Opportunistic Routing for Sensor Wireless Networks: A review

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Abstract - **Opportunistic Routing (OR) is a new method proposed for wireless networks that increases the routing performance in wireless networks. OR leverage the overhearing in networks where transmitted packets can be overheard by more than one node or sensor. OR coordinates between these nodes that can overhear a transmitted packet. In OR, next-hop forwarders can be selected as potential candidates. There-fore, each node in OR can use multiple path to forward its packet towards the destination, where any node that overheard or in other words receives the packet may forward it towards the destination. The decision of relaying the received packets is called the coordination between candidates, where coordination takes place when multiple nodes receive the same packet and they have to decide for them-selves who gets to forward it. OR focuses on transmission reliability and throughput. In this paper, we present a brief introduction to OR protocols where it contains three main components: Routing Metric, Candidates Set Selection and Candidates Coordination. Each main component is given its own section. Lastly, a brief example of some OR protocols are given and compared with each other**

keywords - **Opportunistic Routing, Overhearing, Routing Metrics, Candidates, Coordination**

I. INTRODUCTION

In multihop Wireless Networks (MWNs), the quality of wireless links in terms of packet delivery probability is different for each link. Where the transmission of a packet to a next hop node can be heard by many other neighboring nodes [1]. In unipath routing, for a packet to reach its destination the node that forwards the packet preselects its next-hop node to continue forwarding the packet until it reaches its destination. Where in unipath routing, it does not take advantage of the fact that the transmission of signals from a node to a neighboring node can be heard by many other nodes in its neighborhood. This is where Opportunistic Routing (OR) comes, to increase the performance of MWNs, OR utilizes overhearing in its routing mechanisms (any-path routing) [3]. Where in OR a set of nodes are selected as potential forwarders. Where the nodes in this set will forward the packet after receiving it. This set of nodes is also called the Candidate Set (CS). In CS, each candidate is given a priority, which is the nodes ability to act as the next forwarder. Where the higher abilities are given to those nodes that reach the destination with the lowest costs. The priority depends on different terms such as: the number of hops until a packet reaches its destination, power consumption, expected number of transmissions, etc.

In OR packet route is dynamically built. An example of OR is given in figure 1. Where the source S wants to delivers its packet to the destination D. In unipath routing S predefines its next-hop according to the link quality, where S chooses A as its next hop and the path to the destination would be S-A-B-D. If B overheard the packet sent from S, it has to discard and wait for A to resent the packet to it, because it is not S's next-hop forwarder. This scheme of routing causes many retransmission and wasted network resource may occur. While, in OR: A, B and D are selected as potential candidates. Candidate coordination between the nodes takes affect when two or more nodes receive the transmitted packet and must choose among themselves which to discard and which to keep sending to the destination. Where a sender only broadcasts its packet to its CS, and one of the CS nodes will continue the forwarding process until the packet reaches the destination. In the example figure 1, the priority of node B is higher than node A since its closer to the destination node. So, when S transmits its packet, if A and B receive the packet B will send the packet to the destination and A will discard it. OR decreases the number of retransmissions of a packet, increases the probability of a packet to reach its destination and improves the throughput of the network.

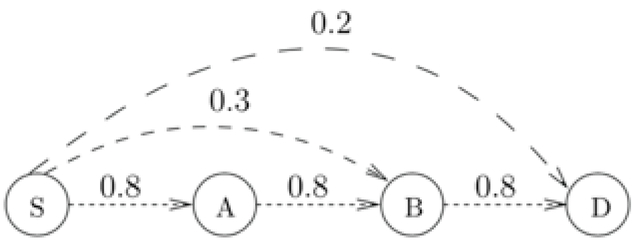

Figure 1: An Example of Opportunistic Routing

The probability of a packet to reach its destination is improved in OR because a virtual link in OR combines the weak links, so the failure probability is fairly reduced. As seen in figure 2, the link between the sender and its neighboring nodes are all weak links, while from the neighboring nodes to the destination are all perfect links. In unipath routing S has to choose one of its

