A Mechanism to Improve the Performance of Zone-Based Broadcasting Protocol in the Recovery Phase

Xiao-Yi Lu, Zhen Fu, In-Sook Lee, Myong-Soon Park*
Department of Computer Science and Engineering,
College of Information and Communications,
Korea University, Seoul 136-701, Korea
{felicity_lu, fuzhen,is7915, myongsp} @ilab.korea.ac.kr

Abstract

Wireless Sensor Networks (WSNs) have been widely used in environment monitoring to collect useful information. Packet broadcasting is an essential communication behavior for establishing a communication path from sink node to an interested region of sensor nodes. ZBP is a cellular based broadcast protocol, and it successfully outperformed simple flooding manner broadcasting and common cellular based approach in two main aspects: first it reduced the number of sensor nodes that forward transmission packets and thus save energy consumption; second, it can efficiently avoid collision by properly arranging broadcasting schedule. However it still faces broadcasting failure caused by blank region of sensors. This paper improves ZBP by introducing an energy efficient recovery mechanism which recovers broadcasting when blank region interrupts the request forwarding. Compared with the simple over-network flooding recovery used by ZBP, our proposed protocol can reduce much energy consumption.

Keywords- Sensor network; broadcasting protocol; zone-based; broadcasting recovery

1. Introduction

In recent years, the combined advances in wireless communications, micro-electro-mechanical system (MEMS) technology, and digital electronics have driven the fast development of wireless sensor networks (WSN) and this development has opened a wide range of applications, including armaments defense, location tracking, widespread environmental sampling and so on. Sensor networks consist of a sink node and a large number of tiny, inexpensive and energy constrained sensor nodes with sensing, computing and wireless communication capabilities. The sink node is a control center which typically initiates a request demand for collecting information from a specific region of WSN for further analysis. The sensor nodes perform distributed sensing tasks and transmit the sensed information to sink node in user-demand and event driven manners through wireless links.

Energy efficiency in WSN is very important since sensor nodes have limited power supply and cannot be easily recharged or replaced when batteries run out. Energy consumption occurs in three domains: sensing, data processing, and communications. In WSNs communications is the major consumer of energy and it consumes about 70% of the entire energy consumption [1]. The communicative behaviors in WSNs can be characterized by two different types: routing (node-to-sink) and broadcasting (sink-to-node or node-to-node). Broadcasting is an essential communication requirement for sink and sensor nodes. Efficient broadcasting protocol is needed

* Corresponding Author

in WSNs to deliver the query information from sink node to all sensor nodes in a specified region, asking these nodes to return environment information.

In developing broadcasting protocol, reducing broadcasting failure is very important. Broadcasting failure may be caused by several reasons, e.g., packet collision, condition interruption or geography distribution of nodes. By well arranging the sensor nodes distribution and broadcasting schedule, the chance of broadcasting failure can be reduced, however it can not be totally avoided, thus the broadcasting recovery is necessary. Usually, recovery is done by simply rebroadcast of the query over network in a flooding manner, which will result in much energy and bandwidth consumption. Hence, a good broadcasting protocol for WSNs should provide efficient recovery mechanism to alleviate both energy and bandwidth consumptions in the re-broadcasting phase.

In this paper, we analyzed some existing broadcasting protocols for WSN, and improved ZBP with providing an energy efficient recovery mechanism, which can recover packet transmission at low cost. The rest of paper is organized as follows. Section 2 illustrates the backgrounds and analysis some existing broadcasting protocols as related work. Our proposed idea is described in Section 3.In Section 4, simulation and comparison result with previous work is given, and we finally make conclusions in Section 5.

2. Related Work

In this section, we first review some existing broadcasting mechanisms and discuss the problems with them, and then present the necessity of our proposed broadcasting recovery mechanism for ZBP.

