The Optimum Path Selection Mechanism for Inter-PAN Communication Using ZigBee

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Abstract— **In recent years, ZigBee Alliance provided effective solution for ubiquitous sensor network environments. However, critical problems like interoperability between various ZigBee networks have not been well addressed. Although recent works have proposed gateway assisted inter-PAN communication but only between fixed PANs. Moreover, there still exists a problem that in inter-PAN communication the selected paths are not optimal. In this paper, we have proposed an energy efficient optimum path selection mechanism, which uses competitive multiple-gateways for inter-PAN communication. Simulation results are also provided to validate the idea.**

I. Introduction

Wireless sensor networks have evolved and emancipated the ubiquitous environment. Ubiquitous environment serves users in a context-aware environment through sensor nodes, which are different from the nodes used in general computing environments such as a home network. However, sensor nodes have location and power supply problems due to their ad hoc wireless nature.

Resources are very limited in a sensor network, so the protocols under ZigBee Alliance are proposed, which have low energy consumption and self-organization making it suitable for ubiquitous environments. In ubiquitous environments, some sensor nodes are fixed, but most of the sensor nodes are attached to moving objects like a person or a vehicle. Ubiquitous networks use sensor nodes to sense a certain phenomenon in the environment and send it to sink(s) or other PANs (Personal Area Networks).

ZigBee networks were designed without interoperability between PANs. However, recently gateway assisted inter-PAN communication has gained much significance in the research community. All of the routing information of inter-PAN communication is stored in the Coordinator. Therefore, when some nodes belonging to different PAN want to communicate with each other, each Coordinator in different PAN and the gateway should be included in the routing path. This results in a non-optimum path selection and thus wastes scarce resources of the network that requires low energy consumption.

In this paper, we have suggested an optimum path selection mechanism for inter-PAN communication for solving the discussed problems. The optimum path selection mechanism uses hop-count competitive gateways such that when two nodes in different PANs communicate each other, resources are consumed efficiently.

The rest of the paper is organized as follows. In section II, some related work in the field is discussed. In section III, the proposed optimum path selection mechanism is defined. In section IV, the performance of the optimum path for inter-PAN communication against intra-PAN communication is analyzed. Finally, in section V, we conclude our work and discuss future work.

II. Related Works

We provide the review of the organization of ZigBee network and related problems.

A. Organization of ZigBee network

The ZigBee network organizes tree-cluster structure through parent-child relationships. The Coordinator, which establishes a new network, is the root node of the tree structure. Therefore, Coordinator is located in the center of the network and child nodes are deployed around the Coordinator in a radial shaped topology. Fig. 1 shows an example of how a general ZigBee network is organized. Coordinator, which is located in the center of the network, leads the network and ZigBee nodes are deployed around the Coordinator representing parent-child relationships. ZigBee network grows by attaching grand-child nodes to these child nodes and so on.

B. Method for inter-PAN communication in ZigBee

Recent research in wireless sensor network does not consider the energy consumption in inter-PAN communication mechanism to be critical. "ZigBee Inter-PAN Communication mechanism" [2] provides gateway assisted inter-PAN communication mechanism. In [2], the authors have proposed that a large scale network, which has a lot of

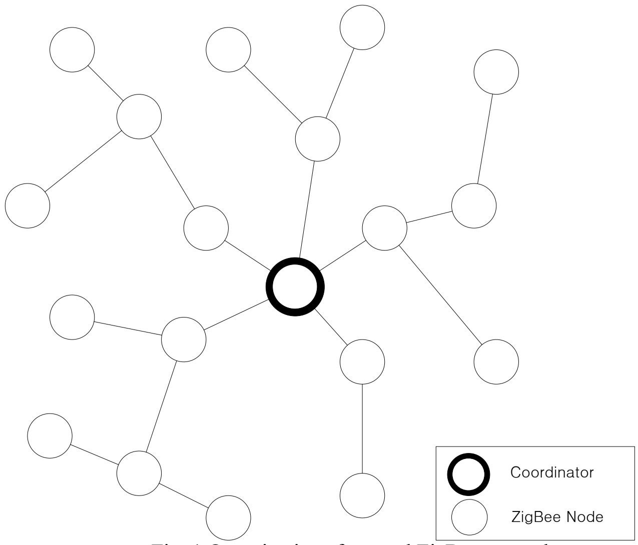

Fig. 1 Organization of general ZigBee network

overhead due to a single collision and broadcast domain, can be subdivided in to many small clustered PANs and gateway assisted communication between small clustered PANs would be used.

