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An Optimal Solution for Sending the Packet Using Energy Efficient Opportunistic Routing

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ABSTRACT— ***Opportunistic routing has been shown to improve the network throughput, by allowing nodes that overhear the transmission and closer to the destination to participate in forwarding the packet, i.e., in forwarder list. The nodes in forwarder list are prioritized and the lower priority forwarder will discard the packet if the packet has been forwarded by a higher priority forwarder. One challenging problem is to select and prioritize forwarder list such that a certain network performance is optimized. In this paper, we focus on selecting and prioritizing forwarder list to minimize energy consumptions by all nodes. We study both cases where the transmission power of each node is fixed or dynamically adjustable. We present an energy efficient opportunistic routing strategy, denoted as EEOR. Our extensive simulations in TOSSIM show that our protocol EEOR performs better than the well-known ExOR protocol (when adapted in sensor networks) in terms of the energy consumption, the packet loss ratio, the average delivery delay.***

Keywords— **Sensor networks, opportunistic routing, energy.**

I. INTRODUCTION

Routing protocol design for wireless networks are often guided by two essential requirements: minimize energy cost or maximize network throughput. The traditional routing protocols in wired networks choose the best sequence of nodes between the source and destination, and forward each packet through that sequence. The majority routing protocols designed for multi-hop wireless networks have typically followed this convention, including those multi-path routing protocols. However, this did not take advantages of the broadcast nature of wireless communications: a node's transmission could be heard by any node within its transmission range. On the other hand, the lossy and dynamic wireless links make it difficult for traditional routing protocols to achieve stable performances.

In wireless networks, various factors, like fading, interference, and multi-path effects, can lead to temporary heavy packet losses in a pre-selected *good* path. In contrast, opportunistic routing, like ExOR and MORE, allows any node that overhears the transmission to participate in forwarding the packet. The routing path is selected on the fly and completely opportunistic based on the current link quality situations. However, this new design paradigm introduces several challenges. One challenge is that multiple nodes may hear a packet and unnecessarily forward the same packet. ExOR deals with this challenge by tying the MAC to the routing, imposing a strict scheduler on routers access to the medium. The scheduler goes in rounds. Forwarders transmit in order such that only one forwarder is allowed to transmit at any time. The other forwarders listen to the transmissions to learn which packets were overhead by each node.

In contrast to ExOR's highly structured scheduler, MORE addresses this challenge with randomness. MORE randomly mixes packets before forwarding them. This ensures that routers which hear the same transmission do not forward the same packet. As a result, MORE does not need a special scheduler; it runs directly on top of 802.11. Both ExOR and MORE showed that this kind of opportunistic routing strategy can improve the wireless network's performance. Finally my paper is organized as follow, section I gives the introduction of the Energy Efficient Opportunistic Routing. Section II is helpful to understand the background of related work about .Section III explains the System modeling. Section IV show the performance of proposed technique and at last section V concludes the paper and followed by references.

II. RELATED WORKS

In this paper, we study how to select and prioritize the forwarding list to minimize the total energy cost of forwarding data to the sink node in a wireless sensor network. Observe that previous protocols, i.e., ExOR and MORE, did not explore the benefit of selecting the appropriate forwarding list to minimize the energy cost. We will investigate this problem through rigorous theoretical analysis as well as extensive simulations. We study two complementary cases (1) the transmission power of each node is fixed (known as non-adjustable transmission model) and (2) each node can adjust its transmission power for each transmission (known as adjustable transmission model). Optimum algorithms to select and prioritize forwarder list in both cases are presented and

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analyzed. It is worth to mention that our analysis does not assume any special energy models. We conducted extensive simulations in TOSSIM to study the performance of proposed algorithms by comparing it with ExOR and traditional routing protocols. It shows that the energy consumption of routing using EEOR is significantly lower than ExOR with random forwarder list and traditional distance vector routing protocols.

III. SYSTEM OF MODELLING

We consider a wireless sensor network and assume that all wireless nodes have distinctive identities, i.e., $i \in [1, n]$. In Section 3 we first assume that every wireless node u has fixed transmission power W . In Section 4, we assume that each node can adjust its transmission power to any value between 0 and W . Let w denote such adjusted transmission power. The multihop wireless network is then modeled by a communication graph G = (V, E), where V is a set of n = |V | wireless nodes and E is a set of directed links. Each directed link (u, v) has a non-negative weight, denoted by w (u, v), which is the minimum transmission power required by node u to send a packet to node v successfully. It is worth to mention that our methods work with any weight function w ().

