Border Node Retransmission Based Probabilistic Broadcast Protocols in Ad-Hoc Networks*

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Abstract

In this paper, we propose some improvements to the flooding protocols that aim to efficiently broadcast a given information through the whole ad-hoc network. These improvements are based on probabilistic approach and decrease the number of emitted packets and hence, the medium occupation. Indeed, it is more interesting to privilege the retransmission by nodes that are located at the radio border of the sender. We observe that the distance between two nodes with full duplex communication can be approximated by comparing their neighbor lists. This leads to broadcasting schemes that do not require position or signal strength information of nodes. Moreover, proposed broadcast protocols require only knowledge of one hop neighborhood and thus need only short hello message. Such protocols are more able to support high mobility networks than protocols that need knowledge of two or more hops neighborhood and then need longer hello messages. We compare our new schemes with variable density and experiments show that the probabilistic approach is efficient.

1 Introduction

A ad-hoc network consists of hosts (that can be mobile or static) with a wireless radio interface. A node can directly communicate with its neighbors. More precisely, a message sent by one node can reach all its neighbors within transmission radius simultaneously. It can also find a route to the other nodes in the network by using other mobiles which forward the message to the addressee. Examples of such networks are packet radio or sensors. They offer large application fields: deploying network in critical zones (military or rescue operations), ubiquitous computing, wireless conference, traffic control, etc.

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A common operation in ad-hoc network is *broadcast*. It consists of diffusing a message from a source node to all the nodes in the network. Broadcast can be used to diffuse an information to the whole network (alarm signal for example). It can also be used for route discovery reactive protocols in ad-hoc networks. For instance, in AODV (Ad Hoc On-demand Distance Vector Routing) [1], a route request is broadcasted in the network. Each node keeps the broadcast ID and the name of the node from which the message has been received. When the correspondent is reached, it replies with a *unicast* (point-to-point) message and then each intermediate node is capable to establish the return route. For more details about ad-hoc networks, the reader can consult [2, 3, 4].

Flooding is traditionally used for broadcasting. It is the following protocol: every mobile, that receives a broadcast message for the first time, sends it to its neighbors. This is very simple and needs only some resources in the nodes (a broadcast table to memorize the last broadcast messages received). This approach offers the advantage to be reliable, but produces a high overhead in the network (because the time to establish this broadcast must be short to ensure a rapid diffusion). The probability of multiple requests at the same time for medium access is very high and the number of collisions dramatically increases, which causes a lot of dropped packets [5].

One of the important problems in the ad-hoc community is to reduce the number of necessary messages for a broadcast. In this paper, we propose some probabilistic solutions that tend to reduce the network overhead. Probabilistic approaches have the advantage to be decentralized algorithms. Furthermore, our improvements give a better chance of rebroadcast to the nodes that are located near the border of the sender radio zone. Actually, we adapt the distance-based scheme [5] to the probabilistic approach. We also reinforce the use of neighbor elimination [6, 7].

Compared to MPR [8] or dominating set based broadcast [9], the protocol proposed in this paper needs only information about one-hop neighbors. HELLO messages in our protocol are very short because they contain only the ID of the sender. Furthermore, the protocol does not require a positioning system, because it compares the neighbor lists and deduces a probabilistic information.

The protocol is well adapted for high mobility ad-hoc networks, with frequent changes in neighbors set. Firstly, the decision for rebroadcast is localized and based on information sent periodicly by the neighbors. Secondly, a node sends a broadcast without imposing its choices to its neighbors. This approach is the opposite of some deterministic algorithms, like MPR or dominating set, which rely on trusting neighbors (*i.e.* the responsibility of rebroadcast packet is shared among some nodes, so failure of nodes or mobility could arise problems).

The main contributions is a scheme that is based on probabilistic approach, topology adaptability, internal-node-based broadcasting algorithms and neighbor elimination scheme.

The paper is organized as follows. A partial review of the previous works about broadcast cost reduction is presented in Section 2. Section 3 overviews our improvements with the probabilistic approaches. Simulation results are presented in Section 4. Section 5 concludes the paper.

