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Mobile agents assisted data collection in wireless sensor networks utilizing ZigBee technology

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ABSTRACT

Wireless sensor networks (WSNs) are being utilized widely in many different industries, including agriculture, medicine, and the military. They contain many distributed sensors to monitor physical or environmental factors, such as temperature, humidity, pressure, etc. and use various communication technologies, including WiFi, radio frequency (RF), Bluetooth, and ZigBee. ZigBee is always a preferred choice for applications in WSNs. ZigBee has remarkable capabilities, such as saving energy and transmitting data over long distances. ZigBee end devices, as well as a ZigBee coordinator (ZC) and a ZigBee router (ZR), are crucial components of the WSNs. This article discusses the fundamentals of the ZigBee network, one of the most popular data transmission technologies in wireless sensor networks (WSNs). Additionally, we want to discuss the ZigBee communication technologies and their applications, particularly in the networks. Different scenarios for mobile agents including their routing protocols in WSNs are considered. Simulation results of different scenarios demonstrate how easily scalability can be achieved and provide a foundation for further ZigBee application development. At last, some conclusions and ideas are presented for considerations.

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1. INTRODUCTION

Wireless sensor network (WSN) models are becoming more and more popular in people's lives [1], [2]. It appears in many fields such as intelligent transportation [3], [4] agriculture [5], medical [6], [7], military [8], [9]. However, the issue of communication and data collection is always one of the issues that many people care about because the amount of data is increasing day by day, the requirements are increasingly strict. Therefore, choosing an effective communication technology and data collection method is one of the most important criteria in WSNs.

We have a variety of communication technologies to choose from for implementation in the network. Research by Okorie *et al*. [10] implement a WSN using Bluetooth communication technology to perform water level monitoring and monitoring of water properties. Research by Chu *et al*. [11] designed a WSN to monitor environmental parameters such as humidity and temperature using Bluetooth communication technology. Besides, research by Hlaing *et al*. [12] use WiFi communication technology to monitor and transmit the user's power consumption to the data processing center. Not only using single communication technology, the combination of Zigbee and WiFi communication technology to deploy WSN models in agriculture to monitor soil moisture, light, and temperature mentioned in paper [13]. Reseach by Shabina [14], deploying a sensor network model using radio frequency (RF) communication technology to monitor parameters such as temperature changes, humidity, pressure, fire and make decisions for necessary actions based on measured data, thereby ensuring the safety of workers working in the mines. One of the disadvantages of the deployment of a WSN model using communication technologies such as WiFi, Bluetooth, or RF is the high energy consumption, and difficult scalability as shown in Table 1.

Table 1. Comparison of Zigbee technology with several other wireless communication technologies

Parameters	Zigbee	WiFi	RF
Communication range	50-1,600 m	50 m	100 m
Operating frequency	850-930 MHz	2.4 GHz	3 KHz-300 GHz
Power consumption	Very low	High	Low
Transfer rate	250 Kbps	11 Mbps	150 Kbps
Complexity	Low	High	Medium
Connection time	30 ms	Up to 3 s	Up to 3 s
Ability of extension	65,000	2,007	65

To tackle the problem of energy consumption, Zigbee communication technology can be considered an effective alternative. In paper [15], [16] a reliable, flexible, and low-cost sensor network system is applied in the industry based on Zigbee communication technology. A sensor network model that uses a flexible Zigbee network architecture, based on reliable data transmission, to provide the necessary information for autonomous decision-making in smart irrigation systems presented in paper [17]–[19].

Today, Zigbee technology has become the global sensor/controller network standard. Some outstanding features of Zigbee technology can be mentioned as follows: i) low energy consumption, simple implementation, and battery life can last up to years. Zigbee has active working modes when transmitting and receiving data or sleep mode to save energy and ii) simple protocol, global implementation, Zigbee's protocol code stack is only 1/4 of that of Bluetooth. This simplicity is important given the cost, interoperability, and maintainability. Therefore, Zigbee communication technology becomes an effective solution for communication problems in the networks.

Most of the research focuses on recommending network architectures and improving routing protocols in WSNs. The main purposes are to save energy consumption for such networks. In another point of view, mobile agents are considered to support the networks since they usually have higher capacities of energy storage, computation, and communications [20]–[22]. This high capacity support sensor to deal with long communication range. Mobile agents became common with WSNs. They can connect to each other and make a mobile network [23], [24]. Data transmitting among the mobile agents or from them to a base-station (BS) can used different technologies as mentioned previously. To our best knowledge, existing work do not address the method of data collection in the network and regardless of the mobility of mobile agents supporting the network data collection process. In this paper, we propose to use mobile agents to assist in data collection of WSNs with different moving speeds, the results are evaluated and discussed in section 5.