For inter-PAN communication, gateways discover nearby PANs and send information of nearby PANs to the respective Coordinators. Therefore, all inter-PAN communication packets are delivered to the Coordinator of the source PAN first. Then Coordinator selects suitable gateway to forward the packets to the destination PAN. In the destination PAN, received inter-PAN packets are forward to the Coordinator. Finally, the packets are delivered to the destination node.

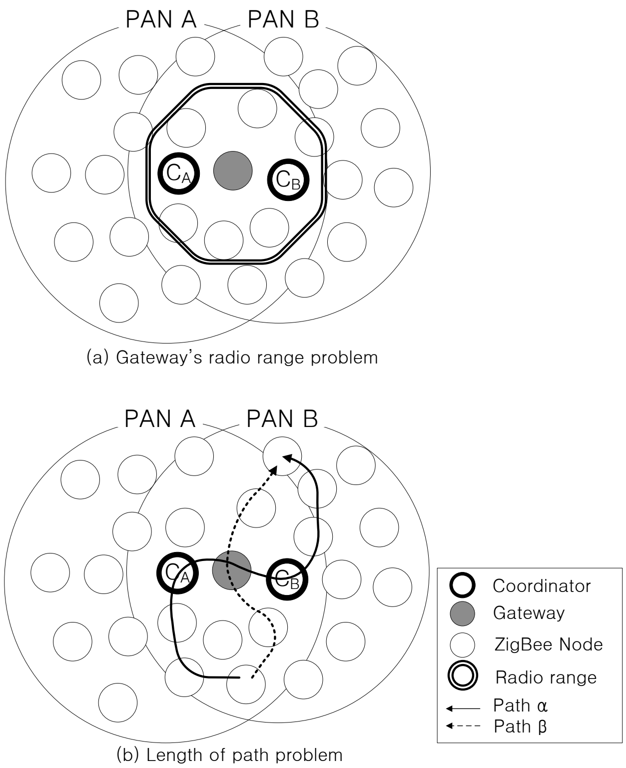

Fig. 2 Problems of gateway's radio range and length of path

Fig. 2 depicts the problems in [2]. In [2], both Coordinators should be located in the gateway's radio range and both Coordinators should be included in the routing path.

If inter-PAN communication is operated successfully through Coordinator-Gateway-Coordinator packet forwarding, Coordinators, which are deployed at the center of each PAN should be located in the gateway's radio range like in Fig. 2 (a). According to [2], both PANs have to be almost overlapped. If PANs are located near but not located in gateway's radio range, they are not able to communicate with each other. Gateways are always fixed and do not belong to any PAN. When a PAN is moved, then the PAN is not able to communicate without gateway. Moreover, routing path is longer than actual distance because communication via each Coordinator and gateway is not optimal, as shown in Fig. 2(b). As the routing path is not optimized, it consumes more energy and resources.

The mechanism implies that we need gateways as assistants for inter-PAN communication. However, gateways operate in intra-PAN routing like other router nodes and as gateway routers for inter-PAN routing. Also, we need optimum routing path selection mechanism without intervention of the Coordinator. In this paper, we have proposed an optimum path selection mechanism for inter-PAN communication with emphasis on consuming minimum resources of the sensor nodes.

III. The Optimum Path Selection Mechanism for Inter-PAN Communication

A. Network model

Different PAN usually uses different frequencies and different channels for congestion control and collision avoidance, as in [3]. Accordingly, nodes in different PANs are usually not able to communicate with each other. However, we assume that gateways are able to communicate with and receive beacons from other gateways in different PANs.

We also assume that a PAN has gateways deployed randomly like other ZigBee nodes. Once the nodes are deployed over the PAN, they remain relatively static in their respective positions.

During inter-PAN communication, inter-PAN packets are sent out to destination PAN via nodes at PAN boundary. In case of [2], if gateway is located in the center of the PAN, PANs should be overlapped for forwarding packets using a gateway. Moreover, if the source node is located in the boundary of the PAN and requires inter-PAN communication then packets move from the boundary to the center of the PAN and move from the center to the boundary again. Therefore it is ideal that gateways are located at the boundary of the PAN, which is able to communicate with other PANs. As shown in Fig. 3, gateways in PAN are deployed randomly.

