Energy-Efficient Oriented Routing Algorithm in Wireless Sensor Networks

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Abstract—**The design and implementation of healthcare system using sensor network technology has been one of the most active research topics currently. The research on wireless sensor network mostly focuses on energy saving, such as duty cycle scheduling, and path routing, such as routing protocol for low power and lossy networks (RPL) which however only takes into account a single metric, reliability or energy, as routing decision. If RPL only considers the reliability metric, nodes will suffer from uneven energy. If it only considers the energy metric, nodes will suffer from the rise of packet loss ratio. In this paper, we propose an energy-oriented routing mechanism to improve RPL routing protocol by combining the expected transmission count (ETX) and remaining energy metrics. The simulation will be conducted to analyze the performance of the proposed mechanism.**

Keywords— ***proactive healthcare system, WSN, RPL, 6LOWPAN***

I. INTRODUCTION

The proactive healthcare systems with wireless sensor network (WSN) technology have been one of the most active research topics currently. The purpose of proactive healthcare systems is to allow patients to have healthcare at home, instead of staying at hospital. Therefore, the tracking/monitoring of health condition and even the integration of ambient information with the health condition by employing the smart devices or Internet of things (IoTs) are under development.

The routing of the sensor nodes, with tracking, monitoring, or sensing information, to the destination node is an important research issue from the viewpoints of path optimization and energy consumption. In a low-power and lossy network (LLN) environment, it is a big challenge to provide the routing maintenance in the lowest costs. Different from the traditional WSN routing protocols, such as AODV and OLSR, the IPv6 routing protocol for low-power and lossy networks (RPL), defined in IETF RFC 6550 [1], provides a routing mechanism in the IPv6 low-power wireless personal area network (6LoWPAN).

For RPL topology, the routes usually are optimized for packets to be sent from or to the sink nodes which act as roots of a directed acyclic graph (DAG) topology. The DAG topology is partitioned into one or more destination oriented DAGs (DODAGs) with one DODAG per sink. The design of RPL basically takes into account only a single metric, reliability or energy, as routing decision metric. If RPL only considers the reliability metric, nodes will suffer from uneven energy. If it only considers the energy metric, nodes will suffer from the rise of packet loss ratio.

Therefore, in this paper we propose an energy-oriented routing mechanism to improve RPL routing protocol by combining the expected transmission count (ETX) and remaining energy metrics. This design is expected to balance the overall network energy consumption and therefore prolong the network lifetime. We will use the COOJA network simulator to analyze the performance of the proposed scheme as compared to RPL in terms of configuration of sink location and energy impact.

II. RELATED WORKS

In order to conduct 6LoWPAN in IoT architecture, the IPv6 packets need to be fragmented and reassembled so that they can be transmitted in IEEE 802.15.4 networks. Also, the routing protocol should be addressed in such a low-power and lossy network environment. We will discuss the related issues related to IoT and RPL routing in this session.

A. Internet Of Thing (IOT)

The IoT concept was first reported by the International Telecommunication Union (ITU) in 2005 [3]. The report indicated that the society in the future will become a “ubiquitous network society”. Lots of smart objects, including the tracking and monitoring devices for proactive healthcare systems, can be connected to the Internet.

Through the idea of IoT, the human to machine (H2M) concept and be easily evolved into machine to machine (M2M) by connecting all the healthcare sensing devices, equipments and products around elderly people staying at home for healthcare. The IoT concept and applications is shown in Fig. 1. Through the IoT concept and related technologies, we will be able to connect to any smart objects at anytime and anywhere.

B. Ipv6 Routing Protocol for Low power and Lossy Networks (RPL)

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The IETF ROLL working group has defined application-specific routing requirements for a LLN routing protocol. It also specified RPL to provide routing mechanism from multiple devices to a control sink and vice versa in LLNs. A set of link and node routing metrics and constraints used for path calculation and selection in LLNs is defined in IETF RFC 6551 [4].

RPL routes usually are optimized for packets to be sent from or to the sink nodes which act as roots of a directed acyclic graph (DAG) topology. The DAG topology is partitioned into one or more destination oriented DAGs (DODAGs) with one DODAG per sink. The topology of DODAG in RPL is established with bidirectional routes and expected to reduce topology complexity for LLNs, as shown in Fig. 2. The traditional WSN routing usually only conducts point to point communication, however, RPL further provides point-to-multipoint or multipoint-to-point routing. The multiple sinks or roots in DAG can be the case with a common backbone, such as a transit link.