To illustrate how we can take advantage of wireless broadcast advantage (WBA), let us consider a network example in Figure 1 (a).

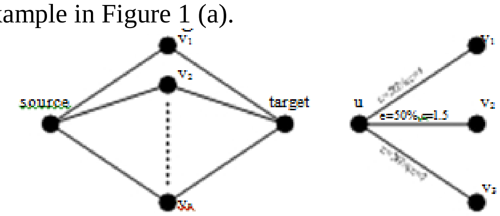

Fig. 1. (a)Wireless Broadcast Advantage. (b) Calculating the expected cost

The advantage of WBA is more obvious in a multi-hop wireless network, especially when a source node and the destination node are far way, i.e., the packet from the source node to a target node must be routed through a multi-hop path. As proposed in ExOR [2], the source node selects a subset of its neighboring nodes as forwarder list. The forwarder list is prioritized to indicate which nodes have higher priority to forward the packet. Then one or more nodes in the forwarder list, which received the packet successfully, will opportunistically act as new source nodes and route the packet to the target node.

In summary, the main ideas of opportunistic routing are as follows. We let Cu (Fwd) denote the expected cost needed by the node u using opportunistic routing strategy to send a packet to the target node when the forwarder list chosen by u is Fwd. For simplicity, we use Cu to denote the expected cost of node u if there are no confusions. Initially, the expected cost of the target node is set to be 0 and the costs of all other nodes are set to be ∞. Using the similar mechanism of distance vector routing, the calculations of the expect cost for each node will be carried out periodically and every node updates its expected cost and forwarder list periodically.

A. Non-Adjustable Power Model

Now we present the main idea on calculating the expected cost for each node and selecting the forwarder list. Consider a node u and its neighbors. We will compute the expected cost of and the forwarder list of node u based on the expected cost of its neighbors whose expected cost of sending data to the given target node has already been computed.

B. Compute the expected cost

In other words, here we want to choose a subset of neighboring nodes N (u) as forwarder list of node u such that the expected cost for u to send a packet to the target is minimized. To understand our method better, we introduce some definitions first. Consider a fixed target. Given a set of nodes S, let S∗ denote the increasingly sorted list of S based on the expected cost by each node in S to send data (via possible relay) to this given target node. Let Fwd (u) denote the forwarder list of node u. To find the expected cost at node u, we first sort the forwarder list Fwd*(u) in increasing order by the expected cost, i.e., Fwd*(u) = {v1, v2, ..., v| Fwd (u)|}, where $i < j \Rightarrow Cvi \leq Cvj$. Let α denote the probability that a packet sent by node u is not received by any node in Fwd*(u). Clearly,

$$\alpha = \prod_{i=1}^{|\mathrm{Fwd}^*(u)|} e_{uv_i}$$

Let ρ denote the probability that a packet sent by node u is received by at least one node in Fwd*(u). Then ρ = 1 − α. Let $C_u^h(\mathrm{Fwd}^*)$ denote the expected energy that node u must consume to send a packet to at least one node in the forwarder list Fwd*.

$$C_u^h(\mathrm{Fwd}^*) = \frac{w}{\rho}$$

When at least one node in the forwarder list received the packet successfully, we need to calculate the expected cost to forward the packet sent by node u. Here we assume that only one node from the forwarder list that received the packet will forward the packet. Although this assumption is very optimistic, as we will explain later, in most cases it is true. The expected cost that we calculate here could be slightly lower than the actual cost when multiple nodes from forwarder list could forward the data packet.

Notice that the communication cost for obtaining agreement among nodes in Fwd on which node will forward data is also a factor that affects the total cost forwarding data

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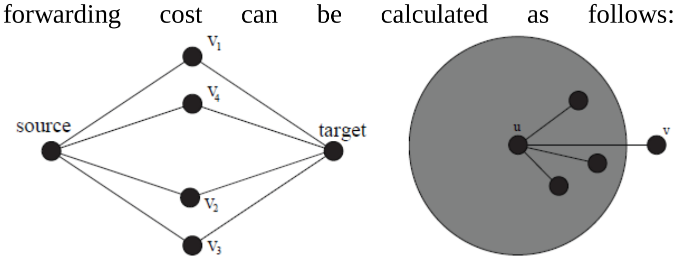
in practice. Let $C_u^c(\mathrm{Fwd}^*)$ denote the communication cost from all nodes in the forwarder list in order to reach an agreement on which node will finally help to relay the packet, $C_u(\mathrm{Fwd}^*)$ is computed as follows: $C_u(\mathrm{Fwd}^*) = C_u^h(\mathrm{Fwd}^*) + C_u^f(\mathrm{Fwd}^*) + C_u^c(\mathrm{Fwd}^*)$

