Low-Cost Multipath Routing Protocol by Adapting Opportunistic Routing in Wireless Sensor Networks

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***Abstract*—The wireless sensor networks (WSNs) are special network which has purpose of gathering information in certain area. The reliability is an important factor in the WSNs for transferring the information to the destination. However, the reliability is decreased while multi-hop transmission of the information because a node which composes the WSNs has limited communication range. Also, the transmission process may suffer from the various factors including the faulty nodes and network congestion. To solve this, the multipath routing protocols, which transfer the information through a multipath to the destination at the same time, have been proposed for improving the reliability. In the existing multipath routing protocols, however, the network scale should be sufficient for constructing multipath to guarantee of the disjoint path and the energy is consumed for multipath construction/maintenance consistently. The energy consumption leads to the reduction of networks lifetime and the restricted network scale may not even ensure the enough reliability. Thus, we proposed Low-Cost Multipath Routing Protocol by Adapting Opportunistic Routing which can reduce consistent energy consumption and less affected by network scale. The proposed protocol exploits the opportunistic routing that improves the single-hop reliability in order to improve the reliability in each path. It reduces the number of paths, which constructed for ensuring the enough reliability. Also, a fewer path reduces the energy consumption and alleviates the restriction of network scale. Simulation results show that the proposed protocol provides the more reliable performance than the existing protocols in the network, which restricted scale, and consumes the less energy.**

***Index Terms*— Wireless Sensor Networks (WSNs); Multipath; Opportunistic Routing (OR); Energy-efficiency.**

I. Introduction

The wireless sensor networks (WSNs), which consists of a large number of small sensor nodes and a sink node, are a special network, which has a purpose of gathering information in a certain area. The reliability is an important factor in the WSNs for successfully transferring the information to the destination [1-2]. However, the sensor nodes have a restricted communication range and a limited resource such as battery, memory, and computational power, etc. The sensor nodes operate a multi-hop fashion for the data transmission because of the restricted communication range. The multi-hop fashion data transmission might cause a decline in the reliability. Also, the transmission process may suffer from the various factors including the faulty nodes and network congestion. Because of these problems, it is difficult to ensure the required reliability.

To solve the problem of the decline in the reliability, the multipath routing protocol [3-5], which transfer the data through the multipath to the destination at the same time, have been proposed. The multipath routing protocol constructs the multipath from the source node to the destination node. The source node can improve the reliability by transferring the data through the multipath. The multipath routing protocol constructs the multipath from the source node to the destination node. The source node can improve the reliability by transferring the data through the multipath. That is, the source node calculates the expected reliability of single path based on the user-required reliability and computes the necessary number of the path for satisfying the required reliability. After that, the source node performs the bifurcation to constructs the multipath and transmits the data through the multipath. However, the lower the expected reliability of single path, these protocols construct/exploit the many paths and consume the much energy. This phenomenon leads to the whole network lifetime shortening. Also, because the range per each path is defined for the path-disjoint in existing multipath protocols, if the network scale is not large enough, the protocols may not construct the path up to the calculated number of the path and cannot satisfy the required reliability. These problems caused by constructing many paths for satisfying the required reliability when the expected reliability of the single path is lower.

To solve these problems, we proposed the multipath routing protocol that exploits the opportunistic routing. The opportunistic routing protocols [6-8] has been known as a reliable communication approach for wireless networks by exploiting the broadcast nature of the wireless medium. Instead of picking a relay node to forward a packet to a destination, a sender node holding a data packet broadcasts to a set of candidate nodes for forwarding, therefore, one of them that successively receives the packet can relay the packet toward the destination. The proposed protocol exploits the opportunistic routing in the data transmission process, improves the expected reliability of each single path. However, it is difficult to directly apply the opportunistic routing which selects one node among a set of candidate nodes because the existing multipath routing