The rest of this paper is organized as follows; section 2 presents the system model which shows the network components and scenarios for different data collection methods. Section 3 describes Zigbee communication technology. Section 4 provides details about routing protocols in Zigbee networks. Section 5 gives simulation results for the scenarios given above. Finally, conclusions and future developments are presented.

2. SYSTEM MODEL

Figure 1 shows a WSN architecture that uses Zigbee communication to collect data. The data from the surroundings is collected by the sensor nodes. This data will then be transmitted to the routers located within the shortest communication range. Then the data from the routers will be forwarded to the coordinator and now the coordinator will connect with other networks to bring the data to the user interface.

There are many possible scenarios during data collection in sensor networks. However, in this paper we assume three scenarios. Scenario 1 is a WSN that uses many static routers to forward data from end devices to the coordinator. Scenario 2 is a WSN that only uses a mobile router moving in an existing trajectory to collect data from sensor nodes and then transfer this data to the coordinator. Scenario 3 is similar to scenario 2 however, the mobile router moves at a higher speed. The purpose of the different scenarios is to evaluate the advantages and disadvantages of each. Therefore, depending on the requirements of the actual problem to apply the scenario to specific applications in the most effective way.

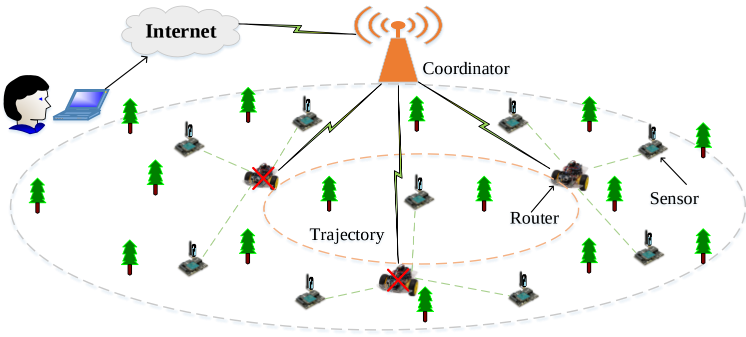


Figure 1. System model

3. OVERVIEW OF ZIGBEE

Zigbee is a wireless technology based on industry standards and was developed to enable low-power, low-cost wireless networks for machine-to-machine (M2M) and internet of things (IoT) applications. Zigbee is an open standard that was designed for applications that require low data rates and low amounts of power. This makes it possible to have a combination of implementations from various manufacturers. In actual use, however, vendors have extended and modified the functionality of Zigbee's products. As a consequence of this, it suffers from interoperability problems. Zigbee supports much lower data rates in comparison to WiFi, which is the network that connects the terminal to the high-speed network. Additionally, Zigbee utilizes the mesh topology protocol to avoid centralized equipment and construct an architecture capable of self-healing.

3.1. Network components

A ZigBee network consists of 3 types of devices:

- Zigbee coordinator (ZC): this is the root device that has the ability to determine the network topology, it also shows how to generate addresses and store the address table. Each network has only one coordinator and it is also the sole component that can communicate with other networks.
- Zigbee router (ZR): ZR has the functions of intermediate routing of data transmission, detection, and mapping of surrounding nodes, monitoring, control, and data collection like normal nodes. Routers are usually active modes to communicate with other elements of the network.
- Zigbee end devices (ZED): these nodes only communicate with the coordinator or router near it, they are considered as the endpoint of the network and are only responsible for operating/reading information from physical (PHY) components. ZED has a simple structure and is usually sleep mode to save energy. They are only "awakened" when they need to receive or send a certain message.

These devices are usually divided into 2 types: full function device (FFD) and reduced function device (RFD). Where FFD can act as a coordinator, router or end device, while RFD can only act as end device in a ZigBee network.

