Optimal Flooding Protocol for Routing in Ad-hoc Networks

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Abstract— **Location discovery is a fundamental problem in wireless ad hoc networks. Most of the ad hoc routing protocols use some form of flooding to discover the location and route of a mobile node. Despite various optimizations, many messages are propagated unnecessarily. We propose the Optimal Flooding Protocol (OFP), based on a variation of *The Covering Problem* that is encountered in geometry, to minimize the unnecessary transmissions drastically and still be able to cover the whole region. OFP out-performs other existing variations of flooding. This simple protocol uses up to 65% to 80% fewer messages than flooding and 50% fewer messages than gossip-based flooding, which has been proposed as one of the best optimized variation of flooding. OFP is scalable with respect to number of nodes; in fact OFP's performance improves with the number of nodes.**

Keywords-optimal flooding; flooding; location discovery; routing in ad-hoc networks; ad-hoc network, wireless networks.

I. INTRODUCTION

A "mobile ad hoc network" (MANET) is an autonomous system of mobile routers (and associated hosts) connected by wireless links--the union of which forms an arbitrary graph. The routers are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion, or may be connected to the larger Internet.

Ad hoc networks, from a routing perspective, can be seen as a multi-hop network with mobile nodes and hence constantly changing routes. With a constantly changing topology it becomes essential to have a distributed algorithm, which incurs the least communication overhead. Given the expensive and limited nature of wireless resources such as bandwidth and power, there is every need to minimize the control message overhead for route discovery.

This paper presents a new protocol for minimizing the control overhead for route/location discovery by doing selective forwarding where only a few selected nodes in the network do the broadcasting. It is assumed that the mobile nodes can discern their relative positions with respect to other nodes in the range of communication. This can be easily achieved by GPS devices [9, 17]. We extend *the Covering Problem,* which deals with covering a region completely using minimum number of circles, for this purpose.

The key advantages of our protocol are: a) OFP is scalable with respect to the number of mobile nodes in the region; b) OFP minimizes the number of unnecessary transmissions to maximum possible extent and outperforms all other variations of flooding; c) It is easy implement OFP.

The rest of this paper is organized as follows: Section 2 discusses related work, Section 3 introduces *The Covering Problem* and a modification of the Covering Problem, Section 4 our approach for optimal flooding, Section 5 presents the simulation results of OFP, Section 6 deals with some analysis and comments of OFP and Section 7 concludes.

II. RELATED WORK

The design of routing algorithms is a fundamental problem in ad hoc networks and several ad hoc routing protocols have been proposed [1-10]. The fundamental requirements of a routing algorithm for mobile ad hoc networks are the ability to adapt to different traffic patterns and incur less control overhead to conserve the limited wireless bandwidth.

DSDV Routing [1] has been proposed as an approach to routing between ad hoc mobile nodes. This approach involves all nodes to maintain a complete list of routes to all the other nodes in the network. Keeping a complete routing table does not reduce the route acquisition latency before transmission of the first packet to the destination. On-demand protocols such as DSR [2], AODV [3], ZRP [4], GOSSIP [5] make use of flooding algorithms (with different variations) assuming that the mobile nodes lack location information; others like LAR [6], DREAM [7] make use of GPS information so that the mobile nodes are aware of their instantaneous locations.

Several optimizations have been proposed to reduce the route discovery overhead. Perkins and Royer propose the algorithm AODV [3] (Ad hoc on demand distance vector routing) that uses a demand driven route-establishment procedure with an expanding-ring search. AODV resorts to pure flooding if the destination is not found in a zone of small radius.

Hass and Pearlman propose ZRP (Zone routing protocol) [4], which uces proactive and reactive approaches in route discovery and route maintenance respectively. Route discovery is performed on-demand but is limited to the initiator's neighborhood, and topology update propagation is limited only to the neighborhood of change.

TORA [8] tries to minimize reaction to topological changes by limiting routing messages to the group of nodes near the change. In this algorithm, it is possible to have longer routes as a result of avoiding the overhead of discovering new routes.

Among all the flooding algorithms, GOSSIP [5] promises the least communication overhead. GOSSIP uses an probabilistic optimized flooding algorithm in which the nodes broadcast received route queries with a probability and thus guarantee a reduction of 35% of control message overhead (when nodes broadcast received messages with a probability of 0.65) as compared to other flooding algorithms. GOSSIP exhibits bimodal behavior in sufficiently large networks i.e. in some executions, gossip dies out prematurely and most of the nodes do not receive the broadcast; and in some the broadcast reaches a significant fraction of the nodes in the network. The fraction of executions in which most of nodes receive the broadcast depends on the gossip probability of the nodes and the topology of the network. So it is possible that nodes that can be reached by ordinary flooding do not receive the broadcast in GOSSIP.