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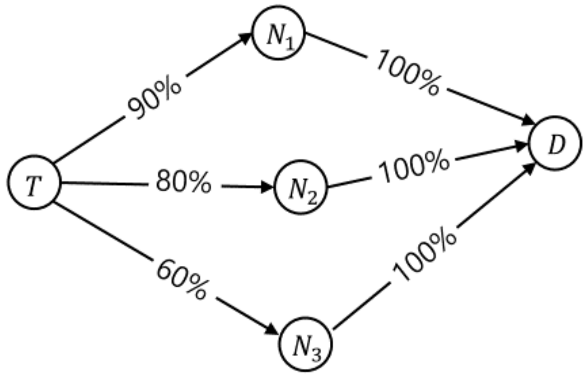

Fig. 1. An example of the opportunistic routing

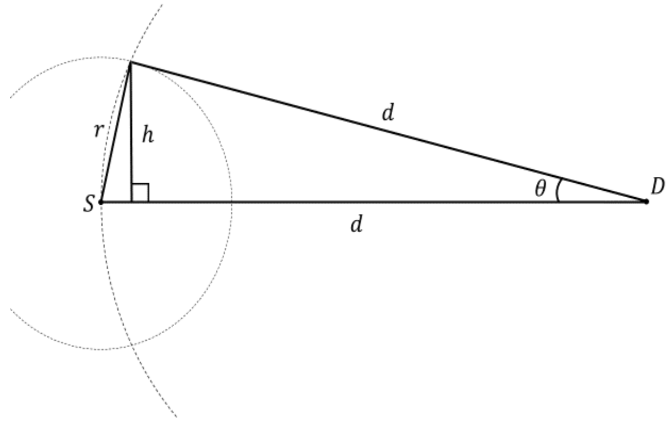

Fig. 2. A calculation of the path width

protocol pre-constructs the multipath and predetermines the next forwarding nodes. Therefore, the proposed protocol calculates the multiple regions to transmit data instead of predetermining the next forwarding node. The multiple regions, which transmitted data by the opportunistic routing, are exploited to path-disjoint. The sender node transfers the data to the destination through the multiple regions at the same time. The opportunistic multipath routing protocol reduces the number of the path, which required ensuring the same reliability with the existing multipath routing protocols. This proposed routing protocol may obtain the following advantages: 1) The whole network lifetime extended by decreasing the energy consumption for multipath construction/maintenance. 2) The lower number of the path means less affecting of network scale than the existing multipath routing protocols. 3) If some nodes on the path damaged, the proposed routing protocol does not need the path recovery process because the proposed routing protocol does not predetermine the next forwarding node.

The remainder of this paper is organized as follows. In section II, we present the proposed routing protocol. The experiment result of the proposed routing protocol is presented in Section III. Finally, the paper is concluded in Section IV.

II. Opportunistic Multipath Routing Protocol

In this paper, we consider a multipath construction and a data delivery process using opportunistic routing. Therefore, we assume that several conditions are satisfied for the fundamental routing in WSNs. Every node knows the location of the sink node through location service protocol [9]. Each node knows its own position by internal GPS or other localization protocol [10] and the information about its one-hop neighbor location with beaconing.

A. Preliminary

In this section, we explain the operation process of opportunistic routing and the effect of the opportunistic routing on the multipath routing. As mentioned earlier, the opportunistic multipath routing protocol improves the transmission success ratio of each path by using the opportunistic routing. The opportunistic routing affords the all of the neighbor nodes, which received the data, the chance to transmit data exploiting the feature of the wireless medium. This will maximize the single hop transmission success ratio of the transmission node.

As an example, Fig. 1 represents a wireless network, which has a transmission success ratio. The forwarding node T selects node N_1 and achieves only 90% transmission success ratio in traditional routing protocols. However, in the opportunistic routing protocol, the forwarding node T gives all neighbor node N_1, N_2, N_3 a chance to transmit data and achieves a transmission success ratio of (1-0.9)*(1-0.9)*(1-0.9) = 99%.

