RESEARCH ON SIMULATION OF WIRELESS SENSOR NETWORK

Liang Wei[1], Yu Haibin[1], Che Chang[2,3], Bai Jieyin[1]

1 Shenyang Institute of Automation, Chineses Academy of Sciences, Shenyang, China 110016
2 Shenyang Jianzhu University, Shenyang, China 110168
3 Shenyang Engineering & Research Institute For Non-Ferrous metallurgy, Shenyang, China 110003

Abstract: Wireless Sensor Network(WSN) is a new kind of measuring and controlling network system. Since simulation resolves the difficulties in large-scale WSN physical systems build-up, it is an important means for WSN R&D work. In this paper, a WSN simulation platform is developed based on a universal hierarchical architecture. And in terms of WSN features, an improved MAC protocol is proposed based on IEEE802.11 protocol. On the simulation platform developed, simulation experiments adopted three kinds of WSN route protocols and two kinds of performance evaluation criteria. Simulation results show that the performance of the proposed MAC protocol is better.

Keywords: Simulation; Control System; Sensor System; System Architectures; Hierarchical Structures; Communication Protocol

1 INTRODUCTION[4]

Wireless Sensor Network(WSN) is a kind of measuring and controlling network system consisting of a mass of ubiquitous tiny sensor nodes that have communication and computing capabilities, and a typical autonomous and intelligent system which can independently accomplish specific duties depending on the changing environment. Compared with traditional network systems, WSN is featured with large-scale, random-deployment, multi-hop communication, self-organization, collaborative working, etc.. These features ensure that WSN find a wild range of applications in sectors of military, industry, health care, home life, environment protection, etc.. WSN is involved with many research fields such as micro-electro-mechanical systems(MEMS), communication, automation, artificial intelligence and so on(Lan, et al., 2002). However, the benefit that WSN will bring to our society is immeasurable. To be sure, WSN gives us a new set of challenges, including limited resources, complicated dynamic topology, and scalability, etc., all of which need to be addressed before we can get real benefits from it. Currently, WSN has won more and more attentions from researchers and governments of various countries, becoming a new R&D focus.

Traditionally, three main techniques used for performance analysis of wired and wireless networks are analytical methods, computer simulation, and physical measurement. However, in the case of WSN many new constraints have emerged, such as limited energy, decentralized collaboration, fault tolerance techniques, and applicable algorithms, since WSN has posed new problems that are quite complex and defying analytical methods that have been proved to be fairly effective for traditional networks. Up to now, few WSN results have been achieved due to its extremity in large-scale and virtual impossibility of measurement. However, simulation may help overcome the difficulties in setting up large-scale physical system to save R&D cost. It seams that simulation is the only feasible approach to

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quantitative analysis of WSN. In fact, simulation has become the main aid to WSN R&D work at present.

Although some researchers are currently engaged in development of WSN simulation schemes(Sung Park et al., 2000; Ahmed and Jennifer, 2003; Sameer, et al., 2004), a comprehensive simulation platform is needed for our project. In addition, it is true that Standard IEEE802.11 of WLAN I has been widely used in simulation and test of WSN at present (Wendi, et al., 1999; Chalermek, et al., 2003), but it is not specially oriented to WSN, with some features and functions not suitable for WSN (Xu and Saadawi, 2001) in spite that it supports multi-hop networks architecture.

In this paper, a universal hierarchical mode architecture of WSN simulation is put forward, based on which a simulation platform is developed. And an improved MAC protocol is presented, which is based on IEEE802.11 and integrate P-ACK mechanism into the broadcast mode, eliminating frame segmentation and reassembly mechanism with reference to the peculiarities of WSN. On our simulation platform great deals of experiments were conducted, performance results of improved MAC protocol being presented and analyzed in combination of detailed examples.

