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Comparison of Opportunistic Routing Protocols in Wireless Sensor Networks (WSNs)

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Abstract: **In our daily lives, Wireless Sensor Networks (WSNs) are used for various applications due to its features like low cost, low power, and ease of implementation. The mentioned features reciprocate its wide use for tracking and monitoring applications. These networks collect the data by means of sensor nodes about physical or chemical parameters, and further, move it towards the sink for additional handling. To attain the data transfer, sensor nodes require routing protocols which provide the best efficient path to establish reliable communication in the networks. Based on the characteristics and capabilities of sensor nodes like energy, communication infrastructure and deployment of nodes, it is difficult to employ within the network. The use of routing protocols, thus, plays a vital role in compromising this difficulty. These protocols rely upon the necessities of different WSN applications. Opportunistic Routing (OR) along with the sensor nodes present in the path, performs forwarding of the data packets to obtain high throughput in unreliable links. Hence, to improve the network lifespan, the selection of an opportunistic energy-efficient routing protocol tends to be a crucial task. A study and comparison of various opportunistic routing protocols is carried out. Depending on the comparison, the algorithms which provide minimum energy consumption and maximum network lifetime are studied for future research.**

Index Terms **- WSN, Opportunistic Routing (OR), OR protocols, Energy Efficiency, Network Lifetime**

I. INTRODUCTION

The basis of wireless sensor networks is its ability to collaborate data from multiple nodes rather than a single node. These nodes form network with fixed as well as mobile sensors. The data obtained by the sensors is transmitted to the sink, also called as destination [6]. The received data is processed with high computing power and high capacity memory. An additional communication interface for establishing connection to the other networks is also provided [1]. In this type of sensor network, the distance for transmission is few meters which are dependent on the transmission power, location, frequency and modulation. All the nodes are required to have a coordination medium between them for sending the information to the sink. Energy Consumption plays the role of a drawback caused in these networks at this stage of transmission. On contrary, it can also be a powerful transmission source. Poor coordination between the sensors whiles simultaneous transmission of two data packets resulted into collision of the packets and triggered data retransmission. The proposed solutions in order to overcome the mentioned drawbacks so as to limit the energy losses and other were the opportunistic routing protocols [1].

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

II. OPPORTUNISTIC ROUTING

Opportunistic Routing is a new routing technique which provides high transmission error rate for mesh networks. In traditional routing, the next neighboring node is chosen before transmission which causes errors at the receiving end. These errors are link or path related. It makes use of broadcasting. One of the most recent opportunistic routing techniques is based on network encoding. It performs in such a manner, where the source broadcasts its packets, and the routers produces a linear combination of the received packets randomly Finally, on receiving all packets, the destination sends an acknowledgment tracing back via the incoming path. Opportunistic Routing follows transmission process with proper coordination between the sensor nodes based on the proximity to the destination. The routing path can be highly unreliable causing changes or breakage [8]. To establish proper and reliable communication, intermediate nodes manage the sensor data during blackout and when the connectivity resumes forwarding is performed [8]. This routing uses broadcast transmission to send packets through multiple relays. The main aim of Opportunistic routing is selecting nodes between the source and the destination. From which the node nearest to the destination will be the first to retransmit data packets [2]. The main two steps are:

1. Selection of the forwarder sets: In order to increase the routing efficiency, it is required to select only the potential nodes between the source and destination.

