Efficient Localized Broadcasting Using Connected Dominating Sets in Wireless Ad Hoc Networks

Geethu Chandran and Jenopaul.S

Abstract—**Broadcasting, one of the fundamaental operations of the wireless ad-hoc networks, can be implemented using two approaches ie static and dynamic.In broadcasting a node disseminates a message to all other nodes within the network.Usually in static approach the forwarding or non-forwarding status of the node is determined by a globally known priority function and local topology information.The static approach can achieve a constant approximation factor to optimal solution only if position information is available which is not possible in all cases.This paper shows that constant approximation to optimal solution can be obtained using connectivity information only.The status of each node is determined 'on-the-fly' ie while the broadcasting process is being done.This local broadcast algorithm can achieve both full delivery and constant approximation to the optimal solution.The security issues can be solved by comparing the expected and perceived packet delivery ratios.**

Keywords— ***Mobile ad hoc networks, distributed algorithms, broadcasting, connected dominating set, constant approximation***

I. INTRODUCTION

Wireless ad hoc networks are now being used to support wireless networks that can be established without the help of any fixed infrastructure. Wireless devices in an ad hoc networks are usually termed as nodes. One of their important characteristic is their limited transmission ranges. Therefore, each node can directly communicate with only those within its transmission range (i.e., its neighbors) and requires other nodes to act as routers in order to communicate with out-of range destinations. One of the fundamental operations in wireless ad hoc networks is broadcasting, where a node transmits a message to all other where each node on receiving a message transmits nodes in the network. This can be achieved through the traditional process of flooding, it to all its ne ighbors. However, flooding can entail a large number of redundant transmissions, which can lead to significant waste of constrained resources such as bandwidth and power.

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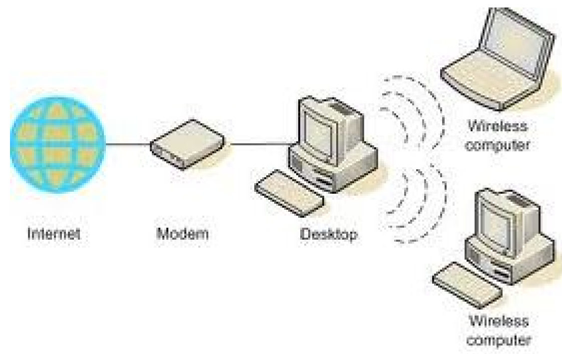

Figure :1-Awireless ad-hoc networks

In general, it is not necessary for every node to forward/transmit the message in order to deliver it to all nodes in the network. A set of nodes form a Dominating Set (DS) if every node in the network is either in the set or has a neighbor in the set. If the nodes in the DS form a connected subgraph then it is called a Connected Dominating Set (CDS). A CDS is hence formed by a source node along with its forwarding nodes. By using only the nodes in the set to forward the message CDS can be used for broadcasting. Therefore, the problems of finding the minimum number of required transmissions (or forwarding nodes) and finding a Minimum Connected Dominating Set (MCDS) can be reduced to each other. Unfortunately, finding a MCDS (and hence minimum number of forwarding nodes) was proven to be NP hard even when the whole network topology is known. A desired objective of many efficient broadcast algorithms is to reduce the total number of transmissions to preferably within a constant factor of its optimum. For local algorithms and in the absence of global network topology information, this is commonly believed to be very difficult or impossible. The existing local broadcast algorithms can be classified based on whether the forwarding nodes are determined statically (based on only local topology information) or dynamically (based on both local topology and broadcast state information). In the static approach, the distinctive feature of local algorithms over other broadcast algorithms is that using local algorithms any local topology changes can affect only the status of those nodes in the neighborhood. Hence, local algorithms can provide scalability as the constructed CDS can be efficiently updated.

