Energy Aware Opportunistic Routing in Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks (WSNs) have been increasingly considered an attractive solution for a plethora of applications, such as unattended event monitoring and tracking. Energy consumption is one of the looming challenges that threaten the successful deployment of these networks, especially when they are designed to operate unattended for long periods of time. In this paper, we are introducing an Energy-Aware Opportunistic Routing protocol (EAOR), for Wireless Sensor Networks, which keeps a balance between the Quality of Service (QoS) and the energy efficiency. The main objective is to maximize network lifespan without increasing the packet delay. We conduct experiments by simulations to evaluate the performance of the proposed protocol against existing ones, in terms of throughput and energy consumption. The experimental results demonstrated that the proposed protocol can deliver better energy distribution, extends the network lifetime up to 25% compared to simple opportunistic routing protocols and decreases the total energy consumption by 35% compared to traditional routing.**

I. INTRODUCTION

Wireless Sensor Networks have a great potential in a variety of applications, such as event monitoring and tracking. Recent advancement in wireless communications and electronics has enabled the development of low-cost, low-power, multi functional sensor nodes that are small in size. However, the unique characteristics of sensor nodes and their wireless communication can pose significant challenges.

Energy consumption is the major challenge in most sensor networks. Usually, sensor networks are designed to operate unattended for long periods of time because battery replacement or rechargeability is sometimes infeasible or impossible. Therefore, the battery charge must be conserved to extend the life of each sensor and the entire sensor network. When applying a routing protocol to a sensor network, the impact that this protocol has on the lifetime of the sensor should always be considered. Energy efficiency should be one of the main concern in the design of the routing protocols for wireless sensor networks. However, in many real-time applications such as industrial process control monitoring and intruder detection [1], the throughput is critical and of prominent concern.

In the design of a routing protocol for wireless sensor networks, the duty cycle mechanism has been adopted, in order to conserve energy [2, 3]. The nodes are at a sleep stage for most of the time, while they wake up for a small fraction of the time. Although the nodes can save energy under low duty cycle protocols, the throughput constrain may not be guaranteed.

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In [4], a detailed cross-layer network architecture was proposed for cognitive networks, based on a new definition of wireless linkage. The new abstract wireless links are redefined as arbitrary mutual co-operations among a set of neighboring (proximity) wireless nodes. In comparison, traditional wireless networking relies on point-to-point ”virtual wired-links” with a predetermined pair of wireless nodes and allotted spectrum. To support multihop wireless communications, a wireless unicast module is introduced under the cognitive networking architecture, which integrates opportunistic routing in providing reliable and high performance end-to-end communications in large-scale wireless sensor networks. In [5], the effect of the network scalability on the performance is further investigated.

The main contribution of this paper is the introduction of an *Energy Aware Opportunistic Routing protocol (EAOR)*, designed for WSNs. EAOR includes crucial energy information exchange along with location information exchange, during the well-know RTS/CTS handshake of opportunistic routing protocols [6]. The core techniques adopted include energy information exchange between the wireless sensor node and the battery as well as relay node prioritization according to the energy level. Extensive experiments are also conducted by simulations, to evaluate the performance of the proposed protocol and compare it with other approaches. The experimental results demonstrated that the proposed protocol can extend the network lifetime.

The rest of this paper is organized as follows. In Section II, the related work is reviewed. The considered routing protocols are presented in Section III while the performance evaluation and simulation results are presented in Section IV followed by conclusions in Section V.

II. RELATED WORKS

The idea of opportunistic routing according to location information was first introduced in [7, 8]. In *Geographic Random Forwarding, (GeRaF)*, each packet carries the location of the sender and the destination and the prioritization of the candidates nodes is based on location information. This technique is simple to be implemented but it does not have any energy constrain. A *Real-time Opportunistic Routing Protocol, (ORTR)* was introduced in [9]. In this approach, the transmission power can be adjusted to follow the delay constrains. However, when a low duty cycle is applied, the forwarded area may not contain any nodes. This is because the neighboring nodes cannot hear a node when it broadcasting. An *Energy-Aware Real-Time Opportunistic Routing, (EARTOR)* is proposed in [10]. EAORTOR tries to maximize the number of requests realized when dealing with sequence of requests. The main restriction is that the requests should arrived one by one. Energy-Aware Opportunistic Routing (EAOR) is then proposed to bridge those gaps mentioned above.