Packet flooding is the common technique for broadcasting a message over WSNs. Many previous protocols [2] require broadcasting a message by every node. In simple packet flooding procedure, usually the sink node initiates a flooding request to the entire network, and each node on receiving the packet rebroadcasts the packet to all its neighbors so that the packet could be delivered to all the nodes in network. Although flooding is simple and common used for constructing a communication path in WSNs, it is obviously that a lot of duplicated packet will be transmitted, and thus it is very costly in consuming bandwidth and energy resource, and will result in serious redundancy, contention and collision, which reduce the success packet delivering rate [3].

To reduce the number of flooding packets, some location aware protocols [4] [5] [6] partition the whole network into several grids or cells. Nodes in each partitioned cell vote for a manager to manage the cell, and only the manager nodes take charge of exchanging messages with managers of neighboring cells. When sink node wishes to establish a broadcasting request, it first sends the request packet to surrounding manager nodes, and then each manager node relays the packet to neighboring manager nodes while at the same time broadcast it to all the nodes inside its cell in a flooding manner. Meanwhile, all the other nodes inside each cell shut down transmitter to avoid duplicated packet forwarding. In this way, by reducing the number of nodes which relay broadcasting packet and duplicated packet forwarding, the energy consumption is greatly saved.

There are two research topics with the basic cell-based management protocol. One is the manager establishment, and the other is the decision of cellular shape.

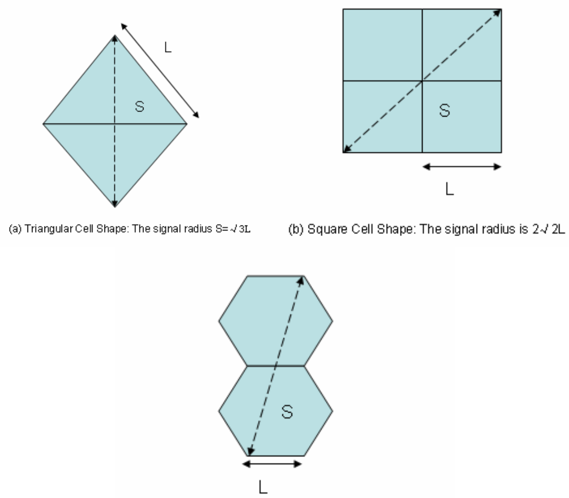
Manager establishment:

The sensor closest to center of a cellular region will be selected as a manager. The manager first broadcasts its ID to other members in the cell, and all the other member nodes return their IDs to the manager and these IDs will be kept in the manager’s cache table. And when the manager receives a relayed broadcast package from other cell managers, it relays the package to other managers and at the same time broadcast it to all the nodes whose IDs have been kept in its cache table.

The shape of a cellular:

A cellular region should be as large as possible to reduce number of manager nodes and thus reduce flooding packets, but at the same, the direct communication between neighboring managers should be guaranteed, thus an upper bound of the size of a cellular region is required.

Suppose the given signal length is S. Compared with triangular region and basic square region, the Regular Hexagon cell can achieve the largest size.



(a) Triangular Cell Shape: The signal radius S=√3L

(b) Square Cell Shape: The signal radius is 2√2L

(c) Hexagon Cell Shape: The signal radius S=√13L

Figure 1: Different Shapes of cells

In Figure 1, the maximum distance between two neighboring cells is S to ensure that each manager can communicate directly with neighboring managers.

Using size formula we can get size of the above three shapes:

Size of Hexagon cell $\approx 0.199S^2$,

Size of Triangular cell $\approx 0.144S^2$

Size of Square cell $\approx 0.125S^2$

From the above equation we can know that with the same signal strength S, the regular the Regular Hexagon cell can achieve the largest size which is near 0.2 S^2 while the size of both a triangular region and a basic square zone region is under 0.15 S^2. So we can know that the regular hexagon cell module is a good choice to reduce flooding and thus save power and bandwidth in sensor network.

Although the cellular-based management (CBM) [5] protocol largely reduces the number of nodes that transmit the flooding packet, however, collision of the packet and contention problem has been another problem of broadcasting protocol which reduces the success rate of packet delivery. As shown in Figure 2, all the manager nodes in CBM participating flooding operation have chance causing packet collision, and as the result, all the nodes in the cellular which are managed by the collided manager nodes can not get the broadcast message.