2 Related Works

Ni *et al.* [5] have analyzed different methods for limiting the overhead in broadcast protocols. The authors study five schemes called probabilistic, counter-based, distance-based, location-based and cluster-based. In the probabilistic scheme, when receiving a broadcast message for the first time, a host rebroadcasts the message with a probability P. The counter-based scheme inhibits the rebroadcast if the message has already been received for more than C times. In the distance-based scheme a node rebroadcasts the message only if the distance between the sender and the receiver is larger than a threshold D. The location-based scheme rebroadcasts the message if the additional coverage due to the new emission is larger than a bound A. Finally, the cluster-based scheme uses a cluster selection algorithm (for example *LowerID* [10]) to create the clusters, then the rebroadcast is done by headclusters and gateways. The authors conclude by the efficiency of the location-based scheme, but these end additional area coverage protocols need a positioning system. However, in our approaches, we don't use positioning systems.

Wu and Li [9] proposed a distributed deterministic algorithm for calculating a dominating set. Let G be the graph of a given wireless network. A set is *dominating* if all the nodes in G are either in the set, or neighbors of nodes belonging to the set. First, the authors describe the concept of an *intermediate* node: a node is an intermediate node if two of its neighbors cannot directly communicate with each other. Furthermore, they propose two rules for reducing the number of internal nodes. Let $N(x)$ denote the neighbor of x and $N[x] = N(x) \cup x$. Let us suppose that each node has an unique id number used as key. An *intergateway* is an intermediate node that is not eliminated by Rule 1 and a *gateway* is an intergateway node that is not eliminated by Rule 2. The diffusion of the broadcast is done by only allowing the gateways nodes to forward the message.

Rule 1 is: consider two intermediate nodes v and u. If $N[v] \subseteq N[u]$ and $key(v) < key(u)$ then node v is not an intergateway node. Rule 2 is: assume u and w are two connected intergateway neighbors of an intergateway v. If $N(v) \subseteq N(u) \cup N(w)$ and $key(v) = min\{key(v), key(u), key(w)\}$ then node v is not a gateway.

Stojmenovic *et al.* proposed in [11] to use the record $key = (degree, x, y)$ instead of the id of the node; $degree$ is the number of neighbors of the node; x and y are its coordinates. When comparing the keys (with Rules 1 and 2), nodes shall compare first their degrees. In case of tie, the coordinates are used to resolve (or the id if positioning service is unavailable). The paper proposed also to use a neighbor elimination and retransmission after negative acknowledgements schemes.

Recently, Qayum *et al.* proposed a deterministic method called *MultiPoint Relaying method* [8] for reliable broadcasting. It selects a minimal set of one-hop neighbors that cover the same network area as the complete set of neighbors. The computation of this minimal set is a NP-complete problem. So the multipoint relay method is a greedy algorithm which works as follows: let us denote $N(x)$ the set of one-hop neighbors of node x, $N^2(x)$ the set of its two-hop neighbors and $MPR(x)$ the selected multipoint relay set of node x. A node is said to be *covered* if it can be directly contacted by a node from $N(x)$. The algorithm is a heuristic: first, add to $MPR(x)$ the nodes from $N(x)$ that are the only neighbors of some nodes in $N^2(x)$. Then, while there still exists some nodes in $N^2(x)$ that are not covered by the nodes into $MPR(x)$, select node in $N(x)$ and put into $MPR(x)$, for which the number of neighbors not covered from $N^2(x)$ is maximal.

These protocols have similar disadvantages. First, they contain overload information in HELLO messages. Every node must have knowledge of the 2-hop-neighbors, so each HELLO message contains a list of the neighbors of the sender node (the dominating set protocol may use positioning systems to avoid this overload information, which is another overhead).

In our approach, the overload is placed into BROADCAST messages. This is better because the number of HELLO messages may significantly exceed the number of BROADCAST messages. It is more suitable for the case of dense network with high bandwidth utilization, where multiple access at the medium can cause lot of dropped packets. Moreover, high node mobility increases the number of hello messages, thus short HELLO messages are better choice. The protocols is also well adapted with network using very low number of BROADCAST packets (sensor networks). Second, the protocols MPR and dominating set are valid if the information about their surroundings is correct. Thus the nodes and their surroundings share responsibility. So, if they are used in an environement with very frequent changes, these schemes will have some imprecisions because they use invalid informations to compute their rebroadcast decision. With MPR, a node can select rebroadcast nodes which have left the communication radius. With dominating set, some nodes do not rebroadcast if they know some nodes in their surrounding will rebroadcast, but this consistency can be broken if some rebroadcast nodes disappear.

Our model is designed to work better than MPR or dominating set under described conditions. The approaches proposed in this paper use a probabilistic decision and are less influenced by changes in neighboring topology than the previous models. In particular, the stochastic protocol is more appropriate for higher mobile networks.

