Reliable Communication Methods for Mutual Complementary Networks

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Abstract. In the future home network, information appliances will be controlled and managed by the use of PLC (Power Line Communication) that enables the No New Wire and ZigBee concepts to be implemented in a ubiquitous sensor network. However, the arrival rate of PLC and the communication quality deterioration of ZigBee are significant problems because the control information for the appliances has to be transmitted reliably. To solve these problems, we examined communication methods that increase the arrival rate in a mutual complementary network environment. These methods improve reliability by mutually complementing, through PLC and ZigBee, the places where nodes can't communicate through only one interface. A comparison of these methods through ns-2 simulations shows that the Table Creation method is more reliable than the other methods we examined.

1 Introduction

The energy consumption of individual homes keeps on increasing. The unified management of home electric appliances would save energy and enhance home security. For these reasons, integrated management of home appliances will become important in the future, and a network that connects home electric appliances will thus be needed. In addition, the ownership ratio of computers in households has increased rapidly and Internet connections have become common. Many people hope to be able to control home appliances from inside and outside their homes. The establishment of a home network, including not only computers and peripherals but also home appliances, can enable such integrated management and remote control of home appliances; therefore, it will become important in the near future.

There are two problems of related th the costs of generalizing the home network. One is the cost of replacing household appliances with information appliances; the other is the cost of establishing the home network. In the latter case, while Ethernet is commonly used as the LAN in an office, it requires new wire to be laid in a home. In fact, a home network environment with No New Wire is desirable.

The use of the electric power lines that have already been laid in a home for communication, and ZigBee [1], which is the wireless standard is suitable for a low-cost home network, have problems with their reliability. The goal of this study is the achievement

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Table 1. Wired and wireless standards

Wired	HomePNA 3.0	c.LINK	HomePlug 1.0
Band	5.5∼9.5 MHz	770∼1030 MHz	4.3∼20.9 MHz
Speed	128 Mbps	270 Mbps	13.75 Mbps
Medium	Telephone line Coaxial cable	Coaxial cable	Power line

Wireless	IEEE802.11b / a / g	Bluetooth	ZigBee	UWB
Band	2.4 / 5 / 5 GHz	2.4 GHz	2.4 GHz	3.1∼10.6 GHz
Speed	22 / 54 / 54 Mbps	1 Mbps	250 kbps	110 / 480 Mbps
Distance	100 / 50 / 100 m	10 m	70 m	10 / 3 m
Price	$8	$3	$3	–
Power	1000 mW	100 mW	30 mW	200 mW

of reliable communications in home networks, and for this, we propose communication methods that improve reachability through a combination of low-reliability communication media.

The rest of the paper is organized as follows. In section II, we describe the necessity of the mutual complementary network which uses media with different features. Section III outlines the communication methods which improve reliability. Section IV describes the results of simulations. Section V ends the paper with a brief summary and concluding remarks.

2 Necessity of Mutual Complementary Network

2.1 Wired Network

While a home network needs to maintain the communications infrastructure wiring new cables costs a lot of money. Therefore, the best way to make a home network is to use the existing in a home. The cables that lilely exist in a home are phone wires, coaxial cables for TV, and electric power lines. HomePNA, c.Link, and HomePlug are wired communication standards that use these communication media, and Table 1 lists their features.

Since these cables are easy to introduce, they are not troublesome for users. However when many appliances are to be connected to a home network, the interfaces of the phone wire and coaxial cable are not necessarily near enough to the appliances. In addition, because such interfaces may already be in use for telephone and TVs, branching filters will be needed. On the other hand, electric power lines are wired throughout houses, and most appliances are connected to outlets; thus power lines are a suitable home network medium. Under the radio law in Japan, PLC (Power Line Communications) is permitted in a bandwidth from 10 to 450 kHz, and it is a low-speed form (less than 10 kbps). However, the low bit rate is still enough for sending control commands, state information, etc.; hence, the PLC is effective for a home network.