2 SIMULATION PLATFORM

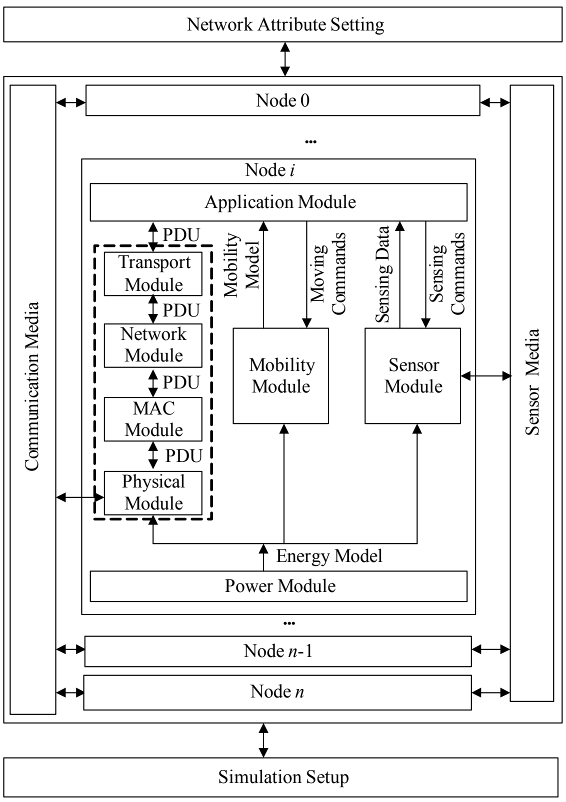


Fig.1. Simulation Platform Architecture of WSN

In this section, a WSN simulation platform developed in our project is described based on a universal hierarchical architecture, which may be divided into three layers as shown in Fig.1, i.e., Module Layer, Node Layer and Network Layer. On this WSN platform, various kinds of algorithms may be tested and compared, for example, WSN routing algorithms, WSN MAC algorithms, Time Synchronization algorithms, Location algorithms, system management algorithms, etc.. And typical application of WSN, for instance, monitoring and measuring, target location, target tracking and so on, also may be emulated on this platform.

2.1 Module Layer

The lowest layer of simulation architecture is Module Layer, which describes the behavior and implementation of various functional modules. The following modules are involved.

Application Module This module is designed for application-orientation, mainly functioning to carry out:

- Data processing. This module receives data from Sensor Module and them transmits to Transport Module. Receiving data from Transport Module, it computes and record statistic parameters, discarding the packets. It also generates node motion commands for Mobility Module according to data from Sensor Module or Transport Module and the model derived from Mobility Module.
- Providing basic services, including time synchronization and node location;
- Providing service interfaces of collaborative application for user, for example, energy scan, topology management, sensor management, etc..

Transport Module This module, receiving PDU from Application Module and Network Module, controls transport, measures end-to-end transport quality and provides Internet access interface.

Network Module Upon receiving PDU from Transport Module and MAC Module, the module carries out route selection for packets, and collects statistics of network performance. This module may be used to test and analyze many kinds of different route algorithms t in a way of comparison, for instance, FLOODING, SPIN, Directed Diffusion(DD), LEACH and so on(Edgar H. Callaway, 2004). Its detail implementation frame is shown in Fig.2(a).

MAC Module This module receives PDU from Network Module or Physical Module and schedules wireless channel access. This module may be used to simulate channel access protocol of data link layer and test many kinds of MAC protocols, such as CSMA/CA, MD and S-MAC, etc.. The detail implementation frame of MAC Module is shown in Fig.2(b).