The improvement of single-hop transmission success ratio can affect an end-to-end transmission success ratio prediction. The number of path of the multipath routing protocols depends on the end-to-end transmission success ratio. Therefore, the improvement of single-hop transmission success ratio by opportunistic routing increases the end-to-end transmission success ratio and decreases the number of the necessary path.

For example, in the network, which has 90 percent of the average transmission success ratio and 8-hop of the expected hop count to the destination, if an application requires 90 percent of the transmission success ratio, the single path to the destination has 43 percent of the transmission success ratio. Therefore, the source node should construct five other paths at least to guarantee the 90 percent of the transmission success ratio. However, when the opportunistic routing applies the routing process, the single path to the destination with an average of 1.5 neighbor nodes has 96 percent of the transmission success ratio. So, the source node should construct two other paths to guarantee the 90 percent of the transmission success ratio.

B. Multipath Construction Process

In this section, we explain the multipath construction process for exploiting opportunistic multipath routing. As mentioned earlier, existing multipath routing protocols calculate the number of multipath for satisfying the required transmission success ratio based on the transmission success ratio to the destination. Also, existing protocols constructs fully disjointed multipath by wireless transmission range to prevent the wireless collision or the communication congestions. It selects the node for transmitting the data within a range of each path. The existing multipath construction process is not suitable for applying the opportunistic routing for improving the transmission success ratio. The opportunistic routing, which affords the all of the neighbor nodes the chance to transmit data, cannot select the node for transmitting ahead because it does not

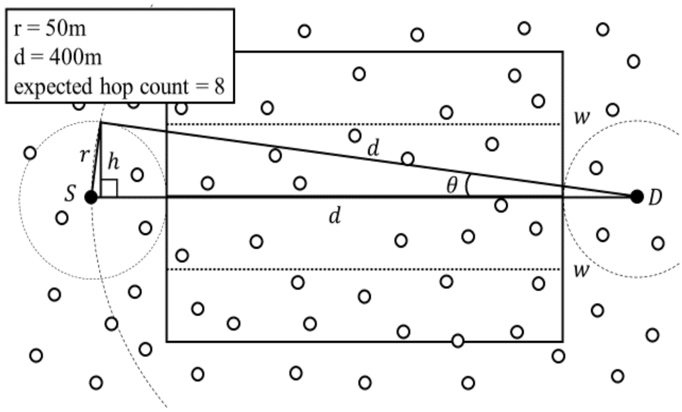

Fig. 3. A multipath construction process

Algorithm 1 Pseudocode of the multipath construction

Input: Location of the source node, Neighbor list,
 The number of neighbor nodes (n),
 Transmission range of the node (r),
 Distance from source node to destination (d),
 Required transmission success ratio ($RTSR$).
Output: The number of path (n_p),
 Path range for opportunistic routing (w)
 Starting point ($s_{x,y}[n_p]$), End point ($e_{x,y}[n_p]$).

//to calculate the path range
$h = d * \sqrt{1-(2d^2 - r^2\ /\ 2 * d^2\ )^2}$
$w = 2*h$
//to calculate the number of path
expected single hop transmission success ratio ($ESHTSR$)
 = 1-(1-average node transmission success ratio)^n
expected single path transmission success ratio ($ESPTSR$)
 $= ESHTSR^{\lceil d/r \rceil}$
$n_p = 2$
while $ESPTSR \le RTSR$
 $ESPTSR = ESPTSR^{n_p}$
 if $ESPTSR \ge RTSR$ **then**
  break;
 else
  $n_p = n_p + 1$
 end if
end while
//to select the starting point and end point.
for *each* $0 \le i < n_p$ **then**
 $s_x[i]$ = x-coordinate of the source node + h
 $s_y[i]$ = y-coordinate of the source node – $(n_p\text{-}2*i\text{-}1)*h$
 $d_x[i]$ = x-coordinate of the source node + d - h
 $d_y[i]$ = y-coordinate of the source node – $(n_p\text{-}2*i\text{-}1)*h$
end for
return w, n_p, $s_{x,y}[n_p]$, $e_{x,y}[n_p]$.

know what node may be selected.