neighboring nodes as the next forwarder, since they all have the same link quality there is no difference between selecting one of them. So, in average traditional routing protocol requires about five transmissions for a packet from S to be received by one of its neighboring nodes. Moreover, in OR, all the neighboring nodes of S are chosen as the set of CS, where their combine link equality has a delivery ratio of $(1-(1-20\%)^5 = 67\%$. Therefore, on average only one additional transmission is needed to deliver the packet from the sleeted candidate to the destination.
OR protocols encapsulate three main components: Routing metric, Candidates Set selection and Candidates coordination [14]. Routing metrics are mathematical models used to prioritize the neighboring nodes in accordance with their ability to reach the destination node with the lower forwarding costs. Candidates Set selection is the tools that the sender uses to sort out and select a candidate for its CS according to routing metrics. Candidates coordination is the tools that sender uses to select one candidate from its CS to forward the packets to its next hop.

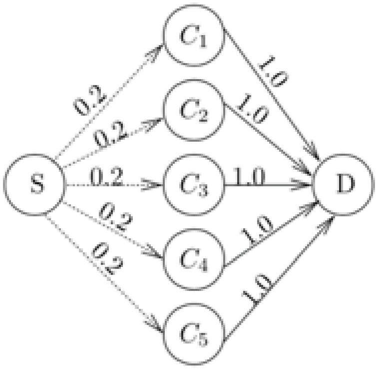

Figure 2: An Example of Virtual Links

II. ROUTING METRICS

The main objective of OR is to reduce the Expected Number of Transmissions (ExNT) for a packet forwarded to the destination. The ExNT plays a big role in the network, since controlling it will result in controlling the end-to-end delay, the jitters and they energy consumption at each node. The network's performance in OR is affected by the finding and ordering of the candidates [4] . Therefore, when using a routing metric, it is very important to make sure that it plays a role in the finding and the ordering of the CSs.
Metrics are classified to local and end-to-end, where a local metric uses local information or link properties of its neighbors. The latter metric is dependent on wireless links and nodes. Using the end-to-end metrics is optimal for choosing a CS, where the better the chosen CS the better the ExNT in the network. It is very important to remember that this comes at a price for computing the end-to-end metrics lead to a significant overhead. In the following, some of the usual used metrics in OR will be briefly mentioned.

2.1 Local Metrics

As mentioned before, local metrics only depend on the information provided at each node, such as:
Distance Progress (DP): DP considers the geographic position of nodes. DP depends on the Euclidean distance between two nodes. Where a node can approximate the remaining distance to reach the destination using beaconing method for information sharing between nodes. DP is used in networks where nodes can select as many candidates as possible, which limits it to specific uses.
Expected Distance Progress (EDP): EDP considers the link delivery probability to reach a node and the node's position. EDP is proposed to improve DP, but failed with DP for not addressing the costs of delay when two candidates have to coordinate between each other [2].
Expected One-hop Throughput (EOT): EOT is a combination of DP, transmission quality and the delay of a MAC medium as a result of coordination. It was proposed to achieve a balance between the advantages of DP and the costs it failed to account for.

2.2 End-to-End Metrics

End-to-end metrics consider the whole network topology information, such as:

Expected Transmission Count (ETX)
ETX considers the number of times a packet has to transmitted/retransmitted on average at a link for it to be received by the destination. ETT is an extension of ETX and it considers the time for a packet to transmitted on a link. Both ETX and ETT are not well suited for OR since they only consider links with the lowest costs [4].

Expected Any-path Transmission (EAX)
EAX considers the ExNT and the multiple paths that can be used in OR. The cost of calculating the EAX is high, since it is of recursive nature. Although, using ExNT for the candidate selection of the EAX is better than using ETX.
All the mentioned metrics only consider the nodes that are awake, disregarding the nodes in sleep mode. Which is a constraint if used in Wireless Sensor Network (WSN) since it uses duty cycling mechanisms [10]. Other metrics have been proposed to solve these problems such as the Estimated Duty Cycle (EDC), where it considers the expected number of duty cycles [5].