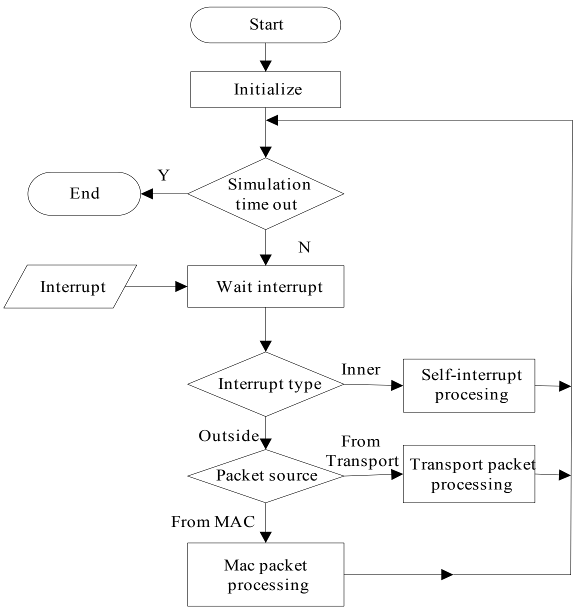
Physical Module This module defines model of physics layer, stimulate wireless channel and antenna, sends and receives packets on wireless channel. It interacts with MAC Module and Communication Media. Additionally, the antenna is generally adopted in an omni-directional mode.

Sensor Module This module mainly functions:

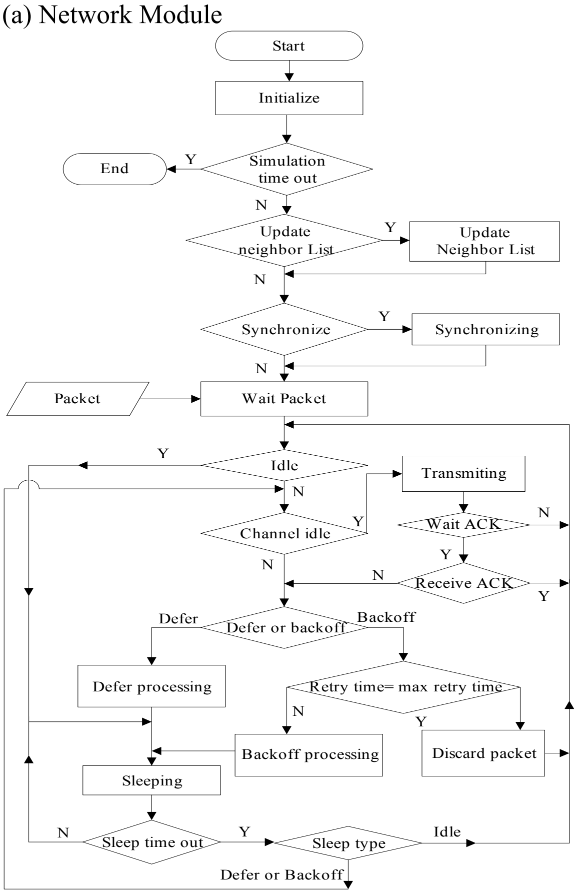
- To capture signals generated by environment via sensor media;
- To roughly process the data acquired, and then send to Application Module.

Power Module This module has functions of energy-production, energy-consuming and energy conservation.

Mobility Module This module defines mobility model of nodes, including node position changes, and realizes the movement of nodes.



(a) Network Module



(b) MAC Module

Fig.2 Implementation of Main Modules

2.2 Node Layer

Node Layer is second layer of the simulation architecture. Nodes are comprised of (1)Sensor Module, (2) Communication Protocol Stack made up of Physical Module, MAC Module, Network Module and Transport Module and able to send information via wireless media, (3) Power Module, (4) mobility Module, and (5) Application Module. Therefore, any node is possessed of communication, computing and mobility capabilities.

According to their features, nodes may be divided into three classes, i.e., sensor nodes, sink nodes and target nodes. Modules are selective e for each kind of nodes depending on actual demands.

2.3 Network Layer

The uppermost layer of this architecture is Network Layer, basically consisting of four parts, namely, Node, Media, Network Attributes and Simulation Setup. WSN Simulation system has many sensor nodes interacting with environment via media and with respect to network attributes and simulation setup. Node is the basic element of simulation system. And selection of node models is important to simulation system. Media is the essential element for nodes' interaction with environment. Media includes Communication Media used in wireless communication and Sensor Media used for environment sensing. Network Attributes is responsible for the decision making work for network size, network topology, network rate and other attributes. Simulation setup is also used to set parameters related to simulation, such as simulation time, statistic parameters, output files and so on.

