Fragmented Opportunistic Routing Algorithm In WSN

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ABSTRACT:

In wireless networks, using traditional unicast routing algorithm is inappropriate due to broadcast nature and spatial diversity of wireless links. Selecting a set of N nodes as next hop in wireless networks instead of one node, increases delivery probability relative to N. This fact led to emerging a new routing schema in wireless network in recent years naming Opportunistic Routing. Opportunistic routing takes advantages of wireless networks to get higher performance metrics by selecting multiple nodes as next hop for each node instead of selecting one node as in traditional routing algorithms, Our proposed Opportunistic routing algorithm (named Fragmented Opportunistic Routing) uses local information and easy to be applicable. It tolerates nodes' failure and changes in network and upon a change in a part of network; there is no needs that all the nodes in network reconfigure their Opportunistic Routing Tables

Keywords:
wireless networks, Multi-hop Wireless Network, Opportunistic Routing

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1. INTRODUCTION:

With the emergence of computer networks, the routing problem has been arisen. Finding the shortest path between two points in a graph roots in 1950 and it's the fundamental of most routing protocols in computer networks so far[1]. With emergence of wireless networks and new circumstances the framework based on unicast transmissions and single-path route doesn’t seem well as in wired traditional networks [2,3]. Group of nodes which are connected by wireless communication links is called a *Multi-hop Wireless Network* (MWN) which receive increasing attention due to their broad applications and low cost of deployment, without relying on existing infrastructure, recently[4-7]. One of the main challenges in MWNs is routing packets from any source to destination. WSNs are one of the best sample of MWNs. One of other differences between Wireless and wired links is common nature of wireless versus dedicated nature of wired. Also wireless links are not as reliable as wired links. The quality may vary during the time considerably. This variation is due to changes in transmission rate, transmission power, distance and path loss between two nodes. Also these types of networks have another difference with wired networks and its channel fading which leads to fluctuation in received signal power. In addition to what have been referred to in above, almost all existing commercial wireless devices are battery powered. This imposes limitations on connectivity and network lifetime and communication links of network.

Most of routing algorithms proposed in MWNs, abstract wireless links as wired links with some assumptions. For example, they may be assumed that if node B is in coverage area of node A with minimum delivery probability equal to 0.2, then there is a link between A and B. as in Figure 1 it is assumed that if a node is in coverage area of another, then there is a link between them. Since all routing protocols in wired networks are developed base on persistent and consistent behavior of wired links, using these routing protocols in wireless networks with alternative and inconsistent behavior of wireless links, results in low delivery ratio and high data overhead. In other words, such abstraction of wired links ignores the broadcast nature and spatial diversity properties of wireless medium. In wireless networks, when a node unicasts a packet to a specific next hop, other nodes which are in effective transmission range of sender and have better position than transmitter to destination, may receive packet correctly, whereas the specified next hop doesn’t receive it. Based on this probability a new routing scheme has been proposed in wireless network namely Opportunistic Routing (OR). OR instead of selecting one node

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as next hop, selects a set of nodes (namely Candidate Set – CS) and based on network condition in transmission time,

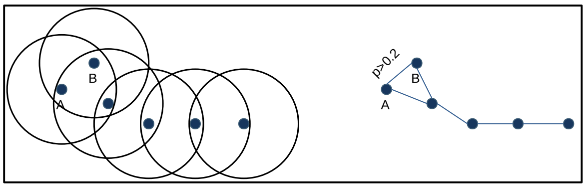

Figure 1: Abstraction of links in wireless networks

A member of candidate set which has received packet correctly (if there is) is selected as next hop. So it avoids unnecessary retransmissions. Opportunistic routing uses the broadcast nature and spatial diversity of wireless communications and becomes an effective mechanism to exploit time-varying links. OR tries to reduce the average number of transmissions required for packet delivery from a source to a destination. Reduced number of transmissions leads to lower delay and higher throughput of network and its distributed load which causes lower jitter. Opportunistic Routing (OR) also have other names such as cooperative forwarding, diversity forwarding, or any-path routing, has been proposed to increase the performance of MWNs by taking advantage of its broadcast nature. A Wireless Sensor Network (WSN) contains hundreds or thousands of these sensor nodes. Sensor nodes can communicate among themselves and directly to a base station. They can be networked to communicate information in an unattended situation. A greater number of sensors allows for sensing over larger geographical regions with greater accuracy. The main characteristic of a wireless sensor network is its multi-hop wireless links and having nodes with constrained resources. Communication is the major source of energy consumption in a sensor node and costs significantly more than computation in WSNs. Opportunistic routing has shown its advantage on energy efficiency compared to traditional routing. However, the existing opportunistic routing schemes like GeRaF[8][9 typically include all the available next-hop neighbors as forwarding candidates, which does not lead to optimal energy efficiency due to the overhead of large candidate set cardinality. In OR, in contrast to traditional routing, instead of preselecting a single specific node to be the next-hop as a forwarder for a packet, an ordered set of nodes (referred to as candidates) are selected as the potential next-hop forwarders. Thus, the source can use multiple potential paths to deliver packets to the destination. More specifically, when the current node transmits a packet, all the