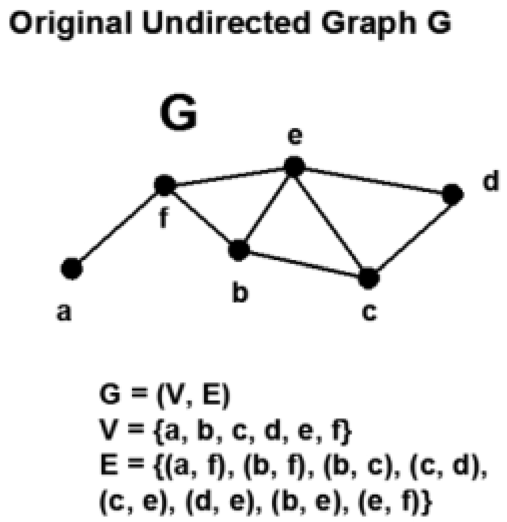

Fig 2:Original undirected graph

The existing local algorithms in this category use a priority function known by all nodes in order to determine the status of each node. Using only local topology information and a globally known priority function, based on the static approach the local broadcast algorithms cannot guarantee a good approximation factor to the optimum solution (i.e., MCDS). On the other hand, in the dynamic approach, the status of each node (hence the CDS) is determined "on-the-fly" during the broadcast progress. Using the dynamic approach, the constructed CDS may vary from one broadcast instance to another even when the whole network topology and the source node remain unchanged. As a result, the broadcast algorithms based on the dynamic approach typically have small maintenance cost and are expected to be robust against node failures and│ changes in network topology.

II. MODEL OF THE NETWORK

We assume that the network consists of a set of nodes V,│V│= N. Each node is equipped with omnidirectional antennas. Every node u 2 V has a unique id, denoted id(u), and every packet is stamped by the id of its source node and a nonce, a randomly generated number by the source node. We can assume that all nodes are located in two-dimensional space. However, all the results presented in this paper can be readily extended to three dimensional ad hoc networks. To model the network, we assume two different nodes u ε V and v ε V are connected by an edge if and only if │uv│ ≤ R, where │uv│ denotes the Euclidean distance between nodes u and v and R is the transmission range of the nodes. Thus, we can represent the communication graph by G (V,R), where V is the set of nodes and R is the transmission range. This model is, up to scaling, identical to the unit disk graph model, which is a typical model for two dimensional ad hoc networks. Practically speaking, however, the transmission range can be of arbitrary shape as the wireless signal propagation can be affected by many unpredictable factors.

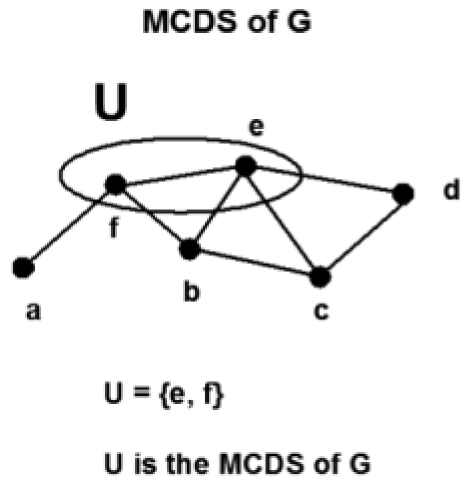

Fig 3:Minimum Connected Dominating Set

Finally, we assume that the network is connected and static during the broadcast and that there is no loss at the MAC/PHY layer. These assumptions are necessary in order to prove whether or not a broadcast algorithm can guarantee full delivery. Note that without these assumptions even flooding cannot guarantee full delivery.

III. BROADCASTING IN THE DYNAMIC APPROACH

Using the dynamic approach, the status (forwarding/ non forwarding) of each node is determined "on-the-fly" as the broadcasting message propagates in the network. Usually in neighbor-designating broadcast algorithms, each forwarding node selects its own subset of its neighbors to forward the packet and in self-pruning algorithms each node determines its own status based on a self-pruning condition after receiving the first or several copies of the message. It was proved that self-pruning broadcast algorithms are able to guarantee both full delivery and a constant approximation factor to the optimum solution (MCDS) . However, the proposed algorithm in uses position information in order to design a strong self-pruning condition. In the last section, it was observed that position information can simplify the problem of reducing the total number of broadcasting nodes. Moreover, acquiring position information may not be possible in some applications. In this section, we design a hybrid (i.e., both neighbor-designating and self-pruning) broadcast algorithm and show that the algorithm can achieve both full delivery and constant approximation using only the connectivity information.