Equation 5 illustrated how to compute the expected cost of a sender to broadcast a packet if the current chosen forwarder list is Fwd*. The cost consists of three parts. The first part is the expected cost for the sender to successfully transmit a packet to at least one receiver in Fwd*. The second part is the expected cost that there is one node in the forwarder list Fwd∗ to help to relay the packet to the final destination node. The third part $C_u^c(\mathrm{Fwd}^*)$ is the communication cost to reach an agreement on choosing the actual relay node. This cost $C_u^c(\mathrm{Fwd}^*)$ is often incurred once when the network is static, while the cost of sending and forwarding depends on the traffic flows.

Without Agreement to Resolve Duplication: Observe that in our previous computation, we assume that we would like to pay an additional cost $C_u^c(\mathrm{Fwd}^*)$ among the forwarding nodes to prevent the scenario when multiple forwarding nodes receive the packet correctly and all decide to forward the packet. When this additional communication is not applied, potentially few nodes may forward the data. This happens when some receiving nodes in Fwd cannot hear from each other directly. Figure 2 illustrates such an example.

In Fig 2, assume (v1, v4) and (v2, v3) are the only neighboring pairs among the forwarding list. If no communications are used to resolve duplicates, (i.e., ($C_u^c(\mathrm{Fwd}^*)$ =0) then the forwarding cost can be calculated as follows:



(a)

(b)

Fig. 2. (a) An example for expected cost calculation. (b) Calculating the expected cost in adjustable transmission power model

Due to the hardness to estimate the agreement cost and considering that most strategies need to pay the communication cost in order to guarantee the 100% data transmission success ratio, we omit the communication cost for agreement when we compute the forwarding list, i.e. formula will be used instead. However, we do count the number of ACK messages used by each node for each packet and use this data as the communication cost in our TOSSIM simulations. We admit that this is may be not accurate enough and we will do further analysis in our future work.

C. Find the optimal forwarder list

So far we have introduced the method to calculate the expected cost for a given node when the forwarder list is given. Next, we discuss how to choose the forwarder list. Consider there are k nodes in N (u) for which an expected cost is already assigned, then there are (2k − 1) choices to select the forwarder list. Finding the expected cost pertaining to each forwarder list is not practical. Here we study the properties of the forwarder list and the expected cost and then we explain how to efficiently choose the optimal forwarder list.

To simplify our arguments, let us introduce a property known as prefix. A set X is called a prefix of an ordered set Y if X is the set of first k elements of Y. So each set Y has (|Y | + 1) prefixes. Now consider node u and its neighboring nodes N(u). Sort the nodes in N (u) based on their expected cost in increasing order, and get N*(u) = {v1, v2... v|N (u)|} such that |N (u)| ≥ i > j > 0 ⇒ Cvi > Cvj. First we show that the optimum forwarder list of node u is a prefix of N*(u).

Theorem 1: The optimum forwarder list of node u must be a prefix of N*(u).

Theorem 2: Consider a node u, a prefix forwarder list Fwd*, and a node vk ∈ N (u) \ Fwd∗. If Cvk < Cu (Fwd*), then Cvk < Cu (Fwd* U {vk}) < Cu (Fwd*). Theorem 2 proves that the expected cost of each node is higher than the expected cost of every node in its forwarder list. This property enables us to take a greedy approach in routing, which will be discussed later.

Theorem 3: Consider a node u, a prefix forwarder list Fwd*, and a node vk ∈ N (u) \ Fwd*. If Cvk > Cu (Fwd∗), then Cu (Fwd∗ U {vk}) > Cu (Fwd∗).

Having these three properties, forwarder list can be selected easily. Algorithm 1 finds the optimum forwarder list and calculates the expected cost for a wireless node. Algorithm 1 works as follows. First it calculates N* (u) and then adds nodes in N (u) to the forwarder list as long as the cost is decreasing. Once the cost starts to increase, it terminates. Based on Theorem 2, before we add a node to the forwarder list we know this operation will increase or decrease the cost. Note Algorithm 1 finds the optimum forwarder list.

