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Opportunistic Routing Protocols for Wireless Sensor Networks: A Survey

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Abstract**:** ***One of the most discussed topics in Wireless Sensor Network (WSN) is the routing protocol used in the networks. These protocols largely affect the performance and the lifetime of the network as transmission of data uses a significant proportion of the total energy in WSNs. The sensors in WSNs run using batteries thereby making energy consumption an important design constraint for them. Over the years a number of protocols have been suggested and implemented, however even today a lot of research is done on routing protocols for WSNs as a part of the continuous effort to increase the lifespan of these networks. Opportunistic routing (OR) is a concept which is a combination of routing protocol and media access control. This paper gives an overview of the concept of OR and discusses its variants.***

Keywords: Wireless sensor networks, Routing protocols, Opportunistic routing, ExOR, EAOR, EQGOR, EFFORT, R3E, OWR

I. INTRODUCTION

Wireless Sensor Networks (WSNs) refer to a network of distributed sensor nodes which monitor a particular environment. The number of sensors in the networks may vary from a few hundreds to several thousand nodes depending on the application. The applications may be as simple as a network monitoring the temperature or humidity levels of a given region or maybe complex military applications which require self-organizing nodes. The sensors in WSN are generally battery-driven; one common requirement irrespective of the application is that the network should have a long lifespan and should not require constant replacement of the battery driving the sensor.

The transceiver in the sensor is responsible for communication with neighboring nodes and also for the transmission of monitored parameters to the sink node. Irrespective of the application the main task of the sensor nodes as shown in Fig 1 is to sense and collect data from a target domain, process the obtained data and transmit the sensed data back to the point of analysis. This process of communication consumes a significant percentage of the overall energy dissipated. Hence, the routing protocols used greatly impact the power consumption, due to which a constant effort is made to improve the efficiency of these protocols.

Routing protocols for WSNs has been a popular topic of research for almost a decade now. There has been a lot of documentation which describe the issues related to routing in WSNs and one of the early papers by Rajashree.V.Biradar et. al. lists and analyses the issues in design of routing protocols [1]. The routing problem as described in [2] presents a very difficult challenge of trade-off between responsiveness (which leads to a lot of overhead due to the continuous exchange of status signals between the nodes) and efficiency. The overhead in a WSN is measured primarily in terms of bandwidth utilization, power consumption, and the processing requirements on the mobile nodes. Hence, the trade-off must also take into account the limited processing capacity and energy constraints of the sensors in the network. The real challenge in designing a routing protocol is balancing the requirements and the constraints of a WSN.

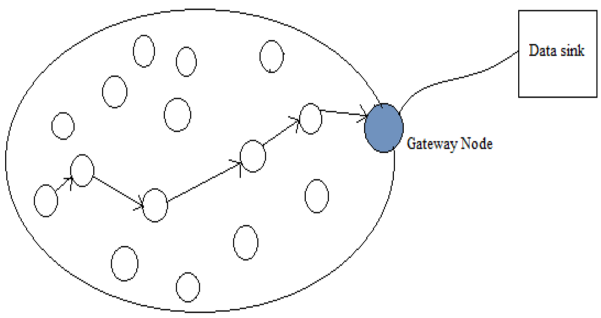

Fig. 1**:** Typical Wireless Sensor Network

This paper is a survey on opportunistic routing (OR) protocol which was introduced about a decade ago, originally designed for Ad Hoc wireless networks but over the years has been modified and adapted to enhance the performance of WSNs by optimizing the routing protocols. The algorithm was designed to transmit packets of the Internet Protocol, which when successfully done would also enable a number of other services.

The rest of this paper is organized into sections. Section II provides a brief overview of the concept of opportunistic routing protocol. Section III discusses the variants of the basic OR protocol and section IV gives a comparative study of the same and Section V concludes the paper.

II. OPPORTUNISTIC ROUTING

The initial work on opportunistic routing was published by Sanjit Biswas and Robert Morris of the MIT Artificial

Intelligence Laboratory in [3]. They called their proposed protocol Extreme Opportunistic Routing (ExOR).

