



Population Based Broadcast in Wireless Ad Hoc and Sensor Networks

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Abstract—Message broadcasting is one of the common ways of communicating in wireless Ad Hoc and sensor networks. By this time several message broadcasting schemes have been devised. Some of them use deterministic methods, which guarantees the message delivery to all the nodes even if it may cause an unpleasant increase in the number of message passing. In contrast there are some methods those using probabilistic schemes that mostly concentrate on minimizing the overlap in message passing. They don't guaranty message delivery to all nodes. We present a new method that like deterministic schemes guarantees 100% coverage and considerably reduce unnecessary message transmissions by detecting dense population areas. To analyze the new method we calculated efficiency parameter and compared it with two others deterministic methods. Besides, we have simulated our method with J-SIM and verified that our theory is correct.

header nodes; overlap nodes; boundary nodes; Communicating protocol; PB; efficiency (key words)

I. INTRODUCTION

Advances in producing miniature size microelectronic devices, peer to peer computing, wireless communications and mobility introduce a new kind of networks that is called mobile ad hoc networks (MANets) and in smaller size wireless sensor network. In fact sensor networks are special case of ad hoc networks. MANets have some specific differences from traditional networks. In contrast with traditional reliable networks (consist of a stationary core network and mobile clients) MANets don't have a stationary core networks and nodes in MANets have mobile ability. These differences prevent MANets to use static tables for routing.

Among the devised broadcasting methods, flooding is considered the simplest one. According to this method each receiving node broadcasts a message only once although flooding guarantees 100% delivery of a message. This method has shortcoming in term of efficiency. In fact, there is some unnecessary message forwarding. This unnecessary forwarding is called broadcast storm problem [5] that reduces the efficiency of this method. To solve this problem two groups of methods have been devised. The first group of methods uses probabilistic schemes. These methods reduce the number of messages forwarding by releasing 100% coverage constraint. This group of methods broadcast a message with fewer number of sending than flooding method, but they don't guaranty that all nodes will receive the broadcasted messages

[1]. The main idea behind these methods is use of probability to decide whether or not to resend a received message. In order to broadcast a message each node calculates a probability (P) and the node will resend the received message only if P is more than a predefined threshold.

The second group of broadcast methods uses deterministic schemes. In this group the nodes that should participate in resending a message are selected based on the network topology [2] [6] [7]. Generally the methods of this group have to find a set of nodes in a way that all the network's nodes exist in it or have been located in one hop distance from it (set members). So these methods can guaranty a full coverage in message delivery. The problem of finding this minimal set is NP complete. Besides, in the absence of global information about the network the problem will become more challenging [1]. This paper presents a deterministic algorithm, but before going through what we have proposed, two deterministic methods have been explained in following briefly.

A. Samalam and et al in [11] have introduced a deterministic method. It relies on the information within 2 hops distance. In [11] the aim is reduce the overlapped area between neighboring senders. In order to achieve this goal periphery nodes are used. Periphery nodes are nodes that have farthest distance from a sender node. In other words p is the periphery node of u if “Equation (1)” satisfies.

$$\#(N(p) \cap N(u)) \leq \#(N(x) \cap N(u)) \quad \forall x \in N(p) \quad (1)$$

In “Equation (1)”, $N(u)$ is the set of neighboring nodes of u and $\#N(u)$ is the number of elements in $N(u)$. Consider that node u has sent a message. Among its neighbor nodes that can forward the message potentially (its periphery nodes), two of them according to their distance from u will be chosen. let's say these node x and w . To broadcast the message, x and w shall be received two messages including header message and the forwarded message.

Another deterministic algorithm is Dominant pruning [9]. Dominant pruning is one of the flooding type algorithms that uses a greedy approach to reduce the number of message forwarding. It is more efficient than blind flooding and self-pruning algorithms. The general idea of dominant pruning algorithm is to use the two hop neighborhood information to avoid unnecessary message forwarding. It can also be considered as an approximation for minimizing flood tree problem [1]. Based on dominant pruning algorithm when a node (v) receives a message from node (u), it prepares a list of

nodes to forward the message in a way that covers the set of neighbors of neighbors of node v (in other words $N(N(v))$).

