Hindawi Publishing Corporation
International Journal of Distributed Sensor Networks
Volume 2014, Article ID 783697, 8 pages
http://dx.doi.org/10.1155/2014/783697

Research Article

Disjointed Multipath Routing for Real-Time Data in Wireless Multimedia Sensor Networks

Junho Park,[1] Mirim Jo,[1] Dongook Seong,[2] and Jaesoo Yoo[1]

[1] *School of Information and Communication Engineering, Chungbuk National University, Cheongju, Chungbuk 361-763, Republic of Korea*
[2] *BOAS Electronics Inc., Industrial Technology Research Park, Cheongju, Chungbuk 361-763, Republic of Korea*

Correspondence should be addressed to Jaesoo Yoo; yjs@chungbuk.ac.kr

Received 4 September 2013; Revised 5 December 2013; Accepted 5 December 2013; Published 16 January 2014

Academic Editor: Seokcheon Lee

Wireless multimedia sensor networks with sensing and processing abilities of multimedia data have recently emerged as one of the most important technologies for high quality monitoring. The routing scheme for multimedia data is an important research issue addressed in wireless multimedia sensor networks. In this paper, we propose a disjointed multipath routing scheme for real-time data transmission in wireless multimedia sensor networks. The proposed scheme uses a hybrid routing protocol based on Bluetooth and Zigbee in order to overcome the limitation of low bandwidth in conventional sensor networks. The proposed scheme also performs disjointed multipath routing based on competition to alleviate the delay of routing path setup. To show the superiority of our proposed scheme, we compare it with the existing scheme through performance evaluation. Our experimental results show that our proposed scheme reduces the end-to-end delay by about 30% and the routing path setup costs by about 22% over the existing scheme. Our scheme also increases data reception rates by about 690% over the existing scheme on average.

1. Introduction

The research on various applications using wireless sensor networks (WSNs) has progressed in the last few years. The sensor nodes in wireless sensor networks basically mount the sensor modules to collect environmental information such as humidity and temperature. In addition, as they have wireless communication modules, a sensor network is constructed and consists of sensor nodes that are connected to each other to collect and transmit sensor readings on the areas of interest to remote areas through multihop communication between nodes [1, 2]. The WSNs have extensive utilization fields from special applications such as observation of safety monitoring and military affair to living applications such as environmental monitoring, modern healthcare, and U-City [3].

The environmental information collected by the sensor nodes depends on the mounted sensor modules on the node. Recently, with the availability of cheap, small and low-powered CMOS cameras, microphones the applications for gathering multimedia contents such as video and sound over WSNs have become more feasible than ever before. Consequently, it enables high-quality environmental monitoring based on multimedia data [4, 5]. As the multimedia data are very large compared to simple scalar data in conventional sensor networks, the network lifetime of the sensor network is significantly reduced due to excessive energy consumption in particular nodes for transmitting the data. Accordingly, the communication schemes of the conventional sensor networks based on low-bandwidth Zigbee are not suitable for transmitting multimedia data in real-time [5].

Recently, the new sensor nodes with a Bluetooth module have been released on the market. The bluetooth is one of the great solutions. Table 1 shows the specifications of the Bluetooth to be used in the proposed scheme and Zigbee is generally applied to the conventional sensor networks. As the Zigbee has 250 Kbps or less of data rate, it is not suitable for real-time transmission of multimedia data requiring bandwidth of scores Mbps. The Bluetooth can be an alternative to overcome the bandwidth limitation of Zigbee.

The maximum data rate supported by Bluetooth is 24 Mbps to enable transmission of images at 720 p/30 fps or higher. However, as a sensor node is required to minimize battery consumption as mentioned above, it is not suitable

Table 1: Comparison between Zigbee and Bluetooth [6].

Criteria	Bluetooth	Zigbee
Standard	IEEE 802.15.1	IEEE 802.15.4
RF frequency	2.4 GHz	868/915 MHz
Data rate	723 Kbps/24 Mbps	250 Kbps
Range (m)	−10/100	−70
Power (W)	0.1	0.05
Battery life (days)	1–20	100–1000+

to use Bluetooth with high energy consumption as a basic communication protocol [6]. In order to overcome these limitations, we propose a novel hybrid transmission scheme that uses both the strengths of Zigbee and Bluetooth. The proposed routing scheme effectively transmits multimedia data by dividing the data of the source node to be transmitted to several neighboring nodes through the Bluetooth and by performing energy-efficient routing for each split data to the sink through the Zigbee. The proposed scheme can minimize path setting overhead generated from the existing scheme by establishing competition-based nonoverlapping multipath for data transmission. In addition, it enables fast reception of the split packets from a frame by eliminating resorting of the received data by ensuring first-in-first-out (FIFO) reception with a separate queue for each path.