The neighbor elimination scheme has been described in [6, 11]. The main idea is that a node will not rebroadcast a message if all the neighbors have been covered by previous transmissions. When a node receives a broadcast message, it can learn which nodes have been covered by the transmission by checking the neighbor list of the transmitter (included in the broadcast message). Then, it adds into its broadcast table an entry with the list of its neighbors, and suppresses from this list all the neighbors of the transmitter for each broadcast message it received. When making rebroadcast decision, the node checks the broadcast cover set. If the set is not empty, then the rebroadcast operation is necessary and is launched.

3 New Broadcasting Algorithms

In [5], the authors show that the probabilistic scheme has poor reachability. The problem comes from the uniformity of the algorithm: every node has the same probability to rebroadcast the message, regardless to the distance between it and the local sender.

The distance-based scheme succeed to reach a large part of the network but don't economize the number of broadcast messages because a host may have heard a broadcast message for many times, but still rebroadcasts the message as none of the transmission distances are below a given distance threshold.

Here, we propose new algorithms to combine the probabilistic and distance schemes in order to exploit the advantages of both approaches. In this paper, the probabilistic scheme is called simple probabilistic scheme or mode 1 and we propose new modes to improve this one.

3.1 Density Aware Probabilistic Flooding (mode 2)

In order to avoid troubles with the variation of topology in the network, this improvement uses some information about the neighborhood topology. It is the same approach as described for simple probabilistic scheme but the probability p is computed from the local density n (*i.e* the number of neighbors). A node is then aware of its environment, because each node periodicly sends *HELLO* messages (short messages that inform the neighbors of the node presence). So, a node that listen to the medium can know its neighbors, and then the local density. A host will rebroadcast flooding messages with the probability $p = f_{mode2}(n)$:

$$f_{mode2}(n) = \frac{k}{n}, \qquad (1)$$

where k is an efficiency parameter to achieve the reachability of the broadcast. The f_{mode2} has been chosen because, intuitively, the optimum probability of broadcast is the inverse of the local density. Furthermore, we have observed the correctness of this assumption from the results of the $mode1$ in Fig.4.

3.2 Border Retransmission Based Probabilistic Flooding (mode 3)

The previous models have the disadvantage to be locally-uniform. Indeed, each node of a given area receives a broadcast and determines the probability according to a constant or from the local density. It is more interesting to privilege the retransmission by nodes that are located at the radio border of the sender. This is similar to additional area coverage scheme [5], but that scheme is position based. We observe that the distance between two nodes with full duplex communication can be evaluated by comparing their neighbor lists.

When two nodes src and $dest$ can contact each other, the union of their communication areas (Z_{src} and Z_{dest}) can be partitioned in three zones (Fig. 1):

- $Z_a = Z_{src} \cap \overline{Z_{dest}}$: the communication area covered only by src,
- $Z_b = \overline{Z_{src}} \cap Z_{dest}$: the communication area covered only by $dest$,
- $Z_c = Z_{src} \cap Z_{dest}$: the communication area covered by both src and $dest$.

The nodes cannot evaluate the zones Z_a, Z_b and Z_c without positioning facilities. But these areas can be characterized by the number of mobiles inside each of them: the neighbors of src (N_a, number of nodes inside the Z_a) the neighbors of $dest$ (N_b, number of nodes inside the Z_b) and the neighbors of src and $dest$ (N_c, number of nodes inside

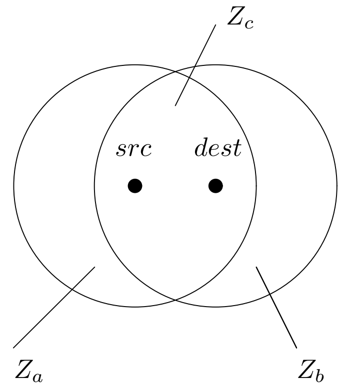

Figure 1: Intersection of the radio areas of nodes src and $dest$.

the Z_c). This approach gives a good approximation in the uniform case for the distance between the src and $dest$. We define the ratio μ by:

$$\mu = \frac{N_b}{N_a + N_c}. \quad (2)$$

When $dest$ wants to know μ, it has to identify its neighbors and the neighbors of src. For that purpose, each node which forwards a broadcast adds the identities[1] of all its neighbors in the message. When a node $dest$ receives the broadcast message, it compares the list from the input message to its own neighbors list. Then it can determine μ and its own probability of sending p with the f_{mode3} formula:

$$f_{mode3}(\mu) = \frac{A - \alpha}{\mathrm{M}^{\sigma}} \mu^{\sigma} + \alpha, \quad (3)$$

with:

- A and α : the roof and floor probability levels (with the values 0.0 and 1.0 respectively in this paper),
- σ : coefficient of convexity (see Fig. 2),
- M : constant which represents the maximal value of μ. This value can be evaluated by the maximal value of the ratio $Z_{\overline{src} \cap dest}/Z_{src}$ which correspond to the case when the distance between src and $dest$ is equal to the transmission radius. Numerically, $\mathrm{M} = \frac{1}{3} + \frac{\sqrt{3}}{2\pi} \cong 0,601$ (see [5]).

3.3 Density Aware and Border Node Retransmission Based Probabilistic Flooding (mode 4)

This mode is a combination of the two previous ones: the probability p of rebroadcast is computed from the local topology and adjusted by the knowledge of the set of non-common neighbors. Equation (3) is reused but the roof level probability A is evaluated with equation (1):

$$f_{mode4}(\mu, k) = \frac{\frac{k}{n} - \alpha}{\mathrm{M}^{\sigma}} \mu^{\sigma} + \alpha. \quad (4)$$

3.4 Density Aware and Border Node Retransmission Based Probabilistic Flooding with Neighbor Elimination (mode 5)

The probabilistic approaches presented above have a disadvantage: all the reachable nodes would not be contacted in the case of a bad random number. In some circumstances, a group of neighbors might not rebroadcast the message. Thus, some nodes will not be contacted. In the worst cases, a partition of the network can occur even if the missed nodes are reachable. A solution presented in [6] is based on a neighbor elimination scheme: each node checks if all the neighbors have received the broadcast message.

For the modes 3 et 4, each node which forward the broadcast message includes the list of its neighbors. The receiver can identify which nodes have been covered by checking the neighbor list of the transmitter and comparing with its own neighbor list. In our algorithm (Fig. 3), each node has a broadcast table BT, where identifier are recorded for each broadcast already received. This table is extended with an improvement: for each new entry in BT, a list of the neighbors from the neighbor table NT of the receiver is added.

```
protocol NeighborElimination()
{
    IF messages receives for the first time
    Get the Broadcast ID bid from the message
    THEN
        Create a entry BT_bid in the Broadcast Table.
        Create a list L_bid with all the IDs in the
            neighbor table.
    END IF

    FOR EACH id included in the message
    DO
        IF id is included in L_bid
            remove id from L_bid
        END IF
    END FOR
}
```

Figure 3: Neighbor elimination algorithm.

The neighbor elimination scheme is used by the nodes which do not broadcast the message according to probabilistic function of the previous mode (f_{mode4}). They are

[1] These Id can be the IP address, the MAC address or an id that depends of the routing protocol

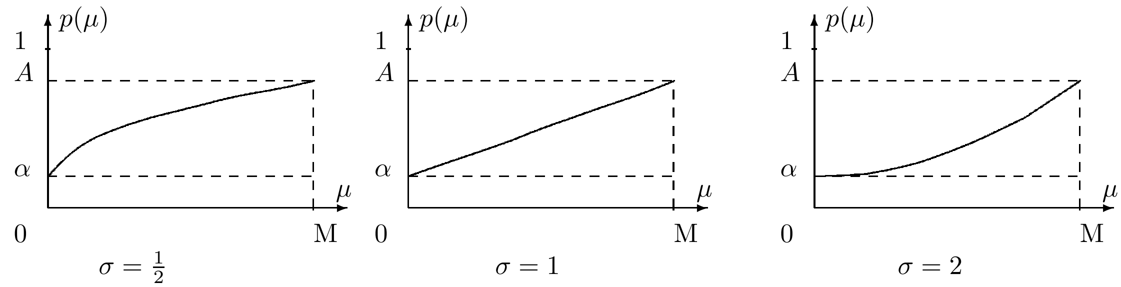

Figure 2: Example of the probability function convexity according to σ parameter.

help mechanism for second retransmission to reach the last nodes.

After a given amount of time T, a node checks the list associated with the broadcast entry in BT. If it is not empty, it rebroadcast the message. The T value must be choose to keep a rapid broadcast, a low chance to collision when rebroadcast, and sufficient delay to listen the emission from neighboring nodes. We use the following formula:

$$T = T_{max} + T_{alea} * x, \quad (5)$$

with T_{max} the minimum fixed time before rebroadcast, T_{alea} the maximum bound for rebroadcast and $x \in [0, 1]$ a random value.