III. ROUTING PROTOCOLS

In this section, a description of a traditional routing, followed by opportunistic routing and the energy aware opportunistic routing is given. Traditional routing will be used as an example of a single hop routing while the other two are multi hop routing protocols.

A. Traditional Single-Hop Routing

Traditional routing that was implemented is based on global route optimization and starts with an initialization phase. The destination node broadcasts a number of packets and every node in the network keeps broadcasting these packets to its neighboring nodes. Some of the packets will be lost due to the *Packet Error Rate* (PER) between the communicating nodes. When this phase is over, every node will know the PER of all the links that this node has with its neighboring nodes. It will also know, the number of the hops that are needed to reach the destination through a number of different paths and the related distance. The PER can be calculated as in [5].

The source node will select the path toward the destination according to the distance from the destination and the link reliability. The selected path will be the shortest path toward the destination consist of links with PER less or equal to a predefined *reliability threshold*, PER_{th}. A link i between a node and one of its neighboring nodes will be considered to be in the path only if $PER(i) \leq PER_{th}$. Finally, from those links the node will always forward the packet over the one that leads to the neighbor which is closer to the destination. All the packets will be delivered to the destination following the same path.

Traditional routing uses two types of packets: DATA and acknowledgment (ACK). When a node transmits a packet, it will store a copy in its buffer and will wait for the ACK. If no ACK is received, either because the DATA packet or the ACK packet was lost, the node will retransmit the DATA packet.

In order to avoid collisions in this protocol, there is a global scheduler that prioritize packet transmissions. The node that is closer to the destination will transmit the packet first while any other node that wants to transmit at the same time will go back to sleep mode. The global scheduler will wake up this node only when it can transmit the packet. The nodes avoid retransmission due to collision because of the use of a global scheduler that decides when a node will transmit the data. In this case the result can be an upper-bound for traditional routing protocols.

B. Opportunistic Routing

Opportunistic routing follows similar approach to [11]. There are four types of packets: Request To Send (RTS), Clear To Send (CTS), DATA and ACK. All the packets transmissions are subjected to PER, while there is no global scheduler.

When a node has a DATA packet to transmit, it stores the packet in a buffer and then broadcasts a RTS packet for this DATA packet to all the neighboring nodes and will wait for a CTS packet. When a neighboring node, n, receives a RTS packet from the transmitter node t, it will reply with a CTS packet after time $T_{Backoff}$, equals to:

$$T_{Backoff} = \frac{C_0}{D_{t,d} - D_{n,d}} + SIFS, t \neq d \quad (1)$$

where $D(t,d)$ is the distance between the transmitter node t and the destination node d, SIFS is the Short Interframe Space and C_0 is a constant related to the distance metric.

The transmitter node will forward the DATA packet to the neighboring node that will reply first with a CTS packet. $T_{Backoff}$ is inverse proportional to the difference $D(t,d) - D(n,d)$. The neighboring node that is closer to the destination will have the smallest $T_{Backoff}$ and will try to reply first with a CTS packet. Any CTS that will arrive to the transmitter after the first one, will be ignored. Any neighboring node that is still during its $T_{Backoff}$ and listen a DATA packet transmission, will drop the CTS packet and go back to sleep mode. If there is no ACK, the node will transmit the DATA packet again to the same node.

As it can be inferred from Eq.(1), the selection criterion of this opportunistic routing protocol is the distance between the node and the destination.

In this approach, the routing path changes dynamically according to the network conditions in every time slot. Opportunistic routing tries to take advantage of the broadcast nature of wireless communications. Since there is no reliability threshold, this approach can follow paths toward the destination that needs less hops than traditional routing. Moreover, in every packet transmission the number of the successfully transmitted RTS and/or CTS packets is different, leading to different next nodes and different paths towards the destination.