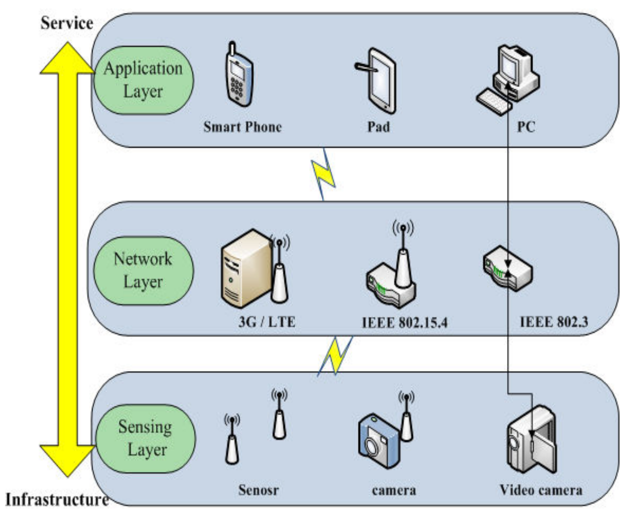

Fig. 1.IoT Applications

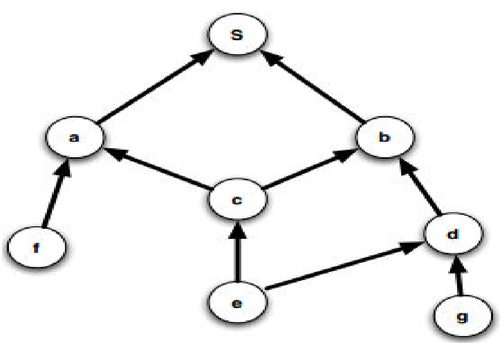

Fig. 2 DODAG topology in RPL

RPL provisions a mechanism, with minimal configuration in the nodes, to disseminate information over the dynamically formed network topology. The control messages in RPL include DODAG Information Object (DIO), Destination Advertisement Object (DAO) and DODAG Information Solicitation (DIS). Through DIO messages, RPL provides routes up towards DODAG roots. On the other hand, RPL employs DAO messages to establish downward routes and the DIS messages could be used to solicit a DIO from a node. The DIO messages, being periodically broadcasted by each node to maintain the DODAG, specify the necessary parameters, including node rank, objective function, IDs, etc.

The design of RPL basically takes into account only a single metric, reliability or energy, as routing decision metric. If RPL only considers the reliability metric, nodes will suffer from uneven energy. If it only considers the energy metric, nodes will suffer from the rise of packet loss ratio.

III. PROPOSED SCHEME

The energy issue is one of the key factors in WSNs. The sensor node is treated as disable and cannot communicate with other nodes when its energy is exhausted or lower than certain value. When the number of disable nodes increases and results in a black hole in the network topology, a sensing node may not reach the sink. Most researches on routing scheme provide a lowest energy consumption path as the routing selection. However, the nodes along this selected path may consume more energy than other nodes. Such unbalanced energy consumption for certain nodes will reduce the overall network lifetime and consequently decrease the network coverage, especially in LLN environment.

In this paper we propose an energy-oriented routing decision algorithm based on IETF RFC 6650 RPL routing protocol. The routing decision is based on the Rank and objective function (OF), where Rank, approximating the node's distance from a DODAG root, is designed to prevent from loop routing and the OF defines how RPL nodes select and optimize routes within a RPL instance. IETF RFC6551 [4] defines how to apply the OF to the decision of routing metrics, including the node metric and link metric. The node metric is the individual node status including node energy and node hops. The link metric indicate the routing quality, including expected transmission count (ETX), throughput and delay. The OF explicitly defines the route selection criteria. However, RPL specifies only one routing metric in DODAG topology.

The link qualities, including latency and packet loss, may significantly influence the network connectivity. The ETX of a link is the predicted number of data transmissions and retransmissions required to deliver a packet over the link. It is calculated by using the forward and reverse delivery ratios, d_f and d_r respectively, of the link. The d_f and d_r are defined as the measured probabilities for a data packet and ACK packet successfully arriving at the receiver and sender, respectively.

And the probability of a transmission being successfully received and acknowledged will be d_f x d_r. Therefore, the expected number of transmission of a link is defined in Eq. (1). For example, the ETX value for a link with 50% forward and reverse delivery ratios is 4.

$$ETX = \frac{1}{d_f \times d_r} \quad (1)$$

Furthermore, the summation of the ETX value at each link along a route is the ETX of the route. The ETX value thus represents the stability of a link or route. The lower the ETX value, the higher the transmission successful rate. The node with lower ETX will be given higher priority as the next hop selection.