Now we explain the problem that we want solve it. In wireless ad hoc or sensor networks when a node transmits a packet, it will be received by all the neighbor nodes which are within the sender's transmission range. In a broadcast transmission, The packet should be received by all the network's nodes, so minimizing the number of packets forwarding is a main problem. To introduce this problem the following parameters have been set up.

- $N(u)$: The set of neighboring nodes of the node u .
- $S(u)$: The set of sender nodes in the vicinity of u .
- $N_s(u) = \bigcup_{t \in S(u)} N(t)$: The set of neighboring node of sender nodes in the vicinity of u .

A node from set of u and its neighbors should forwards the message if has least of intersection with $N_s(u)$ in other words the goal of broadcast algorithms is reduction the number of participating nodes in a packet forwarding. To achieve this goal the overlap area between sender nodes should be minimized. The rest of paper is organized as follows. Section 2 describes proposed method. Sections 3 and 4 illustrate evaluation and simulation of our algorithm (PBB). Finally we conclude the research in section 5.

II. PROPOSED METHOD

Before presenting our algorithm (the population based broadcast algorithm that we call it PBB in brief) in detail, we explain some definition that will be used in our proposed method.

- Cluster is a set of nodes in a way that one node is considered to be the header and probably some nodes as overlap.
- Header node is a one of the cluster's node which has the highest number of neighbors.
- Overlap node is a node that participates in more than one cluster. In other words, it is in the transmission range of more than one header.
- Movement time is a period of time which starts after sending a specific number of messages or take T unit of time and lasts T' unit of time. During this period, the sender nodes group can move and new members can add to the network.
- There are situations which a header node doesn't have any other header or overlap nodes within its transmission range. In order to connect this header to other headers, the header has to find a neighbor that has at least one neighbor in transmission range of another header. These nodes are called boundary nodes.

In the PBB we assume that each node has a unique ID and nodes are deployed randomly in an area. Furthermore nodes communicate with each other via a RF transmission media. The transmission range is same for all the nodes.

A. PBB algorithm

Now a detailed description of PBB will be explained. The PBB consists of 2 parts (Pre-processing and usage). Pre-

processing is the first part that obtain the required information (Fig. 1) and the second part uses the gathered information to broadcast a message in a way that extends network lifetime. In the first step some activities that have been presented in Fig. 1 will be done by nodes.

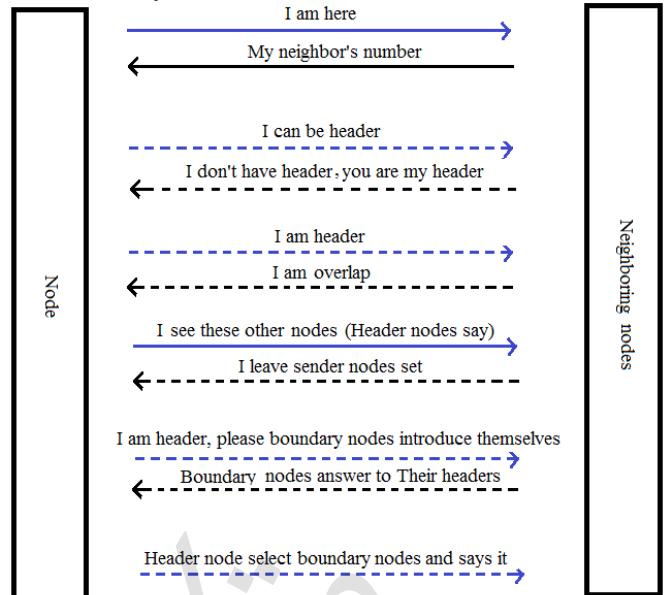


Figure 1. Communicating protocol for collecting data from network

Fig. 1 represents the Communicating protocol. This protocol helps for finding sender nodes in network. In this protocol we have four uncertain send-receive and two certain send-receive blocks. Dashed line shows uncertain message that don't happen constantly for each node. Certain blocks always happen but uncertain blocks sometimes occur.

In the protocol (Fig. 1), first each node makes aware its neighbors from its existence so each node can compute the number of their neighbors and send it to its neighbors. In the second send-receive block, based on the obtained view, a node which has the biggest number of neighbors among its neighbors introduce itself as a candidate header and broadcasts a proper notification message to inform its neighbors then if a non header node that doesn't receive any candidate header notification, encourages one of its neighboring node that has the biggest number of neighbors to introduce itself as a header node.