All the metrics mentioned depend on the delivery property between nodes or the geographic position of nodes. Opportunistic Residual Expected Network Utilities (OpRENU) has been proposed to consider the function of benefit and transmission cost. Where after a successful transmission of a packet. The cost of transmission id deducted and the utility of delivery is defined [2].

III. CANDIDATES COORDINATION

The coordination between candidates is a challenging issue in OR. Where candidates coordinate between themselves to know which will forward the received packet and which to discard it. For successful coordination between nodes, the nodes need to send control messages between one another. Without coordination, the network will suffer from unnecessary transmission, caused by more than one node forwarding the same packet. Therefore, selecting the best candidate to forward the packet and avoiding multiple transmission of the same packet is the core of candidate coordination.

Candidate coordination in this literature can be looked at as control-based or data-based. In the control based method a control packet is used to inform other candidates of whether or not the packet has been received. In the latter method, it does not rely on any control packets [7]. In the following subsection, each approach is explained in more detail.

3.1 Control-Based Candidate Coordination

In this method, each node's CSs are ordered in accordance to a metric. Where a sender receives the control packet from nodes According to their priority by the ordered CS. Control packets can be ACK or Request to Send (RTS)/ Clear to Send (CTS).

3.1.1 Acknowledgment-Based Coordination

In the ACK method, when a candidate receives a packet they will reply back with an ACK message. These messages are sent out in a descending order of the candidates, where the candidate with the higher priory sends first, followed by the lower until the lowest priority candidate. In this method, the best candidate gets to forward the packet and the rest will just discard it.

Some protocols modify the MAC layer of 802.11, where each candidate has its own reserved time to send back an ACK, where in this case the ACK implies that the candidate has indeed received the packet [2]. Moreover, these ACK messages also contain the ID of other high priority candidates that have also received the packet. This is useful when a higher priority candidate received the packet but it's ACK hasn't been received by the sender. So, when a lower priory candidate receives the packet and send back an ACK it will contain the id of that higher priority candidate, so the sender can choose it to relay the packet towards the destination.

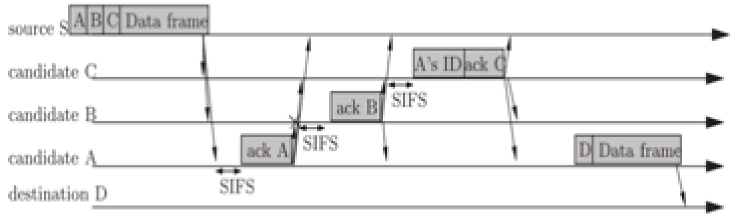

Figure 3: ACK based coordination after modifying the 802.11 MAC example.

As seen in figure 3, an example is set, where we assume that we have a source S and a destination D. Moreover, we assume that the CS of S is {A, B, C}, ordered from the highest to the lowest priority. If all candidate received the packet sent from S, they will transmit their ACK in decreasing order, starting from A and ending at C. In the example, we assume B couldn't hear A's ACK, however, C did. Also, we assume that B could hear C's ACK. Therefore, when C send back an ACK and B is able to receive it, it will know that there is a higher priority candidate that has received the packet (i.e. A) and it will not send the packet. In this example, A will forward the packet and B, C will discard it.

One of the disadvantages of this method is that candidates need to be close to one another. If a node with a lower priority couldn't hear the ACK of a higher priority it will cause duplicate packet transmission. Where another disadvantage lies in the modification of the 802.11 to be able to send ACK in different time slots.

3.1.2 RTS-CTS Coordination

This coordination is based on control messages sent before data packet transmission. Where the sender puts the IDs of the ordered candidate in an RTS packet and broadcasts the packet. After which the transmission of the CTS is based on the order of the candidates. The highest priority candidate replies with a CTS after a period of time equal to a Short Interframe Space (SIF), the next candidate in the priority list will send it's SIF after $2 \times SIF$ and so on. After the sender receives the CTS it will start sending the data packet towards the intended candidate after a delay of SIF. If a candidate overhears the transmission of a data packet it will stop transmitting its own CTS and put its channel on Network Allocation Vector (NAV). This approach prevents multiple transmission of the same packet.