As discussed above, the ETX is defined to be the packet transmission successful rate which provides a selection for a node with relatively stable link as the next hop. Consequently, the nodes with stable and high successful delivery rate may become the bottleneck of the routing which results in unbalanced distribution of traffic as well as residual energy. This eventually results in network partition and reduction in overall network lifetime.

Therefore, we take into account the node's energy issue besides the ETX value in the RPL routing algorithm to balance the energy consumption of nodes and consequently prolong the network lifetime. Fig. 3 illustrates the criteria for route selection, including the ETX value and residual energy of the parent nodes. That means we incorporate the stability of a link and the node's residual energy for our routing path selection.

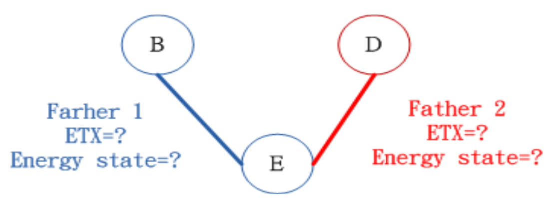

Fig. 3. Route selection criteria

The routing score R for selecting a node as the next hop can be expressed as the following equation,

$$R = \alpha \frac{\text{ETX}}{\text{Maximum ETX}} + (1-\alpha)(1 - \frac{\text{Remaining Energy}}{\text{Maximum Energy}}) \quad (2)$$

where α is the weight between the ETX value and energy consumption. The first item of the right hand side in Eq. (2) represents the ratio of the expected transmission number of one link to the maximum transmission number for all possible links. The second item of the right hand side in Eq. (2) stands for the ratio of the consumed energy of a node to its maximum energy.

The proposed energy-oriented routing decision algorithm is presented in Fig. 4, in which two nodes A and B are calculated and compared to decide the next hop candidate with smaller R value. We set α 0.5 as the primary study in this example. By incorporating the ETX and residual energy of nodes with proper weight, it is expected to provide a optimized routing mechanism which balances the energy consumption and consequently prolong the network lifetime in LLN.

```
define α=0.5;  /* parameters weight */

If (NodeA  &&  NodeB  != Null)
   {
   RA =BestNextHop(Node A );
   RB = BestNextHop(Node B );
   Return  RA<RB ? NodeA:NodeB;
}
 Else Return NodeA;
BestNextHop(Node)
{
   R     =     α[(ETX)/Maximun_ETX]+(1-α)[1-(Remain
Energy/Maximum_Energy)];
   Return R;
}
```

Fig. 4. Energy-oriented routing algorithm

IV. Simulation Result

We use the COOJA[9] network simulator for contiki OS[8] to simulate RPL and analyze the energy consumption of sensing nodes. Contiki is an open source operating system for IoT. Contiki allows tiny and memory-constrained battery-operated low-power systems to communicate with the Internet. Contiki provides three network mechanisms: the uIP TCP/IP stack, which provides IPv4 networking, and the uIPv6 stack, which provides IPv6 networking. Cooja is the Contiki network simulator. Cooja allows users to simulate large and small network topology of Contiki motes. Contiki motes can be emulated at the hardware interface behavior and allow precise inspection of the system behavior.

Because we cannot get the node battery directly from the simulator, therefore, we use energy consumption to calculate the residual energy. The MAC layer of COOJA is X-MAC [7] which defines the battery as 3 voltages. Also, the listening, transmission and CPU energy consumptions are 20mA, 17.7mA and 1.8mA, respectively. From [7], we can apply Eq. (3) to calculate the energy consumption in Eq. (4).

$$P = IV \quad (3)$$

Energy Consumption:

$$T_{cpu} * P_{cpu} + T_{radioRX} * P_{radioRX} + T_{radioTX} * P_{radioTX} \quad (4)$$

In Eq. (3), P, I and V represent the power, current and voltage. In Eq. (4), T_{cpu} and P_{cpu} represent the CPU run time and consumed current, respectively, and $T_{radioRX}$ ($T_{radioTX}$) and $P_{radioRX}$ ($P_{radioTX}$) stand for the receiving (transmitting) time and power, respectively. Therefore, the remaining energy can be obtained from Eq. (5).

$$\text{Remaining energy} = \text{Battery} - \text{Energy Consumption} \quad (5)$$

The simulation parameters are defined in Table 1. The network topology with 4 and 6 nodes simulation is illustrated in Fig. 5, where node 1 is the sink which is responsible for building the overall RPL routing environment and data collection. The rest of nodes in Fig. 5 are sensing nodes which deliver the sensing information to the sink. From the simulation setting, node 4 (as well as nodes 5 and 6 for 6-node case) is unable to communicate with sink directly due to the limitation of transmission range. It requires node 2 or 3 to forward data packets to sink.