So, the proposed protocol constructs a path that can be performed the opportunistic routing. The path has enough range to guarantee the fully disjoint multipath in a situation of exploiting opportunistic routing. The width of the path w can be calculated by the trigonometric ratio and the second law of cosines with the transmission range of node r and the distance from source node to destination d. To explain the calculation

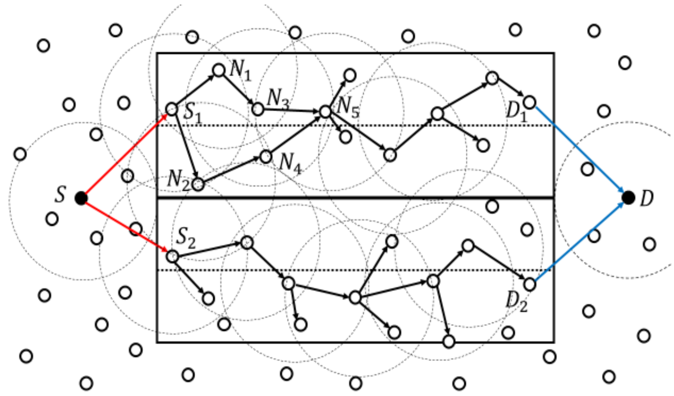

Fig. 4. A data delivery process using opportunistic routing

process of width w through Fig. 2, the width w is 2 * h, h is d * $sin\,\theta$ according to the trigonometric ratio. Also, $\sin\theta$ is $\sqrt{1-cos^2\theta}$ and $cos\,\theta$ is $d^2 + d^2 - r^2\ /\ 2 * d^2$ according to the second law of cosine. In conclusion, width w is $2 * d * \sqrt{1-(2d^2 - r^2\ /\ 2 * d^2\ )^2}$. The calculated width w means a range that has the selectable neighbor nodes for exploiting opportunistic routing.

After calculating the width of each path, the source node calculates the transmission success ratio of the single path that applied the opportunistic routing and calculates the number of the path to guarantee the required transmission success ratio. Finally, the source node allocates the path from the source node to the destination and sets the starting point and the end point of each path for transmitting data. The Algorithm 1 is the pseudo-code of the multipath construction process.

To explain the multipath construction process through Fig. 3, the coordination of source node S is (50, 200) and the coordinat ion of destination node D is (450, 200). The transmission range of each node is 50m and the distance from source node to desti nation is 400m. Also, the average transmission success ratio of each node in the network is 90 percent and the required transmi ssion success ratio of the application is 95 percent. The source node S calculates the path range w. The path range $w = 2*d*\sqrt{1-(2d^2 - r^2\ /\ 2 * d^2\ )^2}$ = 99.8m. The source node has 99 percent of transmission success ratio (= single hop transmissio n success ratio). Thus, the single path transmission success rati o is 92%. To satisfy the required transmission success ratio, the source node determines to construct two paths. Finally, the so urce node calculates the starting points and the end points. In F ig. 3, the starting points are (100, 249.9), (100, 150.1) and the e nd points are (450, 249.9), (450, 150.1).

C. *Data Delivery using Opportunistic Routing*

In this section, we explain the data delivery process through the multipath that constructed earlier. The source node transmits the copy data to each starting point. The starting points, which received copy data from the source node, transmit the data to the end points using opportunistic routing. Each transmission node should designate end point as the temporary destination. These transmission processes prevents the wireless collision or the communication congestions and guarantees the path disjoint. The some of the end point, which successfully received the data, could transmits the data to destination. The Algorithm 2 is the