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candidates that successfully receive it will coordinate with each other to determine which one would actually forward it, while the others will simply discard the packet.

2. TERMINOLOGY

2.1.Candidate Set (CS)

Candidate set is a subset of nodes within the effective transmission range of node *A* as the neighboring node set N_i of node *A*

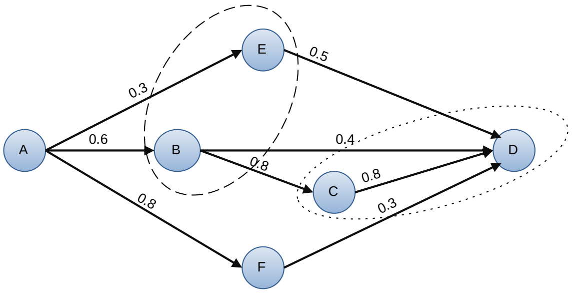

Figure 2: Candidate Set (CS)

We define the set F_i *[10]* shown in Figure 2, as forwarding candidate set, which is a subset of N_i and includes all the nodes selected to be involved in the local opportunistic forwarding set based on a particular candidate selection strategy. F_i is an ordered set, where the order of the elements corresponds to their priority in relaying a received packet.

2.2. Expected Transmission Count

This metric, counts the expected number of transmissions needed to successfully deliver a packet across an unreliable unicast link. With link layer anycast and if J is candidate Set of node i, the ETX becomes the expected number of transmissions until any node in J receives the packet. Its equation is:

$$\text{ETX (i,j)}={}^{1}\!/_{P_{ij}}$$

Where P_{iJ} is the probability that a packet from *i* is received by at least one node in the set of nodes *J*:

$$p_{iJ} = 1 - \prod_{j \in J} (1 - p_{ij})$$

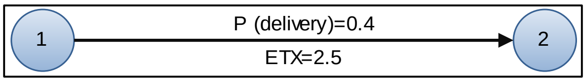

Figure 3: ETX of a link

In other word, ETX is average number of transmission that should be done in order the destination receive packet correctly.

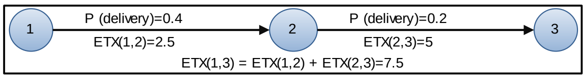

Figure 4: ETX of a path

2.3. Expected Any-path Transmission (EAX)

In fact, EAX is extension of ETX in opportunistic routing and reflects the number of transmissions needed to deliver a packet from a node to its destination through OR. EAX provides a metric for capturing the cost from source to destination assuming a packet could traverse any possible path. Intuitively EAX indicates the average number of transmissions to deliver a packet correctly to a specific destination using opportunistic path.

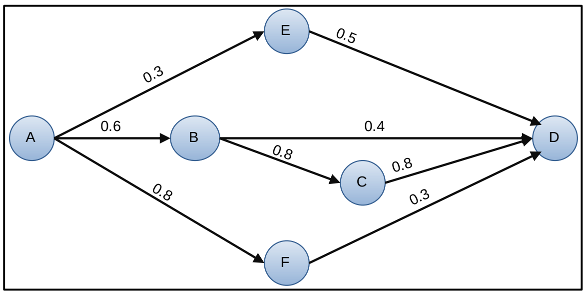

Figure 5: An example to show ETX and EAX difference

In figure 5, we want to calculate EAX for opportunistic path between source A and destination D. $C^{s,d}$ is next hop candidate set and $C_i^{s,d}$ is a candidate relay with priority i (1 is highest priority). Assume delivery probability from node s to $C_i^{s,d}$ is p_i. Then we have:

$$\mathrm{EAX(s,d)} = \frac{1 + \sum_i \mathrm{EAX}\left(C_i^{s,d}, d\right) p_i \prod_{j=1}^{i-1}\left(1 - p_j\right)}{1 - \prod_i (1 - p_i)}$$

Having network in figure 5, assume that node *D* is the destination and node *A* is source. If candidate set of *A* includes *B* and *E*, candidate set of *B* includes *C* and *D* and other nodes' candidate sets contain only one node as shown in figure, let's calculate *ETX* and *EAX* of every node in this network.

