A Routing Scheme with Limited Flooding for Wireless Sensor Networks

Jeongho Son[1], and Tae-Young Byun[2*]

[1]*Electronics and Telecommunications Research Institiute*
2139 Daemyeong, Namgu, Daegu, Rep. of Korea
[2]*School of Computer and Information Communications Engineering,*
Catholic University of Daegu, Gyeogsan-si, Gyeongbuk, Rep. of Korea
phdson@etri.re.kr, tybyun@cu.ac.kr

Abstract

As deployment of sensor networks are recently expanding, a variety of services based on sensor network have been introduced. Nevertheless, problems such as network bandwidth reduction, collision occurrence and performance deterioration due to broadcasting of message in large scale networks have become main challenges. Above all, prolonging of battery lifetime becomes primary challenge to overcome for deploying sensor networks in various fields. In this paper, we present a new routing algorithm based on data-centric routing and address-based routing schemes, which is that query messages are delivered to target area by using address-based routing scheme, then, broadcast scheme is used in target area by inserting additional information of neighbor nodes into the message payload. This method prevents severe broadcast storm caused by broadcasting messages, and also provides reliable data delivery at reasonable level by utilizing address information in message. By computer simulation, our proposed scheme significantly reduces energy consumption caused by broadcasting of messages as well as it improves appropriate data reliability in wireless sensor networks.

Keywords: sensor networks, routing scheme, mixed address mode, broadcast

1. Introduction

Sensor network consists of many sensor nodes which have capabilities of sensing, processing and communication. A specific sensor node is called *sink node* which collects interested data from sensor nodes.

As hardware technologies including MCU with low-power consumption, communication-related chip as well as MAC and routing protocols with low power consumption have been introduced, deployment of sensor networks in real world are increasingly promoted. Although services and applications deploying sensor networks greatly increase, there are still many challenges to overcome. A question about 'How sensor networks can guarantee a reliable data delivery and stable operation & management for a long time' has been the primary challenge in these studies. Generally, a sensor node has a limited power and a sensor network has a difficulty of substitution of exhausted batteries across hazard zone in large area. It is very important to extend network's lifetime as well as sensor node's lifetime. Hardware technology to extend sensor node's lifetime is restricted because it is unlikely that

[*] Corresponding Author

performance of hardware will suddenly be improved. Thus, researchers have given attention to methods for extending sensor network's life time through software solutions recently.

In this paper, we present a simplified routing method that lessens traffic load caused by broadcast storm over sensor network, as a result, to reduce average power consumption of each sensor node. Our method prevents all nodes from participating in forwarding a query-message in flooding method. That is, a query message originated from a source is delivered to a designated node in a target area by unicast, then, designated node is responsible to broadcast the message to all nodes in target or interested area. Here, as the degree of branch out of node varies, the number of nodes of participating in flooding a message also varied. So, we investigate how many degree of branch out of a node in target area is sufficient to flood the message to all nodes in target area efficiently.

The rest of the paper is organized as follows. Section 2 reviews related works about sensor networks overall, and Section 3 explain our proposed scheme in detail. Simulations and results are presented in Section 4. Finally, we conclude our proposed scheme in Section 5.

2. Related Works

2.1 Wireless Sensor Network Standards

Several surveys [1][2][3][4][5], and [6] discussed various aspects on wireless sensor networks. In particular, these surveys also deal with the increasing importance of the ZigBee/IEEE 802.15.4 standards, giving a review of these standards and comparing their solutions with the ideas emerged in the recent literature.

The ZigBee Alliance is an association of companies working together to develop standards (and products) for reliable, cost-effective, low-power wireless networking. ZigBee technology will probably be embedded in a wide range of products and applications across consumer, commercial, industrial and government markets worldwide. ZigBee builds upon the IEEE 802.15.4 standard which defines the physical and MAC layers for low cost, low rate personal area networks. ZigBee defines the network layer specifications for star, tree and peer-to-peer network topologies and provides a framework for application programming in the application layer.

2. 2. Related Routing Scheme

In a WSN environment, where nodes can be deployed at random and in large quantities and the network topology may vary due to sensor failures or energy efficiency decisions, assigning and maintaining hierarchical structures is impractical. The message overhead to maintain the routing tables and the memory space required to store them is not affordable for the energy and resource constrained WSNs.

Reactive protocols such as AODV [7] and DSR [8] alleviate some of these problems (ZigBee actually uses an AODV-based protocol) but questionably scale to very large networks since they depend on flooding for route discovery. Furthermore, DSR requires the management of large route caches and large packet headers to store the path.

Routing protocols for WSNs should be lightweight in both processing power and memory footprint and should require minimal message overhead. Ideally they should be able to route packets based on information exchanged with its neighborhood and should be resilient to node failures and frequent topology changes. For these reasons most of the research on routing in sensor networks has focused on localized protocols which are tree-based or geography-based.

