Power Consumption on Topologies for a Sensor-based Home Network

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Abstract—**Recently home networks, especially wireless sensor networks, have been attracted in many fields of applications, since a very small sensor-device can process information on sensing by itself and it can communicate with the other ones. On the other hand, each sensor-based node in the network is expected to work by a battery for several years. Thus, low power consumption of the node is needed. In this paper, we present power consumption on topologies for a ZigBee sensor-based home network by simulation studies.**

Index Terms—**power consumption, topology, home network, sensor, ZigBee.**

I. INTRODUCTION

Recently, technology of appliances being networked together in the home has been achieved [1]. For example, in the home, devices such as PC, TV, TEL/FAX, air-conditioner, microwave oven, and so on are networked together. However, each device has connected with each other by wired lines, so that the wired lines become very complex in the home. To solve this problem, there is wireless communication [2].

Among many home networks, especially wireless sensor networks have been attracted in many fields of monitoring applications, e.g., health care and food industries, agriculture, and security [5], since a very small sensing-device can process information on sensing by itself and it can communicate with the other ones [3]. In the sensor network, each sensor-based node is expected to work by a battery for a few years. Thus, low power consumption of the node is greatly needed [6],[7].

On the other hand, there are techniques of topology for the sensor-based network as follows: topology evaluation [8]–[10] and topology control [11]–[13]. In addition, among many wireless communication standards for sensor networks, particularly, the standard as ZigBee [5],[6],[14] has been investigated in [15],[16]. There are also techniques of topology in the applications of ZigBee as follows: sensors deployment [17],[18] and power consumption [19]–[21].

However, in the home, when a personal or local area network is built by wireless communication, each device is required to be a build-in the function of wireless communication. In addition, concerning to be used for our daily lives in the home, there are very important issues about the place with the devices located, the deployment of the devices, and the power consumption of the devices. Thus, it is important to know the power consumption on network topologies built in the home.

In this paper, to take account of efficient topologies for the home by wireless communication, we present the power

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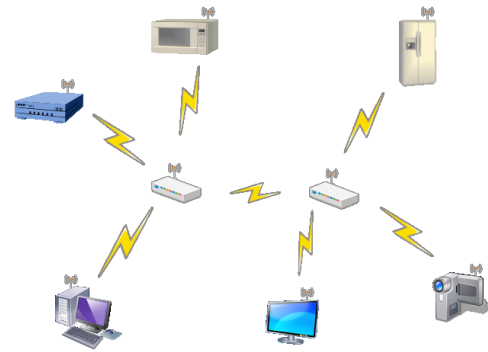

Fig. 1.   An example of a sensor home network.

consumption on topologies for a ZigBee sensor-based home network by simulation studies [23]. Simulation results show that the power consumption can keep low relatively by deploying some relaying nodes on the topologies.

The rest of this paper is structured as follows. Section II gives the sensor-based home network and the power consumption model. Section III describes an overview of ZigBee. In Section IV, we present some simulation methods and the results. We discuss the simulation results in Section V. Finally, Section VI concludes this paper.

II. PRELIMINARIES

A. Sensor-based home network

A home network is a residential personal area network (PAN) or local area network (LAN) for communication between digital devices deployed in the home [1]. The digital devices include a small number of AV, PC, TEL/FAX, home appliances, and so on. These devices are networked together by wired or wireless communication and they are connected with the Internet [2].

On the other hand, since wired lines can be complex between those devices in the home, the lines are expected to be simple. Thus, wireless connection between the devices is preferred to build the network [1],[2]. Furthermore, the speed of data transmission does not need so high in the home. Concerning to the devices used for a long time in the home, the wireless communication standards are also required for low power consumption [4].