3 IMPROVED MAC PROTOCOL BASED ON IEEE802.11

Standard IEEE802.11 was confirmed by experts in LANs and computer domain in 1997, which mainly standardizes physics layer and media access control(MAC) layer of OSI/ISO reference model. At present, IEEE802.11 is adopted as MAC protocol by most researchers on WSN route protocols and WSN classic applications. Nevertheless, it has been revealed from our simulation experiences that IEEE802.11 is not totally adaptable to WSN.

IEEE802.11 has used CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) or DCF (Distributed Coordination Function) protocol. CSMA/CA has taken the advantages of RTS/CTS mechanism to solve those hidden extreme problems and made use of ACK mechanism to guarantee successful transmission of packets.

However, RTS/CTS mechanism under broadcasting mode could not be supported. We have found that If RTS/CTS was added into the broadcasting mode, simulation results indicated that conflicts of RTS/CTS packets had seriously increased extra burden of the network so that very little improved network performance resulted or , even worse. In addition, IEEE802.11 protocol does not adopt ACK mechanism under broadcast communication mode. However, WSN systems adopt mainly the broadcast communication mode, in which most of communications are emergent. Simulation researchers found that there frequently occur packet conflicts in WSN system adopting IEEE802.11 protocol, resulting in serious data loss. But using ACK mechanism of unicast mode in the broadcast mode (named ALL-ACK MAC) may cause explosion of ACK packets to influence system performance. Therefore, in this paper an ACK mechanism is proposed based on probability, namely, P-ACK mechanism, to solve the questions described above. And the MAC algorithm adopting P-ACK mechanism is named P-ACK MAC.

3.1 P-ACK Mechanism

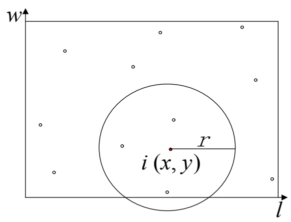


Fig.3 Communication Model Between nodes

As Fig.3 shown, suppose covering area of the wireless sensor network is a rectangle whose length and width is respectively l and w., then we have n+1 nodes in the rectangle. The nodes are distributed uniformly. Radius of communication among the nodes is r. Apparently, solution to node count within the communication radius for Node i (x, y) is a classic binomial distribution problem. According to the nature of binomial distribution, the average neighbor count N_{avg} of Node i is depicted in Eqs.(1).

$$N_{\text{avg}} = n \times p \tag{1}$$

where p is node distributing probability in the communication radius of certain Node i, i.e.

$$p = \frac{S}{l \times w} \tag{2}$$

where S is the mean value of the effective regional areas covered by all sensor nodes, then S follows,

$$S = E(s) \tag{3}$$

where s presents the intersection of $l \times w$ rectangle and the circle whose centre and radius is respectively Node i and r. Because of the WSN features--large-scale and small communication radius, we have only considered the situation of $l \geq 2r$ and $w \geq 2r$, then s can be depicted in Eqs.(4).

$$\begin{aligned} s = {} & \frac{(k_1\alpha + k_2\beta + k_3\pi/2)}{2\pi} \cdot \pi r^2 + \\ & k_4 \min(x, l-x)\min(y, w-y) + \\ & \frac{1}{2}k_1\cos(\alpha) r \min(x, l-x) + \\ & \frac{1}{2}k_2\cos(\beta) r \min(y, w-y) \end{aligned} \tag{4}$$