3.2. ZigBee topologies

The ZigBee standard has three basic network topologies, depending on the specific application that people set up the network in different topologies as shown in Figure 2:

- Star network: the network only has ZC and ZED. When ZC is activated for the first time it becomes the personal area network (PAN) coordinator. Each star network has its own PAN ID to operate independently. The network has a sole ZC that connects to other FFDs and RFDs. ZEDs do not transmit data directly to each other as shown in Figure 2(a).
- Tree topology: this topology is a special kind of mesh topology, where most devices are FFDs and a RFD can connect to the network as a discrete node at the end of the tree branch. Any FFD can act as a coordinator, providing synchronization signals to other devices and coordinators. Therefore, this type of network structure has high coverage and scalability. In this type of network configuration, although there can be many coordinators, there is only one PAN coordinator as shown in Figure 2(b).
- Mesh network: mesh network has the advantage of allowing continuous communication and being able to reconfigure themselves around a shielded path by jumping from node to node until a connection is established. Each node in the mesh has the ability to connect and route traffic with neighboring nodes. The mesh topology is created similar to the star network, but in this network, there is the presence of ZR. ZR plays the role of data routing, and network expansion, and it also has the ability to control and collect data like a normal node as shown in Figure 2(c).

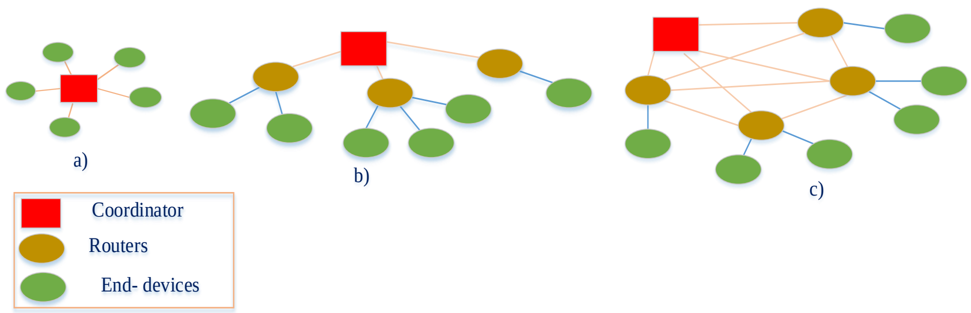


Figure 2. Network topologies (a) star, (b) tress, and (c) mesh

3.3. ZigBee layers

In addition to the two PHY layers and the medium access control (MAC) layer defined by the 802.15.4 standard. The ZigBee standard also has more upper layers of the system including the network layer (NWK), application support layer, device object layer, and application object layers as shown in Figure 3.

The physical layer is the lowest protocol layer and is in charge of controlling and activating the radio transceiver and selecting and monitoring the channel frequency. In addition, it is in charge of communicating with radio-based equipment. Packages are what are used to communicate either data or commands. Each physical layer (PHY) packet consists of a synchronization header (SHR), a PHY header (PHR) that contains information about the frame length, and a PHY payload. The SHR is responsible for receiver synchronization, and the PHY header contains information about the frame length (provided by the upper layer as a frame and including data or commands).

MAC layer: it is responsible for acting as an interface between the PHY layer and the NWK layer. It is accountable for generating Beacons and synchronizing devices in the network that supports beacons. A few different types of frames can be used for the MAC protocol: a beacon frame, a data frame, an acknowledgment frame, or a command frame. A MAC header, a MAC payload with an arbitrary length, and a MAC footer make up its constituent parts.

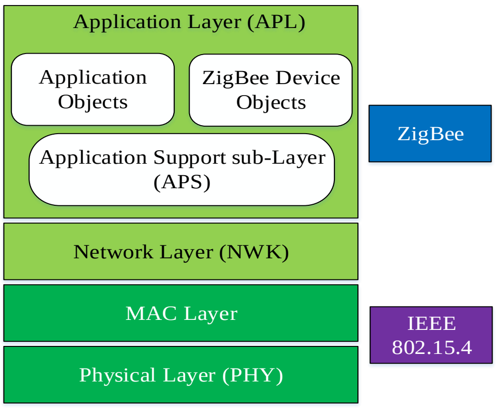


Figure 3. Zigbee layer

The NWK links the application layer (APL) to the MAC layer. It sets up and routes traffic through networks. It creates a new network and chooses the topology of the network. A NWK header and a NWK payload are the two components that make up the NWK framework. The header is where information regarding addressing and control at the network level is stored.

Application support sublayer (APS): it is responsible for providing a set of services by utilizing two entities: the support data application entity and the application support management entity. The application, as well as the NWK. These entities can be accessed using the appropriate service access point (SAP).