The remainder of this paper is organized as follows. Section 2 overviews the existing transmission schemes for multimedia data. In Section 3, we present our disjointed multipath routing for real-time data transmission in wireless multimedia sensor networks. Section 4 shows the simulated experimental results and compares the existing scheme with the proposed scheme. Finally, we present concluding remarks in Section 5.

2. Related Works

Various schemes to transmit data in the conventional sensor networks have been proposed. Representative schemes are tree-topology-based TAG [7], cluster-topology-based HEED [8], greedy-forwarding-based GPSR [9], and so on. Though these schemes are suitable for sending scalar data from the conventional sensor networks and are designed on the basis of the lowbandwidth of Zigbee, multimedia data has a large size which is different from conventional sensor networks that handle scalar data. Therefore, they are not suitable for transmitting mass multimedia data such as video and image.

To solve the problems, many protocols and algorithms have been proposed. All the single-path routing protocols [7–9] for conventional sensor networks take the minimum energy path, whereas the multipath routing schemes distribute traffic among multiple paths instead of routing all the traffic along a single path. In multipath routing scheme, it is necessary to know the number of the required paths and to choose the appropriate paths in the total number of available paths [10]. Clearly, the number and quality of the selected paths dictate the performance of a multipath routing scheme. The existing multipath routing schemes are intended to provide a reliable transmission of data for data synchronization at the destination on an environment with low energy consumption. These are done by efficiently utilizing the energy availability and the received signal strength of the nodes to identify multiple routes to the destination.

The existing multipath routing schemes spread the traffic over the nodes lying on different possible paths between the source and the sink in proportion to their residual energy and received signal strength. The rationale behind traffic spreading is by considering the energy so that the overall lifetime of the network can be increased. The sequence number is assigned to each packet of data for data synchronization at the destination. The objective is to assign more loads to underutilized paths and less loads to over-committed paths so that uniform resource utilization of all available paths can be ensured.

Some of the related works in multipath routing are as follows. The two phase geographic greedy forwarding (TPGF) routing algorithm has two phases [11]. The first phase is responsible for exploring the possible routing path, and the second phase is responsible for optimizing the explored routing path with the least number of hops. A multihop planer model transmits the sensed multimedia data by forwarding it to one of its neighbors which is closer to the sink [12–14]. This approach uses a data aggregation technique that enhances the efficiency of the network by reducing the amount of transmitted data.

Most of the multipath routing protocols are extended versions of DSR [15] and AODV [16]. Only a few research works adopt geographical information to facilitate the on-demand disjointed multipath routing. One such routing protocol is geography-based ad hoc on demand disjoint multipath (GAODM) [17] in an AdHoc network. GAODM uses a push-reliable algorithm which focuses on how to use the push-reliable algorithm to find multiple node/edge disjoint paths based on the flow assignment. A node-disjoint parallel multipath routing algorithm (DPMR) [18] has two key problems. It relies on the single-path routing protocol [9] and has the restrictions of using either clockwise regions or anticlockwise regions, which actually limits the number of routing paths.

Geographic multicast routing (GMR) is a new multicast routing protocol for wireless sensor networks. It is a fullylocalized algorithm that efficiently delivers multicast data messages to multiple destinations. GMR optimizes the cost-over-progress ratio, where the cost is equal to the number of neighbors selected for relaying, and the progress is the overall reduction of the remaining distances to destinations. Maximally radio-disjoint multipath routing for wireless multimedia sensor networks [19] is basically based on path failure. This protocol maintains additional paths to serve as backup on primary path failure. There is also network lifetime maximization with node admission in wireless multimedia sensor networks [20], but due to stringent quality of service (QoS) requirements, it is not possible to admit all the potential sensor nodes into the network. Therefore, this work addresses the node admission into the network in order to maximize the network lifetime.