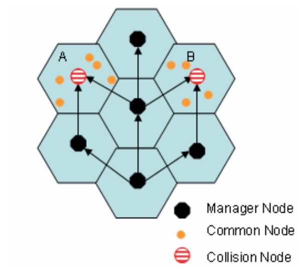


Figure 2: Collision of Manager Nodes

A Zone-based Broadcasting protocol for Wireless Sensor Networks (ZBP) [6] is a protocol that focuses on solving the cellar-level collision phenomenon in CBM. In ZBP, each node that received the interest message from sink node will dynamically transfer the coordinate system according to the zone-ID of source node and determine whether it would forward the message in a distributed manner. ZBP does not involve all the manager nodes into message forwarding, only manager nodes along axis forward message with a well arranged schedule. In this way, the chance of collision can be largely reduced.

Fig 3 can be used to simply describe the coordinate system of ZBP protocol. Let S be the source node and neighboring cellulars of source cellular S are denoted by Ni. Six main axis Xi partition the WSN region into 6 sub regions Ai. And in each sub region Ai, lines parallel to Main Axis Xi with the distance of 3 are defined as Sub-Axis Sk, k>=1, as shown in Figure 4.

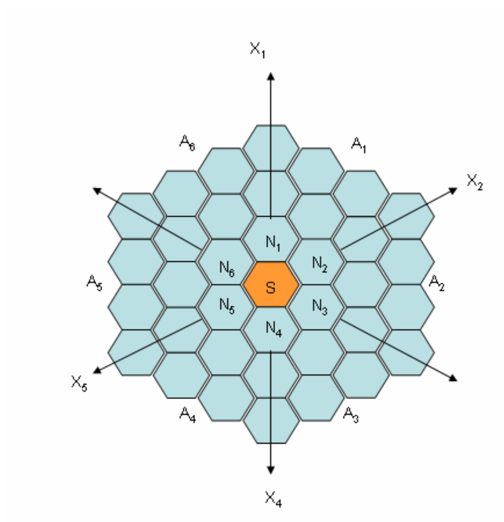


Figure 3: Coordinate System of ZBP

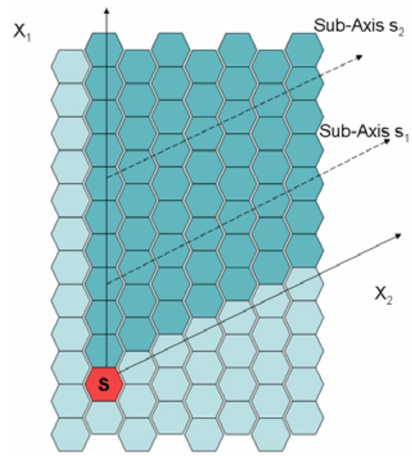


Figure 4: Sub-Axis Si partitions each sub-region Ai into bands with width three.

Assume that main axis Xi belongs to sub-region Ai and main axis Xi+1 belongs to sub-region Ai+1.With the definition of the above concept, ZBP further defines a coordinate transformation mechanism. The new coordinate system is called Source-oriented coordinate system, as shown in Figure 5, and the Source-oriented coordinate system is set up considering of local sub-region information. When a packet is sent across different sub-regions, coordinate transformation is needed to obtain new sub-region coordinate. And the Coordinate Transformation rules are:

/*Manager A in sub-region A_i receives the broadcasting packet from a neighbor sub-region A_j and its coordinate in A_j coordinate system is (X', Y'). Its coordinate in A_i coordinate system (x, y) can be obtained by following transformation rule. */

Rule 1:

If Y' < 0

y = X'-1

x=1

Rule 2:

If X' = 0

x=Y'

y=X'

In this paper, we adopt the same source-oriented coordinate system and Coordinate Transformation rules as ZBP.