The prerequisites for ExOR to work is the presence of a loss-rate-matrix, which contains the probability of successful reception of a packet between each pair of nodes built using link-state flooding or a similar scheme. The forwarding-decision is based on a set of forwarding candidates, which are included in the header of the packets and prioritized by distance. The so obtained forwarding node then retransmits the packet, using a new set of forwarding candidates.

The protocol consists of three main stages: selecting the forwarding nodes, acknowledging transmissions, and deciding whether to forward a received packet.

- The decision which algorithm to use for selecting the forwarding nodes is a very important for the strength of ExOR. A node which wants to forward a packet to a destination identifies the shortest path to this it and creates a loss-rate-matrix. The first node in this path is considered a good candidate for the forwarding job. It's then deleted from the loss-rate-matrix and the whole process is repeated, until the set of forwarding candidates is full.
- ACKs are sent by the forwarding candidates, in the order in which they appear in the packet header. Each ACK contains the ID of its sender and the ID of the highest priority successful recipient known to the ACK's sender. All candidates listen to all slots, before deciding whether to forward a packet or not, thereby suppressing duplicate forwarding to a certain degree.
- All nodes receive not only the packet but also a large subset of acknowledgements using which they can easily decide whether they act as the forwarding node: The packet is forwarded if the highest known ACK-ID is not greater than or equal to the ID of the node itself.

III. VARIANTS OF OPPORTUNISTIC ROUTING PROTOCLS

There have been many versions of opportunistic routing algorithm which have been introduced with minor variations in the process of selecting the forwarding node. While these algorithms inherit the basic advantages of OR algorithm on one side, on the other side they focus on enhancing their performance by using a suitable parameter for selecting the forwarding node. This parameter is dependent on the topology, network and the application requirement. A few of them are discussed in the consecutive subsections and the next section gives a comparative study of the same based on the parameters used in the form of Table I.

A. OPPORTUNISTIC ROUTING FOR WSNS (ORW)

Opportunistic Routing for WSNs (OWR) in [4] is a practical OR scheme for WSNs which extended the original ExOR design for mesh networks. This protocol is designed for a duty-cycled setting and packets are addressed to sets of potential receivers are forwarded by the neighbor that wakes up and successfully receives the packet. This reduces delay which occurs when the source waits for a particular node to wake up and energy consumption for the overall transmission in the network by utilizing all neighbors as potential forwarders.

The protocol functions as follows:

- The sender checks for neighboring nodes which are awake and with minimum EDC which is a parameter defined as the sum of the expected time to reach a potential forwarder, the time to travel from the next hop to the final destination and a small constant accounting for the cost of forwarding.
- When the neighboring nodes wake up; it mainly relies on overhearing and checks for energy on the channel. If the channel is busy the node goes back to sleep; if it is free and the node subsequently receives a packet, then forwards it when providing routing progress and it updates its link quality estimate.
- Unique forwarder selection uses a lightweight coordination protocol to determine a unique forwarder in case the packet was received by multiple nodes.

B. ENERGY-AWARE OPPORTUNISTIC ROUTING PROTOCOL (EAOR)

Energy-Aware Opportunistic Routing protocol (EAOR) described in [5], 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. The difference between this approach and traditional ExOR protocol is the next relay node selection criterion and back-off time that the neighboring node has to wait before reply with a CTS packet.

The protocol functions as follows:

- The transmitter node sends a RTS packet to its neighboring nodes.
- When a neighboring node receives a RTS packet from the transmitter node t, it will reply with a CTS packet after time T.
- A node checks its energy level. If the energy level is low, it does not reply with CTS. In this way, the lifespan of each node is extended.
- If the energy level is high it will respond with CTS and become a forwarding node. If two or more nodes have the same energy levels, the node closer to the destination is preferred.

However, a node with relatively low energy can still participate in some of the DATA packet transmissions if a neighboring node has high energy level and it is not close to the destination (in comparison with other neighboring node) or when some of the neighboring nodes consumes too much energy to be selected as the forwarding node.