Routing Tree. Simple data gathering applications where readings collected by sensors are sent to the sink, possibly with some aggregation along the path, need trivial routing. As the query propagates through network, each node just remembers its parent toward the sink and later forwards it any messages it receives/originates. Directed Diffusion [9][10] is a variant that routes packets along the edges of a DAG rooted at the sink and allows for multipath data delivery. Routing trees are very easy to construct and maintain but this approach is not suitable for more complex applications that require end-to-end communication.

Geograph "greedy" routing. Geographic (or greedy) routing [11]naturally supports end-to-end communication. All nodes are assigned a location according to some flat (i.e., network-wide) coordinate system and a distance is defined for any two locations. Each node periodically broadcasts its location to neighbours. On the basis of the destination location (carried in each data packet) a node forwards the packet to the neighbor that minimizes remaining distance. The first is a localization problem and consists in assigning a tuple of coordinates to each node. An obvious possibility is to use a physical (geographical) coordinate system with nodes equipped with GPS (or manually conFigureured) or let nodes approximate their physical position from connectivity information with only a few GPS-equipped anchor nodes. An alternative to real coordinates is to run a protocol that assigns virtual coordinates to all nodes. Virtual coordinates are not bound to the physical position but only depend on relative position (i.e., node connectivity).

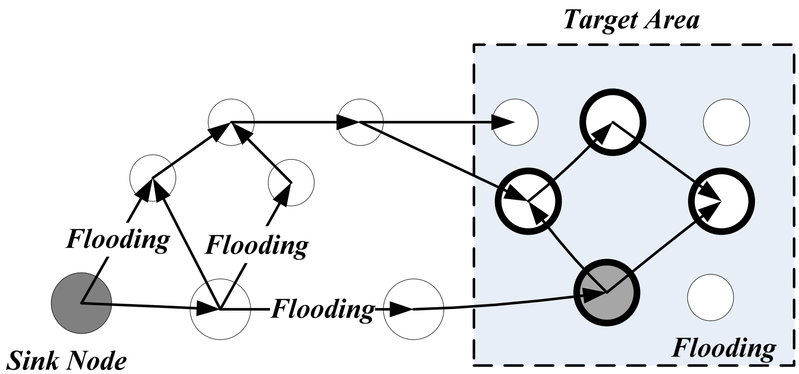
Hierarchical routing. Greedy routing is efficient in areas densely and regularly populated with nodes. It fails in the presence of voids or obstacles that introduce discontinuities in the topological connectivity structure. Recently developed alternatives to greedy routing consider taking a compact representation of the global sensor network topology structure and storing such representation at all nodes. The representation identifies and divides the network into a set of topologically regular regions. A local coordinate system is defined within each region and a greedy-like routing algorithm suffices to perform intra region packet forwarding. The role of the representation is to glue the regions together and drive long range routing across the network. Routing decisions within a given node consist of identifying an inter region path from the current node to the destination, and using local (greedy-like) routing to reach the next region in the path or the final destination (if it is in the current region). One of the disadvantages of these approaches might lie in the complexity of deriving the high level topological structure of the whole network. Also the size of this representation must be small enough to be stored at each node, which precludes very articulated networks (e.g., sparse networks). Finally, local coordinate systems within regions tend to be a little more complex than integer tuples (as in flat greedy routing) and so are the corresponding greedy-like routing functions. Many studies have been performed to find proper solutions to various problems as mentioned above.

Especially, broadcast-based routing schemes [12][13] such as AODV, DSR and directed diffusion have a weakness of highly power assumption due to massive broadcast message which cause to deliver duplicated messages. Also, these duplicated messages reduce the efficient bandwidth over network, and frequent collisions of messages due to reduced bandwidth occur. As a consequence, a series of these events reduce the network lifetime overall. Considering above problems, our contribution is find a proper routing method that as well as maintains reasonable efficient bandwidth.

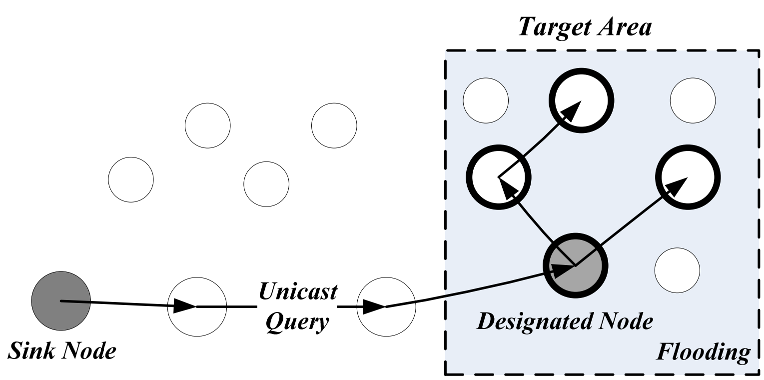
3. Proposed Mixed Address Mode Scheme

We defined characteristics, problems and consumption energy for transceiver in large scale wireless sensor networks in section 2. Especially, we know that the broadcasting storm is a severe problem for network's lifetime.