Table 1. Simulation parameters

Parameter	Value
Operating System	Contiki 2.6
Network Field	300m*300m
Number of Sensor	4, 6
Transmission Range	50m
MAC Layer	X-MAC
Routing Protocol	RPL
RPL Mode	non-storing
DIOIntervalMin	3s
Initial Energy	4400mJ
Simulation Time	60min

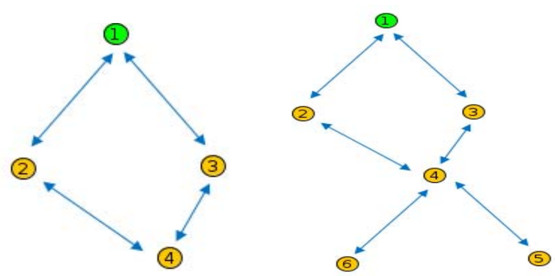

Fig. 5. Network topology

Fig. 6 shows the energy consumption for nodes employing the original RPL mechanism. According to the RPL, node 4 selects the smaller value of ETX, which corresponds to the close node 3 at most of time, to forward data packet to sink. Therefore, the energy consumption in node 3 is much higher than node 2.

The simulated result of the energy consumption for the proposed mechanism is shown in Fig. 7. As we can see in Fig. 7, the energy consumption for nodes 2 and 3 are relatively equal and balanced all over the simulated period. This is because we take both the ETX and residual energy into account for routing selection in our proposed scheme.

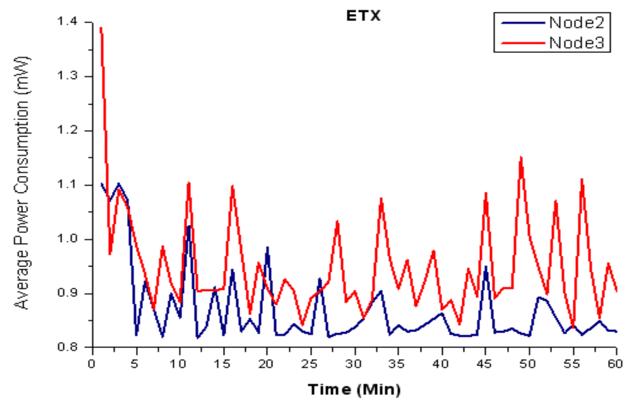

Fig. 6. Energy consumption for original RPL nodes

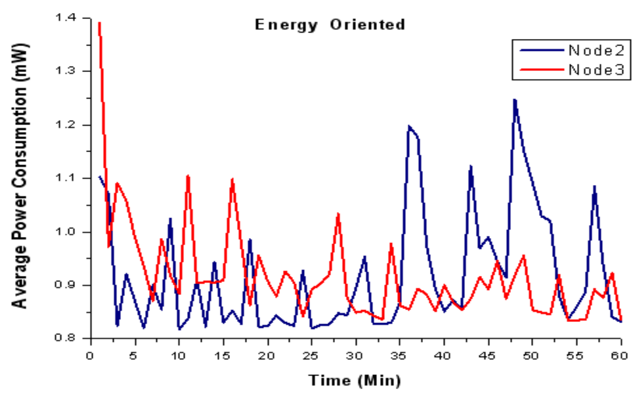

Fig. 7. Energy consumption for proposed mechanism

The 6-node simulation, with node 4 playing as the relay node for nodes 5 and 6, is conducted for further analysis. We also apply constant bit rate (CBR) UDP packets to node 4 as the interference for network situation. Figs. 8 and 9 show the simulation results with 6-node case for RPL and our proposed mechanisms, respectively. Again, the forwarding node 4 in the original RPL selects the next hop according to the link stability only, therefore, the node 3 consumes more energy than node 2 during all simulated period. On the other hand, our proposed scheme, which takes both ETX and residual energy into account for path selection metric, properly switches to the next hop with higher residual energy. Consequently, the energy consumption for different nodes is balanced.