where

$$\alpha = \arcsin\left(\frac{\min(x, l-x)}{r}\right)$$

$$\beta = \arcsin\left(\frac{\min(y, w-y)}{r}\right)$$

$$k_1 = \begin{cases} 1 & (x<r \,\&\, y<r \,\&\, x^2+y^2<r^2) \,\|\, \\ & (x<r \,\&\, w-r<y<w \,\&\, x^2+(w-y)^2<r^2) \\ & \|\, (l-r<x<l \,\&\, y<r \,\&\, (l-x)^2+y^2<r^2) \\ & \|\, (l-r<x<l \,\&\, w-r<y<w \,\&\, \\ & (l-x)^2+(w-y)^2<r^2) \\ 2 & ((x<r \,\|\, l-r<x<l) \,\&\, r \leq y \leq w-r) \,\|\, \\ & (x<r \,\&\, y<r \,\&\, x^2+y^2>r^2) \,\|\, \\ & (x<r \,\&\, w-r<y<w \,\&\, x^2+(w-y)^2>r^2) \\ & \|\, (l-r<x<l \,\&\, y<r \,\&\, (l-x)^2+y^2>r^2) \\ & \|\, (l-r<x<l \,\&\, w-r<y<w \,\&\, \\ & (l-x)^2+(w-y)^2>r^2) \\ 0 & \textit{others} \end{cases}$$

$$k_2 = \begin{cases} 1 & (x<r \,\&\, y<r \,\&\, x^2+y^2<r^2) \,\|\, \\ & (x<r \,\&\, w-r<y<w \,\&\, x^2+(w-y)^2<r^2) \\ & \|\, (l-r<x<l \,\&\, y<r \,\&\, (l-x)^2+y^2<r^2) \\ & \|\, (l-r<x<l \,\&\, w-r<y<w \,\&\, \\ & (l-x)^2+(w-y)^2<r^2) \\ 2 & ((y<r \,\|\, w-r<y<w) \,\&\, r \leq x \leq l-r) \\ & \|\, (x<r \,\&\, y<r \,\&\, x^2+y^2>r^2) \,\|\, \\ & \|\, (x<r \,\&\, w-r<y<w \\ & \&\, x^2+(w-y)^2>r^2) \,\|\, \\ & (l-r<x<l \,\&\, y<r \,\&\, (l-x)^2+y^2>r^2) \\ & \|\, (l-r<x<l \,\&\, w-r<y<w \,\&\, \\ & (l-x)^2+(w-y)^2>r^2) \\ 0 & \textit{others} \end{cases}$$

$$k_3 = \begin{cases} 1 & (x<r \,\&\, y<r \,\&\, x^2+y^2<r^2) \,\|\, (x<r \\ & \&\, w-r<y<w \,\&\, x^2+(w-y)^2<r^2) \\ & \|\, (l-r<x<l \,\&\, y<r \,\&\, (l-x)^2+y^2<r^2) \\ & \|\, (l-r<x<l \,\&\, w-r<y<w \,\&\, \\ & (l-x)^2+(w-y)^2<r^2) \\ 2 & (l-r \leq x \leq l \,\&\, (!w-r \leq y \leq w)) \,\|\, \\ & (w-r \leq y \leq w \,\&\, (!l-r \leq x \leq l)) \\ 4 & l-r \leq x \leq l \,\&\, w-r \leq y \leq w \\ 0 & \textit{others} \end{cases}$$

$$k_4 = \begin{cases} 1 & (x<r \,\|\, y<r) \,\&\, (l-r<x \leq l \,\|\, w-r<y \leq w) \\ 0 & \textit{others} \end{cases}$$

Therefore,

$$S = \frac{1}{l \times w} \int_0^w \int_0^l \begin{pmatrix} \frac{(k_1\alpha + k_2\beta + k_3\pi/2)}{2\pi} \cdot \pi r^2 \\ + k_4 \min(x, l-x)\min(y, w-y) \\ + \frac{1}{2} k_1 \cos(\alpha) r \min(x, l-x) + \\ \frac{1}{2} k_2 \cos(\beta) r \min(y, w-y) \end{pmatrix} dxdy \quad (5)$$

P_{ack} stands for probability of ACK sending for each node,

$$P_{ack} = \frac{1}{N_{avg}} \quad (6)$$

In order to realize P-ACK MAC, following codes are added to the original IEEE802.11.

