Cross-Layer QoS Architecture with Multipath Routing in Wireless Multimedia Sensor Networks

Si-Yeong Bae[1], Sung-Keun Lee[2,†] and Kyoung-Wook Park[3]

[1]*Department of Computer Science, Sunchon National University, Korea*
[2]*Department of Multimedia Engineering, Sunchon National University, Korea*
[3]*Division of Culture Contents, Chonnam National University, Korea*
bsy233@sunchon.ac.kr, sklee@sunchon.ac.kr, zergadiss73@chonnam.ac.kr

Abstract

This paper proposes a multipath routing algorithm using cross-layer architecture in wireless multimedia sensor networks (WMSNs) to provide QoS guaranteed delivery of data. When the algorithm proposed in this study establishes the path from source to destination node, it takes into account a distance to sink node, and energy level and link quality of neighbor nodes. It also specifies a service quality pattern and a service quality level depending on traffic pattern. By doing this, the proposed algorithm can realize a differentiated service with QoS guaranteed data transmission. This algorithm also enables to use multiple paths when delivering data. It helps to alleviate a power consumption concentration that happens at particular set of nodes along the frequently selected route. Concentrated power consumption can cause another problem, that is, route reconfiguration due to routing failure. The proposed algorithm effectively avoids the problem. As a result, the proposed algorithm can improve reliability of sensor network by increasing packet transmission rate and reducing packet loss rate and delay.

Keywords: *QoS, WMSN, Link Quality, Energy Efficiency, Multi-path routing*

1. Introduction

Recently, multimedia data collectable modules such as ultra-small CMOS camera sensor and microphone are widely developed and used. Owing to those technologies, traditional wireless sensor network has been rapidly replaced with wireless multimedia sensor networks (WMSNs) technology [1].

This new technology requires both high computing capability and huge amount of data transmission because it is used for sensing and transferring multimedia data with huge amount. It means that traditional wireless sensor network is not suitable for dealing with multimedia data due to energy constraints of network [2].

Aside from the issues like energy saving and maximizing network lifetime, WMSN has another issue to deal with: support of quality of service (QoS). QoS is required especially for handling real-time data such as object tracking and data gathering. To support real-time data service or reliable data transmission service, there are several problems to solve. The first problem comes from the nature of wireless channel that is unreliable and unpredictable. The second one comes from the fact that nodes are operated using only limited power and they are tricky to recharge. Finally, network topology is frequently changed during operation. Due to those problems, conventional wireless network protocols such as IEEE 802.11 are not suitable

† Corresponding Author

for WMSN even though they are capable of supporting QoS. In wireless sensor network area, QoS supporting issue and energy saving issue have been dealing with separately [1, 3].

This paper proposes multipath routing algorithm using cross-layer to ensure QoS guaranteed data delivery in wireless multimedia sensor network. The proposed algorithm supports a differentiated QoS service by specifying service quality pattern and level according to traffic pattern. Additionally, multipath with high quality links allows the data to be transmitted through various paths. Hence it helps to reduce a power consumption concentration that happens in particular set of nodes along the frequently selected route. Concentrated power consumption can cause power failure along the route. So route reconfiguration can frequently take place. The proposed algorithm helps to avoid route reconfiguration as well. As a result, the proposed mechanism contributes to improving reliability of sensor network by increasing packet transmission rate and reducing packet loss and delay.

This paper is organized as follows. Section 2 reviews related works. Section 3 describes the proposed cross-layer QoS Architecture with multipath routing. Section 4 presents verification and analysis of the proposed routing algorithm. Finally, Section 5 draws on conclusion.

2. Related Work

Cross layer protocol is an optimized and jointly designed network architecture with single stack replacing traditional layered protocol architecture based on OSI 7 layers. Recent works to adopt the cross-layer protocol to wireless network have been conducted with focus on MAC and PHY, MAC and routing, Transport and PHY, and 3-Layer coalescing. The hottest one among them is the work on one-stack protocol combining MAC layer and routing protocol together in order to solve compatibility problem existing between Zigbee Alliance and IEEE802.15.4 [4].

There are routing algorithms using LQI when selecting path, such as on-demand MinLQI and table-driven MultiHopLQI. MinLQI utilizes minimum LQI value from all the links as a metric value for estimating paths. When establishing a path, it selects the path with maximum metric value. In contrast, MultiHopLQI computes a metric value by summing up all the LQI values of all links from sink node to itself.

These routing techniques can improve reliability of data transmission by choosing high-quality link using LQI value. On the other hand, it tends to increase the number of links along the path if there are many links with high quality. Energy consumption also can increase. Furthermore, it does not consider power remainder when selecting nodes. Hence it is unavoidable to include nodes along the path even though their power remains very low. It results to shorten the network lifetime [5, 6, 7].