In this section, we present a new mixed address mode routing scheme which mixes an address-based routing mode and data centric routing mode.



(a) Broadcasting with flooding scheme



(b) Our proposed scheme

Figure. 1. The concept of mixed address mode

Figure. 1(a) is an example of full broadcasting. When each node received new message, the node sends the message using flooding scheme. At that time, the amount of consumption energy to broadcast is about:

$$E_{total} = (E_{rx} * \textit{the average number of neighbors} + E_{tx}) * N \qquad (1)$$

As equation (1) means, the total energy directly depends on the number of all nodes(N) and *the average number of neighbors*. So, the total energy consumed for one broadcast is big so that it can rapidly reduce network's lifetime. Figure. 1(b) illustrates our proposed scheme to limit the range of broadcast with target area information that is included in the message. In our scheme, it uses an address-based routing scheme to deliver by unicast to specific region called especially *target region*. In the target region, our scheme modifies the message into a broadcast message and inserts specific number of neighbors as in-message addresses by a *designated node* which receives a unicast message outside of target zone and forwards the message to one or more nodes in target zone. And then, one or more nodes broadcast the message into the target area. The frame structure is shown in Figure. 2. The frame consists of MAC Frame Header (MHR), Network Frame Header (NHR), Payload, MAC Footer (MFR). The payload field contains a query message like Figure. 2.

MHR	NHR	Payload	MFR

Figure. 2. Frame structure of Zigbee

We uses IEEE 802.15.4 and Zigbee protocol frames and includes a query message in directed diffusion routing. The size of query message could be varied within frame length.

"Send me temperature, humidity information in region A in every 1 minute"

A query message with similar meaning like above is included in Payload field. After the query message is disseminated in Region A, sensor nodes in Region A send sensing information to the sink node that generated the query message.

Figure.3 shows a sequence diagram for processing message over sensor network. Sink node initializes a query message and assembles a frame conforming to address-based mode. The query includes target area, interested properties, and interval, and it is encapsulated with Zigbee frame and IEEE 802.15.4 MAC frame format. While it is forwarded to nodes outside of target area, the MAC address is filled with a unicast address and the query message is routed to a next sensor node by using a legacy routing table. When it comes into target area, the received sensor node called designated node can disassemble the message and designated node knows that it is in target area. Immediately, it makes the message into a broadcast message and selects relay nodes as much as the degree of broadcasting. The degree is selected according to network density or desired coverage for broadcasting or to desired the probability of collision occurrences. And then, one or more selected node's addresses are inserted into the payload field of the query message. When selected nodes receipt the message, these nodes repeat the previous forwarding behavior.

Although all nodes in target area cannot receive the message because the number of nodes is limited, and collision can be occurred, these constraints can be in other scheme using pure IEEE 802.15.4 MAC protocol. We have a positive point of view that it will reduce the collision occurrences and gather information appropriately from selected nodes in the target area. For example, if we want to know temperature in region A where it has 100 nodes, we can determine the temperature from only 20 nodes. When a node(N) has receipt a message(M) and N is not the destination node, a brief procedure can be explained in Figure.4.