IV. THE PROPOSED LOCALIZED BROADCAST ALGORITHM

Suppose each node has a list of its 2-hop neighbors (i.e., nodes that are at most 2 hops away). This can be achieved in two rounds of information exchange. In the first round, each node broadcasts its id to its 1-hop neighbors (simply called neighbors). Thus, at the end of the first round, each node has a list of its neighbors. During the second round, each node transmits its id together with the list of its neighbors. The proposed broadcast algorithm is a hybrid algorithm, combining both neighbor designating and self-pruning algorithms and so every node that broadcasts the message may select some of its neighbors to forward the message. In the proposed broadcast algorithm, each broadcasting node selects at most one of its neighbors. A node should broadcast the message if it is selected for forwarding. Other nodes which are not selected have to decide whether or not to broadcast by themselves. This decision is made based on a self-pruning condition called the coverage condition. To evaluate the coverage condition, every node u maintains a list $List^{cov}_{u}$ (m) for every unique message m. Upon receiving a message m for the first time, $List^{cov}_{u}$ (m) is created and filled with the ids of all neighbors of u and then updated as follows: Suppose u receives m from its neighbor v and assume that v selects w ≠ u to forward the message. Note that w may not be a neighbor of u. However, since w is a neighbor of v, it is at a maximum of 2 hops away from u. Having id's of v and w (included in the message), node u updates $List^{cov}_{u}$ (m) by removing all nodes in $List^{cov}_{u}$ (m) that are a neighbor of either v or w. This update can be done because u has a list of its 2-hop neighbors. Since w will eventually broadcast the message, by updating the list, u removes those neighbors that have received the message or will receive it, finally. Every time u receives a copy of message m it updates $List^{cov}_{u}$ (m) as already been explained. If w = u (i.e., u is selected by v to forward the message), node u updates $List^{cov}_{u}$ (m) by removing only neighbors of v from the list. Note that in this case, u must broadcast the message. However, u has to update $List^{cov}_{u}$ (m) as it needs to select one of its neighbors from the updated list (if it is not empty) to forward the message.

Definition1 (coverage condition). We say the coverage condition for node u is satisfied at time t if $List^{cov}_{u}$ (m) =ϕ at time t.

Algorithm 1 shows our proposed hybrid broadcast algorithm. When a node u receives a message m, it creates a list $List^{cov}_{u}$ (m) if it is not created yet and updates the list as explained earlier. Then, based on whether u was selected to forward or whether the coverage condition is satisfied, u may schedule a broadcast by placing a copy of m in its MAC layer queue. The sources of delay in the MAC layer can be divided into two. Firstly, a message may not be at the head of the queue so it has to wait for other packets to be transmitted. Secondly in contention based channel access mechanisms such as CSMA/CA, to avoid collision, a packet at the head of the queue has to wait for a random amount of time before getting transmitted. In this paper, we assume that a packet can be removed from the MAC layer queue if it is no longer required to be transmitted. Therefore, the broadcast algorithm has access to two functions to manipulate the MAC layer queue. Among the two functions, the first function is the scheduling/placing function, which is used to place a message in the MAC layer queue. We assume that the scheduling function handles duplicate packets, i.e., it does not place the packet in the queue if a copy of it is already in the queue. The second function is used to remove a packet form the queue (it does not do anything if the packet is not in the queue).

Algorithm 1. The proposed hybrid algorithm executed by u

Extract the ids of the broadcasting node and the selected node from the received message m
if u has already broadcast the message m then
Discard the message
Return
end if
if u is receiving m for the first time then
Create and fill the list $List^{cov}_{u}$ (m)
end if
Update the list $List^{cov}_{u}$ (m)
Remove the information the previous node had added to message
if $List^{cov}_{u}$ (m) ; then
Select an id from $List^{cov}_{u}$ (m) and add it to the message
Schedule the message {(*only update the selected id if m is already in the queue*)}
else {(_$List^{cov}_{u}$ (m) ; in this case*)}
if u was selected then
Schedule the message
else
Remove the message from the queue if u has not been selected by any node before
end if
end if

The proposed algorithm obeys the following statements:

1. u discards a received message m if it has broadcast m before.
2. If u is selected to forward the message, it schedules a broadcast (regardless of the coverage condition) and never removes the messages from the queue in future. However, u may change or remove the selected node's id from the scheduled message every time it receives a new copy of the message and updates $List^{cov}_{u}$ (m).
3. Suppose u has not been selected to forward the message by time t and the $List^{cov}_{u}$ (m) becomes empty at time t after an update. Then at time t, it removes the message from the MAC layer queue (if the message has been scheduled before and is still in the queue).
4. If $List^{cov}_{u}$ (m) ≠ϕ then u selects a node from $List^{cov}_{u}$ (m) ≠ϕ to forward the message and adds the id of the selected node in the message. The selection can be done randomly or based on a criteria. For example, u can select the node with the minimum id or the one with maximum battery life-time.
5. If u has been selected to forward and $List^{cov}_{u}$ (m) = ϕ it does not select any node to forward the message. This is the only case where a broadcasting node does not select any of its neighbors to forward the message.