In the third send-receive block, header nodes send notification message to inform their neighbors about their roles, so each node can make a list from its headers. If a node has more than one header in its list, find that its role is overlap. Then overlap nodes broadcast their roles to their neighbors. In the fourth send-receive block, each header node sends list of its neighboring nodes to its vicinity nodes then unnecessary overlap nodes are omitted by pruning process. (The pruning process will be described in section 2.c). The unnecessary overlap nodes send the suitable notification to inform their neighbors that they leave set of sender's nodes.

In the fifth send-receive block the PBB finds boundary nodes, In order to avoid splitting in the sender node set, a

header node that doesn't have any other header or overlap nodes in its vicinity seeks to find boundary nodes. The nodes that are in one and two hops vicinity of such that header can play boundary roles but only two of them are needed. Finally In the sixth send-receive block boundary nodes are invited to be a member of sender nodes set by headers after that the boundary nodes introduce themselves in the fifth send-receive block. As a sample in Fig. 2 first header X selects node 1 among its boundary nodes list then that node (node 1) invites one of its neighbors (node 2) to be as a member of sender nodes set. Due to all of nodes have header and all header are connected by overlaps and boundary nodes so all network's nodes will be cover by sender nodes set and the PBB is a deterministic schema.

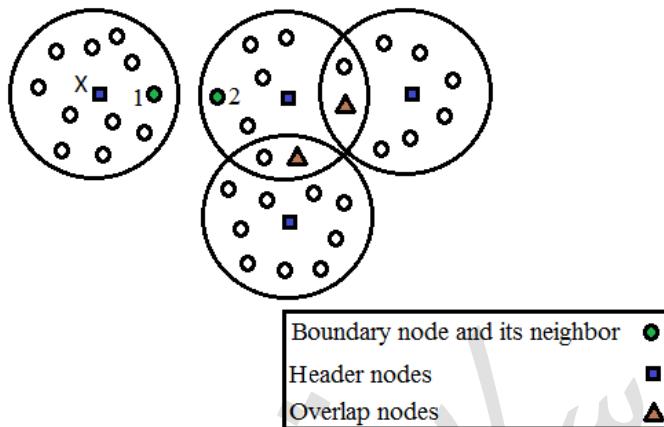


Figure 2. Boundary nodes

The entire of above send-receive blocks, local data sent or received. Furthermore the messages are very short so communication's overhead is small. By doing the above activities, the sender nodes set will be constructed. In Fig. 3 a sample network consist of 10 nodes is shown. As you see in Fig. 3 after finishing the preprocessing step we have three headers and an overlap node.

Node mobility is one of attributes of the PBB. Nodes that aren't one of the members of the sender nodes set can move freely. Of course they should be within the transmission range of at least one member of sender nodes set. Note that the members of sender nodes set are stationary until a specific number of messages sends or take T unit of time. Then within the movement time the members of sender nodes set can move to new place furthermore new nodes can be added to the network in the movement time. Due to considerable amount of saving in the number of message forwards in using part against pre-processing communication, periodical reestablishment of the sender nodes set seems rational and efficient work. Of course for reasonable amount of nodes. We simulated our method in different population (part 4) and found our method is applicable in this range of population (up to 200 nodes).

B. pruning process

The main reason behind the PBB's achievement is the pruning process. This process is mostly helpful in highly populated parts of the network where possibly more header

and in result more overlap nodes are placed. Reducing the number of nodes participate in the sender nodes set is the main aim of pruning process. Recall sender nodes set has the duty of broadcasting a message. By reducing the number of sender nodes members, the number of message forwarding will be reduced so better efficiency can be achieved. The pruning process is responsible for omitting the following roles.