The ant-based routing [21] enables optimal transmission of video data by setting the path to improve QoS on the basis of the ant colony algorithm. It intends to overcome the limitations of bandwidth for the Zigbee by distributing a large amount of multimedia data through multiple paths. However, the ant-based routing suffers from a loss of data packets for high-quality images due to a limitation of bandwidth in source and sink nodes.

As the existing multipath routing schemes [15–21] perform a multipath setting phase for the distributed transmission of multimedia data, path setting packets go and return from source node to the sink and are stored in the routing tables of the transfer nodes when the routing information for each path is located on the paths. However, the path setting processess of the existing multipath routing schemes require packets to go and return n times to set n paths in the worst case. Since they are more frequent under sensor network environments with frequent changes of topology, they cause a great overhead.

We propose a hybrid disjointed multipath routing that combines the Bluetooth and Zigbee. The proposed scheme solves the problem of the loss of multimedia data packets due to bandwidth limitations of the existing schemes and competition-based nonoverlapping multipath setting methods to solve overhead generated from the multipath setting phase.

3. Disjointed Multipath Routing for Real-Time Data Transmission

Representative studies [15–21] in the field of multipath routing in wireless multimedia sensor network perform a multipath setting phase for the distributed transmission of multimedia data; path setting packets go and return from source node to the sink and are stored in the routing tables of the transfer nodes when the routing information for each path is located on the paths. In this process, the ant-based routing protocol transmits the control messages excessively. To overcome this problem, our scheme proposes the competition-based disjointed multipath configuration. It enables a path to be configured with much less communication than the existing multipath routing schemes. Furthermore, since the existing scheme only uses the Zigbee to transmit the multimedia data, it causes transmission delay and packet-loss near source or sink nodes. The proposed scheme minimizes the end-to-end delay and packet-loss for a very large scale of multimedia data through data splitting and transmission using Bluetooth at the source and sink nodes.

In this section, we propose a multiple path transmission scheme for transmitting large multimedia data files in real-time in order to more efficiently utilize the limited bandwidth of a wireless network using the Zigbee. Figure 1 shows the proposed disjointed multipath routing. The source node splits the video data to transmit to neighboring nodes using Bluetooth that has a higher bandwidth than Zigbee. The neighboring nodes receive a split packet of the data transferred to the location of the sink using Zigbee. However, during this process, if routing paths of different packets overlap on a specific node, channel occupation for data transmission is increased due to bandwidth limitation of Zigbee,

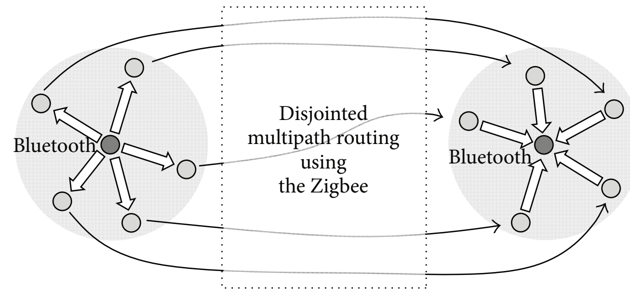

Figure 1: The proposed hybrid disjointed multipath routing.

and thus, the loss of packets and the energy consumption become larger. To overcome these problems, the proposed scheme uses disjointed multipath transmission. The sink receives split packets with separate reception queue and finally combines the original data when all split packets have been received. The reconfiguration of paths is performed by considering the delay time of data transmission on the sink.

3.1. Split of Multimedia Data. The proposed scheme generates transmission packets by splitting the multimedia data. The existing schemes divide paths and transmit the data in the frame. In this case, since the split packets have different transmission times depending on the paths, it is required to sort the frames received on the sink. However, as the proposed scheme has a FIFO pattern of transmission sequencing on individual paths, original multimedia data can be combined without the sorting process in the sink. Figure 2 shows the splitting of a multimedia data (image data or video frames) on the sink. Because a Bluetooth protocol allows up to 8 devices (1 master and 7 slaves), it is possible to pair up 7 additional devices at the same time. Therefore, the packets generated through the splitting of each individual frame including video data are transmitted to a maximum of 7 neighboring nodes of the source node through a Bluetooth module.

The split packet consists of a source node ID, the path IDs with which the packet will be transmitted, and a payload (splitted multimedia data). The source node ID is utilized to identify data transmitted to the sink, while the path ID is used to set the disjointed paths. If there are any IDs of different paths registered on the node for transmission, it is required to select other neighboring nodes as the transfer nodes.