3. Cross-Layer QoS Architecture with Multipath Routing

3.1. Framework Design for guaranteeing QoS

3.1.1. Cross-Layer Architecture

This paper proposes to adopt cross-layer architecture in order to maximize data gathering, minimize delay and achieve energy efficiency for entire network. In proposed architecture, important information from each layer is stored in shared database. Through the shared database, other layer can access information when necessary. The shared database plays an important role of efficient interaction of cross-layer and reducing unnecessary communication overhead that might occur while getting network status information such as QoS requirement, physical channel condition and MAC layer feedback.

3.1.2. Traffic Classification and Control Functionality

This paper determines packet's characteristic depending on a type of application that the packet belongs to, as shown in Figure 1 Packet's priority is determined in two ways: by the application originating the packet or by predefined field in the packet. For example, if the packet comes from real-time data service, the packet has high priority, or if the packet is marked as high priority in the field, the packet has high priority. According to the packet's priority, the packet gets transmitted faster or slower.

Packet's priority is marked at source node by setting service quality pattern and service quality level depending on traffic pattern and data contents. Packet marking algorithm is used for doing this [8]. Service quality pattern is classified as four categories; energy efficiency, delay sensitive type, reliability, and transmission rate. Incorporating with this, service quality level is classified as three levels; green, yellow, and red. Once the service quality level is decided, it is marked in priority field inside packet prior to being transmitted to sink node. In terms of type of levels, green indicates the most significant level, while red indicates the least significant level. Additionally, priority field is used for storing the packet's priority level. For differentiated service, green packet should be guaranteed to transmit first. Red packet is the least important packet, therefore its loss is acceptable because data can be recovered at sink node by combining existing packets. Importance level of yellow packet lies in between that of green and red.

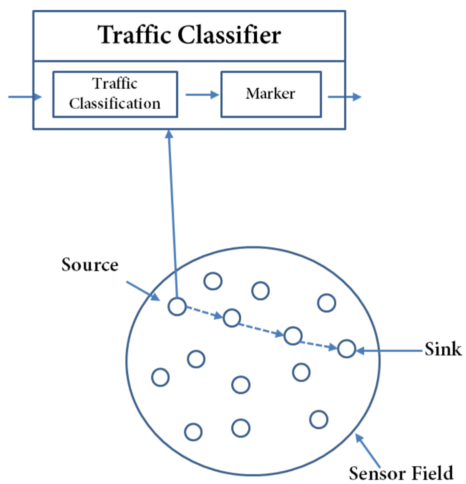

Figure 1. Traffic control of sensor node

3.1.3. Multipath Routing

Source node establishes a path depending on priority field value marked in packet. Traditional protocol tends to select the shortest path when transmitting data. In other words, some nodes along the shortest path are frequently used to send data. Therefore, it shows poor energy efficiency since the nodes excluding the shortest path mostly stay in idle state. Moreover, network lifetime becomes short, which could lead to node failure due to power shortage. Consequently, network path is blocked and reliability is also damaged. The proposed multipath algorithm distributes network traffic into different paths by classifying packets into green, red and yellow packet. Green packet takes the shortest path to aim for high quality transmission, while red packet takes an alternative path considering energy level. Yellow packet, at the middle of green and red, determines the path considering middle level of distance and quality.

3.2. Proposal of multipath routing algorithm

Network condition changes very frequently in WSNs. For this reason, all the mobile nodes residing in network pass their routing information to other mobile nodes periodically. When the routing path is changed, its own routing information is also passed to other nodes. In order to maintain routing information for mobile devices, traditional routing mechanisms generate and send much amount of overhead traffic. It is main cause to degrade energy efficiency and shorten network lifetime. Routing table maintained by sensor node does not have to contain information about all the nodes in network. Only information about paths towards sink node is sufficient to operate the network properly. In addition to this, if information about adjacent neighbor sensor node is included, more various functionalities are possible to implement. The proposed routing mechanism adopts energy efficient routing table developing technique, where key means is broadcast messages sent by sink node periodically [9]. Table 1 illustrates the detailed fields of broadcasting message for routing

Table 1. Fields of broadcasting message for routing

Field	Signification
ID	Broadcasting message Identifier
Flag	To classify broadcasting message into three : first routing construct message, routing table update message and normal broadcasting message
Node Identifier	Sender identifier
Location Information	Sender location information
Hops to Sink	Hop count from current node to sink node
Energy level	Residuary energy level of sender
Path Costs	Path Costs by packet priority

Routing table suggested by this paper consists of following fields. Priority consists of three levels; level one for green packet, level two for yellow packet, and level three for red packet. Next node indicates a node that is supposed to receive sensing data. Hop count denotes the number of hops from sink node. Remaining energy level indicates energy remainder of the node that is supposed to receive sensing data. Location information is the location of the node that is supposed to receive sensing data. Path cost means the cost involving a path heading to sink node for each packet priority.

