International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 8 (September 2014) www.ijirae.com

6 LoWPAN: Efficient Routing Discovery Process for Wireless Sensor Networks (WSNs)

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Abstract— This paper introduces efficient routing discovery process based on 6LoWPAN for wireless sensor networks. This approach is performed in the link layer in order to route the data frame through intermediate sensor nodes without processing the headers in the upper layers. As a result, the routing cost is reduced and the routing efficiency is improved. Further, in the approach, a source node creates multiple separate routing paths using routing discovery process. When one routing path fails, another routing path is randomly selected to work without routing discovery process. This approach also uses the routing path repair algorithm that helps the intermediate node to determine, if the next hop is inaccessible, then it repairs the corresponding routing path to guarantee that the data are correctly routed to the destination node. The performance parameters of the proposed scheme are analysed. The simulation results demonstrate that this approach can decrease the routing cost and curtail the routing delay efficiently.

Keywords— 6LoWPAN wireless sensor networks, link layer, multi-path, routing, sensor node.

I. INTRODUCTION

Wireless Sensor networks are considered as one of the hot research areas in current years [1], [2]. WSNs comprise of a large number of sensor nodes with limited energy constraints that collect the data from interested domain and process to specific domains [3]. With the widespread wireless sensor network applications and the rapid development of the next-generation Internet, 6LoWPAN has become an expected trend in the future [4]. Now-a-days, the only basic framework for 6LoWPAN is defined in [5], [6] but the routing protocols for 6LoWPAN still need to address for further research [7], [8].

The single-path routing scheme for 6LoWPAN1 based on ad hoc on-demand Distance Vector Routing (AODV) is proposed in [9]. In this approach, the cumulative routing costs are adopted as the weights of establishing the best routing path. Moreover, the routing discovery is performed by broadcasting Route Request (RREQ) packets. Thus, a lot of network resources are consumed. The routing scheme based on location information is introduced in [10]. The network is divided into multiple grids based on location coordinates. Each node's address includes its location coordinate. When one node wants to communicate with another node, it launches the routing establishment process according to the location coordinate of the destination node. The solution for integrating networks and fixed IP networks is introduced in [11]. The solution handles the mobility of vehicles based on street layout as well as the distance between vehicles and fixed base stations.

The routing scheme based on clusters is proposed that adopts the hierarchical address structure to achieve the hierarchical routing [12]. The routing establishment and implementation are discussed in detail. However, this scheme does not obtain the routing repair.

The multi-path routing scheme for 6LoWPAN is discussed in [13] that helps the source node to establish the multiple routing paths reaching to the destination node and then ranks the multiple routing paths according to the link cost. The routing path with the minimum link cost is considered as the primary path. If the primary path fails, then the source node chooses another optimal routing path as the primary path to continue routing the data. The 6LoWPAN routing scheme is proposed based on the multi-way tree. In the scheme, maximum number of the child nodes are defined [14]. When the number of child nodes in the multi-way tree is saturated, some nodes are unable to join the multi-way tree due to the lack of the address resources. The source node establishes the routing path reaching the destination node through building the multi-way tree but the scheme is unable to perform the routing path repair.

In addition, maintaining the multi-way tree topology consumes a lot of network resources. Therefore, this paper introduces the multiple-path routing approach for 6LoWPAN WSN, and involves the following contributions.

a. The routing scheme is performed in the link layer to improve the intermediate.
b. The source node maintain the multiple separate routing paths during one routing discovery process. When one routing path fails, another routing path is randomly selected to work without routing discovery process.
c. The routing path repair algorithm is used to help the intermediate node to detect the next hop node whether it is reachable or unreachable, then it repairs the corresponding routing path to ensure that the data are the correctly routed to the destination node. The rest of the paper is organized as follows: In Section II, we present proposed

[1] 6LoWPAN: Acronym of IPv6 over Low power Wireless Personal Area Networks and it is originated from the idea that the smallest devices with low-power and limited processing abilities should contribute in the Internet of things.

architecture of 6LoWPAN WSNs. In section III, we discuss the simulation setup and performance analysis and section IV, concludes the paper.