C. Energy Aware Opportunistic Routing (EAOR)

Energy Aware Opportunistic Routing (EAOR) follows a similar transmission approach as the opportunistic routing. However, the main difference of this approach is the next relay node selection criterion. The relay node that will reply first to a RTS packet is different than that of opportunistic routing. When a neighboring node, n, receives a RTS packet from the transmitter node t, it will reply with a CTS packet after time T_{en_aware}, equals to:

$$T_{en\_aware} = \frac{C_0}{D_{t,d} - D_{n,d}} + \frac{Cons_{energy}}{C_1} + SIFS, t \neq d \quad (2)$$

where $D(t,d)$ is the distance between the transmitter node t and the destination node d, $Cons_{energy}$ is the consumed energy of the neighboring node up to the time that it received the RTS packet and $C1$ is a constant related to the distance metric.

As it can be inferred from Eq.(1) and Eq.(2), the difference between the two opportunistic schemes is the backoff time that the neighboring node has to wait before reply with a CTS packet. In energy aware opportunistic routing, a node checks its energy level. If the energy level is low, it does not reply with a CTS. In this way, the lifespan of each node is extended. When a node has high energy consumption, the probability to get a DATA packet is lower. However, the node can still participate in some of the DATA packet transmissions. If a neighboring node has high energy level, but it is not that close to the destination in comparison with other neighboring nodes, it will start participating in packet transmissions when some of the neighboring nodes consumed too much energy.

Energy aware opportunistic routing tries to transmit the packets over nodes that are close to the destination and also have high energy level. In this way, it can discover more routing paths compared to the opportunistic routing. These paths does not always consist of similar number of hops that the opportunistic paths, however, they consist of nodes that have not been used that much and have high energy levels.

IV. PERFORMANCE EVALUATION AND SIMULATION RESULTS

The discrete event simulation system, OMNeT++ [12], was used for simulations in this work. Three routing protocols were examined: traditional single-hop routing, location-aware opportunistic routing and energy-aware opportunistic routing.

A. Experimental setup

The sensor nodes were uniformly randomly distributed over a $120 \times 120(m^2)$ network field. Each node has a transmission range of 12 meters. For traditional routing the reliability threshold was set at 20% while for the two other protocols we consider links with PER up to 80%. The communication parameters were chosen based on IEEE 802.15.4 and are listed in Table I while the simulation and energy consumption parameters are listed in Table II.

Parameter	Unit	Value
$Length\ of\ the\ data\ (F_d)$	*bit*	100×8
$Wireless\ channel\ path\ loss\ component\ (n)$		2.5
$Constant\ decided\ by\ the\ antenna\ gain\ (A)$	*dB*	-31
$Noise\ Power\ (\sigma_n^2)$	*dBm*	-92

TABLE I: Communication Parameters Setup

Parameter	Unit	Value
$DATA\ packet$	*bit*	100×8
$RTS/CTS\ packet$	*bit*	8×8
$ACK\ packet$	*bit*	8×8
$SIFS$	*µs*	10
$TransmittingPower$	*mW*	15
$ReceivingPower$	*mW*	10
$TransmissionRate$	*kbps*	250
C_0		0.001
C_1		1000

TABLE II: Simulation Parameters

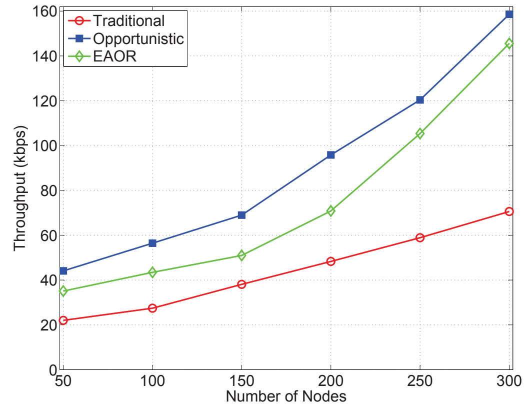


Fig. 1: Throughput under different number of nodes.

B. Performance metrics

The performance of the three routing protocols will be examined in terms of throughput, total energy consumption, network lifetime and energy distribution among the nodes.

