

Interactive-path routing in wireless sensor networks

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Abstract— Beside the common applications in wireless sensor networks (WSNs) such as data-collection which sensing data are carried from sensors to the sink, sometimes a sensor needs to communicate with other sensor or an actuator or between two actuators. Although those communications are not frequently established, those require high reliable transmission. Besides, the nature of resource constraints in WSNs leads to frequently changing topology due to loss link. However, there is no proposal of point-to-point communication applied in WSNs which concerns both reliability, delay issue and resource constraints. Additionally, Reactive Discovery of Point-to-Point in Low Power and Lossy Networks (p2p-rpl) has been proposing to become the standard protocol for routing between two nodes in WSNs. In order to address the above problem and utilize the p2p-rpl protocol, this paper proposes a mechanism to enhance the reliability and minimize the delay is suggested by utilizing interactive-path based on the p2p-rpl routing protocol. And by analyzing, we prove the efficiency of our proposal.

Keywords-interactive-path, routing, wsn

I. INTRODUCTION

Reliable routing is the general name for those mechanisms in which data is transmitted from a node to other node with highly successful delivering ratio. Normally, a reliable routing includes two processes. First, paths from the source to the destination are established. Then, data packet is forwarded to the destination based on those paths. However, nodes in WSNs have resource constrained in terms of energy and memory [1]. Additionally, links in WSNs usually are unstable due to scheduling or sensor node dies. Therefore, the reliability of the established path in WSN is reduced. That leads to loss packet and retransmission issues in WSNs.

To overcome the above obstacle, besides the normal process of setting up a single path from the source to the destination [3], some proposals have focused on building backup route [4~14]. In detail, some approaches [4~12] use multiple paths to send data to the destination simultaneously through two ways. One is dividing the original packets into multiple sub-packets [4~8]. This way seems increase the reliability of the packet forwarding process but in reality, it decreases that reliability. The second is using multiple copies of the original packet, and then, send these packets to the destination [9~12]. Although the mentioned reliability is enhanced, the cost of sending packet rises dramatically because of the copies. Be different from the above proposals, some other approaches utilize the backup route as the alternative route as if the primary route is failed [13, 14]. However, none of them considers the maximizing the reliability, and

minimizing the retransmission of data sending process and resource constraint. For instance, the proposal in [14] has just tried to establish the reliable path by setting up the alternative route at each node in the primary path but does not concerns the above issue.

Besides, the rpl [2] is a standard proactive routing protocol for IPv6 in low power and lossy networks. This protocol setups a routing path from sensors to a sink by constructing a DAG. In DAG, each sink builds a destination oriented DAG (DODAG). To build this DODAG, the sink advertises DODAG information object (DIO) messages to its neighbors. Each time a node receives a DIO message, the node decides whether to join a DODAG, chooses a preferred parent by sending back to the sink a DAO message and sends a DIO to its neighbors. The preferred parent of a node acts as a default next-hop of data packet toward the sink. The process of sending the DIO messages is repeated until all sensors join the DAG.

Additionally, the p2p-rpl [3] routing protocol is proposed to become the standard point-to-point routing protocol in WSNs. This protocol utilizes the rpl routing protocol to discovery the destination. Then, the destination sends the reply message unicast back to the source to setup a path to the destination based on hop-by-hop forwarding or source routing forwarding.

Then, in this paper, we propose an algorithm to address the above problem by establishing the interactive-path. Particularly, the interactive path is based on enhancing the established links between the node in the primary path and the backup path. In addition, this path is set up over the p2p-rpl routing protocol which is soon standard for point-to-point routing in WSNs. And, we also create a mathematical model to prove the advantage of our algorithm.

The rest of this paper is categorized into five sections. Section II describes about our algorithm. Then, the performance evaluation part is included in the section III. Lastly, the conclusion will present in section IV and give the future work for this paper.