Fig 1 shows an example of a sensor-based wireless home network. Table I shows wireless communication standards for PAN suited for the home networks [5],[6]. In Table I, #1 means transmission rate (bps) and #2 does frequency bound (Hz). In this paper, wireless communication is assumed to be used in the home. Also the wireless communication standard as ZigBee (IEEE 802.15.4) is also assumed. Note that the power consumption of ZigBee is assumed to be used for utmost 60 mA in this paper. The upper bound of power for simulations is also for one mA power.

TABLE I
WIRELESS COMMUNICATION STANDARDS FOR THE HOME.

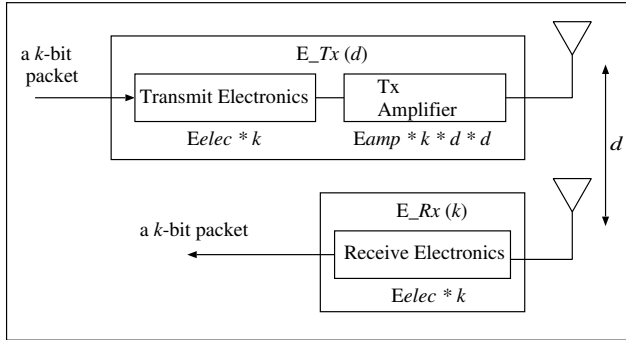| Wireless PAN	ZigBee	Bluetooth	UWB
Standardization	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.15.3a
#1 (bps)	250 k	1 M	480 M
#2 (Hz)	2.4 G (World)	2.4 G	3.1–10.6 G
	868 M (Euro)		
	915 M (USA)		
Distance (m)	10–75	10–100	4–10
Power (mW)	<60	<120	<100

Fig. 2.   The radio model for power consumption in a sensor node.

B. Power consumption in a sensor node

Fig 2 shows the radio model for the power consumption of transmitting and receiving a message in a sensor node [7].

To transmit a k-bit message within a distance d meters using the model, the radio of power ($E_{Tx}(k,d)$) expends in the following Equation 1:

$$
\begin{aligned}
E_{Tx}(k,d) &= E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \\
&= E_{elec} \times k + E_{amp} \times k \times d^2 \quad (1)
\end{aligned}
$$

To receive this message, the radio of power ($E_{Rx}(k)$) expends in the following Equation 2:

$$
E_{Rx}(k) = E_{Rx-elec}(k) = E_{elec} \times k \quad (2)
$$

where $E_{elec} = E_{Tx-elec} = E_{Rx-elec}$. In this paper, it is also assumed the radio dissipates $E_{elec} = 50$ nJ/bit to run the transmitter or receiver circuitry and $E_{amp} = 100$ pJ/bit/m^2.

III. ZIGBEE

In this section, an overview, the devices, and the topologies of ZigBee are described.

A. An Overview of ZigBee

ZigBee [5],[6],[14] is one of the standards for wireless communication at close range, which are used for applications of the sensor network. The communication speed of ZigBee is faster than that of Bluetooth. The distance for data transmission of ZigBee is shorter than that of Bluetooth. The ZigBee has the features of low power-consumption, low cost of hardware, high reliability, and so on. The ZigBee drives about a few years by an AA or LR6 sized alkaline-battery. The speed of data transmission is utmost 250 kbps and the distance of the transmission is about maximum 75 meters. More than 65,000 devices are allowed to connect with each other in the network. The network topologies have a star,
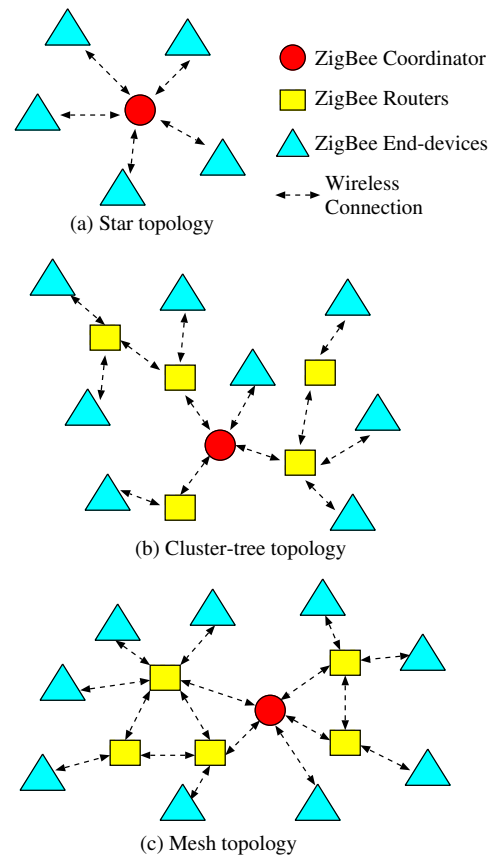