3.2. Disjointed Multipath Configuration. Our scheme proposes the competition-based disjointed multipath configuration algorithm to solve excessive energy consumption on the specific nodes due to the overlapped nodes on several paths. The proposed scheme utilizes a greedy-forwarding-based transmission scheme for the initial transmission. In the greedy forwarding scheme, the entire nodes know the location information of their neighboring nodes and the transmitted packets include the coordinate information of the sink. Using this information, the nodes that receive the packets select the closest node out of their neighboring nodes to transfer the packets. This process is repeatedly carried out until the packet has arrived at the sink. This greedy

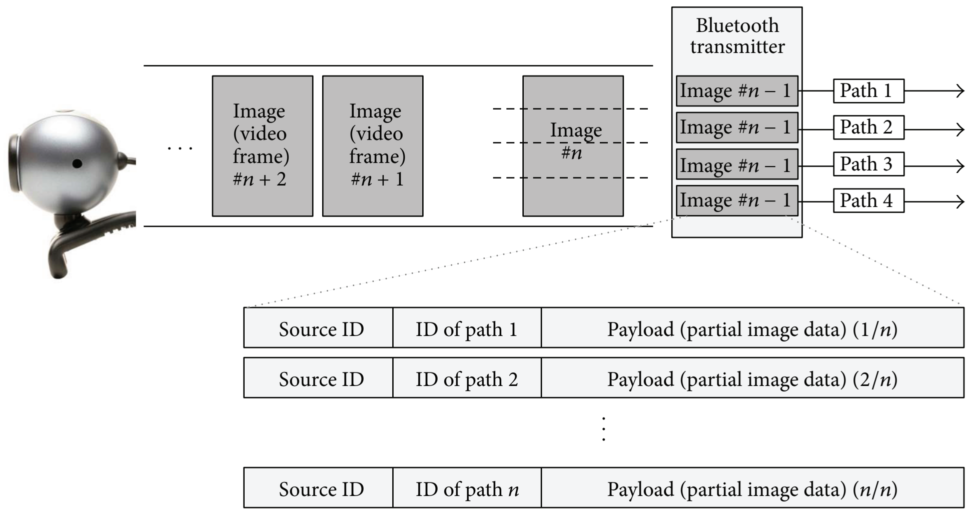

Figure 2: Splitting of multimedia data.

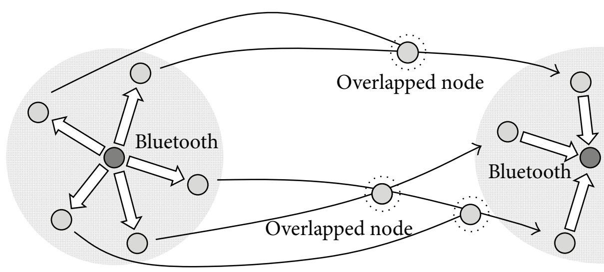

Figure 3: Problem of the multipath transmission scheme.

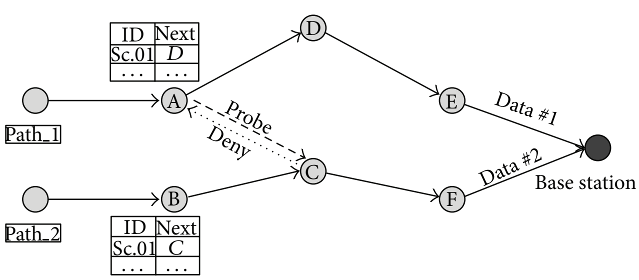

Figure 4: Configuration of competition-based disjointed multipath.

forwarding scheme forms the optimal path to enable data routing when transmitting data through a single path. However, if it is applied to a multipath configuration as shown in Figure 3, it is highly likely to have overlapped nodes that result in energy consumption and the packet-loss of a specific node. Therefore, the proposed scheme proposes a novel competition-based disjointed multipath configuration algorithm.

Figure 4 shows the competition-based disjointed multipath configuration. As shown in Figure 4, packets are simultaneously transmitted from source nodes to path_1 and path_2. In this case, if the path is set as the greedy forwarding as mentioned above, since both paths share the closest *node C* as a transfer node and *node C* transmits more data than the bandwidth of Zigbee, the packet-loss occurs.