Table 1: ETX and EAX of every node

F	E	D	C	B	A	Metric
3.33	2	0	1.25	2.5	4.47	ETX
3.33	2	0	1.25	1.82	3.24	EAX

2.4. Opportunistic Route

Opportunistic route (opp. route) is the set of all possible paths that packets may traverse from a source to a destination, arising from a given assignment of candidate set of each node.

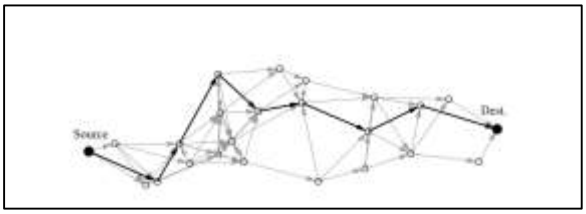

Figure 6: opportunistic route and trajectory[11]

An example of opportunistic route is shown in Figure 6.

2.5. Related Works:

In wireless network when a packet is unicast to a specific next hop, other nodes in transmission range of sender may receive the packet correctly in their physical layer and since the address of receiver in the packet doesn’t belong to them, the packet will be dropped, although they may have better position to destination than sender and the specific intended next hop has not received the packet. Based on this observation, a new routing paradigm naming opportunistic routing in recent years has been proposed for wireless networks. Opportunistic routing integrates MAC and network layer, and with it, each node that wants to send a packet, chooses an ordered set of nodes naming candidate set as its next hop instead of choosing one node as receiver of its packet. Opportunistic routing performance depends on several issues:

1- Choosing forwarding candidates: we may think that including all neighbors improves routing performance and is the most effective policy. But increasing candidate set cardinality results in overhead increase. A trade-off appears in number of candidates and overhead of candidates’ coordination.

2- Candidates' priority: The problem of receiving the packet correctly by more than one node in candidate set is to decide which node is going to forward the packet. This is called the prioritization problem and nodes with the highest priority forward packet. If prioritization is not based on the lowest cost to destination, it decreases the efficiency of routing algorithm.

3- Another problem is candidate coordination; which should be distributed and efficient.

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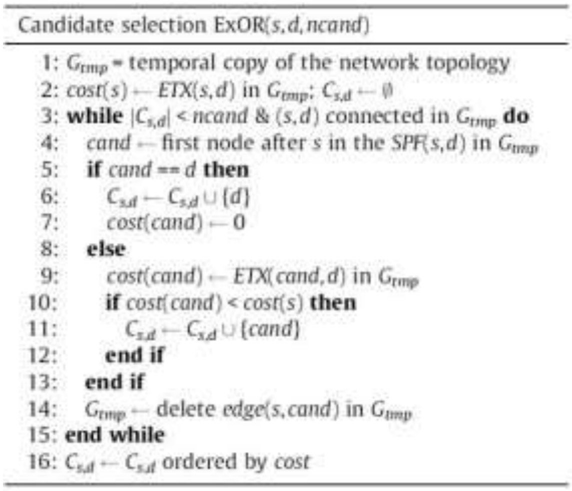
Improved efficiency using opportunistic routing algorithm have been proved and many algorithms have been introduced, but still there are many open problems. In dense sensor network, every node has many neighbors and choosing the best candidate set in dense sensor networks is very difficult and time consuming. In sensor networks always all nodes know their exact or rational position and position of the destination. We can use this position information in our opportunistic routing algorithm. In Most wireless sensor networks, the nodes are fixed and their positions change infrequently. We can design algorithm for a fixed wireless sensor network with lower overhead