Fig. 3.   Topologies for ZigBee.

a cluster-tree, and a mesh. A routing protocol of ZigBee is used the Ad Hoc On-Demand Distance Vector (AODV) Routing [22].

B. Devices of ZigBee

The ZigBee has a physical and logical device. The physical device based on the platform of hardware is classified into two types: FFD (Full Function Device) and RFD (Reduced Function Device). The logical device based on the roles is classified into three types: a ZigBee coordinator, a ZigBee router, and a ZigBee end-device as follows:

- ZigBee coordinator: There exists only one device in the ZigBee network. The device is to start on building the network. This network is built by connecting the coordinator with some devices on demand, which participate in the network. The coordinator also works as the ZigBee router.
- ZigBee router: This device may connect with the ZigBee coordinator, some of the other ZigBee routers, and some ZigBee end-devices, which have already joined in the network. The router transmits messages for multihop routing. The router also has a role of connecting some devices which are just participating in the network.
- ZigBee end-device: This device may connect with the ZigBee coordinator and the ZigBee routers, which have already joined in the network. However, the end-device does not transmit messages for multihop routing. The end-device also has not a role of connecting some devices which are just participating in the network. The end-device includes a light sensor, an air-conditioner controller, and a lighting controller, and so on.
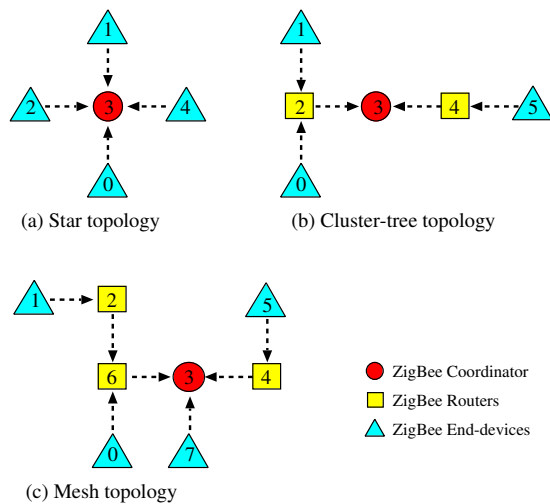
(a) Star topology   (b) Cluster-tree topology

(c) Mesh topology

ZigBee Coordinator
ZigBee Routers
ZigBee End-devices

Fig. 4. Topologies for the simulation 1.

(a) Cluster-tree topology.   (b) Star topology.

Fig. 5.   Deployment of sensor nodes in the home for the simulation 2.

C. Topologies of ZigBee

Fig 3 shows the topologies for ZigBee. There are three types of topology: a star, a cluster-tree, and a mesh as follows.

- Star: This is a star topology which the ZigBee coordinator is connected with ZigBee end-devices. The topology is also the simplest one (Fig 3a).
- Cluster-tree: This is a tree topology which the ZigBee coordinator is as a root and also the ZigBee routers and the ZigBee end-devices are as leaves. The coordinator and the router make the star topology, which they become a center of the star and also they connect with the end-devices (Fig 3b).
- Mesh: This is a mesh topology which the ZigBee coordinator and the ZigBee routers are connected with each other. Each end-device is connected with the coordinator or the router (Fig 3c).