Even though GOSSIP guarantees a reduction in communication overhead, it has inherent fallacies because of its probabilistic model, as there is a possibility that the gossip dies out prematurely. It also suffers from boundary effect i.e., the nodes at the edge of the network may not receive the broadcast. Given the sensitive nature of ad hoc network applications including battlefield situations, we need a robust routing protocol, which ensures that the route discovery method is fail-proof and quick.

Other location information using protocols e.g. LAR [6], GPSR [10] and DREAM [7] need precise physical location of the node and use GPS capability to gather the location information. Our protocol requires that the nodes be capable of calculating their relative positions with respect to the other nodes in their range of communication.

In wireless ad hoc networks, which are implemented on IEEE 802.11 like standard, when a node broadcasts a message all nodes within the range of the transmission get that message. Along with this inherent feature of radio communications, our protocol assumes that the nodes can calculate their relative position with respect to other nodes in their locality (using GPS [9, 17] is an option).

III. BACKGROUND

A. The Covering Problem

The Covering Problem can be stated in one way as follows: "What is the minimum number of circles required to completely cover a given 2-dimensional space."

Kershner [18] showed that no arrangement of circles can cover the plane more efficiently than the hexagonal lattice arrangement shown in Fig.1. Initially, the whole space is covered with regular hexagons, whose each side is R and then, circles are drawn to circumscribe them.

B. Modified covering problem for ad hoc networks

Here, we state a modified version of *The Covering Problem* that finds its application in ad hoc networks as follows:
What is the minimum number of circles of Radius R required to entirely cover a 2-dimensional space with the condition that the center of any circle lies on the circumference of at least one circle. Also, one circle should be centered on the center of the region.

If the range of a mobile node is considered to be R, then the reason behind the condition that the center of a circle should lie on the center of another circle and that one circle should be centered on the center of the region is as follows: A Mobile Ad hoc node has to receive a message for it to retransmit the message and the center of the region is where the Mobile Node that needs to do the flooding operation is located. A possible solution for the Modified Covering Problem is shown in Fig. 2. As done for covering problem, initially the whole region is covered with regular hexagons whose each side is R. Then, with each of the vertices as a center, circles of radius R are drawn.

The following properties of the vertices in Fig. 2 should be noted:

- *Property-1:* Each vertex v is joined to three other vertices.
- *Propery-2:* The lines joining these three vertices to vertex v make an angle of 120^o ($2\pi/3$ radians) with each other.
- *Propety-3:* Each vertex is at a distance of R from each of its neighboring vertices.

Thus, given a vertex v and one of its neighboring vertices, then using the above properties it is very easy to determine the other two neighboring vertices of vertex v.

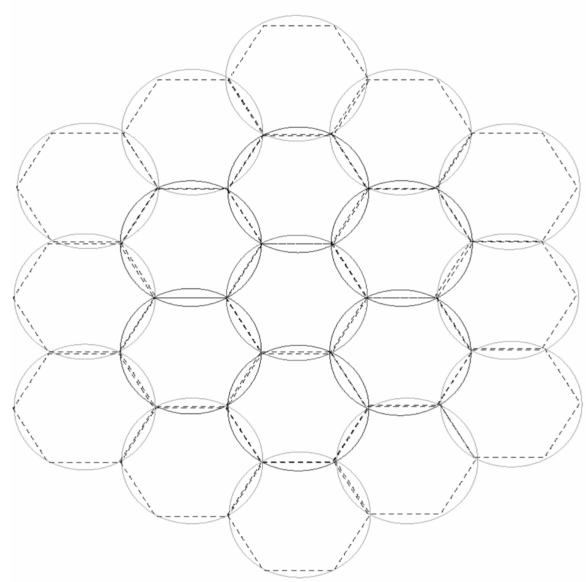

Fig-1: Covering a plane with circles in an efficient way [18].