Algorithm 2 Pseudocode of data delivery process of each transmission node

```
Input: Neighbor list, End point (e), Data (d)
//the node received the data from the previous node
if sequence number of d is same then
  //already received this data.
  drop the data d
else
  //the node received this data for the first time.
  start timer;
  if timer does not expired && received data from others then
     //the other node may transmit data before this node.
     drop the data d
     shut down the timer
  end if
  if timer expired then
   //the node may have high priority than other nodes.
   broadcast the data d to the neighbor nodes in direction of e
  end if
end if
return
```

pseudo-code of the data delivery process of each transmission node in the path. To explain the data delivery process through Fig. 4, the source node S transmits the copy data to each starting point S_1, S_2. The starting points will transmit data to end points as temporary destination. That is, the starting point S_1 transmits data to the end point D_1 and the starting point S_2 transmits data to the end point D_2. When the starting point S_1 performs the opportunistic routing, the transmission nodes N_1, N_2 may receive the data. If the transmission node N_1 has priority according to a baseline of the opportunistic routing and transmits the data through the opportunistic routing, the transmission node N_3 could receive the data. However, the transmission node N_2 cannot overheard the transmission of the node N_1. The transmission node N_2 will transmits the data through the opportunistic routing like the node N_1. In this case, the transmission node N_3 will try to transmit the data to N_5 through the opportunistic routing before the node N_4. After a while the transmission node N_4 will try to transmit the data to N_5 through the opportunistic routing like N_3. Then, the node N_5 receives the data from N_3 and N_4 and will handle the duplicate data and deliver the data to the end point D_2. In case of the starting point S_2, the transmission node on the path will not suffer the duplicate problem. Each node could overhear the data each other and may deliver the data to the end point D_2.

III. Performance Evaluations

In this section, we evaluate the performance of the proposed protocol compared with [4-5] which are disjoint multipath routing protocols. The purpose of simulations is verification that proposed protocol provides the energy efficiency than the comparison protocols in a similar environment.

A. Simulation model

We simulate and analyze the proposed protocol and the other protocols on NS-3.23 simulator [11]. The simulation network

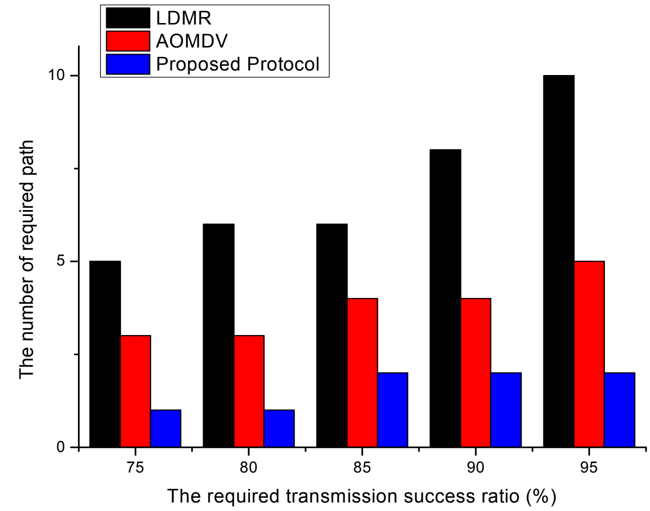

Fig. 5. The number of required path versus the required transmission success ratio.