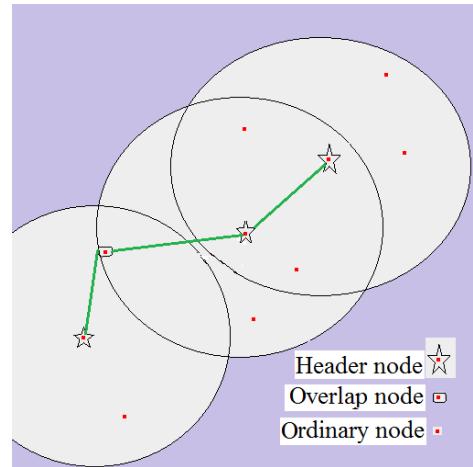


Figure 3. A sample of executing the PBB on a network

Now we explain two pruning steps:

- Whenever two or more overlap nodes are between same headers, only one of them should be kept and the others should be omitted. Fig. 4 part (a) shows 3 overlap nodes between header 1 and 2 but they do same task so only one of them is required and other nodes should be omitted from the sender nodes group.
- Overlap nodes that are between two or more headers which are in the transmission range of each other, should be omitted. Fig. 4 part (b) shows 3 overlap nodes between header 1 and 2, but header 1 and 2 are within each other's transmission range, therefore the overlap nodes are no longer required and should be omitted.

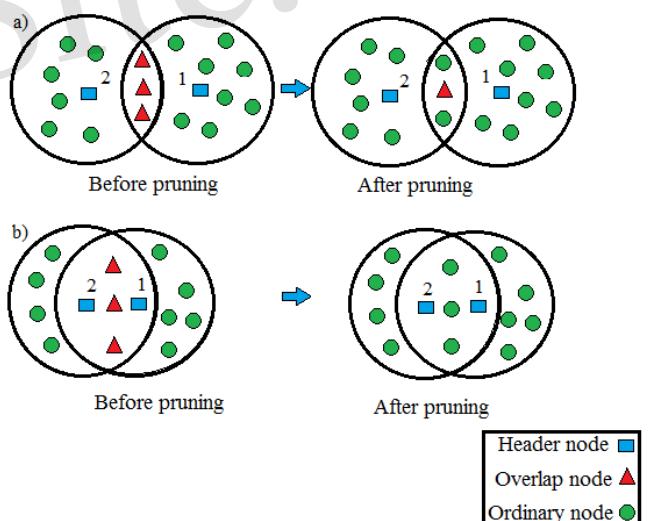


Figure 4. Pruning process

In fact nodes with the above roles are assumed as ordinary nodes. This will help purify the sender nodes group and reducing the number of message forwarding considerably.

III. ANALYSIS

To analyse our method we used mathematical calculation and simulation.

A. Efficiency factor

To compare our method with the other methods, we have applied an efficiency factor, which has been introduced in reference [11] as benchmark factor for comparing different broadcasting schemes.

Before calculating the efficiency of our algorithm we are going to briefly review efficiency factor in [11]. The efficiency of a broadcast schema is calculated by “Equation (2)”.

$$\text{Efficiency} = T_{\text{ideal}} / T_{\text{proposed}} \quad (2)$$

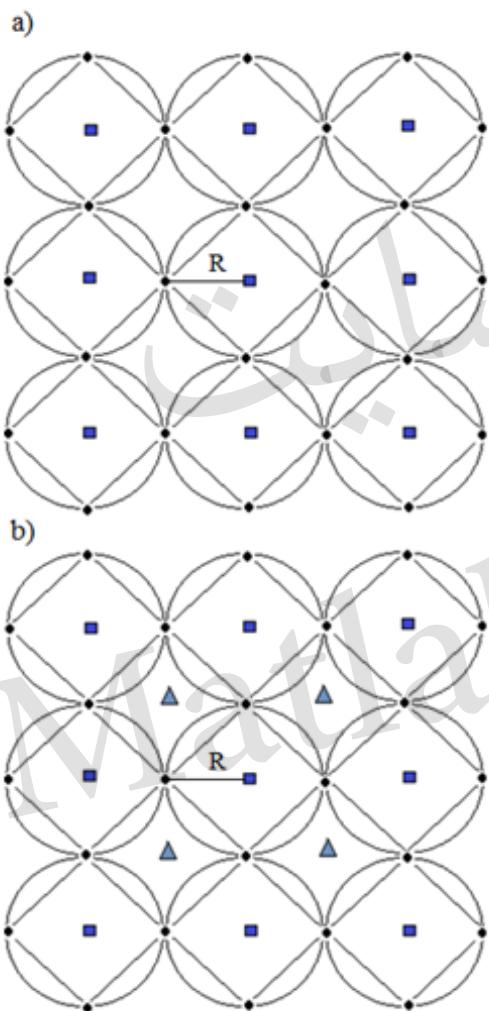


Figure 5. Tessellation of the network for the best and worst case

In the “Equation 2” T_{ideal} and T_{proposed} are:

- T_{ideal} : The required number of forwarding to broadcast a message in the ideal case.