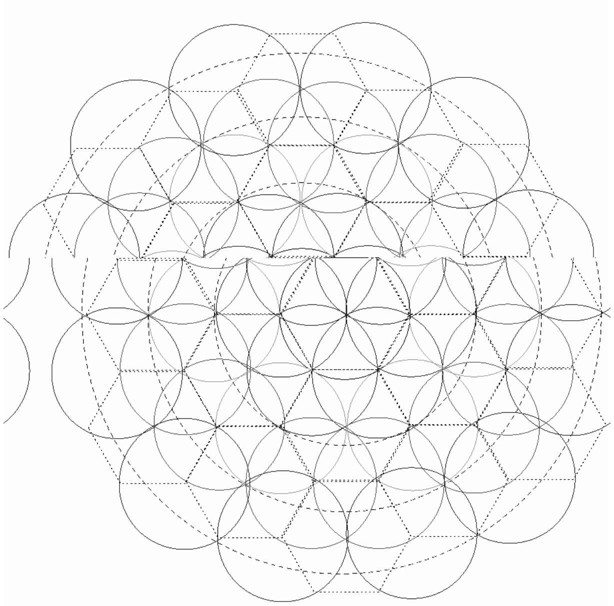

Fig-2: Our Solution for Modified Covering Problem.

The approach followed to solve *the covering problem*, leads us to the proposed optimized flooding protocol for ad hoc networks.

IV. Optimal Flooding Protocol (OFP)

In this section, we present the Optimal Flooding Protocol (OFP) which parallels pure flooding protocols in location and route discovery while keeping the number of transmissions far lesser and near optimal. Flooding achieves the goal of location discovery by letting all the nodes receive the request and having each of them retransmit it again. The intuition behind our protocol is that in order to achieve the goal, there is no need for all nodes to transmit/retransmit the message. Instead, the goal can be achieved if only few strategically selected nodes retransmit the message. The strategy to select such nodes is same as the strategy to solve the Modified Covering Problem, which is presented in Section 3.

In real life, though, it is seldom the case that we find Mobile Nodes (MNs) to be located at the strategically selected locations. Our goal is to extend the Modified Covering Problem to meet this restriction. A simple solution is to select the nearest node to the point selected, to retransmit the message. But, for a MN to retransmit the message, first it should have received the message. Hence, we select the MN that has received the message and is also the nearest to the selected point. The whole protocol is described below.

A. The protocol

The underlying assumption we make is that a Mobile Node knows the location of the other Mobile Nodes that are within its range R. The location of a Mobile Node which is frequently involved in transmission/retransmissions will be known by all other nodes in its range. Otherwise, each MN can be asked to transmit a "Hello Message" at regular intervals. Later in section 6, we present a more elegant solution, though at the expense of introducing some latency.

Let S be the Source Mobile Node that sends the route request. As can be seen in Fig-2, after the first circle centered on the center of region (location of S), six more circles whose centers are located on circumference of the first circle are drawn. These can be considered as first time retransmissions of the request. In the next stage again six more circles are drawn whose centers lie on the circumference of the circles drawn in the first stage. From now on using the properties 1, 2 and 3 presented in section 3, it is very easy to predict the centers of the circles to be drawn in the next stage.

Thus, the Optimal Flooding Protocol is as follows:

At Source Node S: S chooses six MNs in its range R, which form the best approximation of a Regular Hexagon, and transmits their Identities along with the request.

At an Intermediate MN: A Mobile Node upon receiving a request first determines if it is intended that the request be retransmitted by it. Then, if it has to retransmit the message, it checks if it has received the request directly from S.

- If yes, then it calculates the next node to broadcast the request. Let P_s be the location of S, P_i the location intermediate node and P_n the location of next node. Then next node, here, is the node which is nearest to P_n given by $P_n = 2*P_i - P_s$ (as P_i bisects the line joining P_n and P_s). Then, the MN appends the location of Pn to the request and broadcasts the request.
- If the request wasn't received directly from the source S, then, the location of the next node(s) is/are calculated using the properties mentioned in Section 3. Then, the MN using the location of the other MNs in its range finds the MN(s), which is (are) nearest to the location(s) calculated and appends the MN identifier(s) to the request. Then it re-transmits the request.

The MN doesn't re-transmit the request if the following two conditions hold true:

- if no nodes are present in the range of the MN except for the MN from which the request was received or
- if (all) the location(s) of the *next* node(s) that have to re-broad cast the request are out of the region to be covered.

V. Experimental Results

A. Simulation model

We have developed a simulator to evaluate the performance of our protocol. The results are compared to pure flooding and Gossip-based Routing [5]. A Mobile Ad Hoc Network (MANET) of different physical areas and different shapes with different number of nodes were simulated. To be more specific, circular regions of Radius varying from 900m to 3000m and rectangular/square regions of size varying from 900m X 900m to 3000m X 3000m have been simulated. Each mobile node had a transmission range of 300 meters.