- Probability calculation of ACK sending, i.e., P_{ack}, during network initialization period;
- Request to reply ACK during each node sending data packet in the broadcasting mode;
- Generating a random number *rnd* in [0,1] interval according to uniform distribution upon receiving t data packet in the broadcast mode for each node; If *rnd* is smaller than Pack, then ACK information is sent, otherwise no ACK information sent out.

3.2 Cancel Unnecessary Mechanism

MAC layer of IEEE802.11 protocol is able to segment large information packets and reassemble them. The segmentation and reassembly process is totally transparent for the upper layer. In fact, this feature of IEEE802.11 is not suitable for WSN, data packets of WSN are used for transmitting measurement data and the size of packet is very much limited. So, our proposed approach eliminates the mechanism of frame segmentation and reassembly for large size information in IEEE802.11 protocol, thus reducing complexity of the protocol and difficulty of protocol implementation.

4 CASE STUDY

Simulation examples were studied in this section to show the performance and characteristics of the P-ACK MAC protocol. In our simulation, FLOODING, SPIN and DD route algorithm were selected. And P-ACK MAC protocol was compared with IEEE802.11 and ALL-ACK MAC.

The wireless sensor network is data-centered, or, in other words, not interested to single node, but to the data of a certain region or a certain geographical position. Therefore, the rectangle area that wireless sensor network covers has to be divided into $n \times m$ regions as shown in Fig.4. Assume that one of nodes is Sink node, which is responsible for collecting the data of the specific region in network(i.e., source). No doubt the capability of performing function, i.e., whether system can collect expected data, is foremost. However, performance is also important for WSN. Convergence time of network is defined as the time that Sink node spends collecting the data of the specific region, which reflects the average communication delay of network. In addition, energy saving is the key target of WSN. Accordingly, we selected convergence time and energy consumption at the convergence time as the criteria of network performance.

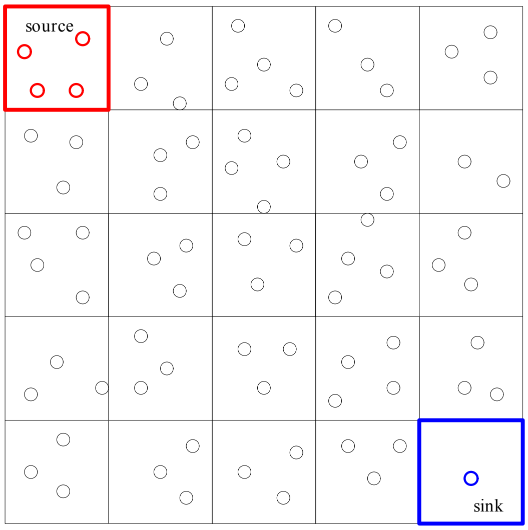
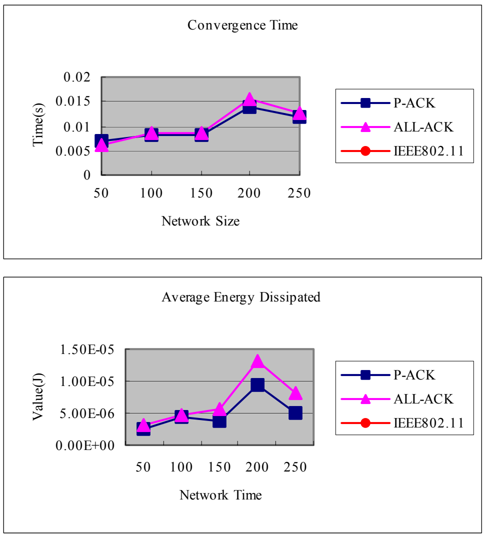