Considering these problems, the proposed scheme sets paths to transmit the data using a *probe message* having only the path IDs before transmitting packets. The node (*node A*) that receives the packet sends the probe message to the neighboring node for transmission first, that is, the closest node (*node C*) to the sink. In this case, the neighboring node that received the *probe message* does not reply when it does not receive the probe messages of other paths, that is, if there is no path already set. If there is no response from the neighboring node that has received the *probe message*, the node that sent the probe message determines that it can participate in its path and registers information of the specific node on its routing table. To the contrary, since the node that receives the packet intends to transmit to the neighboring node that already participates in another path, the neighboring node replies with a *deny message* to refuse the path setting. As an example, in Figure 4, when *node A* sends the *probe message* to *node C*, as *node C* already participates in *path_2*, it replies with a *deny message* against the *probe message* of *node A*, while *node A* recognizes the other neighboring node, *node D*, as a transfer node through the same process as mentioned above and registers the information of the specific node on its routing table. When the routing information of all paths go from the source nodes to the sink through these processes above, multimedia data are transmitted on the basis of the respective path. Algorithm 1 presents the pseudocode of the competition-based disjointed multipath configuration.

Table 2 shows the routing table that is created when the competition-based disjointed multipath configuration algorithm is performed. The *PNodeID* refers to the closest node to the source of the path, that is, the previous node. It is used to request a path resetting from the sink to the source node in the future. The *CNodeID* refers to itself, and the *NNodeID* refers to the next node close to the sink. The *NNodeID* is used for transmitting the packets transferred from the source to the sink. For example, in case of *node C*

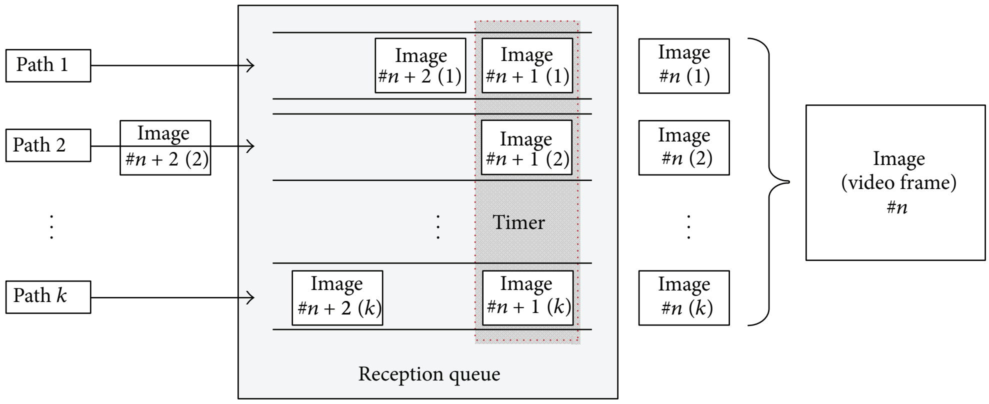

Figure 5: Receiving and combining the split packets.

```
Input:
Segment = Data Packet
  S_neighbors = Unsorted Neighbor Nodes List
  S_sorted_neighbors = Sorted Neighbor Nodes List
  destLoc = Information about the location of the sink
  (1)     S_neighbors = [S_0, S_1, S_2, ..., S_n]
  (2) S_sorted_neighbors = sort(S_neighbors, destLoc)
  (3) FOR EACH S = S_sorted_neighbors[i] DO
  (4) sendProbMsg(s)
  (5)    IF receiveDenyMsg(s) THEN
  (6)          continue
  (7)      ELSE
  (8)          insertNextNodetoRoutingTable(s)
  (9)      break
  (10)      END IF
  (11)   END FOR
  (12) sendDataPacket(segment)
```

Algorithm 1: Configuration of competition-based disjointed multipath.

Table 2: The routing table.

PNodeID	*CNodeID*	*NNodeID*
B	*C*	*F*
...	...	...

in Figure 4, *node B* and *node F* are registered in the routing table as the previous node and the next node, respectively, as shown in Table 2.

3.3. Disjointed Multipath Configuration. The sink stores the received split packets in the reception queues divided by paths and combines them into the original data when all packets with the frame have been received as shown in Figure 5. In the case of *frame* $\#n+2$, it waits until *frame* $\#n+2(2)$ has been received.