2.6. Extremely Opportunistic Routing (ExOR)

Biswas and Morris proposed ExOR[12]; one of the earliest and most referenced OR protocols. . ExOR try to use multiple long but radio lossy links concurrently; hence it can reach high expected progress per transmission in terms of ETX. In ExOR the source node attaches a list of candidate forwarders to each packet prioritized by closeness to the destination. Receivers cache successfully received packets and wait for the end of the batch. The highest priority forwarder then removes the "batch map" of the packet and attaches its own batch map to it and rebroadcasts it. Suppose that q_{ij} is ETX of the link between i and j. An implementation of ExOR is shown below. Its main idea is running shortest pass first with $\text{weight} = {}^{1}/_{q_{ij}}$. In ExOR candidate selection algorithm, first node after s in the shortest path is selected as candidate (cand) if its ETX to the destination (ETX (cand,d)) is less than ETX(s,d). Then the link between s and cand is removed, and this process is repeated until no more paths to d are available, or the maximum number of candidates is reached (|Cs,d| = ncand).



```
Candidate selection ExOR($s, d, ncand$)
$G_{tmp}$ = temporal copy of the network topology
$cost(s) \leftarrow ETX(s,d)$ in $G_{tmp}$; $C_{s,d} \leftarrow \emptyset$
while $|C_{s,d}| < ncand$ & $(s,d)$ connected in $G_{tmp}$ do
    $cand \leftarrow$ first node after $s$ in the $SPF(s,d)$ in $G_{tmp}$
    if $cand == d$ then
        $C_{s,d} \leftarrow C_{s,d} \cup \{d\}$
        $cost(cand) \leftarrow 0$
    else
        $cost(cand) \leftarrow ETX(cand,d)$ in $G_{tmp}$
        if $cost(cand) < cost(s)$ then
            $C_{s,d} \leftarrow C_{s,d} \cup \{cand\}$
        end if
    end if
    $G_{tmp} \leftarrow$ delete $edge(s,cand)$ in $G_{tmp}$
end while
$C_{s,d} \leftarrow C_{s,d}$ ordered by $cost$
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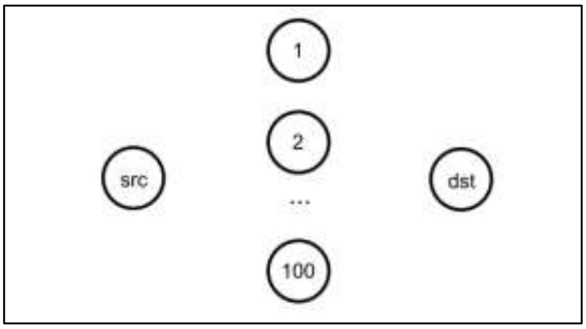

Figure 7: An example that each source's transmission has many chances of being received [12]

The authors of ExOR provide some reasons to prove their approach outperforms the traditional uni-path algorithms. Their first explanation is that each transmission may have more independent probabilities of being received and forwarded as it's all opportunistic routings logic. They have illustrated this reason with an example scenario that we explain it here in figure 7. They assume that delivery probability from the source to each of intermediate nodes is 10% and the delivery probability from each of intermediate node to the destination is 100%. Each traditional routing protocol will select only one of these intermediate nodes as next hop; the high loss rate would require each packet to be sent an average of ten times before being received by the intermediate, in addition to one to get the destination, thus total throughput will be 0.09 times the nominal radio speed. They claim that in this example ExOR would achieve a throughput of roughly 0.5, since the probability of reception of packet by at least one of the intermediate nodes is much more than this probability for a specific node of them.

And the second reason they have provided to outperformance of ExOR compared to traditional routing is that it takes advantage of transmissions that reach unexpectedly far, or fall unexpectedly short. Consider figure 8, as in actual condition, delivery probability decreases when distance increases. If one of traditional uni-path routing protocols is used, then data would be forwarded through some sub-sequence of the chain, for example source-C-E-destination. If a packet transmission from the source falls short of C, but reaches each of A and B, then that transmission is always wasted. In traditional routing the packet should be retransmitted until C receives it correctly. In other hand, if a packet can reach farther than C, for example D or E or even destination receives packet, traditional routing cannot make use of that luck. They claim that ExOR can often take advantage of both of these situations. In the first case, B will re-send the packet, and much

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more progress per transmission is made. In the second case, which is the best, if destination receives packet, the packet has been delivered.

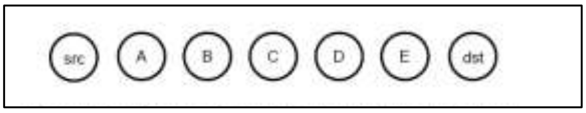
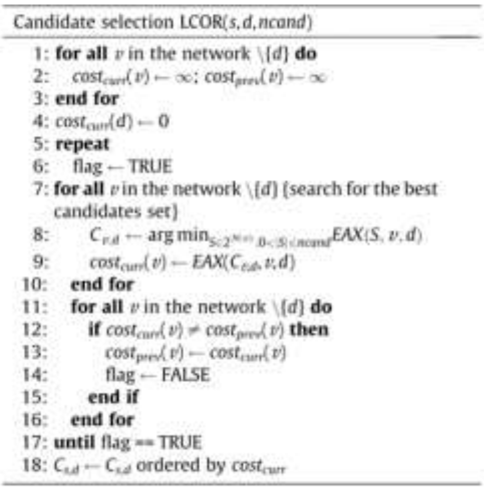


Figure 8: Example in which the source's transmissions may progress differently

They have shown that their proposed approach increases total network capacity as well as individual connection throughput. Its average number of transmissions is less than traditional routing, causing less interference for other users of the network.