II. PROPOSED ARCHITECTURE OF 6LOWPAN WSNS

The link protocol of 6LoWPAN WSN adopts IEEE 802.15.4 [15] that divides nodes into full-function nodes with routing function and reduced-function nodes without routing function. In order to achieve the full integration of 6LoWPAN WSN and the IPv6 Internet, this approach divides 6LoWPAN WSN into multiple clusters. Each cluster contains a cluster head that is a full-function sensor node and multiple cluster members which are reduced-function sensor nodes.

Therefore, 6LoWPAN WSN includes three types of nodes: an access node, a cluster head and a non-cluster head nodes. An access node is a cluster head, which connects 6LoWPAN WSN to the IPv6 Internet, as depicted in Figure 1. In this architecture, an access node or a cluster head is used to forward data and is equal to a router in the IPv6 Internet, and a cluster member is used to collect data for monitoring and is equal to a host in the IPv6 Internet. An access node, a cluster head and non-cluster head nodes are all stationary nodes.

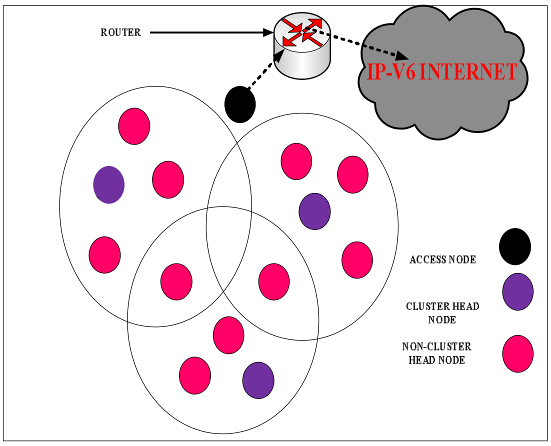

Figure 1: Proposed working protocol for 6 LoWPAN WSNs

A. Proposed structure for IPv6 address

According to the features of 6LoWPAN WSN, the hierarchical IPv6 address structure for 6LoWPAN WSN is proposed and given in Table-I.

TABLE-I: IPv6 address structure for 6LOWPAN WSN

Global Routing Prefix (Bits)	Sensor node ID	
	Cluster head ID (Bits)	Non-Cluster head ID (Bits)
112	8	8

In Table-I, an IPv6 address includes two parts. The first part is global routing prefix, and the global routing prefixes of all nodes in one 6LoWPAN WSN. The second part is sensor node ID which is made up of cluster head ID and non-cluster head node ID. Cluster head ID uniquely identifies a cluster in one 6LoWPAN WSN, and a cluster head's cluster head ID is its initial ID that is unique in 6LoWPAN WSN. The cluster head IDs of all cluster members in one cluster are the same, and the value is equivalent to the cluster head ID of the cluster head in the same cluster. Cluster member ID uniquely identifies a cluster member in one cluster, and a cluster member's cluster member ID is its initial ID that is unique in 6LoWPAN WSN.

In this approach, the cluster member ID of an access node or a cluster head is 0. The use of Sensor node ID as link address involves the gains for example in one cluster, the cluster head IDs of all cluster members are the same, so a cluster member's link address can show its cluster head's link address. Based on this hierarchical address structure, the routing algorithm can be achieved. That is, multiple separate routing paths from the source cluster head to the destination cluster head can be established. Further, the cluster member ID of a cluster head is zero, so the valid length of a cluster head's link address is compressed. As a result, the routing cost and delay are reduced.

B. The cluster generation

After a full-function sensor node starts, it marks itself as a cluster head, sets the initial ID as its cluster head ID, and periodically broadcasts a beacon frame to show its existence [12]. If a reduced-function node ‘A’ receives a beacon frame from a cluster head node ‘J’, then it checks whether it is marked as non-cluster head node. If ‘A’ is non-cluster head node, then it discards the beacon frame. Otherwise, ‘A’ marks itself as a non-cluster head node, and combines J’s cluster head node ID with its initial ID to produce its sensor node ID. In Table-II, we give the routing and temporary routing entry.