As the new coordinate obtained, ZBP further defines only the manager nodes which are lying on either main axis or sub-axis execute the broadcasting operation. When broadcasting a message, the message is firstly passed on by the manager nodes on the main axis, and whenever it goes to a node which is lying on the intersection point of a main axis and a sub-axis Si, it would be further passed on along the sub-axis Si. In this way, with all the manager nodes on the main axis as well as sub-axis involving in broadcasting the message, the message can be successfully broadcasted through the whole network. The procedure is showed in Figure 6

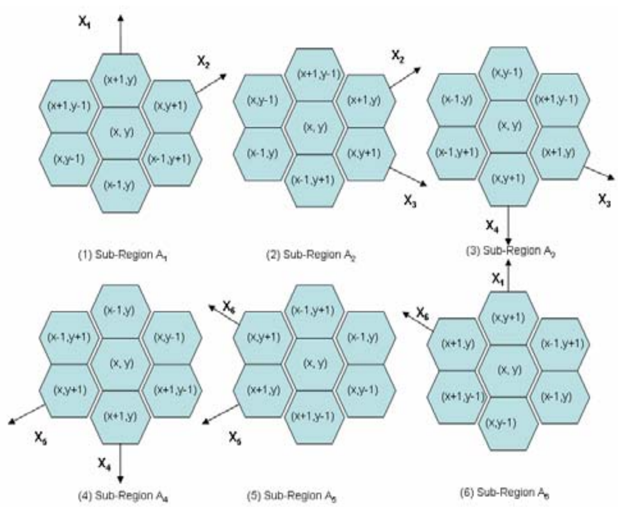


Figure 5: Source-oriented coordinate system

With this transmission rule, packets sent by the determined managers can be successful transmitted to neighbors without collision within a sub-region. And by properly scheduling broadcasting time, ZBP can avoid cross sub-region collision too, and thus the broadcast packet will be successfully transmitted to all the sensor nodes without collision.

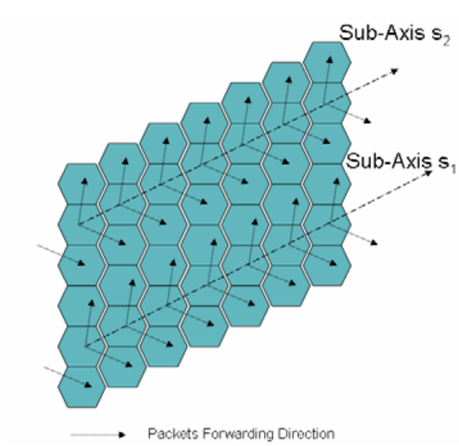


Figure 6: Sub-Axis Si execute broadcasting in Sub-Region Ai

Although ZBP protocol can not only reduce the number of managers executing packet forwarding but also reduce the collision phenomenon, it does not consider the possible existence of blank region in the network. If the sensor nodes are not very evenly distributed or some sensor nodes die from energy exhaustion, some area in the sensor network can not be covered by properly working nodes, we define these areas as "blank region". Since ZBP strongly depends on the axis manager nodes relaying packets through the whole network, the possible existence of blank region on axis will disturb the broadcast schedule. For example in Figure 7, all the nodes in the shadow area can not receive any broadcasting packet because of the blank region.

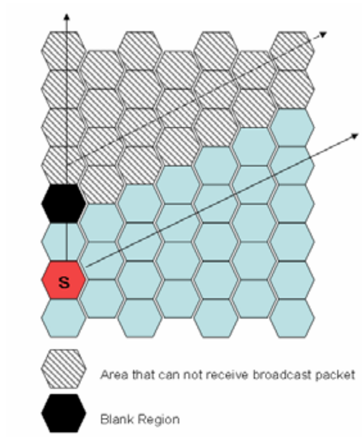


Figure 7: Broadcast Failure Caused by blank region

However in ZBP, whenever a broadcasting failure happens, re-broadcasting will be executed over whole network in a flooding manner, which is obvious not efficient. In this paper, we propose an energy efficient broadcasting recovery mechanism based on ZBP, which can specially solve the broadcasting problem caused by blank region in ZBP.