```
Candidate selection LCOR($s, d, ncand$)
for all $v$ in the network $\setminus\{d\}$ do
    $cost_{curr}(v) \leftarrow \infty$; $cost_{prev}(v) \leftarrow \infty$
end for
$cost_{curr}(d) \leftarrow 0$
repeat
    flag ← TRUE
for all $v$ in the network $\setminus\{d\}$ {search for the best
    candidates set}
        $C_{v,d} \leftarrow \arg\min_{S \subseteq 2^{N(v)},\, 0<|S|\le ncand} EAX(S, v, d)$
        $cost_{curr}(v) \leftarrow EAX(C_{v,d}, v, d)$
    end for
    for all $v$ in the network $\setminus\{d\}$ do
        if $cost_{curr}(v) \neq cost_{prev}(v)$ then
            $cost_{prev}(v) \leftarrow cost_{curr}(v)$
            flag ← FALSE
        end if
    end for
until flag == TRUE
$C_{s,d} \leftarrow C_{s,d}$ ordered by $cost_{curr}$
```

2.7. LCOR

Another OR algorithm is Least Cost Opportunistic Routing[13], The goal of this algorithm is to find the optimal candidates sets. The optimal candidate sets means the sets that minimize the expected number of transmissions of packet across path to destination. Its goal is to find the best CS and best prioritization for them. It can be seen as an extension of the classical distributed Bellman–Ford algorithm in opportunistic routing. The optimal selection of candidate relays must take into consideration the following tradeoff . On the one hand, how much the cardinality of candidate set is increased and the path cost decreased (i.e., the cost to send to any of these candidates that means at least one of them receives the packet). On the other hand, each neighbor that is included in candidate set does not make as much progress as the next hop in the shortest path to the destination. Thus if candidate set cardinality is very large, likelihood of a packet veering away from the shortest route will increase (and even may loop in the routing path created). The algorithm of LCOR proceeds iteratively and at each iteration an exhaustive search over all possible candidates' sets is carried out. It starts by initializing the cost (EAX) of each

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node v to reach the destination d (lines 1–4). Since in the initializing phase the candidates sets for all nodes are empty, the cost to reach the destination for all nodes is equal to 1 (costcurr(v) 1). Note that the cost for the destination d is always equal to 0 (costcurr(d) 0). To find the optimal candidates sets in each iteration, and for every node v except the destination, the algorithm runs an exhaustive search over all possible subsets of N(v) with cardinality not exceeding ncand (line 8). The algorithm terminates when the cost to reach the destination does not change for all nodes in two consecutive iterations (lines 11–16).

2.8. Opportunistic Any-Path Forwarding (OAPF)

OAPF[14] is another sub-optimal opportunistic routing which is hop-by-hop and based on *ETX* and *EAX*. Algorithm 2 shows the pseudo code of OAPF. Assume that node s wants to select its candidate set to reach the destination d. First, it initiates its candidate set $(\widehat{C_{s,d}})$. Assume *v* is neighbor of *d* and *ETX (v, d) <ETX(s, d)* then it would be included in the initial candidate set of *d*. The actual candidate set of s will be a subset of the initial candidate set. Note that, the candidate set of all nodes in the initial candidate set must be selected before *s* and this is done in Line 15 with a recursive function. After that, *s* initiates its candidate set; it should select the best candidate among the nodes in the initial candidate set. With regard to their definition, the best candidate is the one with the minimum expected number of transmissions from *s* to the destination (line 19). Then this best candidate is added to actual candidate set $(C_{s,d})$ of *s* and then removed from its initial set. It tries again to find the best node from its new initial candidate set. It continues this process until there is not any appropriate node to include in the actual candidates set of s, or the cardinality of $C_{s,d}$ reaches the maximum number of candidates (ncand). In the last, the prioritization of candidate set of each node is done by *EAX* of each candidate. many other CS alogrithms have been proposed in recent years. Some of them are MTS, GeRaF, SAF

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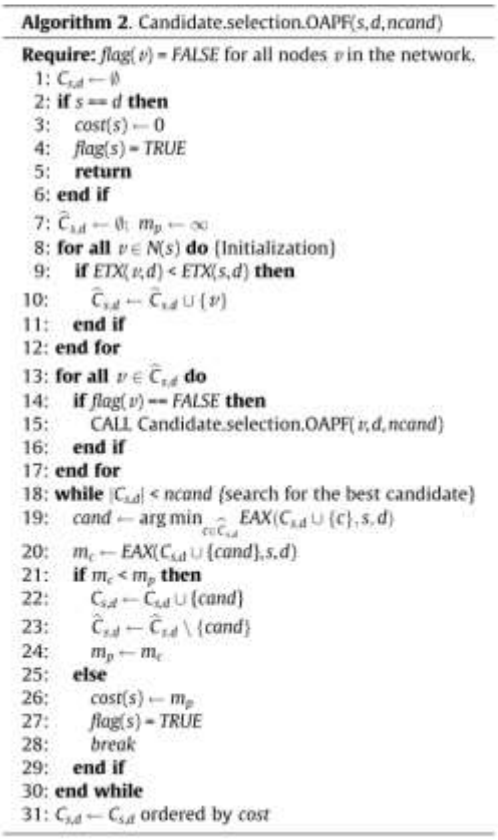

Algorithm 2. Candidate.selection.OAPF($s,d,ncand$)