2. Prioritization among these forwarders: Nodes closest to the destination gain the highest priority. [2]

A comparison between traditional routing and opportunistic routing is shown below:

TABLE I. COMPARISON BETWEEN TRADITIONAL AND OPPORTUNISTIC ROUTING

Type of Routing	Traditional Routing	Opportunistic Routing
Number of Candidates	Relays Alone	Multiple
Type of Relay selected	Fixed	Dynamic
Relay Time Selection	Before	After
Type of Transmission	Unicast	Broadcast
Packages Heard	No	Yes

III. TYPES OF OPPORTUNISTIC ROUTING ALGORITHMS

A. Opportunistic Routing For WSNS (ORW)

Opportunistic WSN routing (OWR) [3] is a functional WSN OR technique extending the original ExOR used for mesh networks. The concept is based for a duty-cycled environment where data packets are transmitted by the neighbouring node who effectively receives the data packets to sets of possible receivers on waking up. It decreases the delay by using all possible forwarder neighbors when the source waits for a node to wake up and the total transmission energy consumption within the network. The protocol functions as follows:

- The sender node looks for its active neighboring nodes with least EDC which is 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 for the cost of forwarding.
- On waking up, the neighboring nodes checks for energy level on the channel relying on overhearing. When the channel is free, the node receives data packets and further forwards it with updates its link quality estimate. If the channel is busy, the node goes back to sleep.
- In case, if the packet reception is done by multiple nodes, a unique forwarder is selected by Unique forwarder selection.

B. Energy-Aware Opportunistic Routing (EAOR) Protocol

Energy-Aware Opportunistic Routing protocol (EAOR) is used for maintaining energy efficiency and Quality of Service (QoS). The proposed idea focuses on increasing network lifespan with no change or slight decrease in packet delay time. It uses the next relay node selection method. Also, it introduces a term called back-off time, i.e., the waiting time required by the neighboring node to wait before getting a reply with a CTS packet [19][3]. It functions as follows:

- The transmitting node directs a RTS packet to its neighboring nodes.
- On reception, a RTS packet from the transmitter node t, the neighboring node replies with a CTS packet after time T.
- The lifespan of each node is increased by considering the energy parameter.
- If the energy level is high, it will act as a forwarding node and acknowledges with CTS.
- In case of low energy level, it does not reply with CTS.
- If two or more nodes have the same energy levels, the node nearer to the destination is chosen.

As mentioned above, a node having low energy level can also be used for transmitting the DATA packets with certain considerations. These might include a neighboring node with high energy level or a node with less proximity to the destination. An additional consideration may be when some of the neighboring nodes draining too much energy selected as forwarding node. EAOR transmits the packets to the nodes having high energy level and those close to the destination [26].

The time parameter is dependent on the neighboring node's consumed energy timed on receiving the RTS packet, the distance between source and destination and a distance metric constant.

C. EFFORT

The EFFORT [20][3] framework prevents sensors from depleting their energy so as to prolong the WSN lifetime. Instead of reducing the energy cost throughout the network by shortest distance based next hop mechanism to reach to the destination; it focuses on increasing the sensor and network lifetime as a whole.

Scarcity Energy Cost (SE-Cost) is a function of residual energy in terms of energy consumption for a sensor which may cause damage to the network lifetime. As a result to minimize this SE-Cost of successful transmission, an OEC metric has been proposed.

OEC refers to the opportunistic end-to-end SE-Cost from a node s to the sink. This metric is 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 [26].

A 2-stage heuristic forwarder-selection structure is proposed along with EFFORT. Each sensor decides its forwarding set for getting proper optimal results.

In the first Extraction Stage, each sensor eliminates the neighbors which do not participate as forwarder making a small set of possible participants.

Secondly, in Inclusion Stage, node s initializes its forwarding set Fs as an empty set. Then, it selects its neighbor with the smallest IEC (Independent End-to-end Cost) value and places it in its forwarding set Fs until the OECs value reaches the threshold. The following functions are carried out:

- During the sending or relaying of data packets, the sensor node tries broadcasting of those causing overhearing by the participants in its forwarding set Fs.
- According to the optimal relay sequence of forwarding set Fs, sequential relaying takes place for each forwarder on successful reception of data sent.
- After this relaying an ACK message is sent to the sender for terminating the forwarding process

- The ACK message includes information about its residual energy, link reliability, and its updated OEC value. This information is piggybacked by the forwarder.
- Based on this information provided in the ACK message, the sender further updates it as soon as it reaches to it.