2.2 Wireless Network

The wireless communication standards, 802.11b/a/g/n, Bluetooth, ZigBee, and UWB (Ultra Wide Band), are applicable to a home network. Table 1 lists their features.

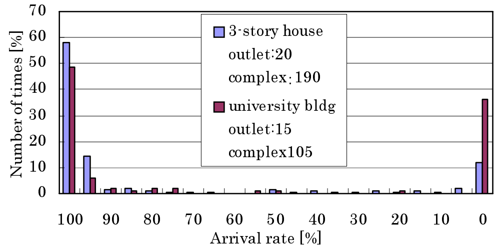

Fig. 1. Arrival rates of PLC in a home and university environment

It is likely that some sensors in the network will be placed where they cannot get power; therefore it is preferable that the power consumption of the communications be low. The range of wireless communications must also span the house. In light of these considerations, ZigBee is suitable for controlling home network appliance. The transmission range of ZigBee is about 30 m, and this is far enough for indoor communications. Its low bit rate of 250 kbps is of no matter, if appliances only exchange control information. Although the price of the ZigBee chip is currently about three dollars, it is likely to become cheaper especially if it becomes popular.

2.3 Mutual Complementary Network

A the home network must be reliable. PLC signals, however, are attenuated by different phases and appliances that exist between communicating equipment may decrease the arrival rate. Figure 1 shows the result of an investigation on the arrival rates for all combinations of outlets that can be used for PLC in a three-story house and a university building in a real environment. The figure shows that the arrival rate of PLC is characteristically either 100% or 0%. In ZigBee, communication quality is degraded by obstacles, transmission distance, and noise.

To solve these problems, we assume a mutual complementary network environment that improves arrival rate by using PLC and ZigBee, and propose communication methods that improve reachability efficiently. The mutual complementary network complements these places where nodes can’t communicate through only one interface.

Figure 2 shows a model of the mutual complementary network. Two phases exist in the electric power line, and the arrival rate of PLC decreases significantly in communications between different phases. We assume that communication between different phases is impossible, and express the power line as two lines in the figure. There is a place where nodes cannot communicate because of the influence of the equipment connected to the power line (on the power line of phase A in the figure). Nodes are numbered in the figure, and each node has PLC and ZigBee interfaces. In PLC, only nodes 1 and 2 or 3 and 4 communicate. In ZigBee, it is possible for nodes in radio wave range to communicate.

2.4 Related Works

Referance [2] proposes a dual communication system that uses wired and wireless communication. The system is suitable for indoor use and is easy to install. The author

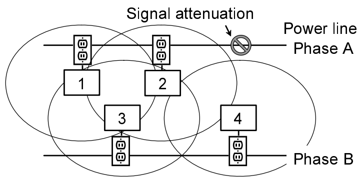

Fig. 2. Network model

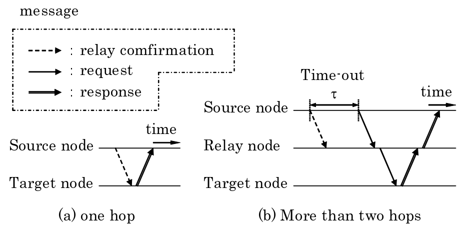

Fig. 3. Forwarding sequence of RC method

proposes a method of ensuring adequate communication quality by combining wired and wireless media. This is statistically shown to be able to improve reliability, and a simple routing [3] that operates under a given set of conditions is described. Our work differs from the literature noted above; We study efficient methods that can accommodate without special conditions.

Although there are several research intended to determine efficient path among routes based on parameters [4] [5], these assume same media as the communication media. Our research is differ from these in point of using media with different charactersistics.