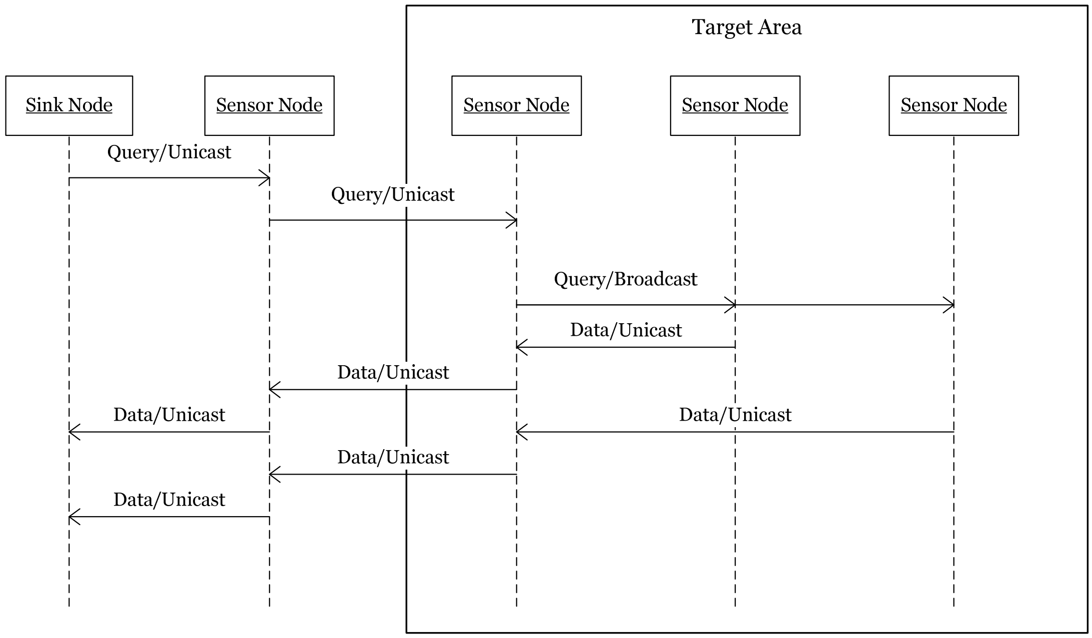


Figure. 3. Sequence diagram of processing in our scheme

```
if (M is delivered in unicast mode)
    if (N is in the target area)
        Broadcast M with 2 neighbor nodes
    else
        Deliver M to next node
    end if
else (M is delivered in Broadcast mode)
    if (N is in the target area && N is in M's payload)
        Broadcast M with 2 selected neighbor nodes
    else
        Drop M
    end if
end if
```

Figure. 4. A simplified proposed routing algorithm

As we mentioned that a broadcast storm affects to network lifetime, it is important to reduce the number of transmission of broadcast message. In our proposed scheme, selection procedure for determining next forwarding nodes is performed on sender in target zone. Here, the degree of broadcasting indicates the number of next forwarding nodes at a temporary sender in target zone. The degree can be increased or decreased by network density or another factor. Hence, it limits the number of broadcasting messages with target area information using mixed address mode. In addition, our proposed scheme can make reverse route of a messages and use in-network processing such as fusion, compression to reduce the number of message transmission.

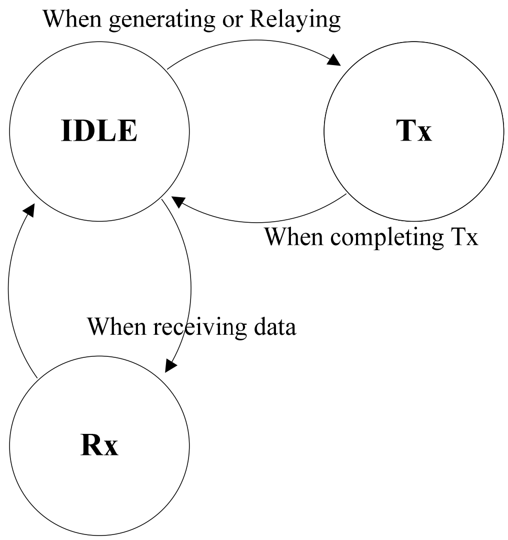


Figure. 5. A state transition diagram of forwarding node

4. Performance Evaluation by Simulation

4.1 Simulation Tool

For performance evaluation of our proposed scheme, we use the CSIM19 that is a kind of the system modeling toolkit from Masquite Software and provides discrete simulation environment[12].

In many cases, a simulation model mimics the behavior of a real system. The usual technique is to represent the active elements of the system with entities and the passive elements of the system as resources. The resources are often implemented in the model as queues (consisting of one or more servers and an internal queue for waiting entities).

CSIM19 is a toolkit for constructing simulation models of complex systems. In a CSIM19 model, the active elements of the system are represented by CSIM processes, and the passive elements by resources such as facilities and storages. A CSIM19 model of a complex system is a C or C++ program in which CSIM19 processes mimic the behavior of the active entities of the system as they compete for use of resources of the system. The statistics collection features of CSIM19 give insight into the performance of the system as reflected in the response times and flow rates of the processes and the utilization of and contention for the resources. Creating a model of a system requires specifying the set of processes and resources which will be used to model the important components of the system.

A detailed our simulation objects are depicted in Figure. 6. Generally, there are three parts in simulation objects using CSIM19, that is, sensor node processor, channel coordinator and simulation timer. Each sensor node processor has a variety of data structures and properties such as location info., communication status, Rx buffer, Tx buffer and events as well as communication timer and packet generation processor. If a node becomes packet generation processor, the node can generates packets based on exponential random backoff.