D. Reliable and Enhanced Energy- Efficient Routing (R3E) Protocol

Reliable and Enhanced Energy-Efficient Routing or R3E [21][3] is a middle-ware bridging between the MAC layer and network layers for providing more flexibility to the WSNs and its link dynamics. The R3E enhancement layer has three main modules [26]:

1. Reliable route discovery module: This module searches and looks after each node's route information. Each node stores the downstream neighbor information while forwarding during reliable route discovery phase.
2. Potential forwarder selection and prioritization module: This module provides an ordered forwarder list in the data packet header for the next-hop. It is responsible for runtime forwarding phase.
3. Forwarding decision module: This module monitors whether or not the node belongs to one of the intended receivers on successfully receiving the data packet. If it does, then, this node stores the incoming data packet and starts a back-off timer. An ACK message in return is to be sent. If no higher priority forwarder is found transmitting an ACK message before its back-off timer ends, broadcasting is carried out. Also, an ACK with data delivery for upper layer to the upper layer which triggers reception at the network layer end. This results in forwarded the outgoing data packet towards the destination via MAC layer.

R3E [3] helps in enhancing the existing routing protocols with reliability and energy-efficient packet delivery by utilizing the local path diversity. This tends to overcome the drawbacks even over unstable wireless links. R3E is responsible for backup requirements during route discovery using a guide path. This guide path helps in sending data packets more effectively without location information and with proper cooperation.

E. Extreme Opportunistic Routing (ExOR) Protocol

ExOR uses a necessary component, i.e., a loss-rate matrix which contains the probability of successful reception of a packet between each pair of nodes implemented using link-state flooding. A set of forwarding candidates in the packet header and distance based prioritization is used for making a decision on forwarding the data packets through the network. A forwarding node from the forwarder set retransmits the packet using a new set of forwarding candidates [26].

ExOR proposes three main stages. These include: selection of forwarding nodes, transmission acknowledgement and decision based on whether or not to forward the received data packet.

1. The strength of ExOR depends on the selection of forwarding nodes based on the required algorithm. A node that forwards a packet to the destination looks out for the shortest path creating a loss-rate-matrix. This path considers the first node as forwarder which gets deleted from the loss-rate-matrix. Until the set of forwarding candidates gets full, this process is repeated.
2. The forwarding candidates send ACKs in the manner as per their presence in the packet header. Each ACK has the information like sender's ID and the known recipient having successful transmission as highest priority. Before taking the decision of forwarding the packet, all the candidates consider all the slots and then, suppress duplicate forwarding to some extent.
3. All nodes receive the packets and a group of ACKs used for determining their role as a forwarding node.
   The forwarded packet is considered on a condition that the highest known ACK ID is smaller or as same as that of the node's ID itself.

F. MAC-independent Opportunistic Routing & Encoding (MORE) scheme

A new protocol called MORE was proposed in order to rectify the disadvantages found in ExOR. MORE [12] [22] is related to ExOR but introduces an intra-flow random network coding to lessen the probability of packet repetition. To enhance the network throughput, integration of network coding with routing protocol can be done. MORE has advantages in two aspects, transparency to MAC layer and compatibility.

MORE has both unicast and multicast traffic with higher network throughput as compared to traditional routing and other routing protocols [22]. Its unicast throughput gain is smaller than its multicast throughput gain. It supports multicasting but no scheduling on MAC layer is carried out.

G. Source Opportunistic Adaptive Routing and proactive link state routing (SOAR) scheme

SOAR [5] [22] is source opportunistic Adaptive Routing and proactive link state routing. This routing uses adaptive rate control in order to reduce overhearing and retransmissions by determining sending rate.