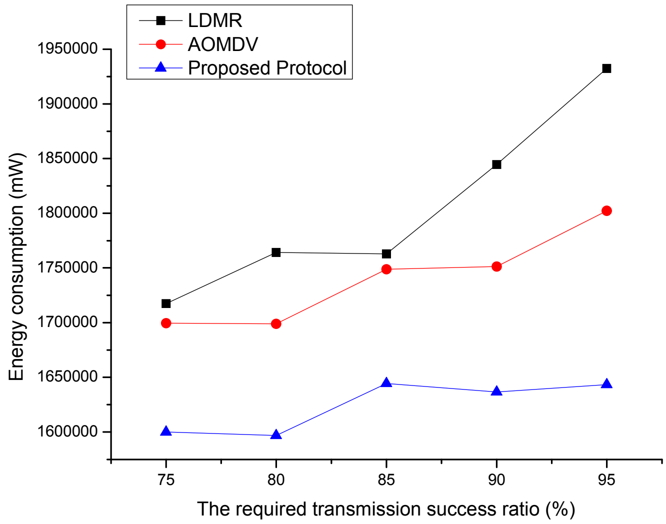

Fig. 6. The energy consumption versus the required transmission success ratio

field is 1000m x 1000m. the half of thousand sensor nodes are randomly distributed in the sensor field. The transmission range of each sensor nodes is 100m. Also, the average transmission success ratio is 85 percent and the application required transmission success ratio is 80 percent. Transmitting, receiving, and idling power consumption of sensor node rates are 33, 25, and 3mW respectively. The device parameters are chosen in reference the MICA2 specification [12]. Each simulation lasts for 1000 seconds and the source generates the data 50 times each simulation. The simulation value is the means of repeat 10 times. An evaluation items and term for our proposed protocol are as follows:

The required success ratio is defined as the ratio which required by the application.

The network size is defined as the width of the network. If the width is limited, it difficult to construct a large number of the multipath.

The required the number of path is defined as the number of

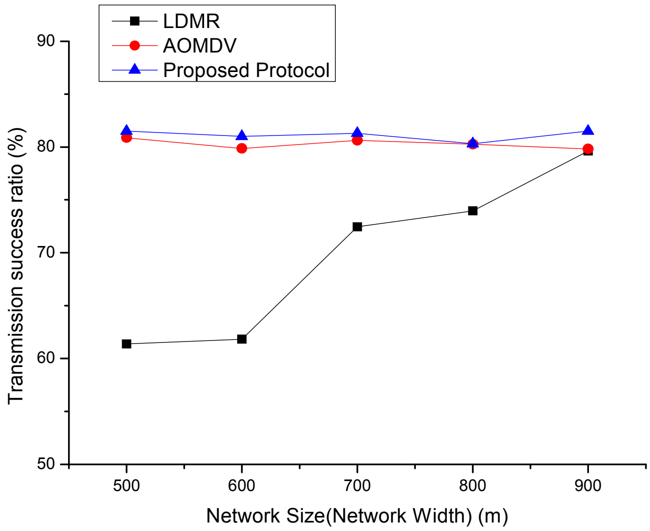

Fig. 7. The transmission success ratio versus the network size (network width)

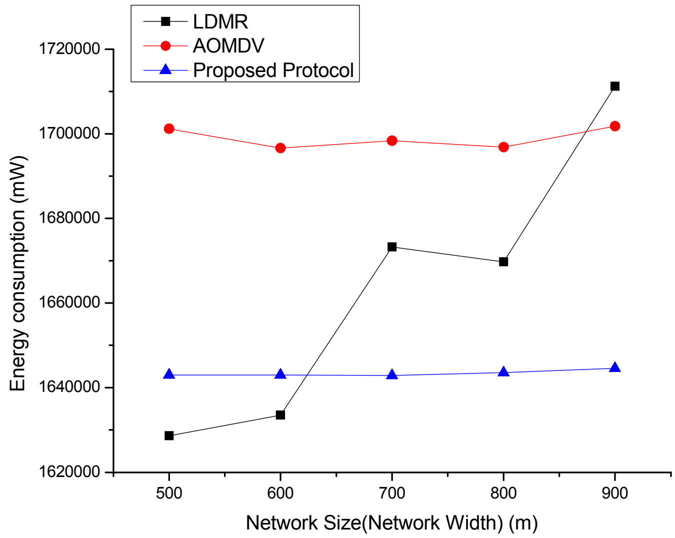

Fig. 8. The energy consumption versus the network size (network width)

path required to guarantee the required success ratio.

The transmission success ratio is defined as the ratio of the number of packet, which success to arrive to destination, to the number of the generated packet by the source node.