The nodes were uniformly distributed all over the region with the density varying from 4 MNs per 300m X 300m region to 100 MNs per 300m X 300m region. By n^2 MNs per 300m X 300m region, we mean to say that one node is randomly placed in every (300/n) m X (300/n) m region. Also, the ideal case where some node always exists at the strategically selected location has also been simulated. We have simulated each case several times and the results presented are the average of all the simulations for that particular case.

B. *Observed results*

Ideal case scenario: We define Ideal Case scenario as follows:

An ideal case is where some node always exists exactly at the strategically selected location.

The number of transmissions required to cover circular and rectangular regions in the ideal case scenario are observed and are as presented in Table-1(A) and Table-1(B).

Next, fixing the density of the MNs in the region, we simulated the number of transmissions needed to cover a square/rectangular region completely. The simulation results are as tabulated in Table-2. The data tabulated in Table-2 can be well viewed with the help of Fig. 3. Fig. 3 gives a plot between the number of transmissions required to cover entire region for varying densities the area of the region. It should be noted that the curves representing number of transmissions for different densities are similar.

Fig. 4 shows the number of transmissions per 300m X 300m region required to cover different areas. It is plotted for different densities. It should be observed that for a particular density, the number of transmissions per 300m X 300m area almost remains constant.

TABLE -1(A) NUMBER OF TRANSMISSIONS REQUIRED TO COVER A CIRCULAR AREA

Radius of Circular region	Number of transmissions
600 m	12
900 m	24
1200 m	42
1500 m	60
1800 m	90
2100 m	126
2400 m	168

TABLE-1(B) NUMBER OF TRANSMISSIONS REQURED TO COVER A RECTANGULAR AREA

Size of the rectangular region	Number of Transmissions
900m X 900m	8
1200m X 1200m	10
1500m X 1500m	16
1800m X 1800m	26
2400m X 2400m	42
3000m X 3000m	74
1200m X 1800m	18
1800m X 2400m	36
2400m X 3000m	54

TABLE – 2 NUMBER OF TRANSMISSIONS VARYING THE MN DENSSITY

	Density of MNs in the region (number of MNs per 300m X 300m)					
Number of Transmissions for size:	Ideal Case	100	25	11	6.25	4
900m X 900m	8	9	9	10	10	11
1200m X 200m	10	11	12	15	17	19
1500m X 500m	16	20	24	28	31	33
1800m X 800m	26	30	35	38	42	48
2400m X 400m	42	48	59	69	78	90
3000m X 000m	74	85	100	118	131	145
1200m X 800m	18	19	22	23	27	33
1800m X 400m	36	41	51	55	62	69
2400m X 000m	54	68	85	90	98	105

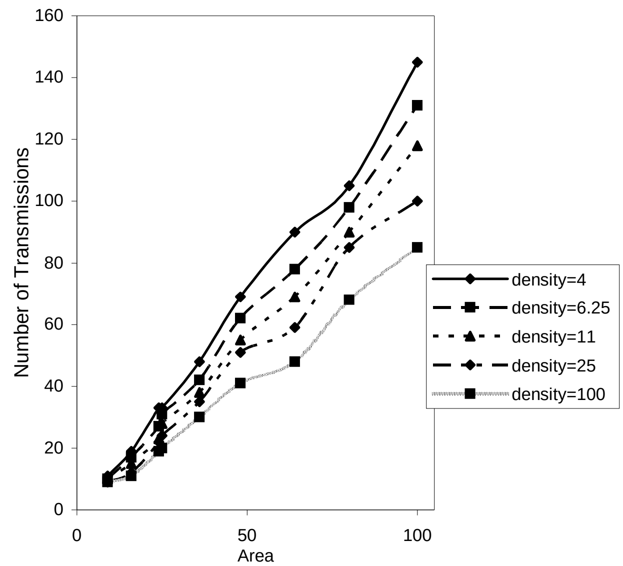

Fig-3 Number of transmissions required to cover an entire region for varying node densities and for different areas

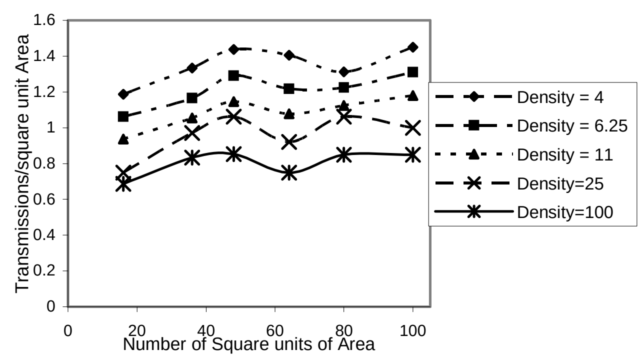

Fig-4 Number of Transmissions per 300m X 300m area for varying node densities and for different areas