The disadvantage of this method is like the ACK-based a modification for the 802.11 is needed. As well as, after the sender sends its data packet by unicast routing to the intended candidate (higher priority candidate). If the candidate couldn't receive the packet, the sender has to retransmit the packet.

3.2 Data-Based Candidate Coordination

Data based coordination doesn't rely on any extra control packet. As opposed to control based approach that needs to perform modification on the 802.11 network cards. Also, the control based needs control packet that may lead to a poor scalability. Data based coordination can be achieved through Timer based or Network Coding (NC) [6]. Which are explained in the following subsections.

3.2.1 Timer-Based Coordination

In timer based coordination, coordination and data forwarding are joined together. Where candidates are ordered according to a metric, and based on their order each is assigned a time slot. Therefore, when candidates receive a packet, they try forwarding the packet according to their order, where the *i'th* candidate forwards the packet in the *i'th* time slot. Candidates keep listening to the channel before they forward the packet (i.e. their time slots). Once a packet has been forwarded by other than them, the candidate will drop their packet. In other words, the candidates with a lower priority will only forward the packet, if the candidates with higher priority didn't forward the packet.

The overheard in this method is the candidate waiting time. Where each candidate has to wait for its time slot to forward the packet. If a high priority candidate had a low link quality and the packet couldn't reach it, the lower priority candidate has to wait for its time slot to be able to forward the packet. Therefore, it has to wait a long time to confirm that it is the one forwarding the packet. Thus, this will increase the waiting time, which in turn, degrades the throughput. Another disadvantage of this method is the duplicate transmission, sometimes lower priority candidate does not overhear higher priority candidate forwarding the packet, which results in a multiple transmission of the same packet.

3.2.2 Network Coding Coordination

In this approach, the flow of packet is split into batches, each of which contain many original packets without coding (native). The source will broadcast packets that are linearly combined. Where the destination can then decode the original packet whenever it receives enough linearly combined coded packets.

NC is able to avoid duplicate transmissions by coding the packets, without the need of any candidate coordination. However, when NC is applied with OR it will cause redundant transmission, which means that some packets do not provide any useful new information. Also, the destination needs to receive enough coded packets so it can decode the original packet, this in turn causes the transmission of several unnecessary packets that degrade the performance of the network. Moreover, the delay which is caused by the coding and the decoding process, increase the end-to-end delay of the transmitted packets

IV. CANDIDATE SELECTIONS ALGORITHMS IN OR

The candidate selection algorithms are the mechanisms the help a node select and sort a group of neighboring nodes as candidates. Where selecting different candidates has a big effect on the performance of the network. Where the selection of good candidates, causes the number of transmissions in the network to decrease.

For a node to be able to select some of it neighboring nodes as candidates, it will need information. These types of information are split into two categorize: topology based and local based. Where in the topology based selection, the candidates are selected based on topological (global) information of the network. In the latter selection, the information used by the node is limited and each node independently determines its candidate sets based on local information [8] .

In the topology based selection the nodes are required to maintain some network state information. Where in most of the two cases selection algorithms use end-to-end in topology based and local metrics in the latter. As mentioned in section 3.

In most cases, the topology based selection provides better performance than the local base does; because the topology based methods select better candidates, since it has more information about the network which is obtained by applying the end-to-end metrics. On the other hand, a node in the topology based has to wait for all its neighboring nodes to choose their CSs so it can select its own candidates. Therefore, the execution time of a topology based algorithm is longer than the local based one.

According to the main goal of OR (reducing the number of packets transmitted in the network), candidate selection algorithms can be divided into two classes, optimum and non-optimum. Where in optimum algorithms candidate set, selection is focused on the import metric in OR (ETX). As for the non-optimum algorithms, they use a heuristic algorithm to find the CSs [9].