The APL is the top layer in the network structure and holds the role of storing application objects and user applications. A ZigBee device has the capacity to store as many as 240 application objects, which are used to manage and control protocol layers. Each application object can incorporate a user-created application profile or a program developed by the ZigBee consortium. Data transmission and reception within the network are the responsibilities of the APL. In the APL, each device's type and function are specified. ZigBee device objects provide the interface between application items, device formatting, and application sublayers.

4. ROUTING PROTOCOL IN ZIGBEE NETWORK

Configuration of tree addresses and tree addressing routing are both part of the tree routing mechanism. When the coordinator is first established in the network, it gives itself the address 0 and sets the depth parameter to 0. In the event that node (i) desires to become a part of the network and associates with node (k), then node (k) will become the father node of node (i). ZigBee's tree structure is displayed in Figure 4. The value of the nwkMaxChildren (C_m) parameter indicates the maximum number of child nodes that may be associated with a router or a coordinator [25].

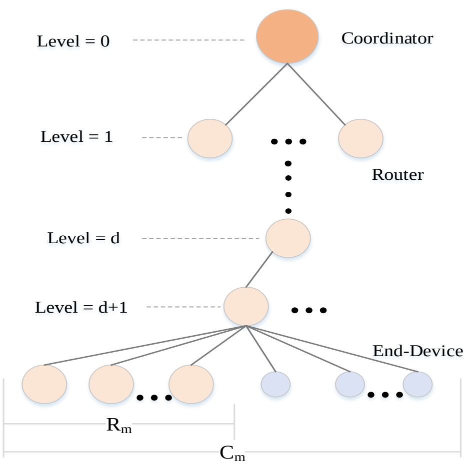


Figure 4. Tree routing of ZigBee

The value of the parameter known as nwkMaxRouters (R_m) indicates the maximum number of children nodes that can act as routers. Within the same network, the C_m and R_m values are typically the same across all of the nodes. A new node (n) is what's known as a RFD, which stands for "reduced function device," and this designation indicates that it is incapable of routing. The network address will be given to the child node (n) by the parent node (k), which will take into account its depth d:

$$A_n = A_k + C_{skip}(d).R_m + n \tag{1}$$

where A_n is network address of node n.

$$A_n = A_k + 1 + C_{skip}(d).(n-1) \tag{2}$$

The size of each sub-block is determined based on a number of predetermined parameters, including: C_m is the limit on the number of children that one parent is allowed to have; L_m represents the greatest possible depth in the spanning-tree network; R_m is the maximum number of routers that a parent is allowed to have in their family. As soon as those parameters are known, we are able to compute the size of the address sub-block at depth d, which we will refer to as C_{skip}, using (3):

$$C_{skip} = \begin{cases} 1 + C_m(L_m - d - 1)\,, & if\ R_m = 1 \\ \frac{1 + C_m - R_m - C_m R_m^{L_m - d - 1}}{1 - R_m}\,, & otherwise \end{cases} \tag{3}$$

We assume that a router will send a data packet on to the destination node, which has the network address D. This router has an address on the network denoted by the A, and its network depth is denoted by the d. It will first determine whether or not this destination node is its child node by evaluating it in accordance with the expression:

$$A < D < A + C_{skip}(d-1) \tag{4}$$

The address of the next hop node is as follows if the destination node is the child node of the sending node:

$$N = \begin{cases} D, & if\ end\ device \\ A + 1 + \frac{D-(A+1)}{C_{skip}(d)} . C_{skip}(d), & otherwise \end{cases} \tag{5}$$

5. SIMULATION MODEL

Simulation and modeling are essential approaches to developing and analyzing systems in terms of time and cost requirements. The simulation demonstrates the system's expected behavior based on the simulation model by simulating the system under various conditions. As a result, this simulation model aims to ascertain the precise model and anticipate how the real system will behave. We will run our simulations in OPNET Modeler 14.5, the industry standard for modeling and simulation environments. This simulation tool gives users access to an all-encompassing development environment, which helps model communication networks and distributed systems. It is possible to play out a variety of scenarios using this version of the simulation.