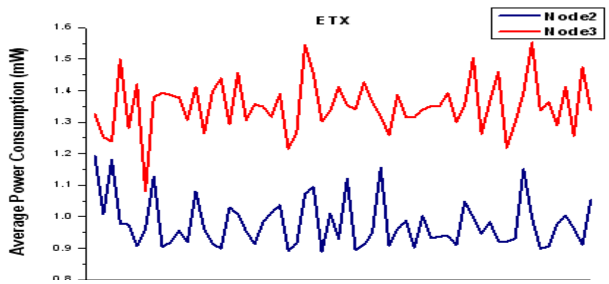

Fig. 8. Energy consumption for RPL 6-node case

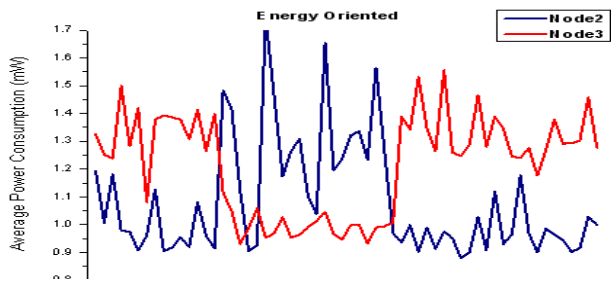

Fig. 9. Energy consumption of 6-node case for proposed mechanism

Figs. 10 and 11 show the simulation results of the remaining energy (node lifetime) for RPL and the proposed mechanisms, respectively. As shown in Fig. 10 for the case of RPL mechanism, node 3 is disabled in about 54 min. although node 2 still maintains more than 800 mJ for processing. However, for some applications, the network lifetime is defined to be ended at 54 min. On the other hand, our proposed energy-oriented routing algorithm which balances the energy consumption for nodes 2 and 3 in this study, therefore, extends the network lifetime as compared to the RPL mechanism. As shown in Fig. 11, node 3 survives till around 60 min. for our proposed mechanism. The overall network lifetime for our proposed energy-oriented routing algorithm increases about 12% as compared to the RPL mechanism.

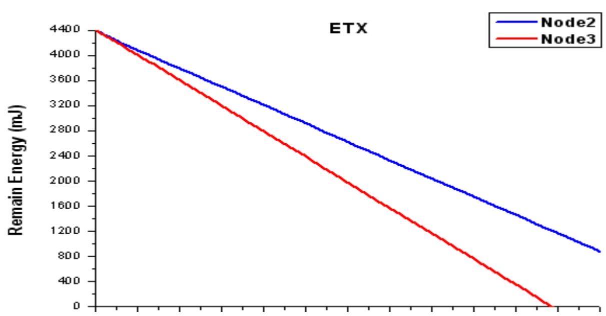

Fig. 10. Remaining Energy of RPL

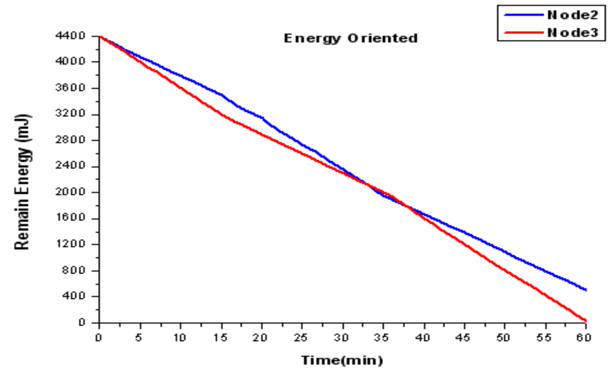

Fig. 11. Remaining Energy for the proposed mechanism

I. CONCLUSIONS

In this paper, we have proposed an energy-oriented routing mechanism to improve RPL routing protocol by incorporating ETX and residual energy metrics for path selection in LLN environment. In order to avoid the energy exhausted of neighboring nodes and consequently result in energy black hole, our proposed energy-oriented routing algorithm provides the switching mechanism for optimized path selection to balance the residual energy of communication nodes. The simulation results in this study confirmed the principle of the design. From the simulation results, the overall network lifetime for our proposed energy-oriented routing algorithm has increased about 12% as compared to the RPL mechanism.

In the future, we will simulate different scenarios with different α value to find the optimized α value with best network lifetime. We will further improve the routing decision with multiple metrics based on RPL routing protocol in LLN.

II. ACKNOWLEDGMENT *(HEADING 5)*

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