3 Communication Methods on a Mutual Complementary Network

3.1 Prerequisites

We are studying communication methods for a mutual complementary network that efficiently increase the arrival rate by using media with different characteristics, in order to solve the cost problem of building a home network environment by using PLC and ZigBee. Our assumptions are as follows. The communication nodes have two network interfaces so that they can communicate with PLC and ZigBee. The node's interfaces are configured with different IDs, and the nodes can identify the IDs uniquely. Each node knows the interfaces IDs of the other node, and can assign the ID of a target node. We assume that data such as control information can be transmitted as one message.

3.2 Broadcast (BC) Method

This is a simple method in which nodes repeatedly broadcasts and propagate messages to the target node. At the start, a transmission source node broadcasts a message in PLC and ZigBee at the same time. If the node receiving the message is the target node, it returns a response. If it isn't a target node and hasn't already received messages of the same ID, it operates as a relay node and it, as well as the source node, broadcasts the message. The message is delivered to the target node by repeating this procedure.

The advantage is that nodes can reliably deliver a message to the destination within a short time. The disadvantage is that this method has the possibility of causing broadcast storm and interfering with transmissions generated by another node.

3.3 Relay Confirmation (RC) Method

In this method, a source node determines whether there is a target node within one hop and confirms the necessity of relaying. If the target node is not within one hop, the message is relayed to the target node. Figure 3 shows the message flow of the RC method. The target node responds after the source node transmits the relay confirmation message when it is within one hop of the source node (Figure 3 (a)). If the target node is farther than two hops from the source node, the source node cannot receive a response to the relay confirmation, and thus it transmits a request message after waiting for the time-out period τ (Figure 3 (b)).

The processing procedure of each node is as follows. First, the transmission source node sends RC messages to a target node with PLC and ZigBee, and it waits for the reply from the target node. If the source node receives the reply before τ has elapsed, the target node exists within the range where the source node can communicate. Thus, the source node realizes that the message arrived at the target node and completes the communication. If time out occurs without the reply arriving, the source node broadcasts a request message with PLC and has another node relay it. The reason the source node broadcasts firstly by PLC is to have all nodes, which are connected with a same-phase line, relay messages; the messages are delivered early to nodes that are connected with different-phase lines. The relay node broadcasts a request message to the target node without sending relay confirmation. Note that a relay node transmits alternately on different media when it transmits to its neighbors. For example, a relay node must broadcast a message with ZigBee after receiving it with PLC. This enables nodes to prevent the broadcast storm while complementing the places in which they cannot communicate through only one interface.

In the RC method, extra traffic can be suppressed because the source node relays only when it cannot transmit directly to a target node. However, the arrival time to the destination increases when there are more than two hops because the source node decides whether a transmission failure has occurred from the time-out.

3.4 Table Creation (TC) Method

OLSR (Optimized Link State Routing) [6] is a routing algorithm that has been discussed by the MANET WG, and we have a plan for proposing a method that uses OLSR. However, we evaluated a TC method in which nodes create only tables of neighbor nodes, instead of the method using OLSR. In this method, all nodes periodically exchange Hello messages and make tables of neighbor nodes that communicate using PLC and ZigBee. Regarding the transmission of a request message, a source node first confirms the table, and then sends the request to the target node if one is found. If there is no target node in the table, the source node tries to detect a node to which it can send the message by either PLC or ZigBee. If a relay node cannot be chosen on these conditions, one is chosen at random from the table. A relay node that receives message chooses the next forwarding node in the same way that source node does.

Broadcasting is not used and the message is sent only to the selected relay node; thus traffic is kept to a minimum. However, when an inappropriate relay node is chosen, there is a possibility that message will not arrive by the shortest path or does not reach the target node.