IV. EVALUATION

In this section, simulation methods and the results are presented.

A. Methods

In this here, to evaluate the power consumption on the topologies in Figs 4 and 5 as described in Subsection II-A, we conducted simulation studies.

We assumed the communication standard as ZigBee as described in Subsection II-A and in Section III. We also assumed that the information on sensing by nodes as end-devices were sent to a node as the coordinator directly or relaying some nodes as the routers, i.e., one way communication from end-devices and/or relaying some routers to the coordinator.

For the information as the packet transmission, we used the NS-2 simulator [24]. The size of a packet was used for 1000 bytes. The total number of packets obtained in the simulations was converted into that of the power consumption by using the model of a sensor node as described in Subsection II-B. The details for simulations are as follows:
Simulation 1: To evaluate the power consumption as the basis for this, we used the topologies in Fig 4. The distance of
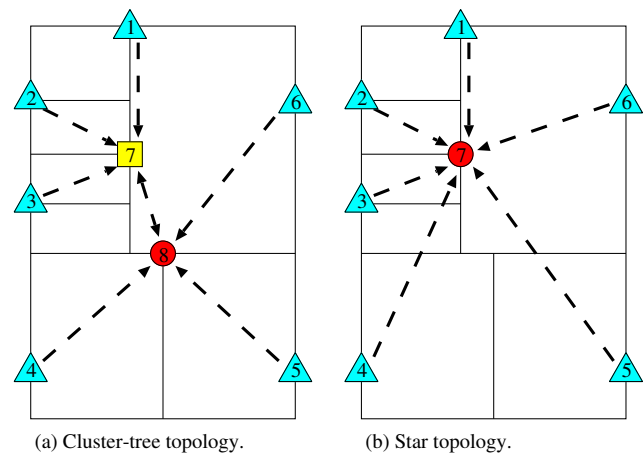
one hop between the nodes was the same on the topologies. The power consumption on each topoloy was evaluated by comparing them. Note that the following parameters were the same in all simulations: 20 meters as the distance for one hop, four steps on running in a simulation, two seconds in each step for the communication time, and the performance of each node. The details in the simulations were as follows:
(a) Star topology: Shown in Fig 4a is used for the simulation. This simulation was run as follows:

Step 1.) Packets are sent from the node 0 to the node 3 for two seconds.
Step 2.) After 0.5 seconds from which the step 1 was finished, packets are sent from the node 1 to the node 3 for two seconds.
Step 3.) After 0.5 seconds from which the step 2 was finished, packets are sent from the node 2 to the node 3 for two seconds.
Step 4.) After 0.5 seconds from which the step 3 was finished, packets are sent from the node 4 to the node 3 for two seconds.

(b) Cluster-tree topology: Shown in Fig 4b is used for the simulation. This simulation was run as follows:

Step 1.) Packets are sent from the node 0 relaying the node 2 to the node 3.
Step 2.) After 0.5 seconds from which the step 1 was finished, packets are sent from the node 1 relaying the node 2 to the node 3.
Step 3.) After 0.5 seconds from which the step 2 was finished, packets are sent from the node 5 relaying the node 4 to the node 3.
Step 4.) After 0.5 seconds from which the step 3 was finished, packets are sent from the node 1 relaying the node 2 to the node 3.