In general, if a packet has been lost during the transmission process, the infinite waiting occurs in a sink. In the proposed scheme, the sink uses the reception queues and timer in order to prevent infinite waiting. Figure 6 shows a node that receives and combines the split packets using a timer and waiting threshold. The sink sets a *maximum waiting time*, receives the packets during that time, and combines them for building the original data when the packet reception rate is over a threshold. If the *packet reception rate* is not over the threshold, the sink does not carry out the frame combination. In Figure 6, the *frame* $\#n + 1$ could not have received *frame* $\#n + 1(2)$ within the *maximum waiting time*. In this case, it only combines the received packets except for *frame* $\#n + 1(2)$ into the original data. In addition, if *frame* $\#n + 3(4)$ has been lost and could not be received within the waiting threshold as in the case of *frame* $\#n + 3(4)$, it carries out combining the received packets except for the respective packets. Algorithm 2 presents the pseudocode that receives and combines the split packets using the timer.

3.4. Path Evaluation and Reconfiguration. The sink receives the split packets with reception queues and combines the respective packets into original data after the *maximum waiting time*. Figure 7 shows the path evaluation and reconfiguration process of the proposed scheme. As shown in Figure 7, it is possible that a path has more hop-counts (transmission cost) than other paths, or the packets transferred through a specific path cannot be received constantly within the *maximum waiting time* or lost due to problems on the node after path setting. In this case, it is possible to solve the problems by setting a new path rather than using the problematic path.

For that purpose, the proposed scheme carries out path evaluation process by considering the delay time. After the initial paths are set, the sink carries out path evaluation after receiving 3 rounds from the source nodes, that is, packets for 3 frames. If a specific path has longer transmission time than *maximum waiting time* or if packets have been constantly lost, it reconfigures.

For path reconfiguration, the sink sends a *path reset message* to the source node through the path to be reconfigured. The *path reset message* includes the number of hop-counts of the path and the message is transferred to the source node. In this process, information of routing tables for each node

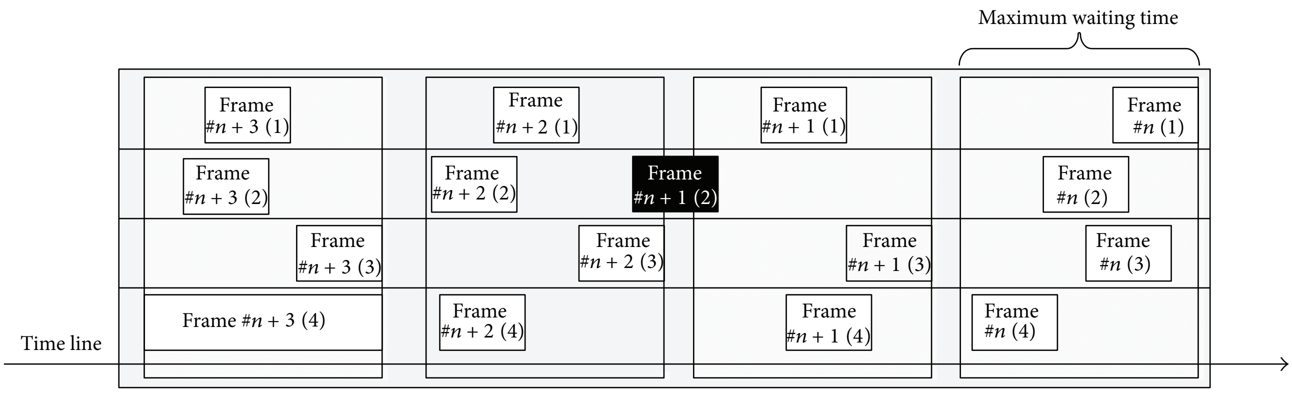

Figure 6: Receiving and combining the split packets using time.