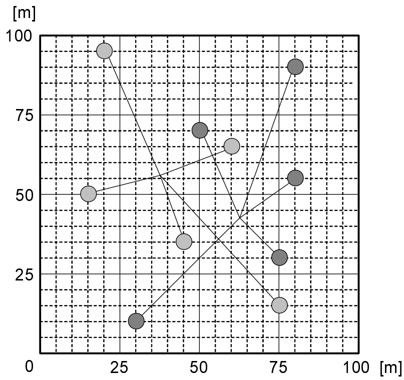

Fig. 4. Topology for evaluation on random arrangement of nodes

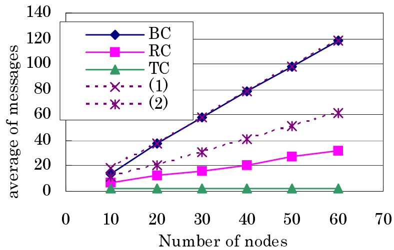

Fig. 5. Average number of messages (Simulation I)

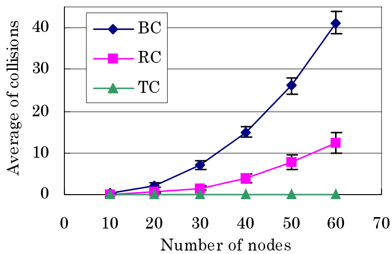

Fig. 6. Average number of collisions (Simulation I)

4 Evaluation

4.1 Simulation Environment

We investigated the properties of the communication methods outlined in the previous section by using the network simulator ns-2 [7]. We assumed that each communication node had both PLC and ZigBee interfaces. As the wired interface, we set the bit rate to 7.5 [kbps] to simulate PLC, and set MAC protocol to Ethernet (IEEE802.3) in order to make a LAN, although SCP (Simple Control Protocol) adopts CSMA/CA. SCP is the communication protocol for home networks that we are planning to use in an actual PLC environment. As the wireless interface, we set the bit rate to 250 [kbps] to simulate ZigBee and set the transmission range to 12 [m], considering indoor communications. We used 802.11 as the MAC protocol instead of CSMA/CA used by ZigBee. Moreover, we set the size of the control information exchanged between each node to 30 [bytes] (referring to SCP) and the time-out τ of the RC method to 200 [ms].

4.2 General Properties (Simulation I)

We investigated the general properties of each method by arranging nodes at random on the square lattice shown in Figure 4. The nodes were arranged at random in two groups, and each group formed a LAN. These two LANs imitated the power line network on which communication between different phases was impossible. Regarding the transmissions, the source and target nodes were chosen at random. We transmitted messages 100 times on networks with 10 to 60 (in increments of 10 nodes).

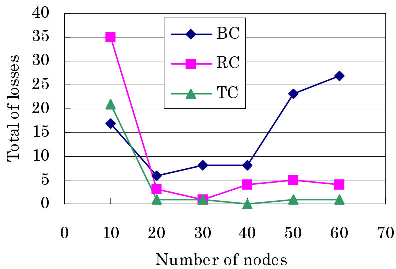

Fig. 7. Total number of losses (Simulation I)

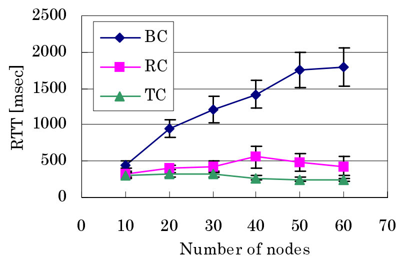

Fig. 8. Mean value of RTT (Simulation I)

To be able to compare each method numerically, we used the total number of messages. If the number of nodes is N, and the number of hops to target node is H, the total number of messages that are generated in one transmission request is calculated as follows.

$$T_{BC} = 2(N - 1) + H \tag{1}$$

$$T_{RC} = N + H + 1 \tag{2}$$

$$(\text{if H==1 then } T_{RC} = 3)$$

$$T_{TC} = 2H \tag{3}$$

4.3 Results of Simulation I

Figure 5 shows the average number of messages forwarded by PLC and ZigBee in one transmission. The value calculated with expressions (1) and (2) are indicated in the figure as a reference. Note that the number of messages includes neither the Hello message nor the message of the MAC layer. Regarding the BC method, the number of messages increases in proportion to the number of nodes as shown in expression (1). Regarding the RC method, when relay confirmation message reaches a target node, the relay broadcasting is skipped. Therefore, the number of messages is smaller than the value calculated with expression (2).