The energy consumption is defined as the total energy consumption of sensor nodes for the transmitting, receiving and idling. Also, it includes the energy consumption of control message to construct the multipath construction.

B. Simulation result

1) Impact of the required success ratio

Fig. 5. show the number of required path versus the required transmission success ratio. As the required transmission success ratio increased, the number of required path increased, too. the transmission success ratio of the single path has calculated based on the single hop transmission success ratio. Therefore, each protocol should construct more paths to increase the transmission success ratio. Especially, this is the only way to increase the transmission success ratio in the LDMR. It's because the LDMR exploits designated nodes on the path. However, the AOMDV constructs the multipath by broadcasting of sink node. the source node in AOMDV can flexibly exploit the different node than the LDMR. The proposed protocol has fewer number of the path. It's because the proposed protocol exploits the opportunistic routing. The opportunistic routing increases the single hop transmission success ratio. So, the proposed protocol has high single path transmission success ratio and fewer number of the path than the other protocols. Fig. 6 shows the energy consumption versus the required transmission success ratio. As the required transmission success ratio increased, the energy consumption of Fig. 6, in common with Fig. 5, increased, too. The energy consumption is related to the number of the path. Therefore, The LDMR, which has the largest number of paths, consumes the more energy than other protocols. The AOMDV consumes the high energy in comparison with the number of paths. It's because the AOMDV exploits the broadcasting to construct multipath in the network initialization phase. So, the energy is consumed in the multipath construction process. However, the proposed protocol does not perform the broadcasting to construct multipath like the AOMDV and does not need many paths to guarantee the transmission success ratio like the LDMR.

2) Impact of the network size

Fig. 7 show the transmission success ratio versus the network size. When the network size is small, the transmission success ratio of LDMR is significantly lower than other protocols. It's because the LDMR requires the enough network size to construct multipath. That is, the LDMR could not construct the enough number of the path in small network. It leads to the decrease in the transmission success ratio. The proposed protocol constructs multipath like the LDMR, but the proposed protocol exploits the opportunistic routing. So, the transmission success ratio of the proposed protocol is unaffected by the network size because the proposed protocol does not need many paths like the LDMR. However, the transmission success ratio of the AOMDV is unaffected by the network size because the AOMDV constructs the multipath by broadcasting. Fig, 8. Show the energy consumption versus the network size. As the network size increased, the energy consumption of Fig. 8, in common with Fig. 7, increased, too. When the network size is small, the energy consumption of LDMR is significantly lower than other protocols like Fig. 7. It's because the LDMR could not construct the enough number of path due to the network size constraint. However, as the network size is increased, the energy consumption is significantly increased. Unlike the LDMR, the AOMDV and the proposed protocol is unaffected by network size. It's because the AOMDV constructs the multipath by broadcasting in the network initialization phase and the proposed protocol does not need many paths like the LDMR due to the high transmission success ratio of the single path. However, the AOMDV consumes the much energy than the proposed protocol because the AOMDV exploits the broadcasting.

IV. CONCLUSIONS

The reliability is an important factor in the wireless sensor network. For improving the reliability, the multipath routing protocols have been studied. However, the network scale should be sufficient for constructing multipath to guarantee of the disjoint path and the energy consistently is consumed for multipath construction/maintenance. The excessive energy consumption lead to the reduction of whole networks life time and the restricted network scale may not even ensure the enough reliability. Thus, we proposed the multipath routing protocol which exploits the opportunistic routing for energy efficiency and releasing the network scale restriction. The proposed protocol constructs the large enough path to exploit the opportunistic routing and calculates the number of path to guarantee the required transmission success ratio. The source node transmits data to destination using the opportunistic routing through the constructed path. Then, the proposed protocol has similar transmission success ratio and low-cost energy consumption in comparison with existing multipath routing protocols in the same environment. The simulation results show the proposed protocol has better energy efficiency with similar transmission success ratio in comparison with existing multipath routing.

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