Suppose we have N-1 routers between the source and destination hosts. Assuming that the waiting delay is negligible, the processing delay at each router and the source node is d_{proc}, the baud rate of each router and the source host is R bits/s, and the propagation delay per link is d_{prop}, then the end-to-end delay is defined as (6) and (7):

$$D_{end-end} = N(d_{proc} + d_{trans} + d_{prop});\ d_{trans} = \frac{L}{R} \tag{6}$$

where L is the packet size;

$$Average\ throughput\ = \frac{S}{T_L - T_F} \tag{7}$$

where S is total size of received packets; T_L is the time when the last packet was received; T_F is time to receive the first packet.

$$PLR(\%)\ = \frac{(P_S - P_R).100}{P_S}(\%) \tag{8}$$

where PLR is packet loss rates; P_S is total packets sent; P_R is total packets received.

5.1. Simulation scenarios

In this paper, we give three simulation scenarios.

- Scenario 1: we use three static routers to collect and forward data from end devices to coordinator as shown in Figure 5(a).
- Scenario 2: we only use one mobile router to replace 3 static routers. The mobile router moves along a definite trajectory at a speed of 10 km/h as shown in Figure 5(b).
- Scenario 3: still the same mobile router use case as scenario 2 but in this scenario the router moves at a speed of 40 km/h.

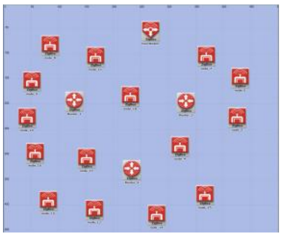
5.2. Simulations results

There are three parameters that we are interested in in the simulation scenarios above which are throughput, packet delay, and packet loss rate. Figure 6(a) shows the throughput with static routers is the blue line, and the red line is the throughput when the router moves at 10 km/h. The green line shows the throughput for the router when traveling at 40 km/h. Throughput is about 13,700 bits/s in the case of a network using three static routers. Throughput is about 6,500 bits/s in the case of a network using only one mobile router moving at a speed of 10 km/s according to the available trajectory as shown in Figure 5(b). Throughput is only about 2,300 bits/s in the case of a network using a mobile router with a speed of 40 km/h. Thus we see that, as the routers move faster, the throughput decreases.

Figure 6(b) shows packet latency for the three scenarios above. The blue line represents average latency for a network scenario using three static routers. The average latency for this scenario is about 0.022 s. The red line represents the average latency for the network scenario using a mobile router traveling at 10 km/h. Average latency now is about 0.018 s. The green line represents the average latency of the scenario where the network uses a mobile router traveling at 40 km/h. The average latency for this scenario is about 0.011 s. Thus, we see that, when the network uses mobile routers, the latency parameter will be lower than when using static routers. The faster the router moves, the lower the latency.

Figure 7 shows packet loss rates in the network for three different scenarios as outlined above. Figure 7(a) shows the packet loss rate in the case of a network using three static routers, the red line shows the number of packets sent, the blue line shows the number of packets received. We see that, in the case of static routers, the packet loss rate is almost 0 %. Figure 7(b) shows the packet loss rate in the case of a network using a mobile router instead of three static routers. The mobile router moves at a speed of 10 km/h. The red line is the total number of packets transmitted; the blue line is the total number of packets received. When we send an average of 4 packets/s, we receive about 3.8 packets/s so the packet loss rate is approximately 5%.

Similar to the above scenarios, Figure 7(c) shows the packet loss rate in the case where the network uses a mobile router to travel at 40 km/h. The red line is the average number of packets sent and the blue line is the average number of packets received. As shown in Figure 7(c), we see that the average total packet sent is 5.9 packets/s but only received 2.0 packets/s so the packet loss rate is approximately 66.1%.


(a)

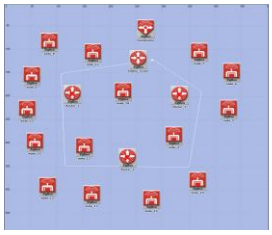
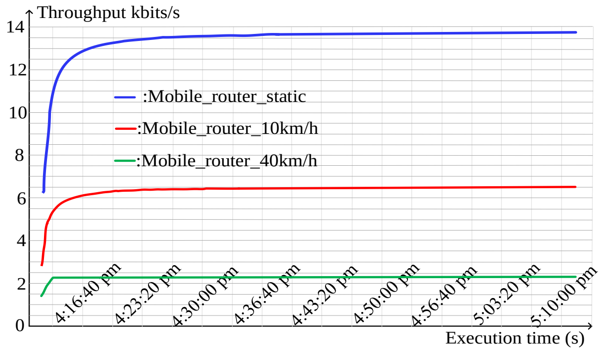
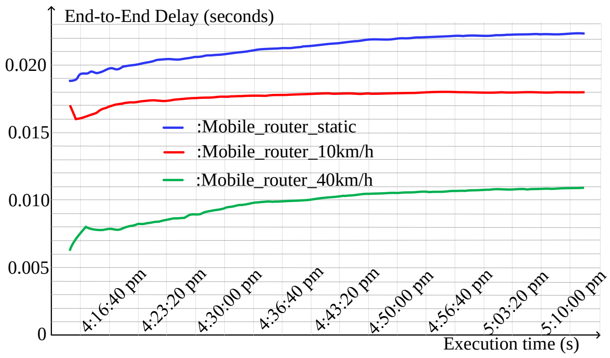