II. INTERACTIVE-PATH

Interactive-path is the concept applied in WSN in which there are two paths and the primary path has relationship with the backup path while transmitting data packets. The primary path is responsible for transmitting packets from the source to the destination. The secondary path is the backup path if there is loss link in the primary path. In this context, each node in the primary path has only a backup node in the secondary path.

Besides, a node in the secondary path has the connection with two nodes in the primary path as is illustrated in the figure 1.

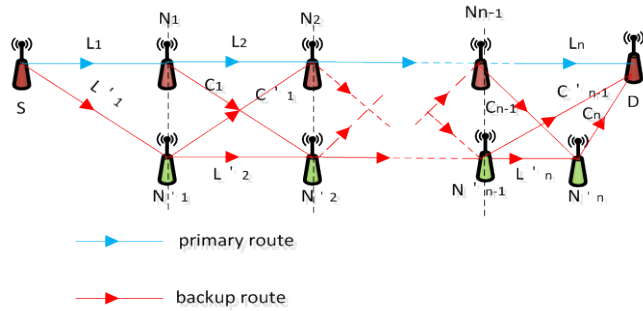


Figure 1. Interactive-path

Once a packet arrives at a node, it has two options. One is forwarded along the primary path and other is along the secondary path. Naturally, by utilizing the backup link at each node, the probability of successful transmission of a packet to the destination is increased. Besides, this algorithm helps to reduce retransmitting the data packets if there is any disruption in the primary path. Furthermore, the number of nodes in the secondary path are estimated and limited by the number of nodes in the primary path. It is because of each node in the primary path has a backup node.

Although the number of links in the two paths is limited, the number of path is explored due to each node in the primary path has two paths to transmit packets to the destination.

This part, we describe the process of setting up the routing path and data forwarding of interactive-part algorithm.

The route establishing algorithm is divided into two parts. One is setting up the primary path. And one is building the secondary path. First, rely on the p2p-rpl routing protocol, a source broadcasts to discover the destination. And based on the ETX metric [15], a node calculates the next-hop back to the source. After the destination receives the broadcasting message, it sends a unicast packet back to the source to establish the primary path through the most preferred next-hop. This packet is relayed until it reaches to the source.

While setting the primary path, the backup path also is established. The setting up process relies on the neighbors of the nodes in the primary node. First, each primary node broadcasts to find out the nearest non-primary neighbor as the backup node. Next, neighbors send one hop-count broadcasting message to the primary path to attach to other primary node with higher rank than the previous primary node. Then, one of the nodes which satisfy the condition of interactive-path above is selected. Next, a confirming message are sent back to establish the connection between the nodes in the primary path and the backup path. Finally, nodes in the secondary path try to connect with others by sending one-hop broadcasting message. After path establishing process, the source starts to forward the data messages. The rule to choose the next-hop is illustrated by the figure 2.