- T_{proposed} : The required number of forwarding to broadcast a message in the specific schema.

In the ideal case each node receives the broadcast message exactly once. So there shouldn't be any overlap in the radio range of sender nodes. Let N be the number of nodes in the network, R be the radio range and ρ be the density of nodes. Hence the covered area by the network will be.

$$\text{Covered area} = N / \rho \quad (3)$$

Therefore the number of transmission in ideal case will be:

$$T_{\text{ideal}} = N / \pi \rho R^2 \quad (4)$$

Since it is difficult to compute the number of needed transmission in a general case, we derive efficiency bounds by considering best case and worst case tessellation of networks. Fig. 5 shows the tessellation of networks in the best case (part (a) of Fig. 5) and the worst case (part (b) of Fig. 5) for the PBB algorithm. These tessellations have been derived from attributes of the PBB operation. In the worst case some header nodes (triangle in Fig. 5 part (b)) have useless role and they repeat a message in an area that its members have received the message and it cause our methods has a bad efficiency.

In Fig. 5 headers are illustrated by rectangles or triangles and overlap nodes are shown with small dark point. Now we are going to calculate the number of required transmission for broadcasting in the PBB. The covered area by nodes is N / ρ furthermore the area of each diamond of Fig. 5 is $2R^2$, so the number of diamonds in the network will be $(N / 2\rho R^2)$, disregarding the area at the edges of network.

In the Fig. 5 part (a) half of diamonds have a node in the center and each of the nodes at the vertices is shared by four diamonds. Hence the average number of nodes in each diamond is

$$\left(\frac{1}{2} \right) \left(1 + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} \right) + \left(0 + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} \right) = \frac{3}{2} \quad (5)$$

In the Fig. 5 part (b), all of diamonds have a node in the center and each of the nodes at the vertices is shared by four diamonds. Hence the average number of nodes in each diamond is

$$\left(1 + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} \right) = 2 \quad (6)$$

Therefore the numbers of transmissions in each case are:

$$\text{for the best case} = \left(\frac{N}{2\rho R^2} \right) \times \left(\frac{3}{2} \right) \quad (7)$$

$$\text{for the worst case} = \left(\frac{N}{2\rho R^2} \right) \times (2) \quad (8)$$

Recall that the efficiency of a tessellation is ratio of the number of transmission in the ideal case to the number needed for a particular tessellation (“Equation (2)”) so the best case has the following efficiency.

$$\text{Efficiency} = \left(\frac{N}{\pi \rho R^2} \right) / \left(\left(\frac{N}{2\rho R^2} \right) \times \left(\frac{3}{2} \right) \right) = 0.4244 \quad (9)$$

And the efficiency of the worst case will be:

$$\text{Efficiency} = \left(\frac{N}{\pi \rho R^2} \right) / \left(\frac{N}{2\rho R^2} \times 2 \right) = 0.3183 \quad (10)$$

In the same way Efficiency bounds of [11] and dominant pruning have declared respectively [0.275, 0.41] and [0.136, 0.275] in [11]. In Fig. 6 the efficiency bounds of these three algorithms is presented. The PBB has better efficiency than both of them.