TABLE-II: Showing Routing and temporary routing entry

Routing entry	**Number of Bits**	**Temporary routing entry**	**Number of Bits**
Destination link address	8 Bits	Destination link address	8 Bits
Next-hop link address	8 Bits	Source link address	8 Bits
Routing cost	8 Bits	Previous hop link address	8 Bits
Lifetime	8 Bits	Routing cost address	8 Bits

C. Routing discovery frame

This approach develops two types of IEEE802.15.4 command frames, including routing query frame and routing response frame that are given in Table-III and IV. In Table-III, the frame control indicates that this frame is a control frame and the sequence number identifies the control frame. The destination address is the broadcasting address 0xffff, and the source address is the sensor node ID of the cluster head forwarding this frame. The command frame identifier is 0x0a that indicates that this frame is a routing query frame. The final address is the cluster head ID of the destination cluster head, and the originator address is the cluster head ID of the source cluster head. The source cost is the hops from the source cluster head to the cluster head forwarding this frame.

TABLE-III: Routing Query Frame

Frame size	**Sequence**	**Destination**	**Source**	**Command**	**Final**	**Originator**	**Source**	**Frame**
16 Bits	8 Bits	16 Bits	16 Bits	8 Bits	8 Bits	8 Bits	8 Bits	16 Bits

TABLE-IV: Routing Response Frame

MAC Header				**MAC payload**				**MAC footer**
Frame control	**Sequence number**	**Destination address**	**Source address**	**Command Frame identifier**	**Final address**	**Originato r address**	**Destination address**	**Frame check sequenc e**
16 Bits	8 Bits	16 Bits	16 Bits	8 Bits	8 Bits	8 Bits	8 Bits	16 Bits

D. Routing formation

If a source non-cluster head node ‘A’ communicates with the destination non-cluster head node ‘B’ whose cluster head is ‘K’, then ‘A’ first sends the data frames to its cluster head node ‘J’. If the routing entry of ‘J’ is reaching to ‘K’, then ‘J’ sends the data frames to the next hop. Otherwise, ‘J’ formulate the routing path reaching to ‘K’ based on the following process:

i. Final address is K’s cluster head node ID, the originator address is J’s cluster head ID, and the source cost is 0.
ii. If ‘K’ receives the routing query frame, then it goes to step vi. Otherwise, it goes to step iii.
iii. If the intermediate cluster head node receiving this frame has a routing entry reaching to ‘K’, then it returns to ‘J’ a routing response frame where the destination link address is the source link address in the routing query frame and the cost is the routing cost in the corresponding routing entry, and goes to step vii. Otherwise, it goes to step iv.

iv. The intermediate cluster head node increases the cost in the routing query frame + 1. If the intermediate cluster head node has not a routing entry where the source link address is 'J' and the destination link address is' K' in the temporary routing table, then it adds into its temporary routing table a new routing entry where the previous-hop link address is the source link address and the routing cost is the cost in the routing query frame, and then broadcasts the routing query frame and goes to step ii. Otherwise, it goes to step v.

v. If the source cost in the routing query frame is less than the routing cost in the routing entry, then the intermediate cluster head node updates the routing cost in the temporary routing entry with the cost in the routing query frame, the previous-hop link address with the source link address in the routing query frame, broadcasts the routing query frame and goes to step ii.

vi. 'K' returns a routing response frame the nodes that forward the routing query frames. In a routing response frame, the destination cost is 0, the final address is the final address in the corresponding routing query frame and the originator address is the originator address in the corresponding routing query frame.

vii. The intermediate cluster head receiving the response frame increases the cost in the routing response frame + 1, and adds into its routing table a routing entry where the destination link address is the final address, the next-hop link address is the source link address, and the routing cost is the destination cost in the routing response frame. If the intermediate cluster head node is 'J', then it goes to step viii. Otherwise, the intermediate cluster head updates the destination address in the routing response frame with the previous-hop link address in the corresponding routing entry, forwards the response frame and deletes the corresponding entry from its temporary table, and goes to step vii.

viii. The multiple separate routing paths from 'J' to 'K' are established successfully, as shown in Figure 2. After multiple separate routing paths from the source cluster head to the destination cluster head are established, the source cluster head randomly selects one routing path from multiple routing paths to perform the communication with the destination cluster head. Therefore, the load balance is achieved.