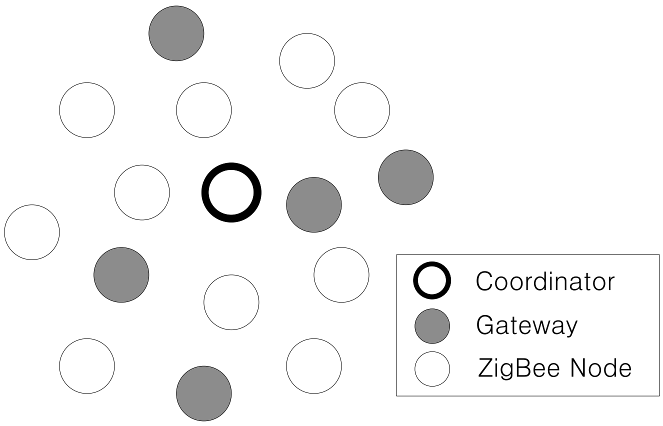

Fig. 3 ZigBee network with gateways

Fig. 3 is an example of gateways-added ZigBee network

B. Operation of gateway

Gateways in PAN work like gateway routers in an AS (Autonomous System) as in [4]. Gateway routers work normally like other general routers in intra network routing, however, gateway routers operate differently in inter network routing. Gateway router is the entrance point of a network. All packets that coming from and destined to a node from the outside network should pass via gateway router. Moreover, gateway router has the responsibility of routing the packets to other gateway router of the destination network.

According to AODV (Ad-hoc On-demand Distance Vector) routing protocol, which is used in ZigBee; any node discovers and selects routing path dynamically using RREQ (Route REQuest) and RREP (Route REPly) messages when routing path is needed as in [1], [5-7]. When two nodes located in different PANs want to communicate with each other; source node starts flooding RREQ message for routing path discovery. In route discovery procedure, gateways are responsible for replying (RREP message) for requested (RREQ) messages. Gateways are also responsible to discover neighbor gateways of other PANs using DiscoverNbrGateway (Discover Neighbor Gateway) primitive. The source PAN gateway finds the routing path to the destination node using the RREP messages.

TABLE I
PROTOTYPE OF DISCOVER NEIGHBOR GATEWAY PRIMITIVE

```
status_t DiscoverNbrGateway
(
        destination PAN ID,
        destination Node's address
)
```

Table 1 is a prototype of discovering neighbor gateway primitives. Gateway, which has received DiscoverNbrGateway message, is able to procure routing path to the destination node using destination node's address parameter and destination PAN id.

Gateway stores the information of external PAN identity and short and extended address of the gateway, learnt through external gateway's beacon, in the neighbor table. As in Fig. 4, it is shown that gateway P gets information of the destination PAN's identity and gateway's addresses through gateway Q. Gateway P stores that information in the neighbor table. If there is another PAN near the gateway, the gateway stores the information of that PAN also.

Gateway Q prepares routing path to the destination node D using destination node's address from received DiscoverNbrGateway messages.

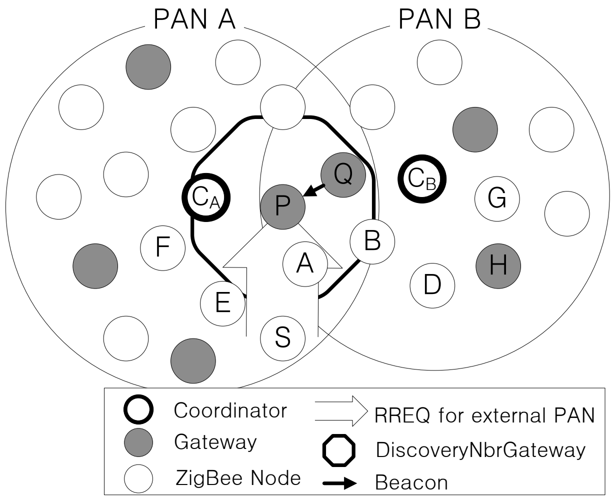

Fig. 4 Discovery Neighbor Gateway operation of gateway

Fig. 4 shows that when gateway receives RREQ message for inter-PAN communication, gateway starts the procedure of discoverNbrGateway primitive.

C. Selection of optimum path for inter-PAN communication

When the source node S in PAN A wants to communicate with the destination node D in PAN B; first of all, an optimal path S-A-P is selected inside PAN A. At the same time gateway P scans gateway Q using DiscoveryNbrGateway primitive. It causes selection of another optimal routing path Q-B-D inside PAN B.