1) Throughput: Throughput is the number of bits divided by the time needed to transport the bits. A number of 100 packets were successfully transmitted from the source to the destination node. The throughput for each protocol and for each network configuration can be seen in Figure 1.

Traditional routing has the lowest throughput over all the other protocols. All the packets follow the same path which is the shortest path that consists of the most reliable links. A packet error or a node failure will delay all the consequent packet transmissions, increasing the delay of the packets and decreasing the throughput. As the number of the nodes in the network increased, there are more reliable paths towards the destination that require less hops and the throughput is increased.

Opportunistic routing performs better over the other two approaches. The next node selection criterion of this approach is the location. It tries to transmit each packet over the path that has the smallest number of hops under the network conditions at the transmission time. For a large number of nodes, the number of the paths is increased and as a consequence throughput is enhanced.

Energy aware opportunistic routing performs worse than opportunistic routing. The reason is that the selection criterion of this approach is a combination of the smallest available path at the transmission time and the energy of the nodes that are in this path. When a neighboring node has participate in many packet transmissions and it has low energy level, this approach will not keep using this node, even if it can deliver the packets to the destination in less number of hops. It is obvious that this will affect throughput performance. However, as the number of the nodes is increased, there are more paths consist of nodes with high energy level and energy aware opportunistic routing tends to have similar performance with opportunistic routing.

2) Total Energy Consumption: The energy consumption is evaluated by simplifying the power consumption of the battery operated nodes. For simulation purposes, the node

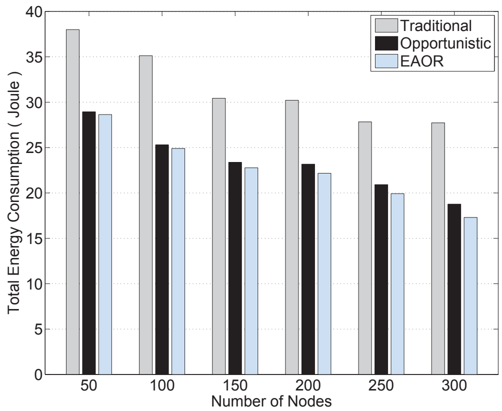


Fig. 2: Total energy consumption under different number of nodes.

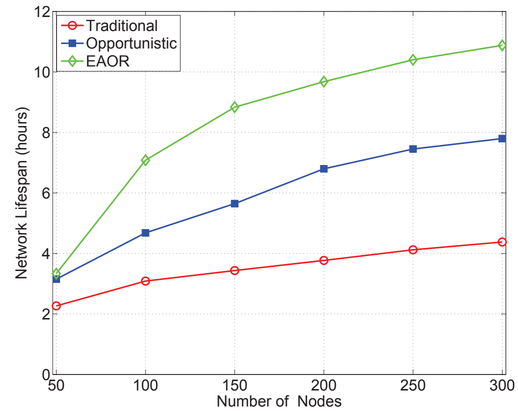


Fig. 3: Network lifetime under different number of nodes.

power consumption in transmitting and receiving/idle modes be denoted by P_{trans} and P_r/i respectively. The sleeping mode power consumption is practically 1000 times smaller than P_{trans} and P_r/i, which is negligible. The source node transmits 100 packets toward the destination node.

Figure 2 shows the total energy consumption of the network for the three different protocols. EAOR performs up to 35% better than traditional routing.

Traditional single hop routing has the worst performance over all the three protocols. This approach keeps using the same nodes for every packet transmission. If a packet is lost or damaged and has to be rescheduled, all the consequent packet transmissions have to be buffered and delayed. The nodes have to remain active for higher time and the energy consumption is higher.The other two protocols are multi-hop and are able to discover different paths toward the destination, leading to better performance in terms of total energy consumption.

Energy aware opportunistic routing performs slightly better than location aware opportunistic routing. The reason is the next node selection criterion. Energy aware opportunistic routing tries to discover paths toward the destination that have less number of hops but also consists of nodes that have high remaining energy. As the number of the nodes in the network increased, the number of the nodes with high remaining energy increased, leading to more paths toward the destination for the energy aware protocol. As a consequence, the difference in the total energy consumption between the two protocols also increased.