In SOAR [26], each sensor node periodically computes and distributes link quality with respect to ETX. Accordingly, a sender node selects a path as default and list of next-hop forwarder nodes to forward the dat3.1 This data is required for broadcasting the data packet altogether. The nodes absent on forwarding list discard the packet for transmission. If present, then, the nodes cache the packet and sets forwarding timer based on the distance close to the destination. If the node is closer to the destination, the packet is forwarded but the timer is set for a small duration. For avoiding unnecessary transmissions which may cause path traffic, collision or disturbance in the on-going transmission, the remaining nodes try to eliminate that packet. SOAR broadcasts data packets at a fixed PHY data rate to achieve effective multiple simultaneous flows and high efficiency..

The four major components included in SOAR are [22]:

1. Adaptive forwarding path selection
2. Priority timer-based forwarding
3. Local loss recovery to efficiently detect and retransmit lost data packets.
4. Adaptive rate control to decide an appropriate sending rate according to the network condition.

In SOAR [22], the forwarding nodes are chosen and prioritized based on priority timer, and duplication of transmissions and retransmissions is done by forwarding timer. Local recovery concerns the forwarding nodes to act as backup for transmission during failure in reception at the destination. Recovery of lost packets using efficient local feedback and local recovery can be done as adaptive rate control adjusts sending rates. SOAR provides proper connection of the forwarding nodes but requires more computations for batch processing.

H. Position based Opportunistic Routing (POR) scheme

Position based Opportunistic Routing (POR) [23] is an efficient wireless broadcasting scheme. POR [22] is based on geographic routing and opportunistic forwarding used for transferring the data packet based on the destination's location information. Assuming their own location as well as the positions of their direct neighbors is known by the nodes.

POR uses MAC dependent opportunistic routing technique. In POR, according to the location of the nodes close to the destination, the forwarding nodes are chosen. This property helps in improving the durability and scalability [30]. Every node maintains the local information that includes the neighbor list, ID record, forwarding table, packet list and packet buffer in it. In case, if the node fails to find his forwarder, packet buffer helps in storing the packets. POR provides greater packet delivery but requires more computations and buffer space for memory [22].

I. Proactive Source Routing (PSR) scheme

In PSR [22], the Breadth First Spanning Tree structure (BFST) has the topological information for each and every node. An effective BFST in each node can be constructed using three processes, namely, periodic route update, neighborhood trimming and streamlined differential updates. These processes are implemented for minimizing the size of BFST that is broadcasted to the neighbor periodically. Iterative processing is carried for route updates and is scattered among all the nodes in the network. The neighboring nodes on receiving BFST with latest information, update it accordingly. Then, this updated BFST is bartered with its neighbors in an iterative manner. The removal of node depends on its participation with the network connectivity which implies to neighborhood trimming.

The detection of loss nodes is carried out as follows [30]:

- A particular node provides with no route update message periodically.
- Transmission failure for a particular node.

Efficient differential update process is used to decrease the overhead by reducing the size of BFST broadcasted to the neighbors randomly. By using compact tree representation and by truncating the differential update messages, this can be carried out. The traits of PSR include loop free routing, proactive source routing and extremely small routing overhead. PSR has very small communication overhead but provides nodes with additional network structure information than distance-vector based protocols [37].

J. Efficient Qos-Aware Geographic Opportunistic Routing (EQGOR)Protocol

Efficient QoS-aware GOR (EQGOR) protocol plays a major role in QoS improvement of WSNs. This is done by considering parameters such as energy efficiency, latency, and time complexity for selecting and prioritizing the forwarding candidate set. In traditional Geographical routing algorithm (GOR) [8], for each hop, the most forwarding tasks are taken into consideration by the first two or three candidates from the forwarding set in the manner they appear in it. In order to obtain an optimal solution, a node requires ordering a very small number of candidates which would lessen time complexity. The following are the functions for forwarding candidate selection [26]:

- Single hop packet progress and packet reception ratio is used where the forwarding candidates set C has nodes sorted in a descending flow in a matrix.
- Initially, the first node of the candidate set is removed from C and put into the forwarding set F. Then, in a sequential manner, nodes from C are checked, whether they are within the transmission range of any node in F or not. If not, then they will be excluded.
- The search process includes trying every possible position in the set F. It also calculates the expected single-hop packet speed values.
- Candidates will be chosen for the remaining nodes in set C which satisfy the hop QoS requirements at a minimum cost by simply adding it to F [22].