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initialize the primary path
initialize the interactive path
while not end of path
    if the node N is primary
        if the sending is successful
            keep sending the current packet to the next
            primary node
        else
            send packet to non-primary node
        endif
    else if the node N is non-primary
        if the transmission from N to next primary node is
        successful
            send packet to that primary node
        else
            send packet to the next non-primary node
        endif
    endif

```

Figure 2. Algorithm of selecting the next-hop in interactive-path routing

III. PERFORMANCE EVALUATION

In this part, our intention is to focus on evaluating the reliability and delay of transmitting data packets between the interactive algorithm and the disjoint routing by comparing probability of packet forwarding process in the best case, the worst case of the interactive-path routing algorithm with the disjoint routing algorithm, and comparing the interval of successive route discovery in case of using each above algorithms by calculating the probability density function (pdf) of them.

A. Probability of packet forwarding process

First, we define $f^p(k)$ is the probability of successful transmission a packet until the k^{th} hop in the primary route, p is the probability of successfully transmitting a packet over a link, and n is the number of hop-count of a path in the primary route and the backup route.

The best case is the case in which every backup-node has connection with both the previous backup node and the next backup node as is showed in figure 1. In this situation, the reliability of established paths is maximized. Based on the above assumption, it is possible to calculate the probability of successful transmitting a packet $f^p(1)$ over the link L_1 is p . However, if link L_1 fails, the packet may be forwarded over the link L'_1 . This process is repeated until the forwarding packet arrives at the destination. The summary of probability at each step is presented in the table 1.

The worst case, in contrast, is defined as every backup-node does not have any connection with either the previous backup node or the next backup node as is showed in figure 4. This case is the worst case in term of delay and reliability because whenever the data packet is transferred throughout the backup route, it has to pass two links in order to reach to the next primary node and does not have the direct connection between nodes in secondary path. Similar to the first case, the

probability of successful transmission of a packet through this network is brief described in the table 1.

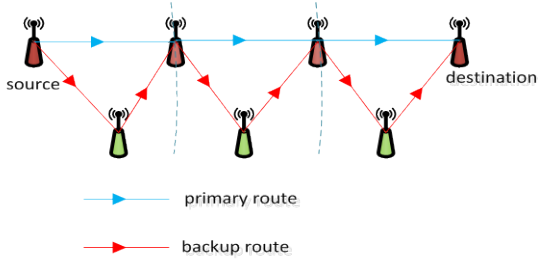


Figure 3. The worst case

TABLE I. PROBABILITY OF TRANSMITTING A ROUTE OVER THE (N-1)-HOP PATH

Hop-count of a path		1	2	n-1	n
Interactive-path: the first case (1)	$f^p(n)$	p	$p^2 * (2-p)$	$(p)^{(n-1)} * (2-p)^n$	$p^n * (2-p)^n$
Interactive-path: the second case (2)	$f^p(n)$	p^* $(1+p-p^2)$	p^{2*} $(1+p-p^2)^2$	$p^{(n-1)*}$ $(1+p-p^2)^{(n-1)}$	$p^n *$ $(1+p-p^2)^n$
Disjoint routing (3)	$f^p(n)$	p	p^2	p^{n-1}	$(2-p)p^n$

TABLE II. COMPARING PROBABILITY OF SUCCESSFUL TRANSMISSION AMONG ABOVE ALGORITHMS

P of (1)/P of (3)	$(2-p)^{n-1}$
P of (2)/P of (3)	$(1+p-p^2)^n / (2-p)$