V. ANALYSIS OF THE PROPOSED BROADCAST ALGORITHM

In this section, it can be proved that the proposed broadcast algorithm guarantees full delivery as well as a constant approximation to the optimum solution irrespective of the forwarding node selection criteria and the random delay in the MAC layer. In order to prove these properties, assume that nodes are static during the broadcast that the network is connected and there is no loss at the MAC/PHY layer. Note that even flooding cannot guarantee full delivery without these assumptions.

Theorem 5. Algorithm 1 guarantees full delivery.

Proof. Every node broadcasts a message at most once. Therefore, the broadcast process eventually terminates. By contradiction, assume that node d has not received the message by the broadcast termination. Since the network is connected, there is a path from the source nodes (the node that initiates the broadcast) to node d. Clearly, we can find two nodes u and v on this path such that u and v are neighbors, u has received the message and v has not received it. The node u did not broadcast the message since v has not received it. Therefore, u has not been selected to broadcast; thus, the coverage condition must have been satisfied for u. As the result, v must have a neighbor w, which has broadcast the message or was selected to broadcast. Note that all the selected nodes will ultimately broadcast the message. This is a contradiction because, based on the assumption, v should not have a broadcasting neighbor.

Lemma 2. *Using Algorithm 1, the number of broadcasting nodes inside any disk $D_{O,R/2}$ centered at an arbitrary point O and with a radius R/2 is at most 32.*

Proof. All nodes inside $D_{O,R/2}$ are neighbors of each other, thus they receive each others messages. The broadcasting nodes can be divided into two types based on whether or not the coverage condition was satisfied for them just before they broadcast the message. Recall that the coverage condition may be satisfied for a broadcasting node if the node has been selected to forward the message. It is because a selected node has to broadcast the message irrespective of the coverage condition. Consider two disks centered at O with radii R/2 and 3R/2 , respectively. Suppose k is the minimum number such that for every set of k nodes w_i ε $D_{O,3R/2}$, $1 \leq i \leq k$, we have

$$\exists i, j \neq i : |wiwj| \leq R \qquad \text{--------------(1)}$$

Following, we find an upper bound on k. By the minimality of k, there must exist k - 1 nodes w_i ε $D_{O,3R/2}$, $1 \leq i \leq k-1$, such that

$$\forall i, j \neq i : |wiwj| > R \qquad \text{-----------------(2)}$$

Consider k -1 disks $D_1; \ldots; D_{k-1}$ with radius R/ 2 centered at wi, $1 \leq i \leq k - 1$, respectively. By (2), $D_1,\ldots,D_{k-1}$ are non overlapping disks. Also, every disk D_i, $1 \leq i \leq k - 1$, resides in $D_{O,2R}$ that is the disk centered at O with radius 2R.It is because, the center of every Disk D_i, $1 \leq i \leq k - 1$, is inside $D_{O,3R/2}$. Thus, by an area argument, we get

$$(k-1)(\prod(R/2)^2) \leq \prod(2R)^2 \qquad \text{---------------(3)}$$

Hence, $k \leq 17$.

We first prove that the number of broadcasting nodes inside $D_{O,R/2}$ for which the coverage condition is not satisfied is at most k -1. We then prove the same upper bound for the number of broadcasting nodes inside $D_{O,R/2}$ for which the coverage condition is satisfied. Consequently, the total number of broadcasting nodes inside $D_{O;R/2}$ is bounded by $2k - 2 \leq 32$. By contradiction, suppose that there are more than k _ 1 broadcasting nodes inside $D_{O;R2}$ for which the coverage condition is not satisfied. Consider the first k broadcasting nodes be $u_1, \ldots, u_k$ ordered chronologically based on their broadcast time, and $a_1, \ldots, a_k$ the corresponding selected neighbor. Thus, for every i, $1 \leq i \leq k$, we have a_i ε $List^{cov}_{ui}(m)$, where $List^{cov}_{ui}(m)$ is the list of node ui at the time it broadcasts the message. Since $u_1, \ldots, u_k$ are all in $D_{O,R/2}$ and for every i, $1 \leq i \leq k$, $|u_i a_i| \leq R$, we get

$$\forall i, 1 \leq i \leq k : a_i \in D_{O,3R/2} \qquad \text{--------------(4)}$$

Thus, by the definition of k, there are two nodes a_i, a_j,i < j such that $|a_i a_j| \leq R$. The node u_i is broadcast before u_j and is a neighbor of it.Hence, u_j is aware of u_i's selected neighbor a_i and removes a_j from $List^{cov}_{uj}$ (m) as soon as it receives the message from u_i. This is a contradiction because a_j ε $List^{cov}_{uj}(m)$ at the time u_j broadcasts.