EQGOR attains a good balance between these multiple purposes. For WSNs where resource limitation of sensor devices is present, it provides a very low time complexity.

K. Energy-Efficient Opportunistic Routing(EEOR) Protocol

For computing the forwarding node list and the expected cost so as to improve energy consumption, a computational method named Energy efficient opportunistic routing protocol (EEOR) is introduced. Different source-destination node pairs are deployed randomly in a WSN.

Nodes in the forwarder list are selected so as to have better performance gain [22]. In order to reduce packet loss ratio and saving the energy cost, EEOR must have the tendency to maintain the network congestion to avoid bottleneck.at the similar instance. All source nodes must have an adjusting nature towards the network flow dynamically. A single packet could be sent at the destination via various paths. Hence, it is necessary to exploit the selfish nodes which opt for multiple nodes as potential forwarders. A node utilizes overheard messages instead of ACK messages with avoidance of any duplication for betterment. This design possesses the merits of an ideal OR including reliability, shorter end-to-end delivery delay and higher energy efficiency [26].

L. Minimum Transmission Energy (MTE)Protocol

MTE is the abbreviation for Minimum Transmission Energy/Power that satisfies the quality of service (QoS) requirement at the reception. It does not assure rational distribution of the energy load between the nodes of a wireless sensor network [25]. The data is scattered over minimum cost routes, where the cost considers the transmission power spent [33]. In MTE, the nodes close to the sink act as relays than those away from the sink. It has a lower standard deviation value for residual energy. It always delivers data in a hop-by-hop technique to the sink node, thus, maintaining balance among the nodes with respect to energy dissipation.

M. Geographic Random Forwarding (GeRaF) Protocol

GeRaF [8] [30] uses geographic routing with a unknown relay sensor. No assurance about a successful transmission and reception of the forwarded data packet from source to the sink by the sender is maintained. GeRaF [28] assumes all the sensors know their physical locations along with the sink's location. GeRaF works effectively when an integrated method of a geographical routing algorithm and an awake-sleep scheduling algorithm is used. In this scenario, there is not mandate requirement for the sensors to know the locations of their neighboring nodes as well as their awake-sleep schedules. The first step for sending the data from source to the sink is to check whether the channel is free or nor. This step will help in avoiding packet collisions. When the channel is found to be idle for some duration of time, the source broadcasts a request-to-send (RTS) message to all of its active (or listening) neighbors. This RTS message has the source and the sink location information. The forwarding area facing the sink is divided into a set of Np regions of different priorities. This differentiation is done such that all points in a region with a higher priority are near to the sink than any point in a region with a lower priority. The priority assessment based on the location information of all active neighboring sensors and the sink is carried out upon receiving the RTS message. The source sensor waits until a CTS message from one of the sensors located in the highest priority region is received in return. For GeRaF [28], the relay sensor nearest to the sink is considered to be the best. It helps in effective and large data packet forwarding to the sink. If the highest priority region is found empty, the source fails to receive a CTS message. Hence, another RTS message is sent which polls the sensors in the second highest priority region. This process continues till the source receives the CTS message. This also means that a relay sensor has been found. Then, the source sends its data packet to the selected relay sensor, which reverts back with an ACK message. The relay sensor acts as the source sensor for getting the second relay sensor. The entire process is repeated until a successful transmission of data packet from the source sensor to the sink is performed. If the neighbors of the sending sensor are not active, there arises a problem where no CTS message is received by the source after sending Np RTS message. In this case, the sending sensor stops for a small duration and retries later. After a certain number of attempts, the sending sensor either finds a relay sensor or scraps the data packet if the maximum allowed number of attempts is reached.