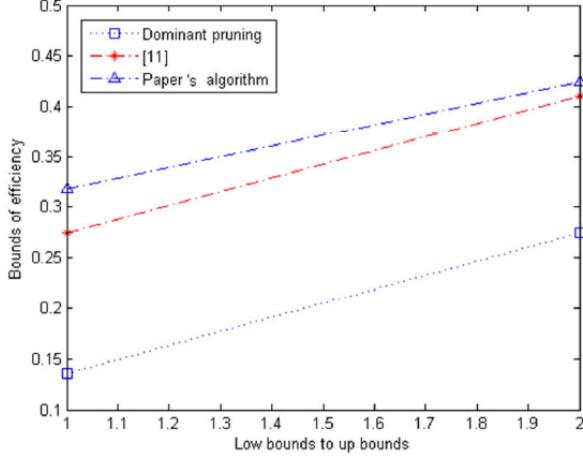


Figure 6. Comparison theory results

IV. SIMULATION

The PBB has been simulated by J-SIM (Java simulator). J-SIM incorporates the capabilities which enabled us to simulate PBB such as message sending or receiving and message queuing. It also provides a high level view of the network. In the simulation we have used a square area with length of 10 unit and nodes are distributed random in it. The number of nodes varies from 50 to 200. The transmission range of each node is 2, 3 or 4 unit. In each particular population 20 experience has been done for each of radio ranges so in the particular population we have done 60 experiences for each of paper algorithm, dominant pruning algorithm and algorithm of [11] (in total 180 experiences has been done for three algorithm in each particular method). Figures 7 and 8 show simulation results from the different views. Fig. 7 shows the efficiency of each experience that we have done for different algorithms and Fig. 8 shows the average efficiency of the PBB, dominant pruning and the algorithm of [11].

As you see in Fig. 7, our algorithm always has better efficiency than dominant pruning and almost better than algorithm of [11]. Amount of this surpass has shown itself better in 4 units radio range. Due to overlap areas between sender nodes have been increased by growing radio range, h our algorithm will be more efficient in larger radio range. However our algorithm has well efficiency with 2 or 3 unit's radio range. Altogether results of simulation have adaptation with theory's part. Furthermore you can see the results of Fig. 8 are similar to comparison theory results (see Fig. 6).

V. CONCLUSION

In this paper we have studied some broadcast schemes and their categories. We have proposed a new method base on

networks population. We called our method PBB. The PBB minimizes overlaps between transmissions with a communication protocol. This protocol has small overhead so it's easy to use it. We have used an efficiency metric [11] for comparing our algorithm with two other algorithms from a transmission perspective.

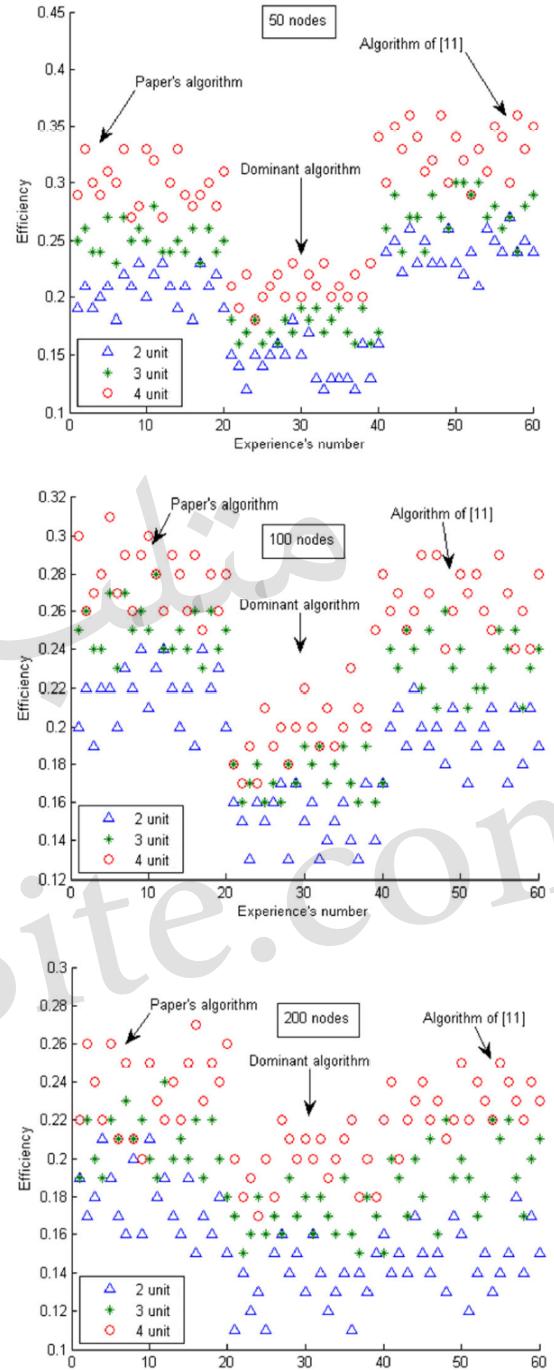


Figure 7. Results of algorithms in simulation

Theory's results showed our algorithm will have better efficiency in real world, so we have simulated our method and tested it over a wide range of nodes and three RF range and found excellent agreement with our prediction in theory.