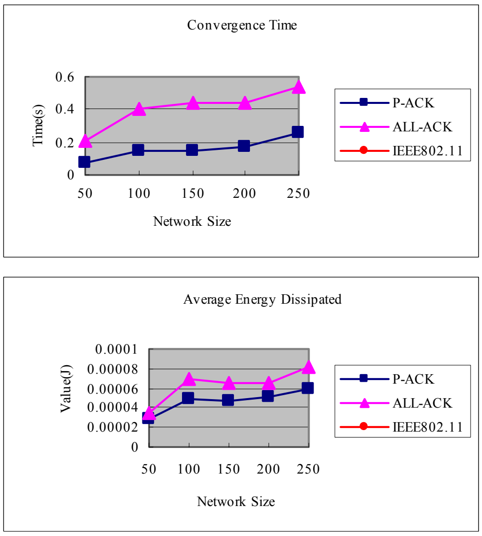
Fig.4 Performance criteria

In each of our experiments, we study five different sensor fields, ranging from 50 to 250 nodes in increment of 50 nodes. Our node field generated by randomly placing the nodes is in a 100m by 100m square, which is divided into 5 by 5 regions. The radius of radio communication of 50-node network is 30m, 100-node is 20m, 150-node is 20m, 200-node is 15m and 250-node is 15m. Other simulation environment was set up as follows: propagation delay of radio being $3{*}10^8$m/s, speed of radio communication, 1Mbps, this test network assumes no losses and no queuing delay, having data packet size of 64 byte, meta-data packet size of 16 byte, and interest packet size of 32, 395mW of receive power dissipation and 660mW of transmit power dissipation.

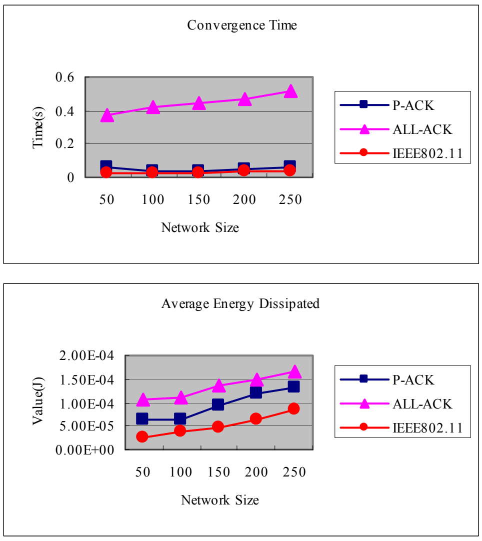
Simulation results are shown in Fig.5 where convergence time and power dissipation comes from experiments performed 50 times. Fig.5(a), (b) and (c) respectively adopts FLOODING, SPIN and DD as route algorithm, where results of DD come from results before reinforcement. In terms of simulation results, IEEE802.11 entirely can not work for FLOODING and SPIN. Although IEEE802.11 has better convergence time and power dissipation than P-ACK MAC, these are about 60 percent of data and approximate 40 percent experiments can not collect data. In other words, IEEE802.11 has great difficulties in perform tasks of WSN. On the side, P-ACK MAC is better than ALL-ACK MAC in all the experiments.



(a) FLOODING



(b) SPIN



(c) DD

Fig.5 Convergence Criteria

In conclusion, simulation results show the P-ACK MAC protocol is better than IEEE802.11 and ALL-ACK MAC not only in function but also in performance.

5 CONCLUSIONS

Due to the super large-scale feature of wireless sensor network, simulation technique has become the important means in WSN R&D work. This paper describes a universal WSN simulation architecture and an accordingly developed WSN simulation platform. Moreover, this paper summarizes defects of IEEE802.11 used in WSN and proposes an improved MAC layer protocol based on IEEE802.11 protocol. Simulation experiments show that the improved MAC protocol(namely, P-ACK MAC) has better performance.

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