(b)

Figure 5. Simulation scenarios; (a) three static routers and (b) one mobile router to replace 3 static routers



(a)



(b)

Figure 6. Throughput and packet delay; (a) throughput of network for different scenarios and (b) delay of data for different scenarios

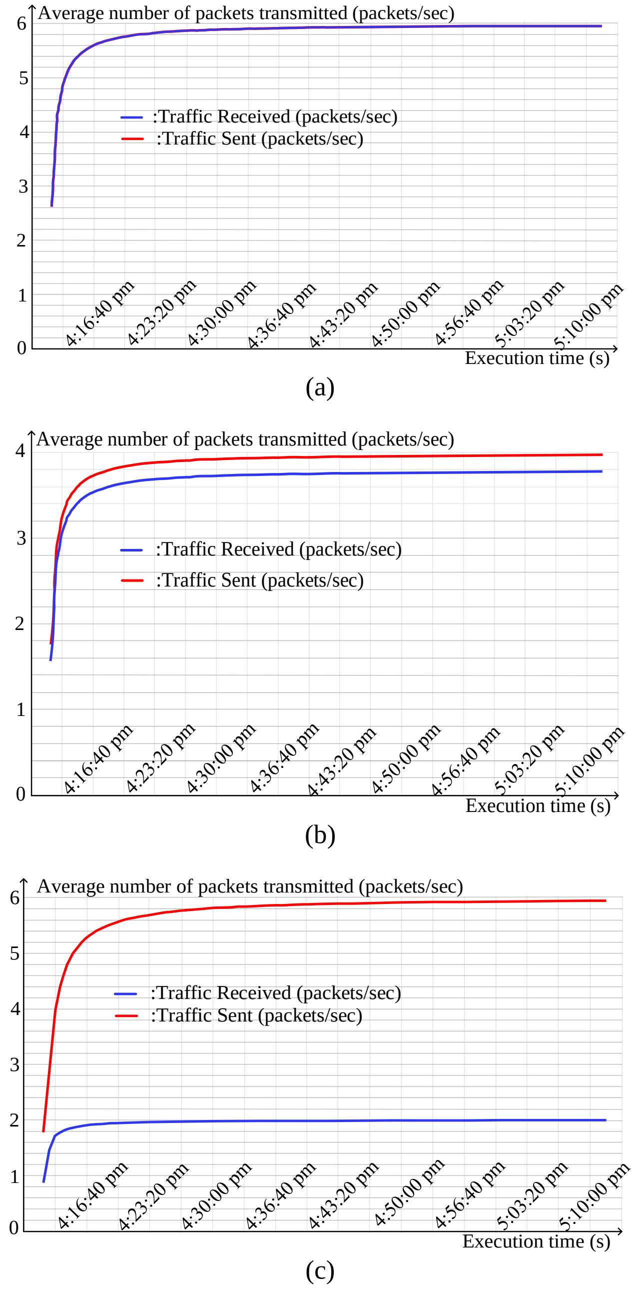


Figure 7. Packets loss rate; (a) packet loss rate in the case of a network using three static routers, (b) packet loss rate when the router moves at 10 km/h and (c) packet loss rate when the router moves at 40 km/h

6. CONCLUSION AND FUTURE WORK

Zigbee is one of the standards suitable for sensor networks. The routing tree mechanism is mentioned and described by formulas to analyze the routing mechanism. In this paper we present different data collection methods using Zigbee communications. The simulation results are run on OPNET software to evaluate the effectiveness of different data collection methods, which are proposed in this paper. From these results, we can see that each method of data collection will be suitable for a specific application. In the future, we will study the optimization of Zigbee network routing.

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