Algorithm 1: ExpectedCostFixedPower (u, N (u), Cu, Fwd)
Input :the expected cost of all its neighboring nodes
Output : the cost Cu and forwarder list Fwd.

1: Set Cu = ∞, Fwd = ∅.
2: Sort the neighboring nodes N* (u) = {v1, v2... v|N (u)|} based on its expected cost in increasing order.
3: **for** (i = 1; i ≤ |N (u)|; i = i + 1) **do**

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4: **if** (Cu > Cvi) **then**
5: Set Fwd = Fwd U vi and compute Cu = Cu (Fwd) based on Equation (5).

Algorithm 2: ExpectedCostAdjustPower (u, Cu, Fwd)
1: Set Cu = ∞, Fwd = ∅
2: Sort nodes in N (u) based on *weight* in increasing order.
3: Let N (u) = {v1, v2, ..., v|N (u)|}
4: **for** (i = 1; i ≤ |N (u)|; i = i + 1) **do**
5: Set w = w (u, vi)
6: Run Algorithm 1,
ExpectedCostFixedPower (u, Nw (u), CrCost, CFwd)
7: **if** Cu > CrCost **then**
8: Set Cu = CrCost and Fwd = CFwd.

Now we are ready to verify our claim that a node may not choose all its neighbors into the forwarder list as the optimum forwarder list at the beginning of this section. Consider a network example illustrated by Figure 1 (b). This would serve as a good example that an optimum forwarder list is not necessarily N (u), as mentioned in the beginning of this section.

D. Adjustable Power Model

In this section we consider the case where a node can adjust its power to any value w ∈ [0, W]. Note that for a given forwarder list, if we decrease w to the weight of the farthest link in Fwd (u) then C_u^h may decrease while C_u^f will remain the same, so using adjustable transmission ranges will give us some marginal improvement.

Algorithm 3: Expected Cost by Opportunistic Routing

Input: target node t, source node s, power w (u, v) and link reliability for each link uv.
Output: the expected cost Cu, t from node u to node t using opportunistic routing and the forwarder list of each node u.
1: ∀u ∈ V, set Cu,t = ∞. Let Ct, t = 0.
2: ∀u ∈ N (t) run Algorithm 1 or 2 to compute Cu, t ⇐ Cu.
3: **repeat**
4: Let v be the node in S1 that has the minimum cost.
5: Let S1 = S1 − {v} and S2 = S2 ∪ {v}.
6: For each u ∈ N (v) ∩ S1, run Algorithm 1 or 2 to compute Cu, t, depending on the power model.
7: **until** no node updated the forwarder list and cost Cu, t.

Algorithm 4: Distributed Computing of Forwarder List and Expected Cost by Opportunistic Routing
Input: target node t, source node s, power w (u, v) and link reliability for each link uv.
Output: the expected cost Cu,t from node u to node t using opportunistic routing and the forwarder list of each node u.
1: ∀u ∈ V, set Cu, t = ∞. Let Ct, t = 0.
2: ∀u ∈ N (t) run Algorithm 1 or 2 to compute Cu, t ⇐ Cu.
3: **repeat**
4: For each u, run Algorithm 1 or 2 to compute Cu,t and update its forwarder list, depending on the power model.
5: Node u sends the new cost Cu,t to all its neighboring nodes.
6: **until** no node updated the forwarder list and cost Cu, t.

When the network does not change, the expected cost Cu,t will not be reduced. The algorithm terminates when no node can reduce its expected cost Cu, t. It is easy to show that Algorithm 4 can terminate in constant rounds and find the correct optimum forwarder list and the cost Cu, t.

IV. PERFORMANCE STUDY IN WSNs

In this section, we present the design details of our Energy Efficient Opportunistic Routing (EEOR) protocol in TinyOS- based wireless sensor network (WSN) simulation environment. In our simulation, we consider the case where there are multiple source/destination pair nodes in a randomly deployed WSN. Our design faces several key challenges. Firstly, all nodes in the forwarder list of a node must agree on next operation, *i.e.*, based on the priorities coming with the packet, which one(s) will finally act as the relay node(s) in order to save energy and increase the throughput.

A. Network Description

We randomly place 100 wireless nodes with transmission range 50 feet in a 300 × 300 feet2 square region. A node uses default CSMA MAC protocol in TinyOS. From 100 wireless nodes we randomly pick 18 pairs of wireless node as source/destination pairs and for each source/destination pair nodes u and v, u will generate a new packet per second, which is heading for v by one- or multi-hop. Notice that the frequency of generating new packet could change when the source node find congestion in the network. We call the number of sending packets as data size. Considering the limited storage capacity of wireless sensor nodes, we set the buffer size to 20. After the buffer of a node is full, it will either drop new packet or replace old packet with new one according to different priorities of packets.