The disjoint routing is used as the compared algorithm with our algorithm. And in this routing protocol, the source establishes a number of separate paths to reach to the destination. In this case, we consider the number of separating path is two. It means there are one primary route and one separating backup route.

Then, we have the comparing table 2 where P is the probability of successful transmission a data packet in each case. Due to $0 \leq p \leq 1$, we easily conclude that the interactive-path is better than the backup path with one backup path in term of successful transmission.

The interactive-path is not only helpful in increasing the probability of successful transmission a packet to the destination, but also avoids retransmitting as if there is a loss link in the intermediate node. In other words, this helps reduce delay of sending a packet to the destination. More clearly, once a broken link occurs, in the disjoint routing there is no alternative link for that broken link. Then, the data packet should be retransmission from the source. This costs energy and time for sending new packet and even creating new route. Differently, the interactive-path routing utilizes the backup path as the alternative path for a packet if there is any broken link exists. In order to analysis this delay more detail, the next

part will calculate pdf of the interval of successive route discovery in each approach.

B. pdf of interval of successive route discovery

This part is to compare the interval of successive route discovery between our algorithm and the disjoint routing algorithm. More clearly, we estimate the expected value of this time interval by calculating the pdf value of that. Therefore, we create a mathematic model which relies on some assumptions. First, the lifetime of a wireless link between a pair of node is a random variable. Over the path from the source to the destination, there are totally k links and k-1 intermediate nodes. Let L_i be the i^{th} link in the route. The lifetime of L_i is denoted by X_{L_i} .

We consider the model for routing from a source S to the destination D where let $\bar{L}_i$ represents for link L_i fails, $\bar{P}_i$ represents for path L_i fails, and T is the time between successive route discoveries and the time until the next route discovery T is the time until event E is true. And we consider two cases:

In disjoint routing algorithm, $E = \bar{P}_1 \bar{P}_2 \dots \bar{P}_n$, n is the number of established path. The lifetime of route P_i and link L_i are the exponential random variables X_{P_i} and X_{L_i} , respectively [16]. Therefore, $T = \max(X_{P_1}, X_{P_2}, \dots, X_{P_n})$ (1). The cumulative distribution function of T: $F_T(t) = \prod_{i=1}^n (1 - e^{-\theta_i t})$ (2) with $\theta_i = \frac{k_i}{l}$. k is the length of path P_i and l is the lifetime of a link. Then, the probability density function (pdf) of T is:

$$f_T(t) = \sum_{j=1}^n \left(\frac{\theta_j e^{-\theta_j t}}{1 - e^{-\theta_j t}} \right) \prod_{i=1}^n (1 - e^{-\theta_i t}) \quad (3)$$

In interactive-path routing algorithm, along the path $SN_1N_2 \dots N_{n-1}D$, $SN'_1N'_2 \dots N'_{n-1}D$ as is shown in the figure [1], similar to E, we define $E_1, E_2, E_3, \dots, E_{n-1}, E'_1, E'_2, E'_3, \dots, E'_{n-1}$, respectively. However instead starting from the S, the sub-network starts from $N_1N_2, \dots, N_{n-1}N'_1, N'_2, \dots, N'_{n-1}$ to the destination. And similar to T, we define $T_1, T_2, T_3, \dots, T_{n-1}, T'_1, T'_2, T'_3, \dots, T'_{n-1}$ which respectively response for the events $E_1, E_2, E_3, \dots, E_{n-1}, E'_1, E'_2, E'_3, \dots, E'_{n-1}$. Then, we recursively calculate:

$$E = \bar{L}_1 \bar{L}'_1 + E_1 \bar{L}_1 + E'_1 \bar{L}'_1 \quad (4)$$

$$E_i = \bar{L}_{i+1} \bar{C}_i + E_{i+1} \bar{L}_{i+1} + E'_{i+1} \bar{C}_i \quad (5)$$

$$E'_i = \bar{L}'_{i+1} \bar{C}'_i + E_{i+1} \bar{C}'_i + E'_{i+1} \bar{L}'_{i+1} \quad (6)$$

$$E_{n-1} = \bar{L}_n (\bar{C}_{n-1} + \bar{C}_n) \quad (7) \text{ and } E'_{n-1} = \bar{C}'_{n-1} (\bar{L}'_n + \bar{C}_n) \quad (8)$$

Therefore:

$$T = \min(\max(X_{L_1}, X_{L'_1}), \max(T_1, X_{L_1}), \max(T'_1, X_{L'_1})) \quad (9)$$

$$T_i = \min(\max(X_{L_{i+1}}, X_{C_{i+1}}), \max(T_{i+1}, X_{L_{i+1}}), \max(T'_{i+1}, X_{C_{i+1}})) \quad (10)$$

$$T'_i = \min(\max(X_{L'_{i+1}}, X_{C'_{i+1}}), \max(T_{i+1}, X_{C'_{i+1}}), \max(T'_{i+1}, X_{L'_{i+1}})) \quad (11)$$

$$T_{n-1} = \max(X_{L_n}, \min(X_{C_{n-1}}, X_{C_n})) \quad (12)$$

$$T'_{n-1} = \max(X_{C'_{n-1}}, \min(X_{L'_n}, X_{C_n})) \quad (13)$$

Then, based on the following equations: The pdf of $A = \min(Z_1, Z_2, Z_3, \dots, Z_k)$ is $f_A(t) = \sum_{i=1}^k (f_{Z_i}(t) \prod_{j=1, j \neq i}^k (1 - F_{Z_j}(t)))$ (14) [16] with $F_{Z_j}(t)$ is the cdf of Z_j . And the pdf of $B = \max$

$(Z_1, Z_2, Z_3, \dots, Z_k)$ is $f_B(t) = \sum_{i=1}^k (f_{Z_i}(t) \prod_{j=1, j \neq i}^k (F_{Z_j}(t)))$ (15) [16] with $F_{Z_j}(t)$ is the cdf of Z_j . And based on the symmetric topology, recursive calculation, we easily estimate:

The pdf of T_{n-1} and T'_{n-1} is: $f_{T_{n-1}}(t) = f_{T'_{n-1}}(t) = \theta e^{-\theta t} (2 - e^{-\theta t})$ (16) with $\theta = \frac{1}{l}$

The pdf of $\max(T'_{i+1}, X_{L'_{i+1}})$:

$$f_{T_{i+1}X_{L_{i+1}}}(t) = f_{T'_{i+1}X_{C_{i+1}}}(t) = f_{T_{i+1}, X_{C'_i}}(t) = f_{T'_{i+1}, X_{L'_{i+1}}}(t) = \theta e^{-\theta t} * F_{T_{i+1}}(t) + f_{T_{i+1}}(t) * (1 - e^{-\theta t}) \quad (17)$$

The cdf of $\max(T_{i+1}X_{L_{i+1}})$, $\max(T'_{i+1}X_{C_{i+1}})$, $\max(T_{i+1}, X_{C'_i})$, $\max(T'_{i+1}, X_{L'_{i+1}})$:

$$F_{T_{i+1}X_{L_{i+1}}}(t) = F_{T'_{i+1}X_{C_{i+1}}}(t) = F_{T_{i+1}, X_{C'_i}}(t) = F_{T'_{i+1}, X_{L'_{i+1}}}(t)$$

The pdf of T_i, T'_i :

$$f_{T_i}(t) = f_{T'_i}(t) = 2\theta e^{-\theta t} (1 - F_{T_{i+1}X_{L_{i+1}}}(t)) + (1 - e^{-\theta t}) f_{T_{i+1}X_{L_{i+1}}}(t) \quad (18)$$

Finally, the pdf of T $f_T(t) = 2\theta e^{-\theta t} (1 - F_{T_1}(t)) + (1 - e^{-\theta t}) f_{T_1}(t)$ (19)

Based on the pdf of interval of successive route discovery when applying the node disjoint routing algorithm (3) and the interactive-path route discovery (19), we utilize the numerical technique to estimate the expected value of that parameter in each case. The result is shown in the figure 4.

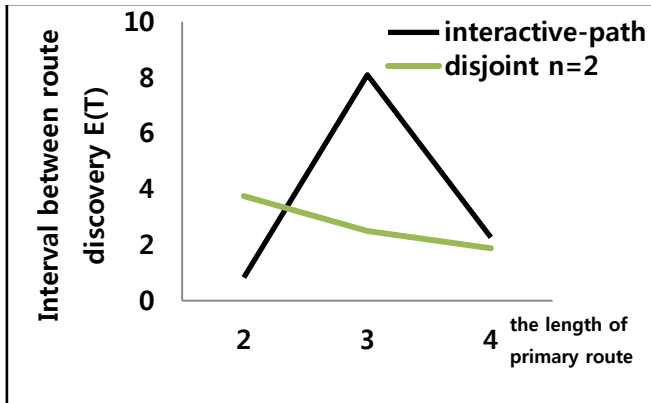


Figure 4. Comparing the expected interval of successive route discovery between interactive-path routing algorithm and disjoint routing algorithm

From the above figure, we can conclude that when the primary route is very short ($k=2$), the destination is very near the source, then disjoint routing algorithm is little better than the interactive-path routing algorithm. However, when the length of the primary route is longer, the interactive-path routing is better than the disjoint-path routing due to the number of path increases exponentially.

IV. CONCLUSION

This paper has presented a backup path setup mechanism for point-to-point routing protocol in WSNs by utilizing the interactive-path concept. This mechanism allows sensor nodes to send packets over the backup path without discovering the point-to-point path in case of path failure, thus improving the reliability of point-to-point transmission. By comparing our