3) Network lifetime: Network lifetime is defined as the interval between the beginning of a packet transmission of the network time until the first node failure due to battery depletion. Under the assumption that the sensor nodes operating on a pair of AA batteries with $1000mAh$ capacity, each sensor node will have an initial energy of:

$$\begin{aligned} \textit{Initial Energy (J)} &= capacity(Ah) \times voltage(V) \times time(s) \\ &= 1 \times 2 \times 1.5 \times (60 \times 60) = 10800J \end{aligned} \tag{3}$$

According to the simulation results, Firure 3 shows the network lifetime under the different protocols. EAOR performs up to 25% better than single opportunistic routing.

Traditional routing keeps using the same nodes for packet transmission, resulting to the lowers network lifetime. Moreover, when one of the nodes that participate in the packet transmission runs out of energy, the packets can't reach the destination and there should be another initialization phase in the network to find another path. The other two approaches do not require an initialization phase after the first node battery depletion because they can dynamically change the path and use nodes that they do have energy to transmit the packet.

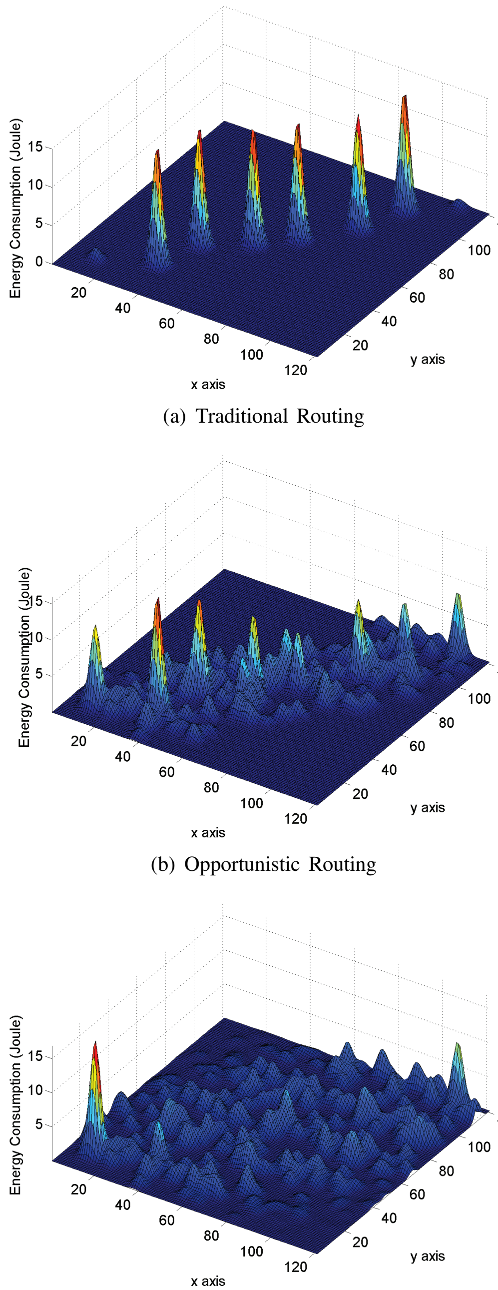
Opportunistic routing performs better than traditional routing but worse than energy aware opportunistic routing. Energy aware opportunistic routing tries to maximize the network lifetime. It can discover paths that consist of nodes with high energy level while it also avoid using nodes that they already have participate enough times in packet transmission. As the number of the relay nodes increased, the number of the possible paths also increased, leading to an increase at the network lifetime.

4) Energy Distribution: Energy distribution is used to illustrate the energy consumption of each node in the network. The network consist of 300 nodes, uniformly and randomly distributed.

Figure 4 shows the energy distribution for the three different protocols. As illustrated in Figure 4(a), traditional routing uses the same nodes toward the destination. Energy consumption at those nodes is high, while the rest of the nodes in the network consumes negligible energy during idle state.