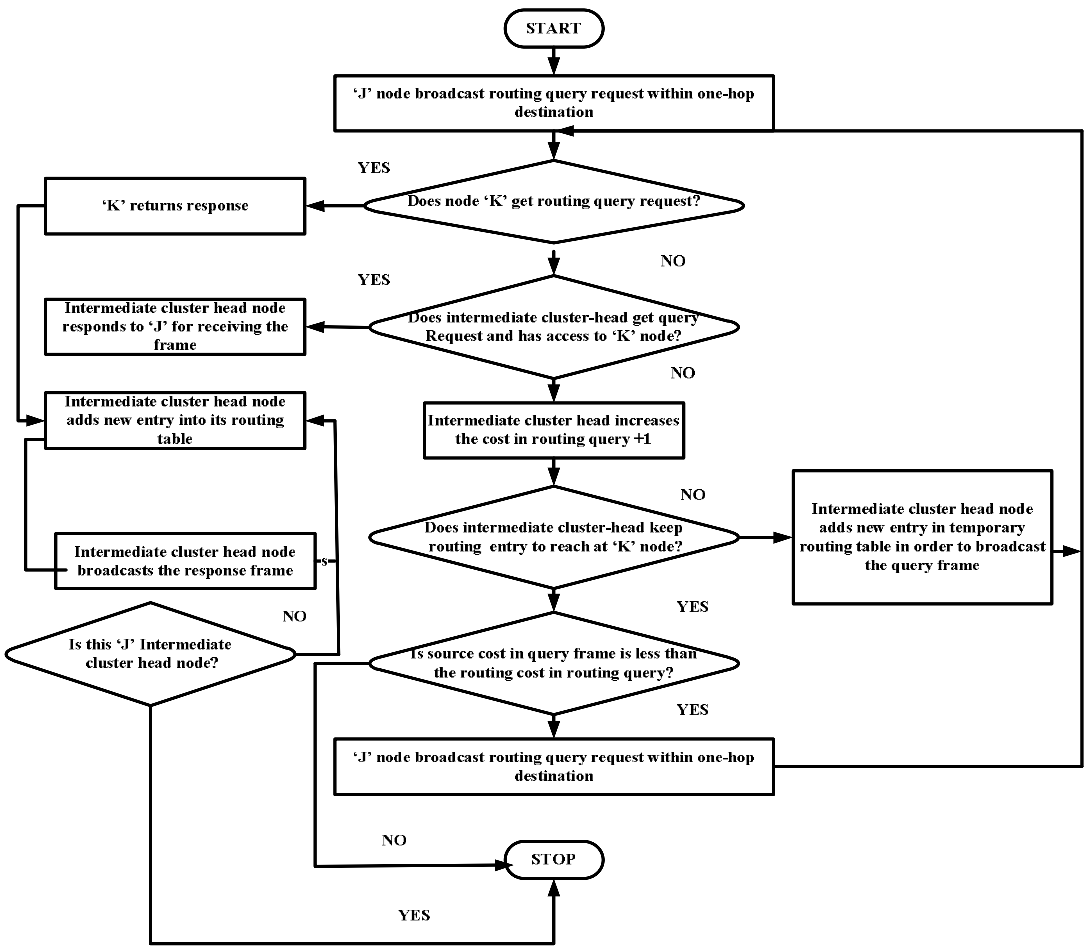

Figure 2: Showing complete multi-hop routing formation process for 6 LoWPAN Wireless Sensor Networks

E. Routing path repair

An intermediate cluster head node ‘A’ receives a data frame destined for a non-cluster head node ‘N’ whose cluster head node is ‘J’. If ‘A’ detects that the next hop reaching ‘J’ is unreachable, then it randomly selects another routing path reaching ‘J’. If all the routing paths reaching .J’ fail, then it establishes a routing path reaching ‘J’ according to the algorithm.