The path with k nodes consists of a set of nodes to deliver data from source node *x* to sink node *y*. Since assuming that network is densely deployed, it can also be assumed that multiple paths exist between *x* and *y*. When a node a selects next node b in order to send packet with priority, *pri* towards sink node, cost for the path, C_a^{pri} is defined as (equation 1).

$$C_a^{pri} = \min_{b \in N_a} \left\{ \alpha_{pri} \left(\frac{d_{by} + 1}{d_{ay} + 1} - 0.5 \right) \times \beta_{pri} \left(1 - \frac{LQI_b}{256} \right) \times \gamma_{pri} \left(1 - \frac{e_b^{res}}{e_b^{init}} \right) + C_b^{pri} \right\} \quad (1)$$

where pri denotes priority mark, $pri \in$ {Green, Yellow, Red}, N_a is a set of neighbor nodes of node a. d_{ay} denotes hop distance from node a to sink node y. d_{by} denotes hop distance between node b and sink node y. e_b^{init} is an initial energy level of node b, and e_b^{res} is remaining energy level of node b. LQI_b is link quality value for node b, ranging from 0 to 255. $\left(\frac{d_{by}+1}{d_{ay}+1} - 0.5\right)$, $\left(1 - \frac{LQI_b}{256}\right)$ and $\left(1 - \frac{e_b^{res}}{e_b^{init}}\right)$denote hop distance, link quality and cost depending of energy remainder respectively, ranging from 0 to 1.

α_{pri}, $\beta_{pri}$and γ_{pri} are weighted value differently set depending on packet's priority. Since green packet has highest priority, hop counts and link quality should be considered rather than energy level when setting the weighted values. If the nodes have the same hop counts, link quality needs to be considered subsequently. Therefore, α_{Green} and β_{Green} is supposed to set to low value, whereas $\gamma_{Green}$is set to high value. Yellow packet has middle level of priority. Therefore, hop count, link quality and energy level should be considered in balanced manner. Finally, red packet has the lowest priority, hence energy level needs to be considered first rather than hop count and link quality. In order to minimize energy consumption, γ_{Red} is set to low weighted value, whereas α_{Red} and β_{Red} are set to be high.

4. Verification and Analysis

Figure 2 presents a sensor network configuration for validation and analysis of our QoS architecture. Configured sensor network has 25 nodes that are formed 5x5 grid construction. Node n(x,y) has only four direct dissemination: n(x±1,y) and n(x,y±1). Sink transmits the broadcast packet for the routing table update. We consider that e_init= 1, 0<e_res<1 and LQI values of links are between 60 and 110.

Figure 3 shows routing table of nodes that is n(0,4), n(3,4), n(4,3). Node n(0,4) updates routing table when 'receive waiting timer' is done because n(0,4) has only 2 neighbor nodes. The priority of routing table is determined based on the priority field of packet. To choose a next node, minimum path cost for each neighbor node needs to be computed. Based on the results, one neighbor node is selected with having minimum path cost for each priority. As a result of verification, green packets were reliably transmitted showing lower packet loss rate and lower delay, since they were transmitted through high-quality link with the shortest path.

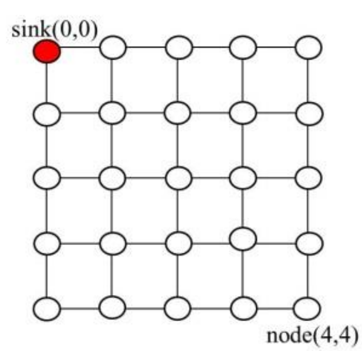

Figure 2. Configuration of nodes

Regarding red packets, it was observed that the number of lost packets were less than that in conventional algorithm. It is mainly because the proposed algorithm considers energy remainder when selecting path in case of red packet transmission.

Therefore, the proposed algorithm is also efficient in respective of reliability even in case of red packet. In transmitting yellow packets, overall transmission rate improved because yellow packet could use substantial resources by taking an alternative path. The results indicate that the multipath routing algorithm proposed in this paper could provide QoS guaranteed packet delivery and support energy efficient routing service since it selects a neighbor node with use of minimum path cost for each packet priority.