Fig. 5 and Fig. 6 describe the details about these optimal paths selection. First of all source node S floods RREQ message in PAN A. Gateways, which are located near destination PAN, respond using RREP message as discussed in section III B. Source node S selects minimum hop-counted gateway amongst the gateways that replied the request using RREP messages. Hence, an optimum path between the source node S and the gateway P is selected. While gateway responses to source node S using RREP message, the

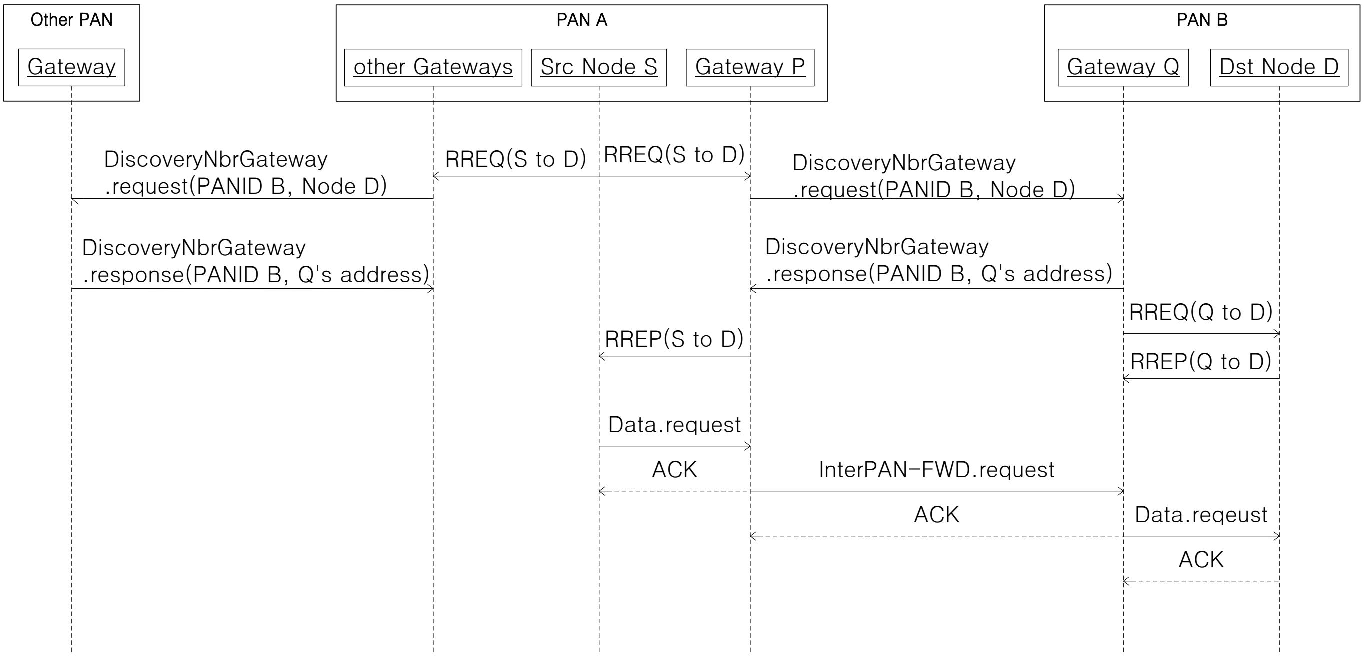

Fig. 5 Sequence chart of inter-PAN communication

optimum path Q-B-D is selected through AODV routing protocol in the PAN B.

Method specified in [2] selects path like S-E-F-C_A-P (or Q)-C_B-G-H-D because each Coordinator and gateway should be included in the path. However, our mechanism selects the path S-A-P-Q-B-D, which is smaller and consumes fewer resources.

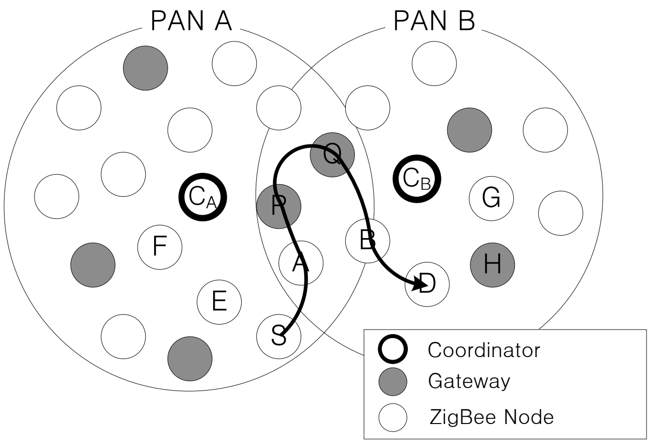

Fig. 6 Selected optimum path for inter-PAN communication

Fig. 5 shows the sequence chart of establishing an optimal routing path and communication in the network shown in Fig. 4. Fig. 6 shows the selected optimum routing path in the same network.