III. Simulation Setup and Performance Analysis

We have simulated our proposed approach using NS-2 and compared with MLOAD [10], and the performance parameters include the average routing discovery cost, the average routing discovery delay, the average routing cost and the average routing delay. Among them, the average routing discovery cost is measured by the average cost consumed by establishing multiple routing paths from the source node to the destination node, the average routing discovery delay is measured by the average time taken by establishing multiple routing paths from the source node to the destination node, the average routing cost is measured by the cost consumed by routing the packets from the source node to the destination node, and the average routing delay is measured by the time taken by routing the packets from the source node to the destination node. The simulation parameters are shown in Table-V.

TABLE-V: Simulation Parameters

Parameters	Values
Communication range of a sensor node	50 m
Sensing range	30 m
Application used	CBR
MAC	IEEE 802.15.4
Packet Transmission frequency	2 packet/S
Packet size	128 bytes
Simulation Time	20 minutes
Total number of sensor nodes	360
Simulative area	250 m x 250 m

When the ratio of the full-function sensor nodes to the reduced-function sensor nodes is 1/4, the simulation results of the average routing discovery cost and the average routing discovery delay are given in Figure 3 and 4.

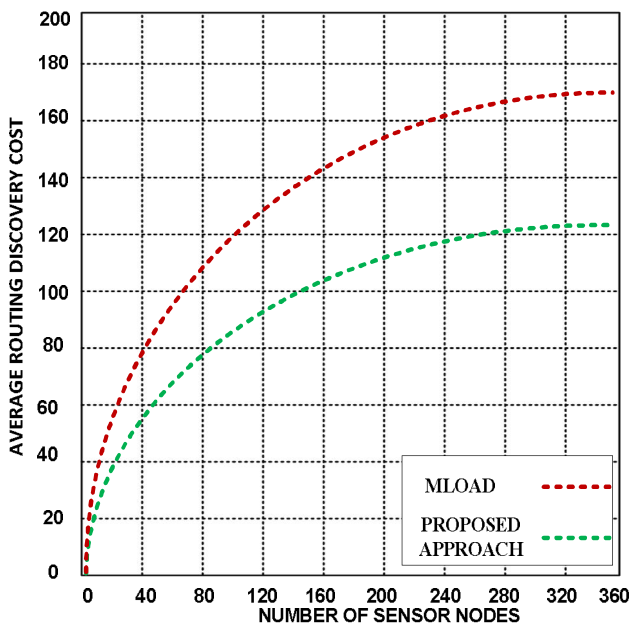

Figure 3: Average routing discovery cost

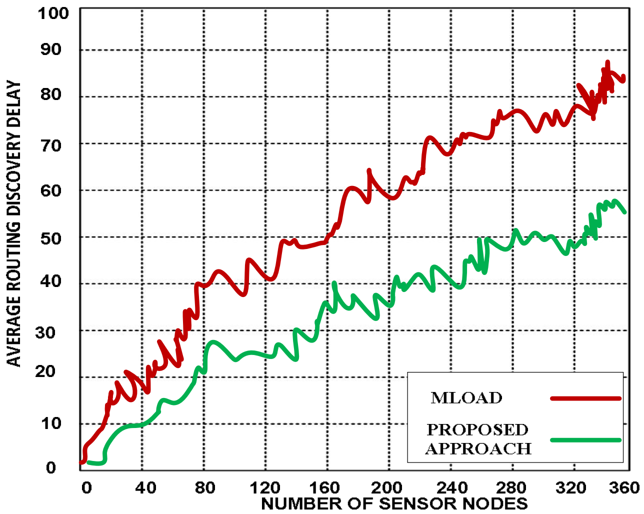

Figure 4: Average routing discovery delay

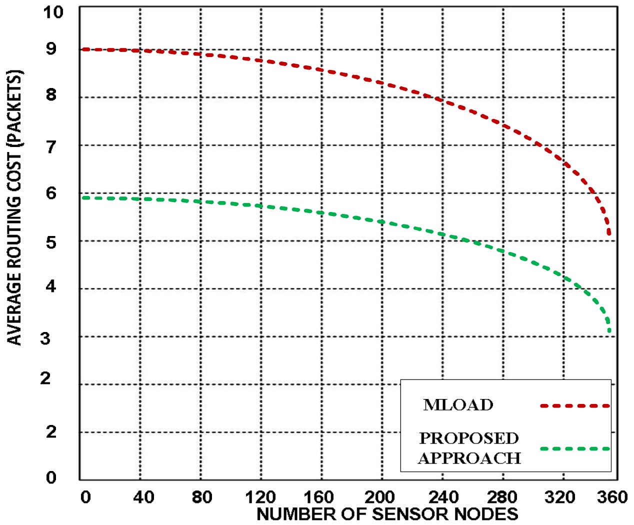

Figure 5: Average routing cost

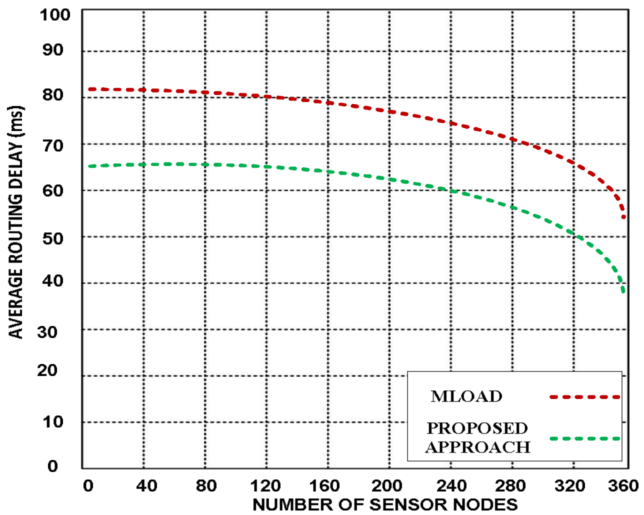

Figure 6: Average routing delay

It is observed from Figure 3, 4, 5 and 6 that the proposed scheme performs better than MLOAD, and the reasons are analysed as follows:

i- The proposed routing scheme is performed in the link layer, and the intermediate nodes can attain the routing functions by only dealing with the frame header in the link layer2, when the routing path from the source node to the destination node fails, MLOAD reselects a routing path to resend the data without performing the routing repair, and the proposed scheme repair the routing path from the upstream node of the failed node to the destination node and then resends the data through the repaired routing path. Therefore, the performance of the proposed scheme is better.

ii- In MLOAD, the source node always selects the primary routing path to route the data while in the proposed scheme the source node randomly selects one routing path from multiple routing paths to route data frames. Therefore the proposed scheme attains the loading balance and shortens the routing delay.

iii- In MLOAD, if the common nodes shared by multiple routing paths fail, then these routing paths all fail simultaneously. In this situation, the source node has to launch the routing discovery process to reestablish the routing paths. In the proposed scheme, multiple routing paths from the source node to the destination node are separated, and there is not a shared common node in multiple routing paths. Therefore, when a routing path fails, other routing paths can still work normally. As a result, the routing robustness is increased.

IV. CONCLUSION

This paper introduces the multi-path routing scheme for 6LoWPAN WSN. The proposed routing approach is performed in the link layer, so during the routing process the intermediate nodes attain the routing function without processing the upper headers. In this scheme, the source sensor node creates the multiple disjoint routing paths reaching the destination node through one routing discovery process, so the failure of one path does not impact on the normal work of other paths. To demonstrate the soundness of the proposed approach, we reported some interesting results by using ns2.35-RC7. Based on the simulation results, we validate that the proposed routing scheme can reduce the routing cost and shorten the routing delay effectively.

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