```
Require: $flag(v) = FALSE$ for all nodes $v$ in the network.
$C_{s,d} \leftarrow \emptyset$
if $s == d$ then
    $cost(s) \leftarrow 0$
    $flag(s) = TRUE$
    return
end if
$\widehat{C}_{s,d} \leftarrow \emptyset$; $m_p \leftarrow \infty$
for all $v \in N(s)$ do {Initialization}
    if $ETX(v,d) < ETX(s,d)$ then
        $\widehat{C}_{s,d} \leftarrow \widehat{C}_{s,d} \cup \{v\}$
    end if
end for
for all $v \in \widehat{C}_{s,d}$ do
    if $flag(v) == FALSE$ then
        CALL Candidate.selection.OAPF($v,d,ncand$)
    end if
end for
while $|C_{s,d}| < ncand$ {search for the best candidate}
    $cand \leftarrow \arg\min_{c \in \widehat{C}_{s,d}} EAX(C_{s,d} \cup \{c\}, s, d)$
    $m_c \leftarrow EAX(C_{s,d} \cup \{cand\}, s, d)$
    if $m_c < m_p$ then
        $C_{s,d} \leftarrow C_{s,d} \cup \{cand\}$
        $\widehat{C}_{s,d} \leftarrow \widehat{C}_{s,d} \setminus \{cand\}$
        $m_p \leftarrow m_c$
    else
        $cost(s) \leftarrow m_p$
        $flag(s) = TRUE$
        break
    end if
end while
$C_{s,d} \leftarrow C_{s,d}$ ordered by $cost$
```

Most of opportunistic routing algorithms that have been proposed so far are centralized. Thus they are not scalable and have single point of failure. Least Cost Opportunistic Routing has exponential complexity. In LCOR, in order to compute candidates' sets of source, the computation of all the necessary candidates' sets should be done. This is because that these algorithms are based on EAX metric which require each of neighbors' cost to destination. In ExOR which is not centralized, it can be proved that it isn't optimal [15], in addition to that, there is no limitation on cardinality of candidate set and in none of proposed works, the overhead of candidate set coordination has been considered. Although it has been shown [16] that if members of candidate set exceed than a specific value (3 or 4), the algorithm performance metrics do not experience much enhancement and this fact has not been considered in these proposed algorithms. Another problem with most of these proposed algorithms (like MTS, LCOR or OAPF) is mobility. Each movement that changes the neighbors or candidate set of a specific node makes some nodes or sometimes the whole network to calculate their candidate sets again and they need information from all the nodes in network for this purpose. This imposes a great computational and communicational overhead on the network. Shortest Any-path First transmission (SAF) is operating like Bellman-Ford minimum distance vector. It has been

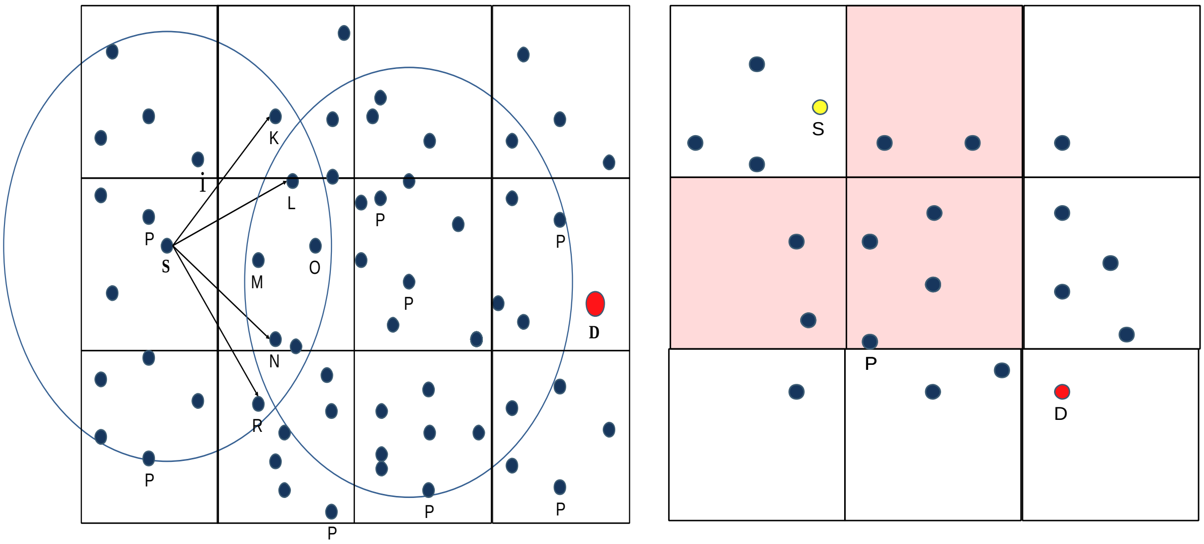

Figure 9: procedure of selecting grid and node.