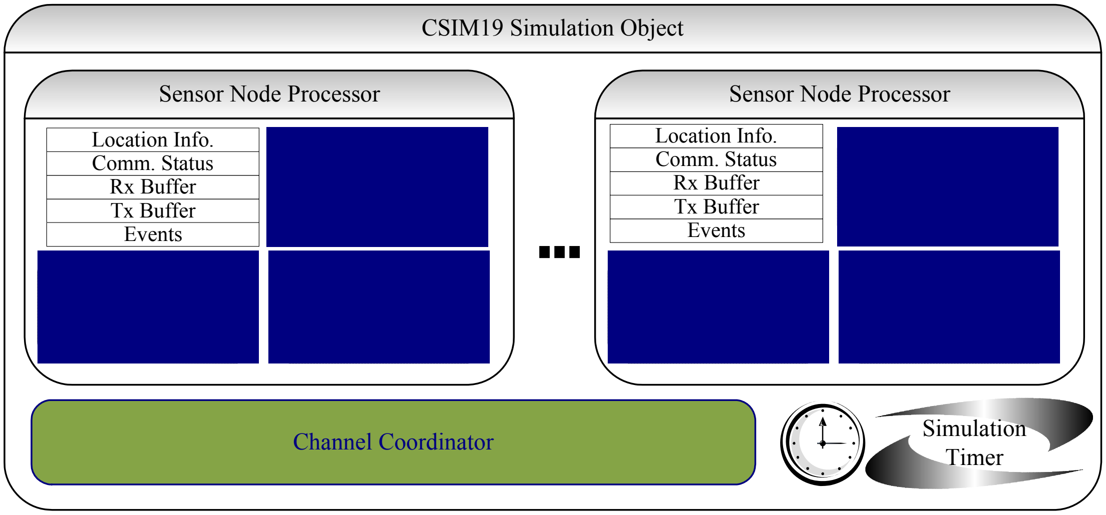


Figure. 6. CSIM Simulation Objects

4.2 Simulation Parameters and Results

The simulation parameters for performance evaluation are listed in Table 1. Basically, we use IEEE 802.15.4 MAC protocol parameters with recommended value in the standard specification.

Table 1. Parameters for simulation scenarios.

Metrics	Value	Note
minBE	**3**	Minimum number of binary backoffs
maxBe	**5**	Maximum number of binary backoffs
Bandwidth	**250kb/s**	62.5ksymbols/s
CSMA backoffs	**4**	The number of retries

We randomly deploy fixed 150 nodes including one sink node in 1000m * 1000m field, and transmission range of each node is 100m. We assume that each node knows neighbor's location as well as its location information. The neighbor information is collected by 'hello' message. The message length is 100 bytes that include MAC header, MAC footer, Network header, payload, and node IDs of broadcast candidates. Each node operates in non-beacon mode with binary backoff algorithm so that it starts backoff algorithm and sends the message if channel is idle.

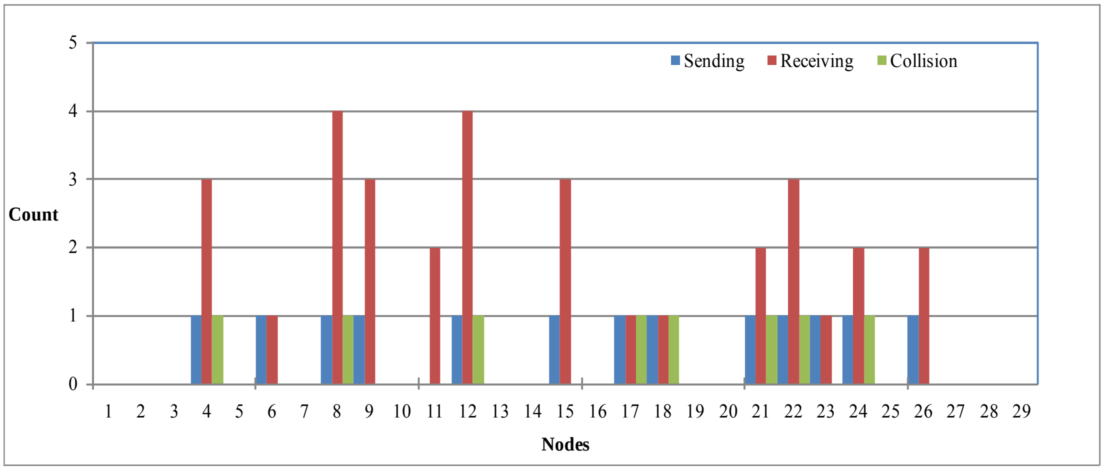


Figure. 7. The result of broadcasting in whole area with full flooding

We evaluate the number of sending, receiving, and colliding of broadcasting messages in whole area. We deploy 29 nodes in the target area in Figure. 7. Only 13 nodes among them receive the query message. In the result of Figure. 7, we can find that message delivery is interfered by collision occurrence. Consequently, not all nodes can receive the message due to collision occurrence.