Opportunistic routing uses different paths toward the destination by using different nodes, Figure 4(b). The selection criterion of these nodes in the distance of each node from the destination. Hence, the energy distribution is better than traditional routing. The nodes that are used are close to the shortest path between the source and the destination.

Energy aware routing performs better over all the other two approaches in terms of energy distribution, Figure 4(c). It uses nodes that are close enough to the destination and also have enough energy consumption. Some of the nodes that are used, might be away from the shortest path between the node and the



(a) Traditional Routing

(b) Opportunistic Routing

(c) Energy Aware Opportunistic Routing

Fig. 4: Distribution of energy consumption in the network.

destination. However, the total energy consumption is better than opportunistic routing, as it was shown in Figure 2.

According to the simulation results depicted in Figure 4, after transmitting the same number of packets the maximum energy consumption in a single node in traditional routing is 15J, in opportunistic routing is 12J and in EAOR is 7J.

V. CONCLUSION

In this paper, an energy-aware opportunistic routing protocol for wireless sensor network was introduced. The proposed protocol tends to balance energy consumption and quality of service. Simulation results have shown that EAOR has similar performance with opportunistic routing, in terms of throughput in large scale networks, while energy distribution is higher, network lifespan is significantly extended up to 25% compared to single opportunistic routing and total energy consumption is better up to 35% compared to traditional routing.

REFERENCES

[1] Junyoung Heo, Jiman Hong, and Yookun Cho, "Earq: Energy aware routing for real-time and reliable communication in wireless industrial sensor networks," *IEEE Transactions on Industrial Informatics*, vol. 5, no. 1, pp. 3 –11, Feb. 2009.

[2] Feng Wang and Jiangchuan Liu, "Duty-cycle-aware broadcast in wireless sensor networks," *in Proceedings of IEEE INFOCOM conference*, pp. 468 – 476, April 2009.

[3] Yu Gu and Tian He, "Dynamic switching-based data forwarding for low-duty-cycle wireless sensor networks," *IEEE Transactions on Mobile Computing*, vol. 10, no. 12, pp. 1741 –1754, Dec. 2011.

[4] Liang Song and Dimitrios Hatzinakos, "Cognitive networking of large scale wireless systems," *Int. J. Commun. Netw. Distrib. Syst.*, vol. 2, no. 4, pp. 452–475, June 2009.

[5] Petros Spachos, Liang Song, and Dimitrios Hatzinakos, "Comparison of traditional and opportunistic multihop routing in wireless networking scalability," *in Proceedings of the 26th Biennial Symposium on Communications (QBSC 2012)*, May 2012.

[6] Sanjit Biswas and Robert Morris, "Opportunistic routing in multi-hop wireless networks," *SIGCOMM Comput. Commun. Rev.*, vol. 34, no. 1, pp. 69–74, 2004.

[7] Michele Zorzi and Ramesh R. Rao, "Geographic random forwarding (geraf) for ad hoc and sensor networks: Energy and latency performance," *IEEE Transactions on Mobile Computing*, vol. 2, no. 4, pp. 349–365, 2003.

[8] Michele Zorzi and Ramesh R. Rao, "Geographic random forwarding (geraf) for ad hoc and sensor networks: Multihop performance," *IEEE Transactions on Mobile Computing*, vol. 2, no. 4, pp. 337–348, 2003.

[9] Junwhan Kim and Binoy Ravindran, "Opportunistic real-time routing in multi-hop wireless sensor networks," *in Proceedings of the ACM symposium on Applied Computing (SAC)*, pp. 2197–2201, 2009.

[10] Wei Yang, Weifa Liang, and Wenhua Dou, "Energy-aware real-time opportunistic routing for wireless ad hoc networks," *in Proceedings of the IEEE Global Communications Conference (GLOBECOM 2010)*, pp. 1–6, Dec. 2010.

[11] Petros Spachos, Liang Song, and Dimitrios Hatzinakos, "Performance comparison of opportunistic routing schemes in wireless sensor networks," *in Proceedings of the Ninth Annual Communication Networks and Services Research (CNSR 2011) conference*, pp. 271–277, May 2011.

[12] OMNeT++ discrete event simulator, "http://www.omnetpp.org," .