proved that it's optimal in sense of Expected Number of Transmission metric[17], but like other algorithms, it needs the information from all nodes in network and any failure and movement of any node in network may lead to very bad performance metrics. Sometimes a suboptimal answer in a rational time and with much less energy consumption is much better than an optimal answer in much more times and with high energy consumption. Therefore, we have proposed an opportunistic routing algorithm that every node uses local information and get neighbor position. In Our proposed algorithm, every node partitions the network space to grids with specific size and selects nodes as its candidate set according to grids they belong to. The proposed algorithm imposes limitation on size of candidate set. Hence coordination of candidate set members doesn't impose high computational and communicational overhead on algorithm. Also our algorithm is fault tolerance because any changes and failure in a node in network, just has impact on some of its adjacent. In mobile networks, there might be no needs to any changes in any routing table or a little number of nodes may be affected.

2.9.FOR[1] Methodology

Sometimes a suboptimal answer in a rational time with less energy consumption is much better than an optimal answer in longer duration of time with high energy consumption. We want propose an opportunistic routing algorithm that imposes very low communicational and operational overhead on network with acceptable energy

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[1] Fragmented Opportunistic Routing

consumption on one hand, which is distributed on the other hand and each node just uses its neighborhood information. We are about to develop a distributed algorithm and reach good performance in case of expected number of transmission (EAX). But we don't think ideal. We lose optimality and in reality it's a trade-off between optimality and applicability and complexity. The proposed method will be shown later.

In the first step, each sensor node makes its grid table and neighbor table. The grid sizes in all nodes in a grid are the same. The grid table per each destination has a row that contains of IDs of candidate grids.

Table 2: Grid table

Grid ID 3	Grid ID 2	Grid ID 3	Destination
I-003	I-002	I-001	Dest 1
I-009	I-011	I-012	Dest 2

After that each node create Neighbor Table, There is also one raw for Neighbor tables for each destination. In each row, 4 candidates relay (if exist) and an update time exists. First two nodes are chosen from the grid with the highest priority and each of two other nodes are chosen from two other grids with the second highest priority. In our scenarios, we have only one destination, so neighbor table only contains a row.

Table 3: Neighbor Table

Destination	CR1	CR2	CR3	CR4	Time
Dest 1	003	004	045	031	00.12
Dest 2	011	034	062	004	00.18

Suppose that a mobile sensor node tries to send a data packet to the sink. This source node knows its own position as well as the position of the sink, so it can make sure the transmission direction. We only use this direction to explain how to determine candidate grids. In Partitioned Opportunistic Routing, the three grids across calculated direction are selected to be candidate grids. As we said earlier the number of candidate grids is 3. The source node then makes a grid table with these candidate grids and a neighbor table. All these grids are prioritized according to their priorities.