It remains to prove that the number of broadcasting nodes inside $D_{O,R/2}$ for which the coverage condition is satisfied is at most k _ 1. By contradiction, suppose that there are at least k broadcasting nodes inside DO;R2 for which the coverage condition is satisfied. Let $v_1, \ldots, v_k$ ε $D_{O,R2}$ be the first k broadcasting nodes, arranged chronologically based on their broadcast time. Note that a broadcasting node must have been selected (by another node) to forward the message if its coverage condition is fulfilled. Let $b_1, b_2, \ldots, b_k$ be the nodes that selected $v_1, \ldots, v_k$ to forward the message. Therefore, for every i, $1 \leq i \leq k$, we have b_i ε $D_{O,3R/2}$. Also, for every i,$1 \leq i \leq k$ and every j, $1 \leq j \leq k$ and $j \neq i$, we get $b_i \neq b_j$, because each node can select a maximum of one other node to forward. By the definition of k, there must exist two nodes bi and bj, i < j such that $|b_i bj| \leq R$. This is a contradiction because b_i and b_j are neighbors and b_j receives the b_j broadcast message, thus v_j $List^{cov}_{bj}(m)$ as v_i and v_j are neighbors.

Corollary 1. *Let u be any node in the network. Using the proposed Algorithm , the number of broadcasting nodes within the transmission range of u is at most 224.*

Proof. All the nodes within the transmission range of u (including u) are inside a disk with radius R. A disk with radius R can be covered with at most seven disks with radius R/2 . Thus, by Lemma 2, the number of broadcasting nodes within the transmission range of u is at most 7 × 32 = 224.

Theorem 6. *Algorithm 1 has a constant approximation factor to the optimal solution (MCDS). Moreover, the approximation factor is at most 224.*

Proof. Let S_{MCDS} be a MCDS and S_{Alg} be the set of broadcasting nodes using Algorithm 1. Let u be any node in S_{MCDS}. By Corollary 1, the number of broadcasting nodes within the transmission range of u is at most 224. Note that every broadcasting node is within the transmission range of at least one node in S_{MCDS}, because S_{MCDS} is a dominating set. Hence

$$|S_{Alg}| \leq 224 \times |S_{MCDS}| . \quad \text{-----------(5)}$$

VI. IMPLEMENTING STRONG COVERAGE CONDITION

As proven, the proposed broadcast algorithm guarantees that the total number of transmissions is always within a constant factor of the minimum number of required ones. However, the number of transmissions may be further reduced by slightly modifying the broadcast algorithm. As explained earlier, in the proposed algorithm, a selected node has to broadcast the message even if its coverage condition is satisfied. Nevertheless, in some cases, a selected node can avoid broadcasting. For example, a selected node u can abort transmission (by removing the message from the queue) at time t if by time t and based on its collected information, all its neighbors have received the message. This idea can be implemented as follows:

Suppose, for each unique message m, every node u maintains and updates an extra list $List^{str}_u$ (m). Similar to $List^{cov}_u$ (m), $List^{str}_u$ (m) is created and filled with the ids of u's neighbors upon the first reception of message m. Also, every time u receives m, it updates $List^{str}_u$ (m) as follows: Let v be the broadcasting node and $w \neq u$ the selected node by v. Node u first removes the nodes in $List^{str}_u$ (m) that are neighbors of v. If the priority of w (e.g., its id) is higher than u, it also removes the nodes in $List^{str}_u$ (m) that are neighbors of w. To further reduce the number of redundant transmissions, a selected node can abort broadcasting m under the following strong coverage condition.

Definition 2 (strong coverage condition). *It can be said that the strong coverage condition is satisfied for node u at time t if* $List^{str}_u(m) = \phi$ *at time t.*

Note that the strong coverage condition is only used by selected nodes to check whether they need to broadcast. Other nodes make a decision based on the previously defined coverage condition (a weaker condition). The following theorem states that the full delivery is guaranteed if the selected nodes abort transmissions when the strong coverage condition is satisfied. Using a similar approach to that used in the proof of Lemma 2, it can be proven that this extension of the algorithm also achieves a constant approximation factor.