3. Main Idea

In the proposed idea, we adopt the same Source-oriented coordinate system and Coordinate Transformation rules as ZBP.

Based on ZBP, when a manager node lying on the axis broadcasts a packet, it will firstly send a request packet to neighboring manager nodes with the purpose of informing packet transmission, and at the same time, it will setup a back off timer, which is long enough to get return acknowledge packet form the informed nodes, and if no acknowledge packet returns from certain nodes when timer expires, we can say blank region exists there.

To simplify the research, we classify the types of blank region into two kinds according to their position, which are 1) non-axis blank region (blank region in common cells area), and 2) axis blank region (blank region on either main axis or sub-axis). The detailed recovery mechanism is described individually as follows:

1. Non-axis blank region:

No special recover operation is needed in this case, because non-axis manager nodes do not participate in the packets relaying, they only receive broadcasting packets.

2. Axis blank region

In ZBP the messages are transmitted one by one along the axis, so if there is any blank region on main axis or sub-axis, the region behind the blank region can not receive any broadcasted messages. So the recover mechanism is especially important here. Flooding is a simply way to recover, but obviously, it is not efficient because it consumes a lot both in terms of transmission energy and bandwidth. The recover mechanism we proposed does not only consider the full coverage of recovery, but also the recovering efficiency, which means we try to minimize the number of packets needed to be re-transmitted.

The recover procedure in this case can be simply described as "finding other routes to the destination", which means when the current axis manager node notices that the next manager node along the axis belongs to blank region, it marks the packet as recovery packet and finds other neighboring manager nodes to relay the recovery packet. In normal ZBP protocol, only the manager nodes on the axis can transmit information packets, however in our proposed idea, we use common manager nodes to relay recover packet to recover broadcasting. Notice here, common manager nodes only relay recovery packet, and for the packets without recovery mark, they still only receive them without passing on. The purpose of "finding other routes" is to relay the recovery packet to an available axis manager node, which is on the same axis as that the blank region covers and behind the blank region as soon as possible. When the axis manager node behind blank region gets the recovery packet, it cancels its recovery mark, and continues the broadcasting operation following the simple ZBP manner.

This procedure involves 6 followings steps as shown in Figure 8.

Notice that all the coordinates in Figure 8 stand for relative position of the current relaying node (x, y), so when the current relaying node changes, the absolute positions of its neighboring manager nodes change too, but their relationship will stay the same as Figure 8 describes. Each recovery step has a unique serial number, and each step checks the availability of the neighboring manager node on the location given by the accompanied coordinate and passes the broadcasting packet to it if it is available. All six steps are strongly related, and they are executed one by one circularly. When relaying the recovery packet, each node also transmits a three bit information packet as the piggyback message indicating the current operation step. The recovering procedure starts when original broadcasting is interrupted by blank region, however, there is no fixable initial step of the recover operation, and the start step depends on which operation step the current node is taking and the result of it. Suppose the current relaying node is A (x, y) on axis and it is taking step N (N is an integer and $6>N>=1$) and finds blank region, the recovery operation starts from step N+1, and if it is taking step 6, the recovery process will start from step 1. And during the recovery procedure, if node A continuously finds blank region, A will continue recovery operation steps clockwise, and whenever a node B belonging to non-blank-region is found, the packet will be passed to B, and B will continue the recovery operation reversely, which means the anticlockwise previous step of current one will be executed.

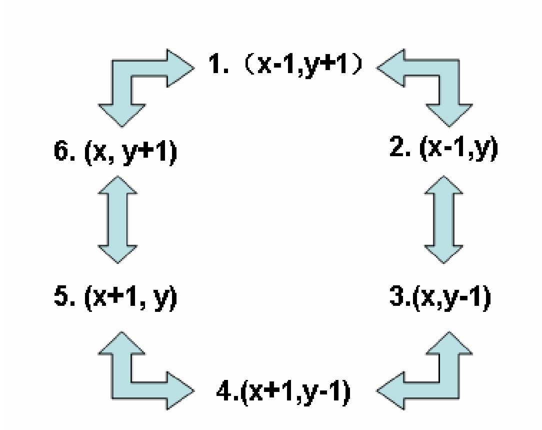


Figure 8: Recovery operation table: (The coordinate is based on Source-oriented coordinate system, and it shows the position of manager node which the current operation is checking for availability.)