Then, the source node broadcasts the packet. Every sensor node has timer to show the time that node have to start forwarding the packet if no higher priority nodes have transmitted the packet. So, the node with highest priority does not wait any time, while

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the lowest priority node must wait for the longest time. The lower one grid's priority, the longer its delay is.

All nodes received the packet determine their priorities according to packet they have received, the information of the neighbor table included at the head of the packet. Then they listen to ACK for this. For a node received the packet, if it don't receive ACK until its window, it forwards the packet and broadcasts an ACK. It is a sign for lower priority candidate relays in the neighbor table through flooding. This process continues until the packet reaches the sink.

3.RESULTS

We use Prowler [18] simulator to simulate algorithm. We use EAX as the main performance metric and compare it with other opportunistic routing algorithms that we introduced in previous sections.

Table 4: Simulation parameters

Parameters	Value
Frequency	916.5 MHz
Data rate	50 kbps
MAC	Simple carrier sense Multiple Access

Figure 10 shows average number of transmissions in different densities for an optimal uni-path algorithm. Our proposed algorithm and three opportunistic routing algorithms were explained in previous sections.

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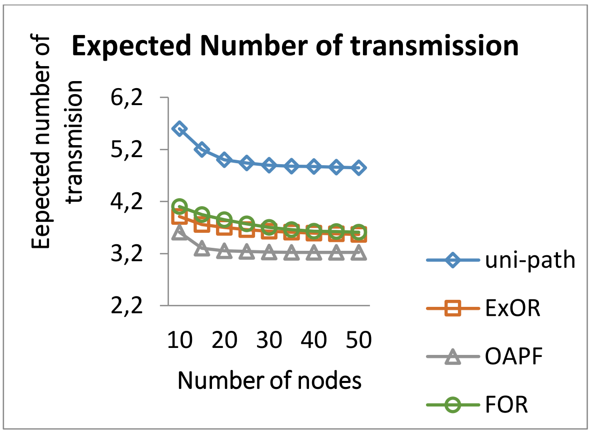

Figure 10: Expected Number of transmission

As we see, FOR and any other opportunistic routing algorithms have better performance than any other optimal uni-path algorithm. But in comparison, other opportunistic routing algorithms have better expected number of transmission.

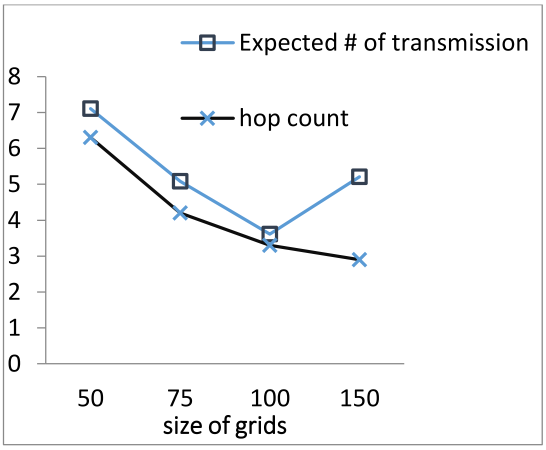

Figure 11: Size of Grid and hop count

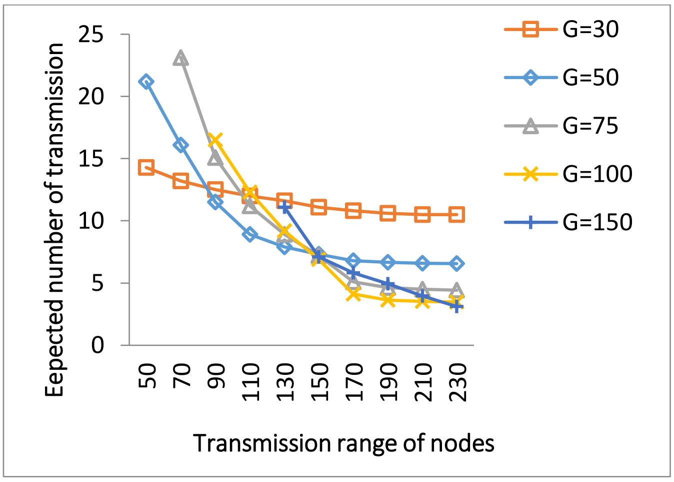

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Figure 12: transmission range, EAX and grid size

Figure 11 shows inefficiency of hop count metric, because if we had chosen grid size based on this metric, the size would be equal to 150 meters for each grid and it would impose great overhead, delay and energy consumption on nodes. As transmission range increases, the average number of transmission converges to the number of grids in path to destination. It is hard to find an analytical approach to calculate optimal transmission range in every scenario and it will be open for next researches. But we can find it through simulations and we can find optimal grid size for each transmission range. As an example, when we have grid size of 110 meters, the best grid size based on EAX, is 50 meters. Although some other parameters like density can affect this, but we have fixed them in this experiment.

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