The time T is dependent on the distance between the transmitter node t and the destination node d, CE the consumed energy of the neighboring node up to the time that it received the RTS packet and a constant related to the distance metric.

Energy aware opportunistic routing tries to transmit the packets over nodes that are close to the destination and also have high energy level.

C. EFFORT PROTOCOL

The EFFORT framework proposed in [6] focuses on preventing the critical sensors from draining their energy, and, thus, prolonging the lifetime of a WSN rather than aiming to reduce the end-to-end energy cost by selecting the next-hops that have shortest geographic distances to the destination.

Scarcity Energy Cost (SE-Cost) of energy consumption for a sensor is defined as a function of residual energy. SE-Cost can be viewed as the damage to the network-lifetime, and the proposed OEC metric aims at minimizing the overall SE-Cost of each end-to-end transmission to prolong the lifetime.

OEC indicates the opportunistic end-to-end SE-Cost from a node s to the sink, which equals the sum of the SE-Cost of transmitting data from s, the SE-Cost of receiving data by all forwarders, the opportunistic end-to-end SE-Cost from its forwarders to the sink, and the SE-Cost of retransmission.

A two-stage heuristic forwarder-selection algorithm enables each sensor to efficiently decide its forwarding set that performs almost as well as the optimal one does. First, in Extraction Stage each sensor prunes the neighbors that must not be its forwarder, narrowing the possible candidates down to a smaller set.

Second, in Inclusion Stage, s initializes its forwarding set Fs as an empty set and iteratively chooses the neighbor that has the smallest IEC (Independent End-to-end Cost) value and puts it into Fs until the OECs value cannot be improved, i.e., decreased.

This protocol functions as follows:

- When a sensor needs to send or relay packets, it broadcasts those packets, which can be overheard by the candidates in its forwarding set F.
- If the node receives data to be sent to a particular destination from the sender correctly then, each forwarder in F sequentially relays the packets according to the optimal relay sequence of F.
- Once a forwarder in F relays the packets, it issues an ACK message that notifies sender s to terminate data forwarding.
- The forwarder can piggyback the information about its residual energy, link reliability, and its updated OEC value in the ACK message.
- Upon receiving ACK, sender s can update its OECs value based on the information embedded in ACK packet received.

D. EFFICIENT QoS-AWARE GOR (EQGOR)

Efficient QoS-aware GOR (EQGOR) protocol introduced in [7] tries to improve the QoS of the WSN by selecting and prioritizing the forwarding candidate set in a manner that considers energy efficiency, latency, and time complexity.

In traditional Geographical routing algorithm (GOR) [10] it was noticed that most forwarding tasks for each hop are taken by the first two or three candidates in the ordered forwarding candidate set. If this property is exploited a node may only need to order a very small number of candidates to obtain a close optimal solution, by which the algorithm's time complexity can be effectively reduced. The protocol's forwarding candidate selection functions as follows:

- For sending node the forwarding candidates set, C consists of nodes are sorted in a descending fashion according to a metric based on the Single hop packet progress and packet reception ratio.
- Initially, the first node of the candidate set is placed into the forwarding set F and removed from C. Then, it is checked if nodes in C in sequence, are within the transmission range of any node in F, if not it will be eliminated.
- The searching procedure is to try every possible inserting position in F, and calculate the expected single-hop packet speed values.
- For the remaining nodes in C, candidates will be selected to meet the hop QoS requirements at a minimum cost by simply appending to F.

EQGOR achieves a good balance between these multiple objectives, and has a very low time complexity, which is specifically tailored for WSNs considering the resource limitation of sensor devices.