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============================================================
                    Path Node pos[4][3]
------------------------------------------------------------
    Hop to Sink : 7
    Next node(Path Cost)of  Green Packet : [3][3] (0.825)
                           Yellow Packet : [3][3] (1.096)
                              Red Packet : [4][4] (1.381)
------------------------------------------------------------
    Next Node(pos infor) : [3][3]
    Hops To Sink : 6
    Path Cost of Green Packet : 0.655
                Yellow Packet : 0.809
                   Red Packet : 1.042
    Energy Level : 0.65
    LQI: 90
------------------------------------------------------------
    Next Node(pos infor) : [4][2]
    Hops To Sink : 6
    Path Cost of Green Packet : 0.672
                Yellow Packet : 0.843
                   Red Packet : 1.084
    Energy Level : 0.70
    LQI: 80
------------------------------------------------------------
    Next Node(pos infor) : [4][4]
    Hops To Sink : 8
    Path Cost of Green Packet : 0.896
                Yellow Packet : 1.142
                   Red Packet : 1.247
    Energy Level : 0.92
    LQI: 85
============================================================
============================================================
                    Path Node pos[3][4]
------------------------------------------------------------
    Hop to Sink : 7
    Next node(Path Cost)of  Green Packet : [2][4] (0.798)
                           Yellow Packet : [3][3] (1.114)
                              Red Packet : [4][4] (1.385)
------------------------------------------------------------
    Next Node(pos infor) : [2][4]
    Hops To Sink : 6
    Path Cost of Green Packet : 0.625
                Yellow Packet : 0.844
                   Red Packet : 1.044
    Energy Level : 0.60
    LQI: 108
------------------------------------------------------------
    Next Node(pos infor) : [3][3]
    Hops To Sink : 6
    Path Cost of Green Packet : 0.655
                Yellow Packet : 0.809
                   Red Packet : 1.042
    Energy Level : 0.65
    LQI: 80
------------------------------------------------------------
    Next Node(pos infor) : [4][4]
    Hops To Sink : 8
    Path Cost of Green Packet : 0.896
                Yellow Packet : 1.142
                   Red Packet : 1.247
    Energy Level : 0.92
    LQI: 80
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============================================================
                    Path Node pos[0][4]
------------------------------------------------------------

    Hop to Sink : 4
    Next node(Path Cost)of  Green Packet : [0][3] (0.507)
                           Yellow Packet : [0][3] (0.796)
                              Red Packet : [1][4] (0.983)
------------------------------------------------------------

    Next Node(pos infor) : [0][3]
    Hops To Sink : 3
    Path Cost of Green Packet : 0.327
                Yellow Packet : 0.492
                   Red Packet : 0.624
    Energy Level : 0.55
    LQI: 85
------------------------------------------------------------

    Next Node(pos infor) : [1][4]
    Hops To Sink : 5
    Path Cost of Green Packet : 0.502
                Yellow Packet : 0.702
                   Red Packet : 0.812
    Energy Level : 0.90
    LQI: 100
============================================================
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Figure 3. Routing table

5. Conclusion

This paper aims to design enhanced multipath routing algorithm to provide differentiated service with guarantee of QoS. To realize differentiated service, the proposed algorithm considers data priority that is determined based on application classification for the packet. In addition to this, the proposed mechanism adopts shared database, which is useful for efficient interaction for cross-layer and avoiding unnecessary communication overhead that might take place when getting network information such as QoS requirement, physical channel condition and MAC layer feedback. Source node establishes multiple paths using LQI value that indicates hop count to sink node, energy level about neighbor node and link quality. By establishing multipath with high-quality link, energy consumption can be distributed into nodes around the network. It also helps to avoid occurrence of path reconfiguration while routing. As a result, the proposed algorithm contributes to high packet transmission rate, low packet loss and low delay. Therefore this mechanism can improve reliability of sensor network.

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Authors

Si-Yeong Bae

Si-Yeong Bae received the B.S. degree in information and communication from Seoil University, Seoul, Korea, in 2006, the M.S. degree in computer education from Hankuk University of Foreign Studies, Seoul, Korea, in 2008, and the Ph.D. student in computer science at the Sunchon National University, Suncheon, Korea, since 2009. Her current research interests include wireless sensor network, Database, routing protocol, combinatorial optimization.

Sung-Keun Lee (Corresponding Author)

Sung-Keun Lee received the B.S., M.S., and Ph. D. degrees in electronics engineering from Korea University, Seoul, Korea, in 1985, 1987, and 1995, respectively. From 1987 to 1992, he was with Samsung electronics Co., Ltd, Korea. He joined the department of Multimedia Engineering, Sunchon National University, Suncheon, Korea, in 1997, where he is currently a Professor. His research interests include energy efficient Ethernet, wireless sensor network, multimedia communication and Internet QoS.

Kyoung-Wook Park

Kyoung-Wook Park received the B.S. degree from Sunchon National University, Suncheon, Korea, in 1997, his M.S degree from department of computer science and statistics, Chonnam National University, Gwangju, Korea, in 1999, his Ph.D. degree from department of computer science, Chonnam National University, Gwangju, Korea, in 2004. His current research interests are parallel and distribution processing, graph theory, theory of computation, bioinformatics and Augmented Reality.

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