V. OVERVIEW OF OR ROUTING PROTOCOLS USED WITH WSN

In the following section, we give a few noted examples of OR protocols that meet Wireless Sensor Networks. WSN has many requirements the most important are: reliability and energy efficiency where in OR the focus is on high throughput with disregard to energy consumption. Another WSN requirement is its duty cycling environments where nodes are in sleep state most of the time, as for OR's main essence is overhearing which doesn't go with the duty cycling environment of WSN nodes. Finally, complexity of unique forwarder selection in WSN, where the packet sizes are small and time slots can't be assigned. As for the counter part of OR it increments the ids of nodes in the packets and some protocols use time slots assigned for candidates as we have seen in previous sections.

All of these requirements make OR hard to integrate with WSN, therefore, a lot of protocols have been written by multiple researchers to try and solve these problems. Some of these protocols are:

a) ORW (Low Power, Low Delay: Opportunistic Routing Meets Duty Cycling):

ORW [11] transmits packets opportunistically in duty cycled sensor networks. Where, the first node that wakes up, receives the packet and provides routing progress gets to forward the packet towards the destination. ORW introduces the EDC metric which is the number of wake ups until a packet has reached its destination across possibly multiple hops.

ORW utilizes the EDC metric as a global routing metric. EDC computes the expected number of wakes until the packet has reached its destination. Where EDC defines the number of wake ups as the sum of three terms: the expected time needed to forward the packet, the time needed to forward the packet from the selected forwarder to the intended destination and a small constant that accounts to the cost of forwarding the packet.

Opportunistic Routing Protocol for Asynchronous Duty Cycled WSNS (ORR and ORIA) [12, 13], are almost similar to ORW. Both are based on EDC with minor differences. ORR removes the third term in ORW (i.e. the forwarding cost from EDC) and adds the residual energy parameter to the first term of EDC. ORIA considers two metrics EDC and Hop-Count.

b) Load-Balanced Opportunistic Routing for Asynchronous Duty-cycled WSN (LORA):

This protocol aimed to solve the problems of duplicate packets cause by candidates simultaneously waking up, by restricting the number of candidates and to counterbalance between the sender's waiting time and the duplicate packet problems it proposed a new protocol.
In LORA [14], each node defines a Candidates Zone (CZ) where the packets generated by the node will be routed by any path within the CZ. Only the nodes within the CZ are allowed to be selected as candidates.
As for the metric used in this protocol, it uses the multiplication of four distributions OR metric which is the: direction distribution, transmission distance distribution, perpendicular-distance distribution and residual energy distribution.

c) Energy Efficient Opportunistic Routing in WSN (EEOR):
This protocol was proposed to solve the problems that raised in ExOR [15] and MORE [16]. Both of these protocols tried to solve the challenge in opportunistic routing where multiple nodes may overhear a packet and unnecessarily forward that packet. ExOR tried to solve this problem by tying the MAC to the routing, where it imposed a strict scheduler on the router's access to the medium. The scheduler would go in round and forwarders transmit in order, such that only one forwarder is allowed to transmit at any given time. Whereas, the other forwarders listen to the transmission and learn which of the packets were overheard by which node.
As for MORE, to make sure the router that overhears the same transmission do not forward the same packet; it took the approach of randomly mixing the packets before forwarding them. Both ExOR and MORE didn't take advantage of selecting the optimal forwarder list to minimize the energy consumption cost.
EEOR [17] was proposed to select and portion the forwarder list in order to minimize the total energy cost of forwarding data to the sink in a WSN. The protocol proposed two models for selecting the optimal forwarder list for each wireless node where in the Non-Adjustable power model it computes the expected cost based on the expected cost of its neighbors. As for the Adjustable power model the expected cost is found by sorting the nodes in the forwarder list of a node, then order them based on their weight of the link that connects them to that node then adjusting the power by increasing it until it reaches the transmission power limit or no more neighbors are in reach. After which the expected cost can be calculated and the optimal forwarder list is chooses from the nodes that induce the minimum cost.

VI. Conclusion

In this article we addressed critical issues existing in wireless networks, the delivery ratio, dropping packets as well as latency, this paper summarizes few existing opportunistic protocols for wireless sensor networks, discussing their advantages and disadvantages, given detailed discussion on the metrics used and the schemes existing.

VII. Acknowledgment

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VIII. References

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