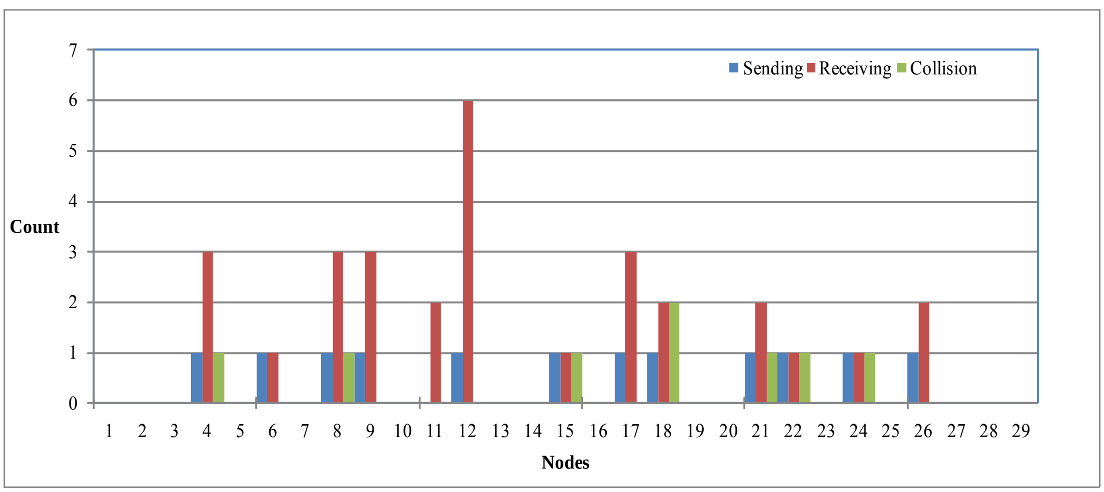


Figure. 8. The result of broadcasting in the target area with (full flooding)

In next scenario, we use full flooding scheme only in target area. It is different to the previous scenario. As shown in Figure. 8, the number of received nodes is 12 that is 1 less than that of the previous scenario. It has valuable meaning in view that there is no need to broadcast message into a whole network.

Table 2. Comparison of the number of transmissions, receptions, and collisions

Items	Whole area flooding	Target area flooding
The number of transmissions	**104**	**19**
The number of receptions	**232**	**41**
The number of collisions	**96**	**8**

In Table 2, our scheme with full flooding in target area can reduce significantly the number of transmissions, receptions, and collisions.

