network where the node-to-coordinator distance is typically less than 500 meters.

Another advantage is the SoC design of CC1110, which allows a small size wireless module to be integrated in the water meter circuit. Moreover, with the support of Texas Instrument network protocols (SimpliciTi and wireless M-Bus) for CC1110 transceiver, we can design an efficient star routing network for one Cluster in Figure 1, with a support of range extender in order to extend the network coverage.

Table II
Testing Range Result Table.

	0 dBm	10 dBm
Line of sight	1.2 Km	1.5 km
Obstacle	430 m	550 m
Indoor testing	5 walls	7 walls

4 Simulation and Results

In this section, by using the network simulation 2 (NS-2) tool, the proposed network is simulated with many scenarios (by changing network and hardware parameters) in order to evaluate the packet collision ratio, transmission latency and energy consumption. The goal of this simulation is to determine a practical number of nodes per one cluster, node-to-node distance and transmission output power.

We used a NS-2 library code of IEEE 802.15.4 standard (defined by The City College of New York and Samsung Advanced Institute of Technology, USA [17])

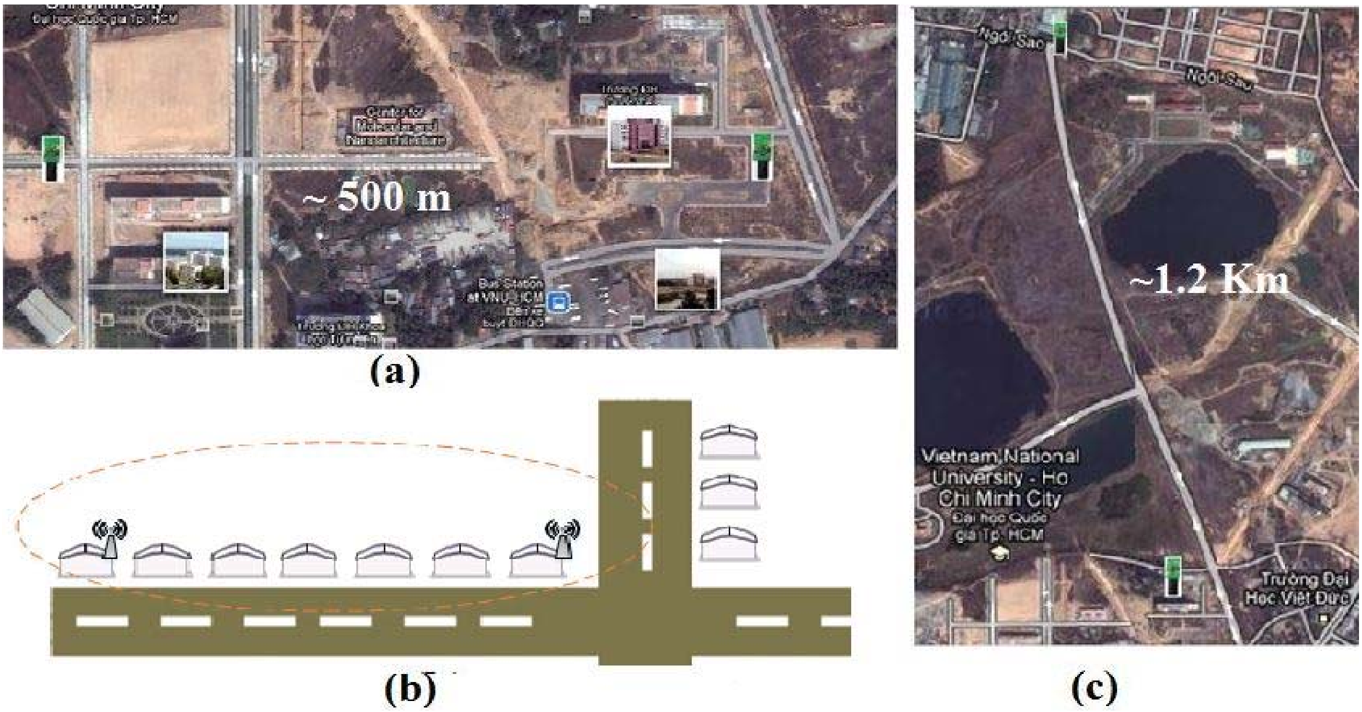

Figure 5. CC1110 real case range testing. (a) Testing through obstacles (b) Urban environment testing (c) Free-space line-of-sight.

Table III
Simulation Parameters.