Next we compare OFP with pure flooding and GOSSIP. In the best case, the number of transmissions in GOSSIP is 65% of the number of transmissions in flooding. Fig. 5 compares the performance of OFP, Flooding and GOSSIP in terms of number of transmissions for different areas. As it can be seen, while number of transmissions taken by Flooding and GOSSIP linearly increases with the number of nodes, number of transmissions taken by OFP decreases slightly with increase in density. Actually it slowly approaches the number observed in the ideal case.

While Fig. 5 deals with absolute number of transmissions, Fig. 6 deals with the number of transmissions per 300m X 300m area. Again, it is clear that,

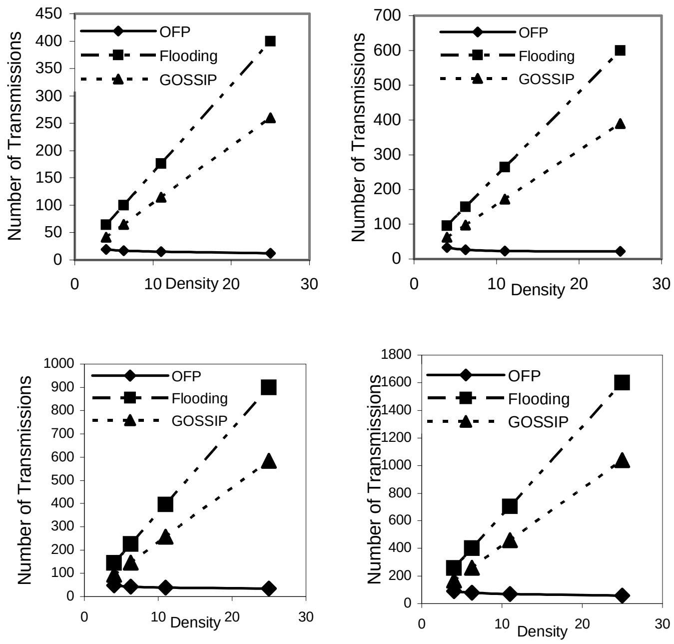

Fig-5 Number of Transmissions as Density varies for areas (a) 1200m X 1200m (b) 1200m X 1800m (c) 1800m X 1800m (d) 1800m X 2400m

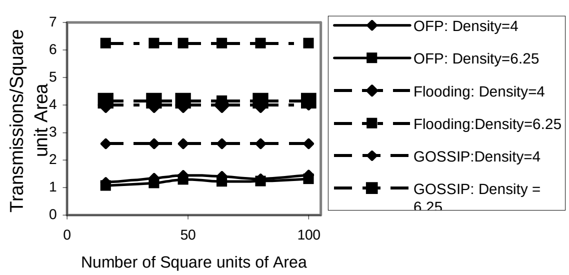

Fig-6 Number of Transmissions per 300m X 300m area for varying node densities as compared to Flooding and GOSSIP

the number of transmissions per 300m X 300m area for Flooding and GOSSIP if proportional to the density, for OFP this value almost remains a constant and is much lower than all the other variations of flooding.

VI. ANALYSIS AND COMMENTS

A. Effect of non-uniform distribution and gaps

In our simulation results, we have assumed that the nodes are distributed uniformly in the region. In this section we present a few comments in case the distribution is non-uniform and there are some regions of the order R X R where no MN node is located. We argue that even in this case OPF performs very well. This is because each transmitting node receives the request from three different directions, and hence the absence of nodes in a region in one direction doesn't isolate the node and the node still gets the request.

Consider Fig. 7. Consider that no nodes are present in the 600m X 600m square region. And consider a mobile node MN_a situated just outside the square as shown. Even in this case, MNa receives the request along the path shown in the figure. The only difference is the number of transmissions taken to reach MN_a. Also any node that can be reached by pure flooding can be reached by OFP.

B. Length of routes

The length of the routes found by using OFP might be geographically longer than those found by flooding. But, still we argue that, in most of the cases, with respect to the number of MNs in the path, the routes found by OFP are more efficient. In most of the cases the path deviates from the direct line connecting the Source and Destination by as much as 60^o. But, while doing this, it tries to keep number of MNs in the path minimum. In case of paths found by flooding, the emphasis is in minimizing the length of the path. Because of this, the number of nodes in the path might be much more than the number in the best path possible. If there are more nodes near the line joining the source and the destination, then more than necessary nodes are included in the path.