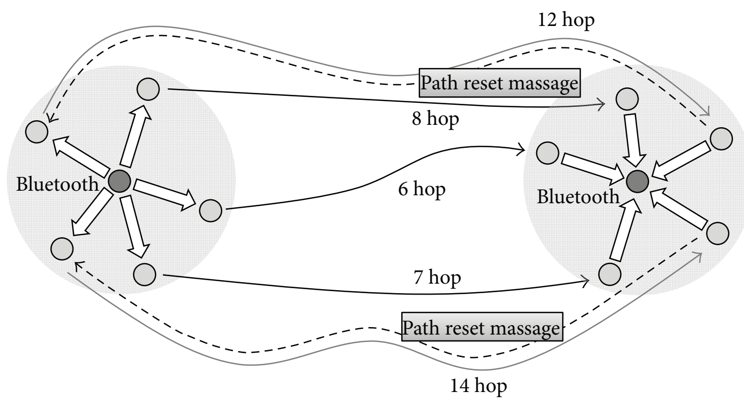

Figure 7: Path evaluation and reconfiguration.

```
Input:
γ = Packet(Segments) Reception Rate
Timer = Maximum Waiting Time
IF Timer == End THEN
    IF count(Received Segments) > γ THEN
FOR EACH s = slot[i] DO
IF s is empty THEN
                s = NULL
      ELSE
            continue
            END IF
    END FOR
          combine(thisFrame)
        ELSE
          eliminate(thisFrame)
        END IF
Timer.restart()
    END IF
```

Algorithm 2: Receiving and combining the split packets.

is deleted. After the source node has received the *path reset message*, it performs the reconfiguration. Different from the initial path configuration process, the path reconfiguration reduces the number of hop-counts per path and allows node overlapping on the path considering equivalent energy consumption.

The path reconfiguration is the same as the initial path configuration process. However, different from the initial path configuration, the node receiving a *probe message* containing information about the path reconfiguration sends the value of its residual energy to the node that sent the probe message. It reduces the hop-counts of the paths and shortens transmission delay time by allowing path overlaps for the node with a lot of the residual energy considering the remaining energy of nodes.

4. Performance Evaluation

We have developed a simulator based on JAVA to evaluate our proposed scheme and the existing schemes [21]. The detailed simulation parameters are shown in Table 3. We assume that 10,000 sensors are deployed uniformly in a 1,000 × 1,000 (m) network field. The energy consumption for sending a message is determined by a constant function $S \cdot (C_t + C_a \cdot D^2)$, where S is the message size, C_t is the transmission cost, C_a is the amplification cost, and D is the distance of message transmission. We set $C_t = 50$ nJ/b and $C_a = 100$ pJ/b/m^2 in the simulation. The energy consumption for receiving

Table 3: Simulation Parameters.

Parameters	Values
Number of distributed sensor nodes (EA)	10000
Size of sensor network fields (m)	1000 × 1000
Multimedia data (p/fps)	720/30
Radius of communication (m)	10
Data rate of bluetooth (Mbps)	24
Number of multiple paths (bytes)	7
Rate of data generation (packets/sec)	600 (CBR)
Size of data (bytes)	316

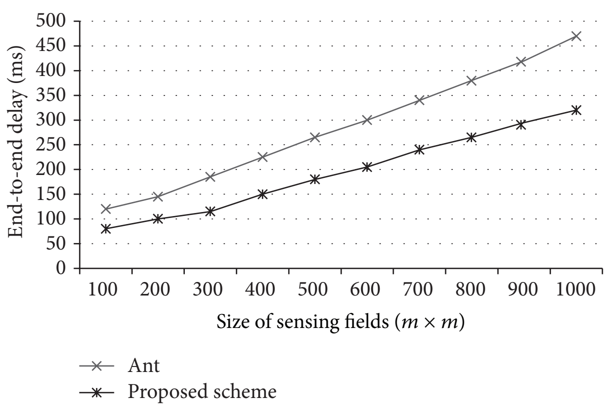

Figure 8: End-to-End delay.

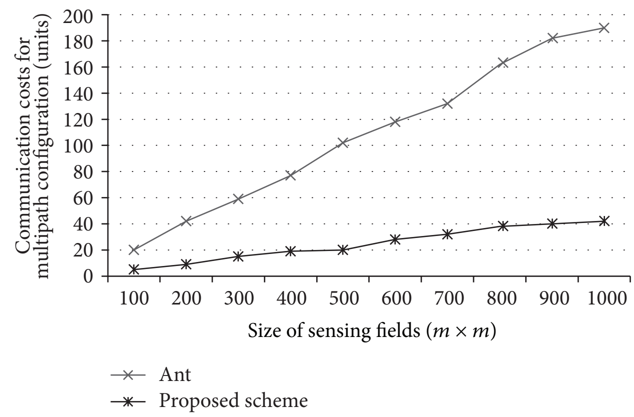

Figure 9: Communication costs for multipath configuration.