Theorem 7. Suppose Alg-str is a modified version of Algorithm 1 in which each node maintains two lists $List^{cov}_u$ (m) and $List^{str}_u$ (m) and selected nodes can avoid broadcasting under the strong coverage condition. Full delivery can be guaranteed using Alg-str.

VII.SECURITY IN WIRELESS AD-HOC NETWORKS

The wireless ad-hoc networks are easily prone to attacks from malicious nodes that can result in loss of information.The expected and the perceived packet delivery ratios can be compared and in case of abnormalities we can check for the presence of malicious nodes.If the perceived packet delivery ratio is lesser than the expected ratio then we can assume that the packets are being lost.

VIII. EXPERIMENTAL RESULTS

One of the major contributions of this work is the design of a local broadcast algorithm based on the dynamic approach (Algorithm 1) that can achieve both full delivery and a constant approximation factor to the optimum solution without using position information. The simulation experiment is done by distributing the nodes in a square of size of 1,000 ×1,000 m^2. The transmission range is set to 250 m and number of nodes to50.When the simulation begins hello messages are exchanged between the nodes.Then the broadcasting is initiated by a random node after waiting for a stipulated period of time.The x-axis of the

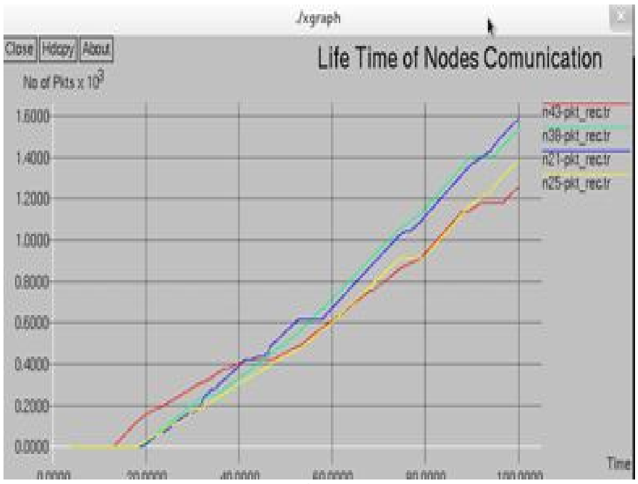

Fig 4:Number of packets versus time

graph shows the number of packets transmitted while y-axis gives the time taken.The number of packets increases drastically after formation of connected dominating sets.Figure 5 shows an instance of broadcasting.The green dots show the various nodes that are receiving the broadcasted packets after the formation of the connected set.

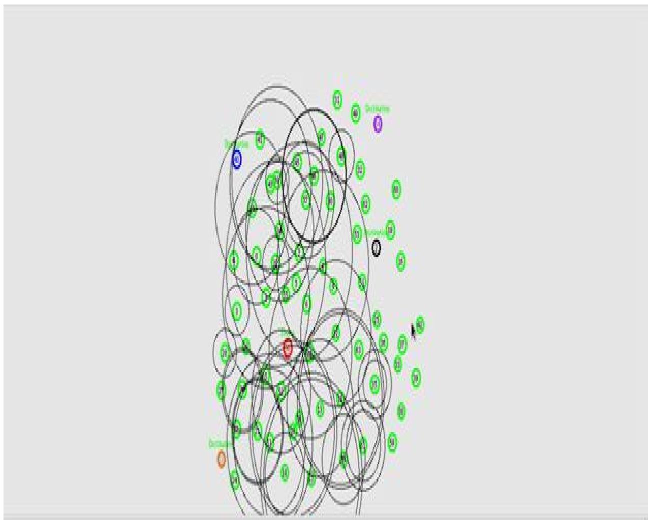

Fig 5:An instance of using the broadcast algorithm

VIII. CONCLUSIONS

In this paper, the capabilities of local broadcast algorithms in reducing the total number of transmissions that are required to achieve full deliverywas investigated. As proven, local broadcast algorithms based on the static approach cannot guarantee a small sized CDS if the position information is not available. It was shown that having relative position information can greatly simplify the problem of reducing the total number of selected nodes using the static approach. In fact, it can be shown that a constant approximation factor is achievable using position information. But by using the dynamic approach, it was shown that a constant approximation is possible using (approximate) position information. This paper shows that local broadcast algorithms that are based on the dynamic approach do not require position information to guarantee a constant approximation factor.

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