To summarize, more the density of the nodes in the region, in the path discovered by flooding, higher would be the number of nodes in a path between two given locations, which implies more number of transmissions and hence lower utilization. But, this is not the case with OFP. With OFP, higher the density, more optimal would the path be. But, still it is true that in some cases, the paths discovered by OFP are a bit longer than the best path available, but still they are more optimal than the ones discovered by flooding.

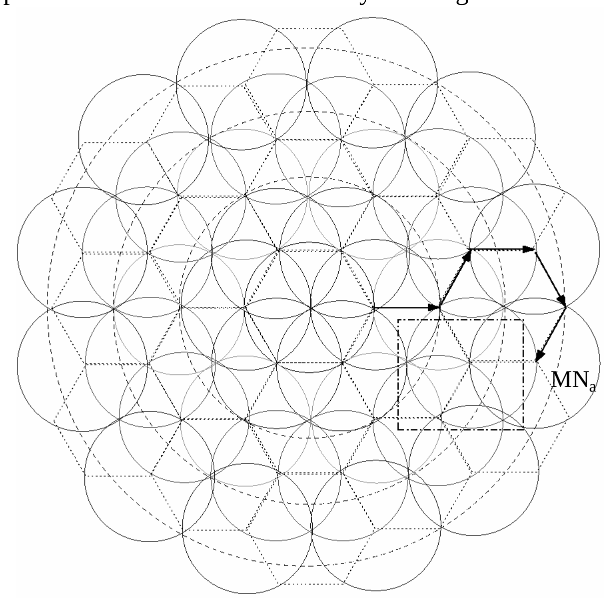

Fig-7 Effect of absence of nodes in some part of region

C. *Avoiding Hello messages*

It has been assumed that each mobile node (MN) knows the location information of all other MNs that are in its range of communication. This information is used to decide which MNs have to broadcast the request. This assumption can be avoided. In the protocol presented a mobile node decides which other mobile nodes, in its locality, have to retransmit the message and which others shouldn't. If instead, a MN decides for itself, if it has to broadcast or not, then there is no need for other MNs to know its location. To incorporate this, the above protocol has to be modified as follows:

A mobile node, which has to broadcast a request, as usual calculates the location(s) of the next node(s) using the properties mentioned in Section 3. Then, it appends the location(s) to the request and broadcasts it. When a MN receives a request packet, it computes its distance from the location specified, waits for a time interval that is proportional to the distance before deciding to broadcast or not. If the MN receives another identical request from some other node that is nearer to the specified location before the end of the time interval, the MN doesn't broadcast the request; else, it broadcasts it.

To elaborate, consider two mobile nodes: MN1 and MN2 located at a distance of d1 and d2 (d1>d2) from a given location L. Because d1>d2, the time interval that MN1 has to wait is more than the time interval MN2 has to wait and hence, MN1 before the end of its time interval receives a broadcast from MN2 and hence at the end of its time interval, decides not to broadcast the request. But, this may not be the case always. For example in CDMA, where each MN waits for the channel to be free before broadcasting, sometimes MN1 may not receive the broadcast request from MN2. But still, it doesn't affect the protocol efficiency a lot except for increasing the total number of transmissions.

The trade off with this modification is between the "Hello messages" and the latency introduced in discovering the location. In the simulations we just implement the protocol as presented earlier making the assumption that a MN has the location information of other MNs in its range.

VII. CONCLUSION

Despite the various optimizations, with flooding based routing, many routing messages are propagated unnecessarily. We have presented a protocol that can achieve the objective of flooding with no/little unnecessary transmissions.

OFP also has a number of advantages over other approaches considered in the literature. The best thing about OFP is that, it is scalable with respect to the number of nodes in the network. This understanding is supported both by analytical results and our experiments. While there are fundamental limits to the amount of non-local traffic that can be sent in large networks, due to problems of scaling [16], OFP should still be useful in large networks when non-local messages need to be sent. In fact it performs slightly better for non-local traffic than local traffic. It is far less clear how well other optimizations considered in the literature will perform in large networks. More over the performance gets better as the density increases. Also, OFP easily outperforms Gossip-based routing which is the most optimized flooding variation. Our Protocol is very simple and easy to incorporate into existing protocols.

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