algorithm and disjoint routing algorithm in term of the reliability of routing process and analysis the expected interval of successive route discovery, we have concreted the above conclusion. For future work, we will implement our algorithm in the simulator and real testbed.

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REFERENCES

- [1] D.S.J.D. Couto, D. Aguayo, J. Bicket, R. Morris, "A high-throughput path metric for multi-hop wireless routing," *Wireless Network*, 2005.
- [2] T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, JP. Vasseur, R. Alexander, "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks," RFC6550, Mar. 2012.
- [3] M. Goyal, E. Baccelli, M. Philipp, A. Brandt, J. Martocci, "Reactive Discovery of Point-to-Point Routes in Low Power and Lossy Networks," draft-ietf-roll-p2p-rpl-14, Oct. 2012.
- [4] W. Lou, "An Efficient N-to-1 Multipath Routing Protocol in Wireless Sensor Networks," In *Proceedings of the 2nd IEEE International Conference on Mobile Ad-hoc and Sensor System (MASS '05)*, Washington, DC, USA, Nov. 2005, pp. 672-680.
- [5] W. Lou, Y. Kwon, "H-SPREAD: A Hybrid Multipath Scheme for Secure and Reliable Data Collection in Wireless Sensor Networks," *IEEE Transaction on Vehicle Technique*, 2006, pp. 1320-1330.
- [6] Y.M. Lu, V.W.S. Wong, "An Energy-Efficient Multipath Routing Protocol for Wireless Sensor Networks," *International Journal on Communication System*, 2007, 20, 747-766.
- [7] P. Hurni, T. Braun, "Energy-Efficient Multi-Path Routing in Wireless Sensor Networks," In *Proceedings of the 7th International Conference on Ad-Hoc, Mobile and Wireless Networks (ADHOC-NOW '08)*, Sophia Antipolis, France, Sep. 2008, pp. 72-85.
- [8] J.Y. Teo, Y. Ha, C.K. Tham, "Interference-Minimized Multipath Routing with Congestion Control in Wireless Sensor Network for High-Rate Streaming," *IEEE Transaction on Mobile Computing*, 2008, pp. 1124-1137.
- [9] B. Deb, S. Bhatnagar, B. Nath, "ReInForM: Reliable Information Forwarding Using Multiple Paths in Sensor Networks," In *Proceedings of the 28th Annual IEEE International Conference on Local Computer Networks (LCN'03)*, Bonn, Germany, Oct. 2003, pp. 406-415.
- [10] E. Felemban, C.G. Lee, E. Ekici, "MMSPEED: Multipath Multi-SPEED Protocol for QoS Guarantee of Reliability and Timeliness in Wireless Sensor Networks," *IEEE Trans. Mobile Comput*, 2006, pp. 738-754.
- [11] X. Huang, Y. Fang, "Multiconstrained QoS Multipath Routing in Wireless Sensor Networks," *J. Wirel. Netw.* 2007, pp. 465-478.
- [12] A. Bagula, K. Mazandu, "Energy Constrained Multipath Routing in Wireless Sensor Networks," In *Proceeding of the 5th International Conference on Ubiquitous Intelligence and Computing*, Oslo, Norway, June 2008, pp. 453-467.
- [13] H. Hassanein, J. Luo, "Reliable Energy Aware Routing in Wireless Sensor Networks," In *Proceedings of 2nd IEEE Workshop on Dependability and Security in Sensor Networks and Systems*, Los Alamitos, CA, USA, April 2006, pp. 54-64.
- [14] D. Ganesan, R. Govindan, S. Shenker, D. Estrin, "Highly-Resilient, Energy-Efficient Multipath Routing in Wireless Sensor Networks," *Mobile Computing Communication*, 2001, pp. 11-25.
- [15] JP. Vasseur, M. Kim, K. Pister, N. Dejean, D. Bathel, "Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks," rfc6551, 2012.
- [16] N.K.Chi, "Hybrid Multipath Routing in Mobile Ad hoc Networks", master thesis, soongsil university, Korea 2011.