Protocol	SimpliciTI
Antenna	Ommi Antenna
Propagation model	Two Ray Ground
Transmitted power	0 dBm to 10 dBm
Received sensitivity	-110 dBm at 1.2 kbps
Distance node to node	5 meters to 15 meters
Number of nodes	5 to 50 nodes
Frequency band	868 MHz

and modified it to adapt to the SimpliciTI protocol. In physical layer, propagation model is chosen as Two Ray model. The number of nodes varies from 5 to 50 nodes for one cluster. The output power is set between 0 dBm to 10 dBm. Node to node distance changes from 5 to 15 meters. In Table III, simulation parameters of the physical layer are shown. Based on the network topology design in Section 2, Figure 6 shows the network topology that is used in simulation scenarios.

4.1 Packet Collision Ratio and Delay

In Figure 7, simulations estimate the packet loss due to the packet collision when changing the size of the cluster (it means changing the number of nodes per cluster). The packets loss due to collision is calculated by

$$\text{packet\_loss} = \frac{\text{packet\_sent} - \text{packet\_receive}}{100}.$$

Based on the simulation result in Figure 7, we can observe that number of lost packets due to collision

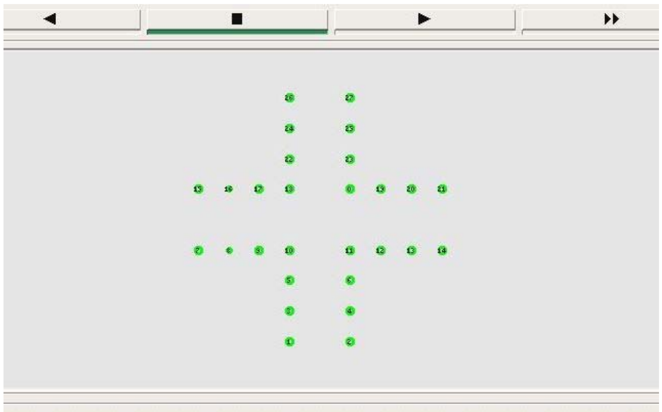

Figure 6. Network topology in simulation scenarios.

increases to 24% when the number of nodes in the network is 50. In a secured wireless transmission, CSMA/CA technique is used to resend a lost packet and to ensure all dropped packets will be resent correctly 100%, so that the packet loss by collision less than 30% can be acceptable for a wireless network design.

In considering an actual urban population density in Hochiminh-city, as well as required facilities for deployment and maintenance, each cluster in our network should have 30 to 50 nodes.

In the next simulation scenario, the number of nodes per cluster is fixed at 30, but the transmitted power is changed from 0 to 10 dBm and the node-to-node distance is also varied from 5 to 20 meters. The goal of this scenario is to observe the changing of packet loss by collision as function of the node-to-node distance.

When the node-to-node distance of cluster is less than 20 meters, 10 dBm output power generates more

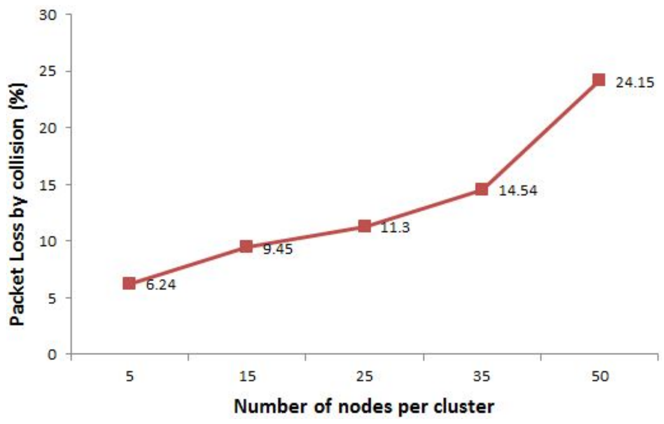

Figure 7. Packets collision loss when increasing cluster size.

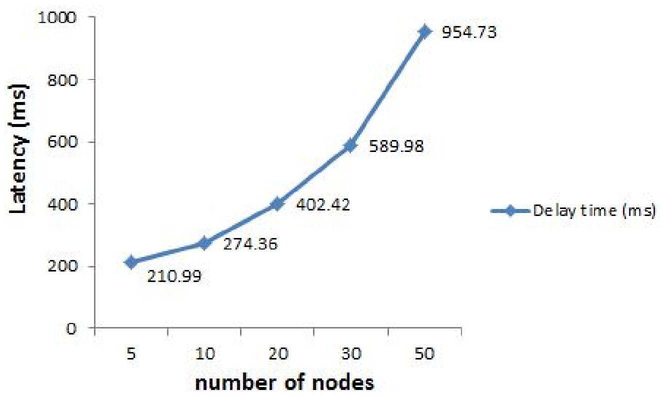

Figure 9. Latency of network.