E. RELIABLE AND ENHANCED ENERGY-EFFICIENT ROUTING (R3E)

Reliable and Enhanced Energy-Efficient Routing or R3E in [8], is a middle-ware design across the MAC and the network layers to increase the resilience to link dynamics for WSNs. The R3E enhancement layer consists of three main modules:

- Reliable route discovery module: It finds and maintains the route information for each node. During the route discovery phase, each node involved in the cooperative forwarding process stores the downstream neighborhood information.
- Potential forwarder selection and prioritization module: Responsible for the runtime forwarding phase and attaching ordered forwarder list in the data packet header for the next-hop.
- Forwarding decision module: When a node successfully receives a data packet, the forwarding decision module checks whether it is one of the intended receivers. If yes, this node will cache the incoming packet and start a back-off timer to return an ACK-message. If there is no other forwarder candidate with higher priority transmitting an ACK before its back-off timer expires, it will broadcast and ACK and deliver the packet to the upper layer,i.e., trigger a receiving event in the network layer. Finally, the outgoing packet will be submitted to the MAClayer and forwarded towards the destination.

R3E is designed to enhance existing routing protocols to provide reliable and energy-efficient packet delivery against the unreliable wireless links by utilizing the local path diversity. A back-off scheme during the route-discovery phase to find a robust guide path provides more cooperative forwarding opportunities. Along this guide path, data packets progress toward the destination through nodes' cooperation without utilizing the location information.

F. ENERGY EFFICIENT OPPORTUNISTIC PROTOCOL (EEOR)

Energy efficient opportunistic protocol (EEOR) described in [9] uses a different computational method for calculating the forwarding node list and the expected cost in an attempt to optimize the energy consumption. It considers the following design constraints taking into account a case where there are multiple source/destination pair nodes in a randomly deployed WSN.

Nodes in the forwarder list of a node must agree on next operation, since agreement involves communication and thus increasing the overhead, one must guarantee that it will not overwhelm the performance gain brought by EEOR.

The EEOR protocol should be able to handle the network congestion, to avoid bottleneck in order to decrease packet loss ratio and save the energy cost at the same time. All source nodes should be able to dynamically adjust their network flows.

A single packet could arrive at the destination through multiple paths, it is necessary to introduce certain penalty scheme in order to punish the selfish nodes, e.g., those nodes that choose too many nodes as potential forwarders.

A node can utilize overheard messages to reduce the needs of ACK messages. Actually, to utilize this snooped information to avoid duplication is one important strategy in the design.

The design inherits the advantages of OR, thus achieving shorter end-to-end delivery delay, higher energy efficiency, and reliability.

IV. COMPARISON BETWEEN THE PROTOCOLS

This section compares the various algorithms described in the previous sections. Table I summarizes the parameters considered for the forwarding set or node selection in the different algorithms discussed in the previous section.

TABLE I: COMPARISON OF PROTOCOLS

Protocol	Forwarding node selection criteria
ExOR	Distance
OWR	Duty-cycle and EDC
EAOR	Current energy level and energy consumption to forward data to destination
EFFORT	Residual Energy and scarcity energy cost
EQGOR	Single hop packet progress and packet reception ratio
R3E	Link reliability and energy
EEOR	Energy consumption

V. CONCLUSION

Routing algorithms greatly influence the performance of Wireless Sensor Networks and hence are constantly evolving, aiming at finding the most optimal and efficient solution for routing of data. Opportunistic routing algorithm is designed for multi-hop networks and uses an approach different from traditional reactive protocols as it chooses amongst a set of nodes, called the forwarding node set, for the next hop forwarding.

The parameters used for selecting this node, determines the efficiency of the algorithm. Energy being one of the most important and challenging constraints on Wireless Sensor Network routing algorithm is the main criteria for most algorithms. While algorithms like EFFORT and EEOR take into consideration the residual energy some other algorithms focus on reducing the overall energy consumption of the network. With real-time relay of data, data delivered late can be consequently redundant due to the time constraints associated with them. In such cases the Quality of Service is an important parameter to be taken into consideration and QOS enhancing protocols based on opportunistic routing, like EQGOR fare better than traditional QOS based protocols.

The advantages of opportunistic routing algorithms combined with an intelligent choice of parameters to determine the forwarding nodes (depending on the requirement) and a smart way of selecting the next hop node from that list make for efficient routing algorithms.

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