Figure 6 shows the average number of collisions in one transmission. It can be seen that the number of collisions increases with the number of nodes.

Figure 7 shows the total of loss after 100 transmissions. Messages were considered lost if the reply message did not reach the source node because of collisions and there was no reachable path to the target node. All methods had many lost messages on the network with only ten nodes. The reason is that a node not within wireless communication range could not forward to a node connected to power line of the opposite phase. Moreover, the BC method's losses increased because of collisions in the networks with more than 20 nodes.

Figure 8 shows the mean value of the round trip time (RTT). In spite of its timeout of relay confirmation, the RC method had a much lower than the BC method had. Many messages are transmitted in the BC method; therefore, collision avoidance using CSMA/CA happened frequently. Consequently, the BC method had a large RTT.

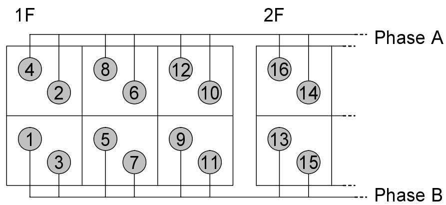

Fig. 9. Topology for evaluation in a home environment

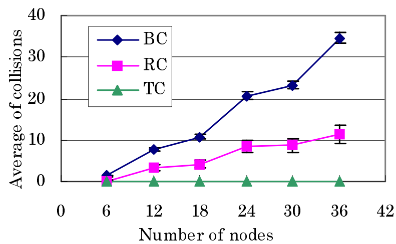

Fig. 10. Average number of collisions (Simulation II)

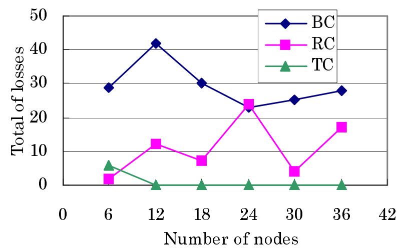

Fig. 11. Total losses (Simulation II)

4.4 Evaluation in a Home Environment (Simulation II)

We confirmed the properties of the proposed methods by using a topology for a house (Figure 9). The environment had six rooms on each floor and two nodes on the left side and right side of each room. The wireless range of the nodes is shown in the figure. For example, node 5 on the left side of a room was able to communicate with nods 3, 6, and 7. On the other hand, node 6 on the right side of a room was able to communicate with nodes 5, 8, and 12. In addition, all nodes in the room of the upper side were connected with a power line of phase A, and those on the lower side were connected with a phase B line. We chose the source node and target node at random, and transmitted messages 100 times for networks of 6 to 36 nodes (increment of 6).

4.5 Results of Simulation II

Figure 10 shows the average number of collisions in one transmission, and Figure 11 shows the total losses in 100 transmissions. Compared with Figure 6 and Figure 10, there are more collisions in Figure 10. Regarding Figure 11, many losses occurred, especially in the BC method. It seems that the reason for the BC and RC methods having more losses is the influence of hidden terminals. The node topology was orderly (Figure 9); therefore, there is a possibility that interference could be caused by nodes that cannot communicate with each other.

4.6 Considerations

The results of the two simulations show there are many collisions and losses in networks using the BC and RC method. The TC method had better results. Therefore, we found that the table method was the most effective. As for the BC and RC methods, it seems that the arrival rate was high without collisions. Thus, if a technique for reducing collision can be used, a better result might be obtained.

5 Conclusion

We discussed the necessity of a mutual complementary network which possessing transmission media having different features. We focused on the reliability of the network and proposed potential communication methods. The results of simulations, indicated that the availability of the TC method is the best.

We have to strengthen the reliability; thus, we will investigate ways to improve the methods discussed in this paper. Furthermore, we have a plan for deploying the methods in an actual environment and evaluating the reliability of their transmissions under realistic circumstances.

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