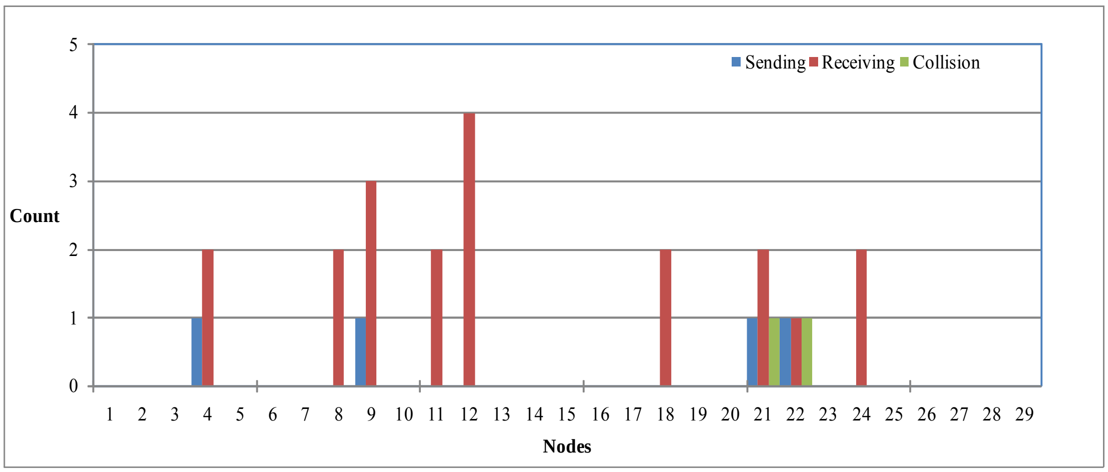


Figure. 9. The result of 3 nodes broadcasting in target area

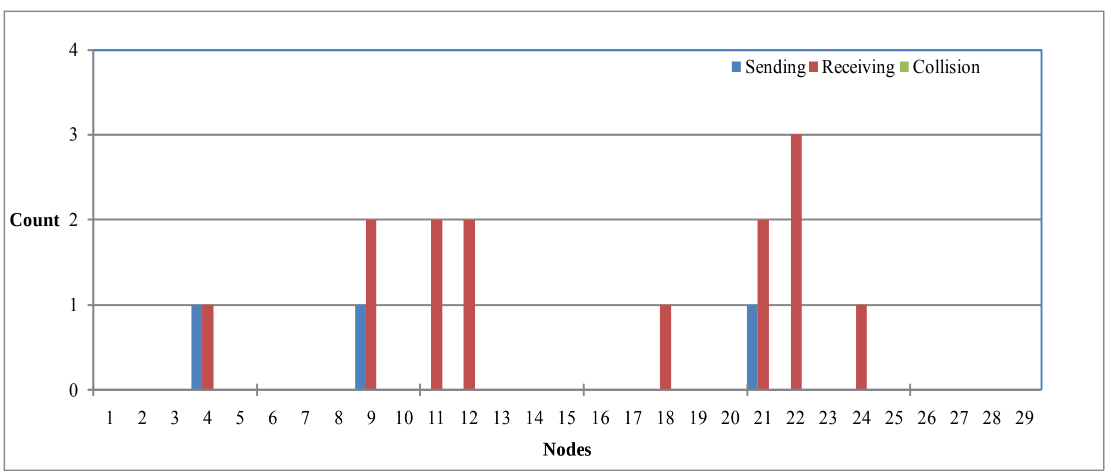


Figure. 10. The result of 2 nodes broadcasting in target area

Finally, our scheme with limited broadcasting is evaluated, and the results are shown in Figure. 9 and Figure. 10 respectively. The number of receipt nodes in Figure. 9 and Figure. 10 is not much different to each other. However, only 8 nodes receive the query message and no node experiences collisions in Figure. 9.

According to the results, we can reduce the number of transmissions and collision by limiting the degree of broadcasting, and our scheme can prolong the network lifetime overall. In addition, the proposed scheme can be applied to large scale sensor networks with different network density.

5. Conclusion and Future Works

We proposed a routing protocol using mixed address mode to reduce the number of broadcasts. The sensor nodes out of a target region do not broadcast so that many sensor nodes can save their energy. As increasing or decreasing the broadcasting degree, the number of sensor nodes sensing in a target area is controlled in large scale and dense sensor networks. Our proposed scheme also gives a chance to aggregate sensing data in network using reverse paths, opposite paths of query message delivery. In future works, we will deal with algorithms to select candidates to broadcast that can spread out in target area more efficiently.

References

[1] Pradnya Gajbhiye, and Anjali Mahajan, "A Survey of Architecture and Node deployment in Wireless Sensor Network", Prodeedings of ICADIWT 2008, IEEE, 2008, pp. 426-430.

[2] Th. Arampatzis, and J. Lygeros, S. Maesis, "A Survey of Applications of Wireless Sensors and Wireless Sensor Networks", Intelligent Control, IEEE, 2005, pp. 719-724.

[3] Elena Fasol, Michele Rossi, Jorg Widmer, and Michele Zorzi, "In-Network Aggregation Techniques For Wireless Sensor Networks: A Survey", Wireless Communications, IEEE, 2007, vol. 14, pp. 70-87.

[4] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless Sensor Networks: A Survey", Communications Magazine, IEEE, 2002, vol. 40, pp. 102-114.

[5] Marcos Augusto M. Vieira, Claudionor N. Coelho. Jr, Diogenes Cecilio da silva Junior, and Jose M. da Mata, "Survey on Wireless Sensor Network Devices", Proceedings of ETFA'03, IEEE, 2003, vol. 1, pp. 537-544.

[6] Ahmed A. Ahmed, Hongchi Shi, and Yi Shang, "A Survey on Network Protocols For Wireless Sensor Networks", Proceedings of ITRE 2003, IEEE, 2003, pp. 301-305.

[7] C.E. Perkins, and E.M. Royer, "Ad-hoc on-demand distance vector routing", Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications 1999, New Orleans, LA, USA, 1999, pp. 90–100.

[8] D.B. Johnson, and D.A. Maltz, "Dynamic source routing in ad hoc wireless networks", Mobile Computing, Kluwer Academic Publishers, Dordrecht, 1996, vol. 353, pp. 153-181

[9] Chalermek Intanagonwiwat, Ramesh govindan, Deborah Estrin, John heidemann, and Fabio Silva, "Directed Diffusion for Wireless Sensor Networking. Networking", IEEE/ACM Transactions, 2003, vol. 11, pp. 2-16,

[10] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed diffusion: a scalable and robust communication paradigm for sensor networks", Proceedings of the 6th International Conference on Mobile Computing and Networking 2000, Boston, MA, USA, 2000, pp. 56–67

[11] Juan A. Sanchez, Pedro M. Ruiz, Jennifer Liu, and Ivan Stojmenovic, "Bandwidth-Efficient Geographic Multicast Routing Protocol for Wireless Sensor Networks", Sensors Journal, IEEE, 2007, vol. 7, pp. 627-636.

[12] Herb Schwetman, "CSIM19: A Poerful Tool for Building System Models", Proceedings of the 2001 Winter Simulation Conference, 2001, pp. 250-255

[13] A. Mizumoto, H. Yamaguchi, and K. Taniguchi, "Cost-conscious geographic multicast on MANET", Proceedings of 1st IEEE Commun. Society Conference, Sensors, Mesh and Ad Hoc Communication Networks

(SECON ’04), October 2004, pp. 44–53.