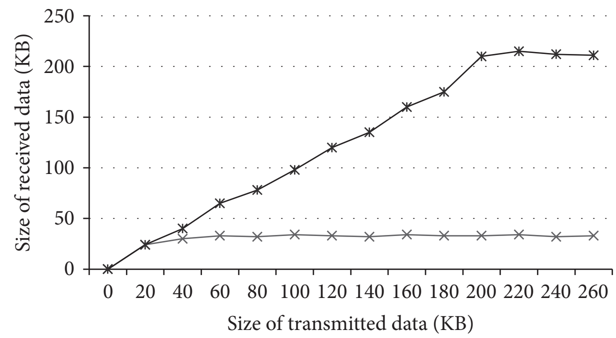

Figure 10: Amount of reception data.

a message is determined by a cost function ($S \cdot C_r$), where S is the message size and C_r is the transmission cost. We set $C_r = 50$ nJ/b in the simulation [10, 11].

Figure 8 shows the end-to-end delay according to the network sizes. End-to-end delay is one of the important QoS parameters that we consider when designing our proposed routing protocol to handle the real-time traffic and deliver the packets. End-to-end delay is the time duration from the time that a source node sends its data packet to the time that the sink receives it. It can be measured as the sum of transmission delay, propagation delay, and queuing delay at each hop. The proposed scheme minimizes the end-to-end delay for a very large scale of multimedia data through data splitting and transmission using Bluetooth at the source nodes and the sink. However, since the existing scheme only uses the Zigbee to transmit the multimedia data, it causes a transmission delay nearby source or sink nodes. As a result, our scheme reduces the end-to-end delay by about 30% over the existing scheme.

Figure 9 shows the communication cost for multipath configuration according to the network sizes. The unit means the number of communications and time to configure the path. The existing scheme requires packets to go and return them several times to establish a path from the source node to the sink. Therefore, the larger the network size, the greater the communication cost required to configure the multipath. However, as the proposed scheme uses the competition-based disjointed multipath configuration, it enables a path to be configured with much less communication than the existing scheme. As a result, our scheme reduces communication costs to set the multipath by about 22% over the existing scheme.

Figure 10 shows the amount of reception data based on the size of the multimedia data. The existing scheme simply distributes transmission packets through the multipath. Since it is based on the Zigbee, most packets suffer from data transmission delay or packet-loss around the nodes near the source nodes or the base station. On the contrary, as the proposed scheme uses a high data rate of Bluetooth on the source nodes or base station, it is possible to utilize the maximum bandwidth of the multipath. As a result, our scheme increases the amount of the received data over the existing scheme by about 690% on average.

5. Conclusion

In this paper, we have analyzed the problems of the existing data transmission schemes for high capacity multimedia data and have proposed a novel disjointed multipath routing scheme for real-time data transmission. The proposed scheme has increased data reception rate for a very large scale of multimedia data through data splitting and transmission using Bluetooth at the source nodes and the base station. Moreover, we have proposed the competition-based disjointed multipath configuration algorithm. The proposed scheme has minimized the path configuration overheads of the existing schemes. It has also enabled fast receipt by ensuring FIFO with separate queues and by removing the sorting process of the received packets. Our scheme reduces the end-to-end delay to transmit the multimedia data and the communication cost to set the multipath and improves the amount of the received data over the existing scheme. In the near future, we will adjust the compression scheme for multimedia data to reduce the amount of transmission data. We will also perform the performance evaluation on the real-world applications.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

This research was supported by the MSIP (Ministry of Science, ICT, and Future Planning), Korea, under the ITRC (Information Technology Research Center) support program (NIPA-2013-H0301-13-4009) supervised by the NIPA (National IT Industry Promotion Agency), the MSIP (Ministry of Science, ICT, and Future Planning), Korea, under the CITRC (Convergence Information Technology Research Center) support program (NIPA-2013-H0401-13-2011) supervised by the NIPA (National IT Industry Promotion Agency) and the Ministry of Education (MOE) and National Research Foundation of Korea (NRF) through the Human Resource Training Project for Regional Innovation (no. 2013H1B8A2032298).

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