As described in ZBP protocol, there are six sub coordinate systems corresponding to six sub regions. When the blank region is big, in order to find other route relaying packets bypass blank region, we have to relay packet crossing different sub-regions. As showed in Figure 9, cell R is the current cell, and the black cells belong to blank region, and the nodes A, B, C to I stand for relaying cells in recovery phase. From the figure we can easily know that the relay nodes are from both sub-region 1 and sub-region 2. Since all the nodes in this paper use their own sub-region coordinate system, so in this case, the relay node A, B, G, H and I adopt coordinate system of sub-region 1 while the relay node C, D, E and F adopt sub-region 2 coordinate system. As a result, when the relay of packet needs to come cross different sub-regions, coordinates transformation is needed, and correspondingly, the recovery rules should be verified as follows.

1. (x-1, y+1)，（y+1, 0）if x=1 across sub-region clockwise

2. (x+1, y-1), (y, 1) if x=1 across sub-region clockwise

3. (x, y-1)

4. (x+1, y-1), (y+1, x-1) if y=0 across sub-region anticlockwise

5. (x+1, y), (y+1, x) if y=0 across sub-region anticlockwise

6. (x, y+1)

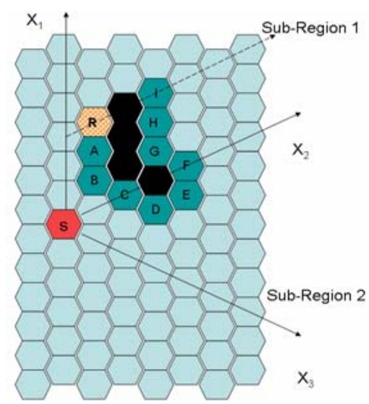


Figure 9: Cross Sub-Region packet relaying in broadcasting recovery: (With the verified rules, the relaying nodes in this example are from A to I in alphabet order.)

From the description above we can know that because we adopt the Source-oriented coordinate system, and each manager node only considers the relative position of its neighboring manager nodes to relay packet, the complexity of the recovery algorithm is low. Thus our proposed idea will not cause extra computation overhead and delay.

In the next part, we will evaluate the performance of our proposed energy efficient broadcasting recover mechanism.

4. Simulation

To evaluate our proposed idea, we simulated ZBP with Energy Efficient Broadcasting Recovering Mechanism (EER) and simple ZBP using the number of sensor nodes randomly generated varies ranging from 1500 to 4500, and the network size is 100mx100m with the sink node locating at the center of it. All the sensor nodes and sink node are stationary. Same as ZBP, in this paper we define the broadcasting overhead as both the bandwidth and power consumptions of sensor networks. The overhead increases with the number of sensor nodes which relay broadcasting packet. In this paper, we use the percentage of sensor nodes that forward packet as the evaluation metric, and the forwarding nodes here involve both the nodes transmit packet in original broadcasting phase and the nodes relay packet in recovering phase.

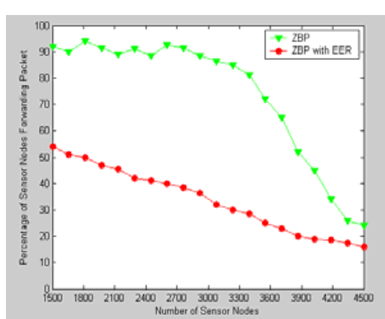


Figure 10: Compare Broadcasting Overhead of ZBP and ZBP with EER

From Fig 10 we can see that when the density of sensor nodes is comparatively small, our proposed idea can well outperform ZBP. This result is because when the nodes density is small, the chance of blank region is high, and thus the requirement of broadcasting recovery is high. While ZBP uses flooding manner recovery method, our proposed idea can largely reduce the re-broadcasting overhead by reducing the number of nodes relaying packets in broadcasting recovery phase.