B. Performance Evaluation

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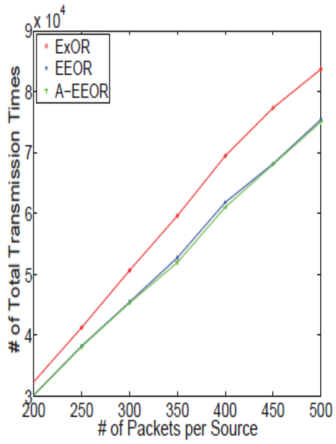

Figure3: Total transmission

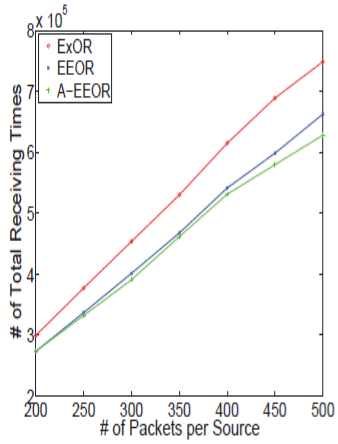

Figure 4: Total received packets

As we can see from the figures, both transmission times and receiving times of ExOR are larger than EEOR's. This is due to the following reasons. First, for a node u in ExOR, it will always choose more neighbors into forwarder list for a packet under the constraint of penalty. However, in EEOR, when a node u chooses forwarder list for a packet, it will not only consider the expected cost of sorted neighbors, but also consider the increment cost by adding a node to the forwarder list such that u will not add a new neighbor to the forwarder list if doing so will increase the expected cost.

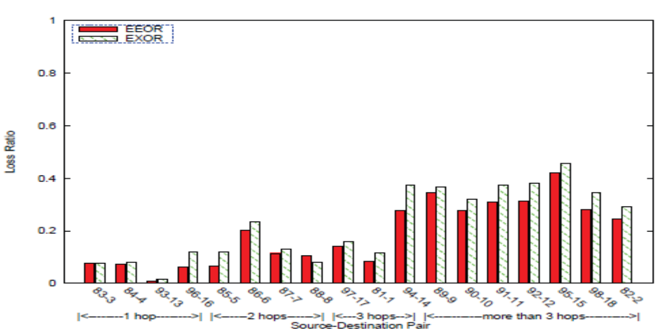

Figure 5: Packet loss ratio

C. *File Transmission and Throughput*

A number of energy efficient routing protocols have been proposed recently combining with a variety techniques. Most existing power aware protocols did not consider the packet losses of the wireless links. They assumed that the wireless links are reliable and then tried to theoretically provide performance guarantees. There are some other protocols proposed recently to remedy the unreliability of the wireless channels such as using multi-path routing, building reliable backbone and using energy efficient reliable routing structure. In, Dong and Banerjee addressed the problem of energy-efficient reliable wireless communication in the presence of unreliable or lossy wireless link layers in multi-hop wireless networks. Their main focus is on single path routing. Banerjee and Misra explored the effect of lossy links on energy efficient routing and solved the problem of finding the minimum energy paths in the hop-by-hop retransmission model.

MORE randomly mixes packets before forwarding them. MORE needs no special scheduler to coordinate routers and can run directly on top of 802.11. Experimental results from a 20-node wireless test bed show that MORE's median unicast throughput is 22% higher than ExOR, and the gains rise to 45% over ExOR when there is a chance of spatial reuse. In addition to EXOR, propose another opportunistic any-path forwarding protocol. Notice that ExOR and MORE were designed for large file transferring in wireless static mesh networks where energy saving is not a concern. Our protocol focused on minimizing the energy consumption of data forwarding in wireless sensor networks.

V. CONCLUSION AND FUTURE WORK

Several interesting and challenging problems are left unsolved here. An interesting question is to design efficient protocols for selecting optimum forwarder list for multicast and broadcast. A challenge is to compute the expected cost accurately when we need to consider the additional overhead by sensor nodes for agreeing a unique node in the forwarder list to forward the data when multiple nodes could have potentially received the data correctly. It is interesting to design protocols using opportunistic routing that deliver the data most reliably, or deliver the data with the minimum delay.

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Biography

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