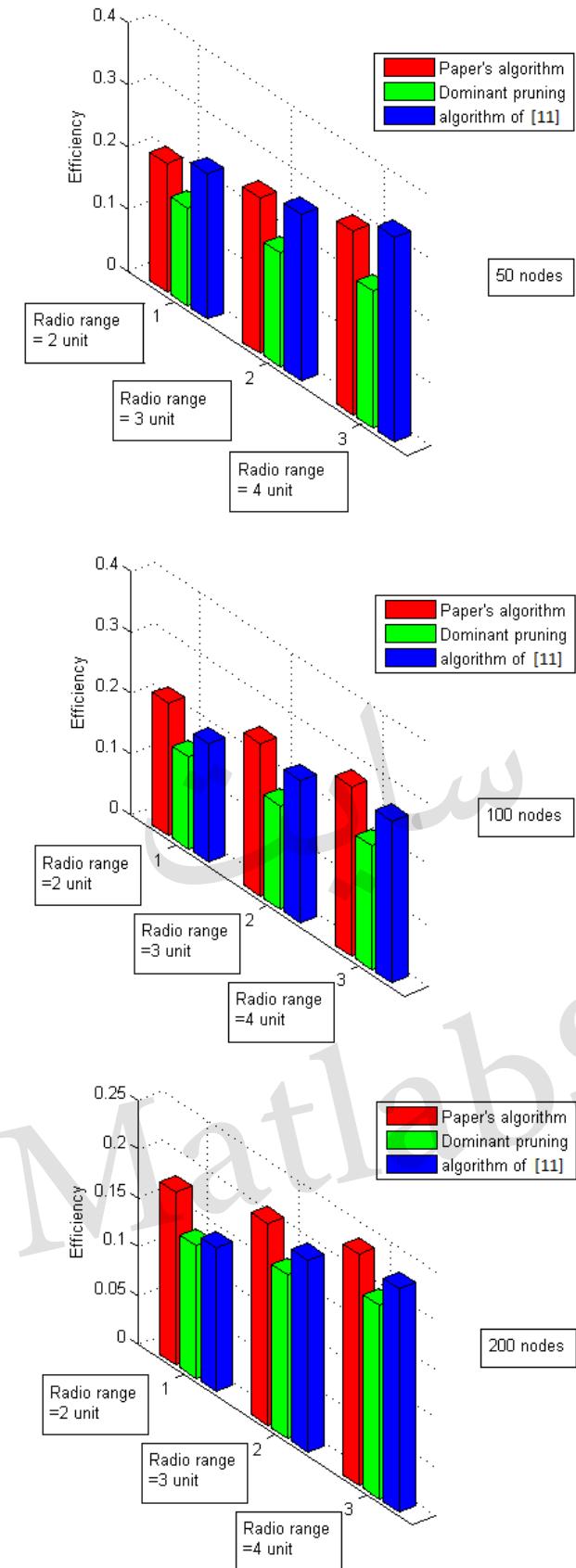


Figure 8. Compare average results

There is some advantage in our algorithm such as, nodes don't need large memory for storing neighbor's data (see protocol), just small messages is sent to the neighbors by each node, so our algorithm doesn't take much energy from network's nodes, this point increases network's lifetime. Additionally sender nodes vary within movement time successively and new nodes can add too, so it can improve the networks lifetime consequently. Our proposed algorithm can be used for event detection [12, 13] activities and other applications such as military and industrial applications that need efficient communications [14, 16]. Our algorithm will show its efficiency in these applications. Furthermore for future works the PBB can be used for the networks that contain nodes with different radio ranges. Another work can be improving the pruning process to get nearer to ideal efficiency of the PBB (0.4244).

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