N. Energy-Saving via Opportunistic Routing (ENS_OR) Protocol

ENS_OR is used to increase the energy-saving of WSNs with opportunistic routing while transmitting data from source to the destination [24].

ENS_OR introduced a new concept called energy equivalent node (EEN). This concept selects relay nodes by using OR theory, which helps in enhancing the optimal transmission distance for energy saving and increasing the network lifetime. As sensor nodes are static in nature, each sensor node has unique information. This uniqueness is derived with information like the distance of the sensor node to the sink and the residual energy of each node. These parameters are crucial for determining the optimal transmission distance. Also, these parameters play an important role when it come in taking the required OR decision [29].

ENS_OR chooses a forwarder set and prioritizes nodes in it. This is done according to their effective optimal transmission distance and residual energy level. These nodes in the forwarder set have more residual energy in comparison with the chosen forwarder candidates. Also, these nodes are nearer to EENs [15].

During transmission process, at the initial state, all the neighboring nodes included in the forwarder set take decision based on a packet broadcasting provided . Then, prioritization of nodes is done according to the minimum energy consumption. The packet is accepted by the highest priority node while the remaining nodes will repudiate the packet. Until the packet successfully reaches the sink, the task of prioritization is continued using priority list. Once the source node starts packet transmission, the timer is set ON at all the nodes in the forwarder list. In case, if a packet fails to reach the next- relay node within the transmission time, all the nodes in the forwarder list tend to drop the packet and source node, then, retransmits it. After the packet reaches the destination, acknowledgment is sent to the source node and the source node transmits the next packet [16].

IV. Comparative Analysis Of Protocols

Based on the research we can, thus, jot down the points considering the comparison between routing protocols on the mentioned factors.

TABLE II. Comparison Table of OR Protocols

Name of the Protocol	Power Usage	Data Aggreg -ation	Scalability	Data Delivery	QoS
ExOR	Moderate	Yes	Poor	Continuous	No
R3E	Moderate	Yes	Moderate	Event-driven	Yes
EEOR	Low	Yes	Moderate	EVENT-DRIVEN	Yes
EAOR	Low	No	Poor	Continuous	No
MORE	Low	Yes	Good	Event-driven	Yes
SOAR	Low	Yes	Good	Event-driven	Yes
POR	Moderate	Yes	Good	Continuous	No
EQGOR	Low	Yes	Good	Continuous	Yes
PSR	Moderate	No	Moderate	Proactive	Yes
EEFORT	Low	Yes	Good	Active	Yes
GeRaF	Moderate	Yes	Good	Continuous	Yes
MTE	Low	Yes	Moderate	Continuous	Yes
ENS_OR	Low	Yes	Good	Event-driven	Yes

TABLE III. Comparison Of Selected Routing Protocols

Parameters	Protocols		
	GeRaF	***MTE***	***ENS_OR***
Forwarding List of Selection	Hop-by-Hop	End-to-End	End-to-End
Prioritization on nodes	Geo-distance	ENT	Residual Energy
Co-ordination in forwarding list	RTS-CTS	ACK	Data-Based
Packet duplication	Yes	-	-
End-to-End constraint	-	-	-
Energy Efficient	-	-	Yes
Compatible with	Ad Hoc Networks	Wireless Sensor Networks	Wireless Sensor Networks

ENS_OR is better than MTE and GeRaF for better performance.

V. Conclusion

Opportunistic Routing is an emerging area of research with limited but prominent set of research results. In this paper, we presented a comprehensive survey of opportunistic routing techniques for WSNs. We also discussed various opportunistic routing protocols, and the design tradeoffs between energy and communication compatibilities in some of the routing paradigm along with their advantages and disadvantages. Although several of these routing techniques look promising, there are still many challenges that need to be solved in WSNs. We highlighted those challenges and pinpointed future research directions in this regard. Also, based upon the comparative analysis, ENS-OR, GeRaf and MTE tend to meet our expectations in terms of energy saving and maintaining efficiency throughout the network.

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