(c) Mesh topology: Shown in Fig 4c is used for the simulation. This simulation was run as follows:

Step 1.) Packets are sent from the node 0 relaying the node 6 to the node 3.
Step 2.) After 0.5 seconds from which the step 1 was finished, packets are sent from the node 7 to the node 3 directly.
Step 3.) After 0.5 seconds from which the step 2 was finished, packets are sent from the node 5 relaying the node 4 to the node 3.
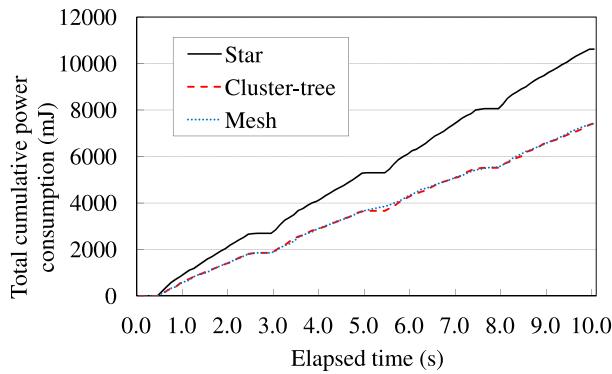
Fig. 6. Results of the simulation 1.

Dist. (m)	Betw. nodes		Transmitting (J)	Receiving (J)
	Fig 5a	Fig 5b		
$\sqrt{5}$	(7,8)	–	1.89645×10^{-4}	0.486348×10^{-4}
$\sqrt{9}$	(2,7)	(2,7)	3.52793×10^{-4}	0.480466×10^{-4}
$\sqrt{9}$	(3,7)	(3,7)	3.52793×10^{-4}	0.480466×10^{-4}
$\sqrt{17}$	(1,7)	(1,7)	5.74077×10^{-4}	0.486327×10^{-4}
$\sqrt{18}$	(4,8)	(6,7)	5.97764×10^{-4}	0.638235×10^{-4}
$\sqrt{18}$	(5,8)	–	5.97764×10^{-4}	0.638235×10^{-4}
$\sqrt{18}$	(6,8)	–	5.97764×10^{-4}	0.638235×10^{-4}
$\sqrt{29}$	–	(4,7)	10.31789×10^{-4}	0.480466×10^{-4}
$\sqrt{41}$	–	(5,7)	14.02568×10^{-4}	0.480466×10^{-4}

Step 4.) After 0.5 seconds from which the step 3 was finished, packets are sent from the node 1 relaying the nodes 2 and 6 to the node 3.

Simulation 2: To evaluate the power consumption by the node deployment in the home, we used the deployment in Fig 5. As shown in Fig 5, concerning to one of the general homes in Japan, the dimensions of the home were used as nine meters in length and six meters in width. At least one node was assumed to be deployed in each room. To know the information about our daily lives or security, e.g., temperature, humidity, captured images, and etc., we assumed that a node can sense information within the radius of three meters.

On the other hand, when some ZigBee end-devices are deployed in the home practically, we have to take into account some obstacles such as walls, doors, and furniture because the radio wave of ZigBee end-devices makes it weaken caused by the obstacles. Thus, the valid radio wave being weaken was used for the simulations in Fig 5. In Fig 5a, the network topology was using the cluster-tree one with the total number of nodes as eight. In Fig 5b, the network topology was using the star one with the total number of nodes as seven. Packets were sent between the nodes in Fig 5 in turn during one second.

B. Results

Fig 6 shows the total cumulative power consumption for elapsed time on topologies by the simulation 1. As shown in Fig 6, the power consumption of the star topology shows the worst performance among the topologies. The power consumption of the cluster-tree topology is almost identical to that of the mesh one.

Table II shows the distances between nodes and their power consumption obtained by the simulation 2 and by the Equations 1 and 2. From this table and the Equation 2, the power consumption at receiving in each node is almost the same regardless of the distance. On the other hand, the power consumption at transmitting in each node is increasing in proportion to the square of the distance from the Equation 1. Tables III shows the power consumption of each node in Fig 5a. Also Table IV shows those in Fig 5b. The sum of the total power consumption in Tables III is larger than that in Table IV.

V. DISCUSSION

In this section, we discuss the power consumption on topologies and the deployment of sensor nodes in the home.