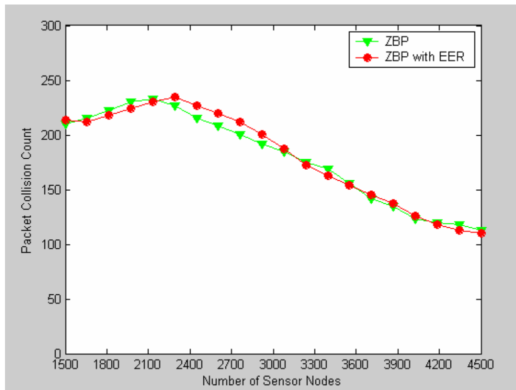


Figure11: Compare Broadcasting Collision of ZBP and ZBP with EER

Since we use the "recovery mark" to identify the packet re-broadcast, and common manager nodes only relay re-broadcast packet, the recovery approach we proposed dose not result in extra collision with the original broadcasting approach. As shown in Fig 11, packet collision count in ZBP and ZBP with EER is nearly the same.

5. Conclusion & Future Work

ZBP protocol can not only reduce the number of managers executing packet forwarding but also reduce the collision phenomenon, however it strongly depends on axis manager nodes relaying packet and thus may have unavoidable broadcasting failure caused by blank region on axis. Simple over network flooding manner re-broadcasting is not efficient for broadcasting recovery since it results in much energy and bandwidth consumption. This paper proposed an energy efficient recovering mechanism based on ZBP which does not only consider the full coverage but also the energy efficiency of recovery. The proposed idea improved ZBP by minimizing the number of packets needed to be re-transmitted during recovery phase, and thus can reduce both energy and bandwidth consumption.

In this paper, the coordinate system is pre-defined and is the same as ZBP. It is obviously that using the static coordinate system here would bring much energy consumption for the nodes lies on axis, since they mainly take charge of packets relay, and this un-balanced energy consumption may cause many chance of the existence of blank regions. In the future work, we plan to analysis whether the periodical transformation of coordinate system works, with the purpose to achieve balanced energy consumption and thus prolong the network lifetimes.

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Authors

Xiaoyi Lu

Received a B.S. degree in Science of Computer and Technology from Beijing Institute of Technology, China, 2004, and M.S. degree in Computer Science from Korea University, Korea, 2007. Her research interests include Ubiquitous Computing, Embedded System, Ad-Hoc Network and Wireless Sensor Network.

Zhen Fu

Received a B.S. degree in Computer Science from Wuhan University, China, 2004, and M.S. degree in Computer Science from Korea University, Korea, 2007. His research interests include Ubiquitous Computing, Embedded System, Ad-Hoc Network and Wireless Sensor Network.

InSook Lee

InSook Lee received her B.E. degree in Dongduk Women's University in Korea 2002. She is now studying Computing Science as a Master Student in Korea University since 2006. Her research fields including Information Management and Information System, Ubiquitous Computing, Embedded System, Wireless Sensor Networks and RFID.

Myong-Soon Park

Received a B.S. degree in Electronics Engineering from Seoul National University, Korea, 1975, and M.S. degree in Electrical Engineering. University of Utah, 1982, and Ph. D. degree Electrical and Computer Engineering. University of Iowa, 1985. From 1975-1980, he was a researcher in ADD and during 1985-1987, he worked as an Assistant Professor of Dept. of Electrical Engineering and Computer Science in the Marquette University. From 1987-1988 he was hired as an Assistant Professor of Dept. of Computer Science, Electronic and Electrical Engineering, POSTECH, and after then till now, he is working as the Professor of Dept of Computer Science and Engineering of Korea University. His research interests include Parallel Processing, Clustering, Internet Computing, Networks on Storage, Embedded Systems, Mobile IP and Wireless Communications.