IV. Performance Evaluation

To evaluate the performance of our proposed scheme we have performed simulations using NS-2 on Fedora Core 3. The IEEE 802.15.4 Medium Access Control Protocol is employed as the Data Link Layer. In the simulations, we have 2 PANs, each with 30 nodes deployed over an area of 100x100 square meters. The initial location of each node is assigned randomly however, the initial location of PAN is assigned close to the other PAN. We have compared our proposed optimum path selection mechanism for inter-PAN communication with [2]. Table III shows the matrices that are used to realize the performance of proposed scheme:

TABLE III
Parameters Used in Simulations and Their Values

Parameter	Value
Bandwidth	250K bps
Initial battery	2 J
Packet size	1K bits

We have performed the simulation by changing distance of PANs and measured consumption of energy.

Fig. 7 shows the end-to-end delay evaluated graph when the distance between the Coordinator of the PANs changes. In Fig. 7, we can see that the inter-PAN communication has less delay than that of [2] because the proposed scheme selects the routing path, which does not include the Coordinators of both PANs. End-to-end delay of [2] is fixed because packets are transmitted regardless of distance parameter from source node to Coordinator in source PAN and from Coordinator to destination node in destination PAN. Inter-PAN communication given in [2] is impossible when the distance is

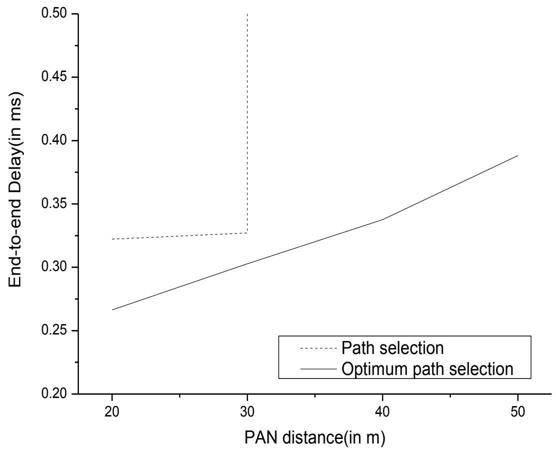

Fig. 7 Average of end-to-end delay

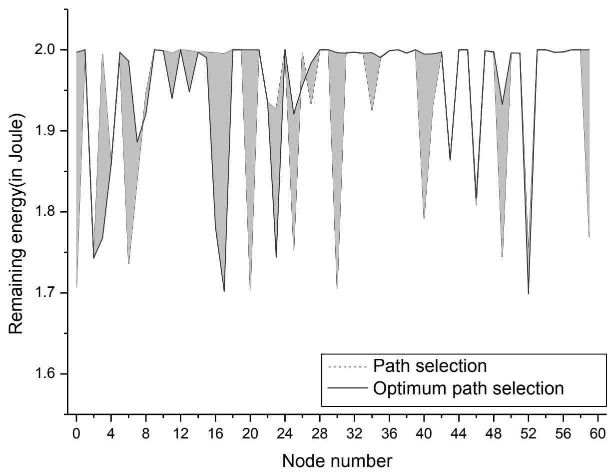

Fig. 8 Average remaining energy per node

over 30 meters. It has infinite delay because Coordinators of both PANs are located outside the radio range of gateway.

Fig. 8 shows the remaining energy at each node. Proposed mechanism makes no odds with [2] with respect to consumed energy by each node for communication. However, the number of nodes used is less in proposed mechanism than that of [2]. Therefore, the proposed mechanism has more energy efficiency in a broader sense.

From the above results of simulations, the optimum path selection mechanism for inter-PAN communication has the following characteristics; it is able to communicate between close PANs even if they are nearly overlapped PANs and it consumes energy efficiently. In the view of total energy consumption and time, the proposed mechanism is more effective.

V. CONCLUSIONS

In this paper, we have presented the optimum routing path for inter-PAN communication using gateways as assistant. In [2], Coordinator selects gateway to forward the packets to other PAN and gateway just has the responsibility of forwarding packet from one Coordinator to another. Therefore, the routing path cannot be optimized. Selecting non-optimal paths waste energy in selecting useless intermediate nodes. So we proposed an energy efficient optimal path selection mechanism for inter PAN communication using gateway-gateway communication without using the Coordinators as intermediate nodes.

We are currently working on using an effective routing metric for path selection instead of hop count in ZigBee environment. Making paths between two PANs, which are not in direct contact, is left as the future work.

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