A. Power consumption on topologies

In the simulation 1, since the time for communication between nodes was fixed but the amount of data was not fixed, the power consumption of the simple star topology shows high in Fig 6. However, since the model of power consumption in a sensor node mostly depends on the amount of the processing information and the distance for communication [7], the power consumption can be low by a star topology when a sensor network has built with the short distance for communication and the small area. On the other hand, when the sensor network has built with the long distance for communication and the large area, the power consumption can be high by a cluster-tree or mesh topology.

In the routing protocol AODV [22] used for ZigBee, some delay may arise at starting communication. The more the number of hops is increasing, the more the delay is becoming larger. In this paper, since communication between nodes on which the star, the cluster-tree, and the mesh topologies were used for one, two, and at most three hops, respectively, the star topology with the least hops has resulted in the least delay. However, due to the one hop delay, the communication of sending packets in the star topology has taken much time rather than that in the other ones. Thus, the power consumption of the star topology has shown larger than that of the other topologies in this paper.

The power consumption of the cluster-tree topology was almost the same as that of the mesh one. This is because the maximum number of hops on the mesh topology is larger than that on the cluster-tree one. Also because the total number of hops in the four steps on running a simulation is almost the same on the cluster-tree and mesh topologies and because all nodes have the same function for the simulations. In practical communication, since a node of the mesh topology should have memory used for a routing table, the power consumption on the mesh one may be higher than that on the other topologies. Thus, the mesh topology is reliable in routing, but the cluster-tree one could be superior to the other ones in power consumption.

B. Deployment of sensor nodes in the home

In the simulation 2, the rate that the radio wave has weaken caused by some obstacles such as walls, doors, and furniture was used as constant. In case that the deployment of nodes are considered for the obstacles, the power consumption can keep low relatively by deploying some relaying nodes.

TABLE III

POWER CONSUMPTION OF EACH NODE IN FIG 5A.

Node (No.)	Transmitting (J)	Receiving (J)
1	3.52793×10^{-4}	0.0
2	1.89645×10^{-4}	0.0
3	1.89645×10^{-4}	0.0
4	5.97764×10^{-4}	0.0
5	5.97764×10^{-4}	0.0
6	5.74077×10^{-4}	0.0
7	1.89645×10^{-4}	1.93951×10^{-4}
8	1.89645×10^{-4}	2.24914×10^{-4}
Sum.	28.80978×10^{-4}	4.18865×10^{-4}

TABLE IV

POWER CONSUMPTION OF EACH NODE IN FIG 5B.

Node (No.)	Transmitting (J)	Receiving (J)
1	3.52793×10^{-4}	0.0
2	1.89645×10^{-4}	0.0
3	1.89645×10^{-4}	0.0
4	10.31789×10^{-4}	0.0
5	14.02568×10^{-4}	0.0
6	5.74077×10^{-4}	0.0
7	0.0	2.90042×10^{-4}
Sum.	37.40517×10^{-4}	2.90042×10^{-4}

However, an actual value of the ratio will be different by the material of obstacle, the deployment of the nodes, and etc. When a topology has built by the nodes being deployed as the number of nodes decreased, the distance between the nodes become longer. As a result, the power consumption cannot keep low.

On the other hand, a large room such as a living room has little obstacle such as walls. In the cluster-tree topology, since there are some relaying nodes, the power of sending and receiving at the nodes has consumed. Thus, the cluster-tree topology is suite to the home with several rooms.

VI. CONCLUSIONS

In this paper, power consumption on topologies for a sensor-based home network built by wireless device as ZigBee is presented and it is evaluated by simulation studies. Simulation results show that the power consumption of a node at receiving messages can keep constant to some extent regardless of the distance between the nodes. On the other hand, the consumption at transmitting messages is increasing in proportion to the square of the distance between the nodes.

Further research issues remain to be explored: these include comparing power consumption by other wireless communication standards and by combination of various topologies.

ACKNOWLEDGMENT

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