[14] G. G. Finn, “Routing and addressing problems in large metropolitan-scale internetworks,” Univ. Southern California, Information Sciences Institute, Los Angeles, CA, Tech. Rep. ISI/RR-87-180, March 1987.

[15] P. Bose, P. Morin, I. Stojmenovic, and J. Urrutia, “Routing with guaranteed delivery in ad hoc wireless networks”, Wireless Network., 2001, vol. 7, no. 6, pp. 609–616.

[16] H. Takagi and L. Kleinrock, “Optimal transmission ranges for randomly distributed packet radio terminals”, IEEE Transactions in Communications, 1984, vol. 32, no. 3, pp. 246–247.

[17] H. Fler, M. Mauve, H. Hartenstein, C. Lochert, D. Vollmer, D. Herrmann, and W. Franz, “Position-based routing in Ad-hoc wireless networks”, Inter-Vehicle-Communications Based on Ad Hoc Networking Principles—The FleetNet Project. Karlsruhe, Germany, Universittsverlag Karlsruhe, 2005, pp. 117–143.

[18] I. Stojmenovic, “Position-based routing in Ad hoc networks”, IEEE Communication Magazine, 2002, vol. 40, no. 7, pp. 128–134.

[19] J. Li, J. Jannotti, D. S. J. D. Couto, D. R. Karger, and R. Morris, “A scalable location service for geographic Ad hoc routing”, Proceedings of 6th Annu. ACM/IEEE Int. Conf. Mobile Computing and Networking (MobiCom’00), 2000, pp. 120–130.

[20] D. Liu, I. Stojmenovic, and X. Jia, “A scalable quorum based location service in ad hoc and sensor networks”, in Proceedings of 3rd IEEE Int. Conf. Mobile Ad-Hoc and Sensor Syst. (MASS ’06), 2006.

[21] L. Lazos and R. Poovendran, “SeRLoc: Robust localization for wireless sensor networks”, ACM Transactions in Sensors Networks, 2005, vol. 1, no. 1, pp. 73–100.

[22] M. Mauve, H. Füβler, J. Widmer, and T. Lang, “Position-based multicast routing for mobile ad-hoc Networks”, ACM SIGMOBILE Mobile Computing and Communications Review, 2003, vol. 7, no. 3, pp. 53–55.

[23] M. Transier, H. Füβler, J. Widmer, M. Mauve, and W. Effelsberg, “Scalable position-based multicast for mobile ad-hoc networks”, First Int. Workshop on Broadband Wireless Multimedia: Algorithms, Architectures and Applications (BroadWim ’04), Oct. 2004.

Authors

Jeongho Son received a B.E. in computer engineering from Kyongju University and M.E.in information and communication, Ph.D. degree in computer engineering from Kyungpook National University in 2002 and 2007 respectively. Currently, he has been a senior researcher in Electronics and Telecommunications Research Institute (ETRI), Korea since 2009. He had worked at Ubiquitous Technology Research Center (UTRC) in Daegu University, Korea from 2007 to 2009. He has experiences of development and research for wireless sensor networks such as IEEE 802.15.4 and ZigBee for large scale sensor networks. His current project includes development and design of embedded systems such as operating systems (AUTOSAR OS), network protocol and topologies of ECUs in automobiles. He also has interests in protocols of home networks, local area networks and body area networks, and vehicle area networks including ITS, Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication.

Tae-Young Byun received a B.E., M.E., and Ph.D. degree in computer engineering from Kyungpook National University in 1994, 1997 and 2000, respectively. Currently, he is an associate professor in the School of Computer and Information Communications Engineering at Catholic University of Daegu, Korea since 2003. He had been an assistant professor of Computer and Electronic Engineering, Kyongju University, Kyongju, Korea from 2000 to 2003. He joined SKC Co., Ltd., Korea in 1994. From 1998 to 1999, he had been a chief director of

Sevit Information Co., Ltd., Korea. Since 2003, he has been a technical advisor in Mobilus Co., Ltd., Korea. Also, he has been a visiting lecturer for education of GSM/GPRS/UMTS in Samsung Electronics Co., Ltd., Korea. As a technical advisor, he has participated in Daegu Regional Innovation Agency, Gyeongbuk Regional Innovation Agency, and Mobile Technology Communication Center, Daegu, Korea since 2004. He has published more than 90 papers in journals and refereed conference proceedings and he holds a KOREA patent in IP multicast over ATM networks. His current research projects include design and testing of embedded systems that consist of home gateway and home server for smart home, design and testing of a personal communicator which can control remote devices including a robot, home appliances etc., and implementation of prototype of inter-vehicle communication system with GPS module for providing safety driving. His main research interests include multimedia communication system, next generation IP(IPv6), wireless sensor networks and mobile communications.