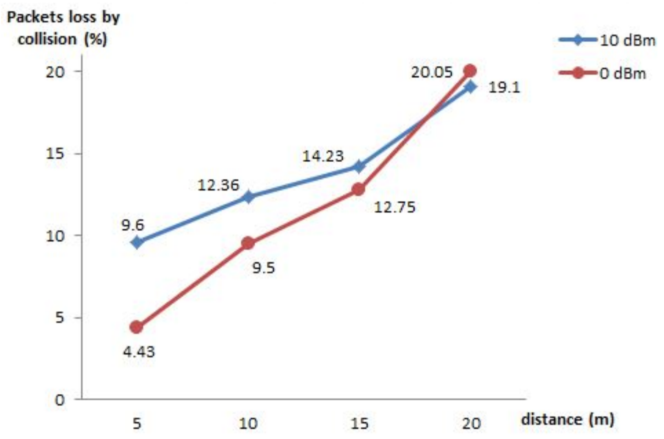

Figure 8. Packet loss with different output power and distances.

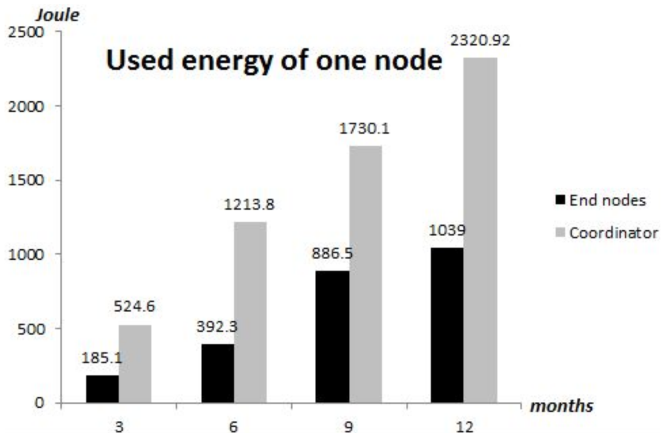

Figure 10. Energy consumption of one node after 1 year.

interference to other nodes than 0 dBm output power. This is why the packet loss due to collision is higher. In the practical case of urban city where the distance of each household is less than 15 meters (i.e. the node-to-node distance between two nodes is less than 15 meters), based on Figure 8, the automatic data collection network can operate stably with packet loss by collision less than 12.75%. Hence, the output power should be chosen at 0 dBm instead of 10 dBm in order to reduce the energy consumption of the wireless node.

The simulation result in Figure 9 illustrates the transmission delay time of a whole network when increasing the number of nodes. The packet size is set to 20 bytes and each node sends 400 packets. We can observe that the transmission delay time is less than 1000 ms when the number of nodes per cluster is up to 50. We can have a conclusion that the transmission latency is less than 1 second with the number of nodes per cluster less than 50.

4.2 Energy Consumption

Consider two AAA batteries to be used for one wireless end node and assume that one battery of 1.5 V delivers 900 mAh; the energy contained in the two batteries is 2700 mWh (equal to 9720 Joules). We would like to warranty that batteries for a wireless end node should last at least 5 years; for this purpose we run simulations for a cluster of 30 nodes in order to estimate the energy consumption of end and coordinator nodes for one year.

Let us assume that the remote center needs to collect meter data two times per day for tracking and maintaining the service, so that all end nodes have to transmit their data twice every day. To save energy, after finishing the transmission, all these End devices nodes should switch to the sleep mode.

Based on the transceiver datasheet [18], the current consumption of a wireless node (transceiver and MCU) active in the transmission mode is 21 mA (TX mode at 0 dBm output power), in the reception mode is 18.7 mA (RX mode), and in the sleep mode is 0.005 mA. Figure 10 shows the energy consumption of the coordinator node and the average energy consumption of one End node in a cluster for 1 year.

We can observe that the energy consumption of the coordinator is always much higher than the consumption of one end node since it must receive packets all time and then forward these packets to the remote center while the end nodes are switching to the sleep mode. Moreover, the average energy consumption of the end node is 1039 Joules, so that the 9720 Joules energy contained in the two AAA batteries in one end node can last up to 9 years.

5 Conclusion

In this paper, a design of a low cost and low power consumption wireless sensor network for an automatic water meter reading system in the urban environment is proposed. In the proposed network, meter hardware design, energy efficient wireless hardware and optimized data collection network topology have been investigated to ensure the automatic and long term operation with a normal AAA dual-battery power supply.

Through NS-2 network simulation, the packet loss due to collision, the packet delivery delay and the energy consumption of wireless nodes have also been performed in this paper.

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