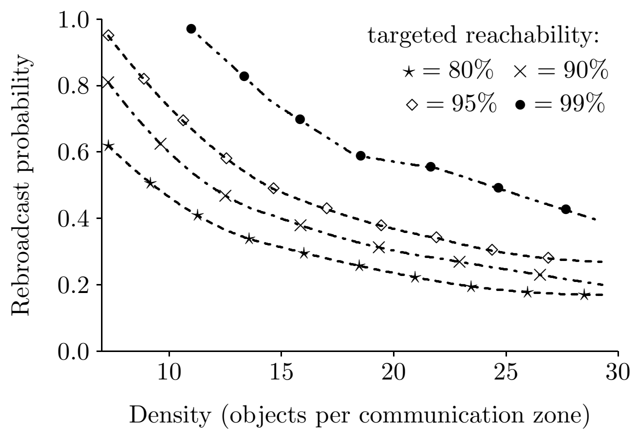

Figure 4: Simple Probabilistic Flooding (mode 1): Optimal forwarding probability according to a given reachability.

4 Performance Evaluation of Broadcasting Algorithms

We used the discrete-event simulator NS-2. The parameters that are fixed in our simulations are the transmission radius (250 meters), the size of the overall area (2000x670). The number of nodes can be 25, 50, 75, 100, 125, 150, 175 or 200 (equivalent to a density of 4, 7, 11, 15, 18, 22, 26 and 30 neighbors by communication area). In each case, the simulator executes 500 broadcasts.
The observed performances are:

- *REachability (RE)*: the percentage of mobile hosts receiving the broadcast message divided by the total number of mobile hosts that are reachable, directly or indirectly,
- *Saved ReBroadcast (SRB)*: $(r - t)/r$ where r is the number of hosts receiving the broadcast message, and t the number of hosts that actually transmitted the message.

Fig. 4 shows the rebroadcast probability p needed to reach 99%, 95%, 90% and 80% of the network when using the Simple Probabilistic Flooding (mode 1). This scheme is relatively inefficient, especially in low density (the results are not very interesting when $p < 0.7$, because the number of saved broadcast messages is inverse of to the rebroadcast probability). In fact, the approach is too homogeneous: each mobile has the same rebroadcast probability, whatever its position or the local density may be. Theses results have been already shown in [5].

Fig. 5 presents the performance of the Density Aware Probabilistic Flooding (mode 2). The results are very close to the previous model. No startup setup is needed: the nodes deduce by themselves the probability p which is necessary for a good rediffusion. Furthermore, the parameter k (used in the formula (1)) is very useful for *partial broadcast*. It diffuses the information to a part of the nodes, independently of the density: the percentage of reached nodes in the network is independent of the density.

Fig. 6 presents the performance of Border Retransmission Based Probabilistic Flooding (mode 3). Here, the parameters A and α are kept fixed at $A = 1.0$ and $\alpha = 0.0$. This model is better than the simple probabilistic one but still presents some problems. For instance, the average portion of the nodes that re-send the broadcast messages is constant when the density grows up (except in low densities). The reason is obvious: the formula (3) does not take into account the density. Thus, a constant fraction of the neighbors will

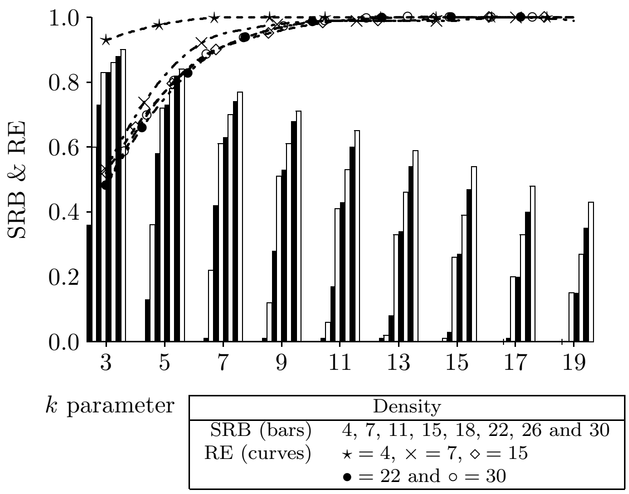

Figure 5: Density Aware Probabilistic Flooding (mode 2): parameter k vs. reachability (shown in lines) and saved rebroadcast (shown in bars).

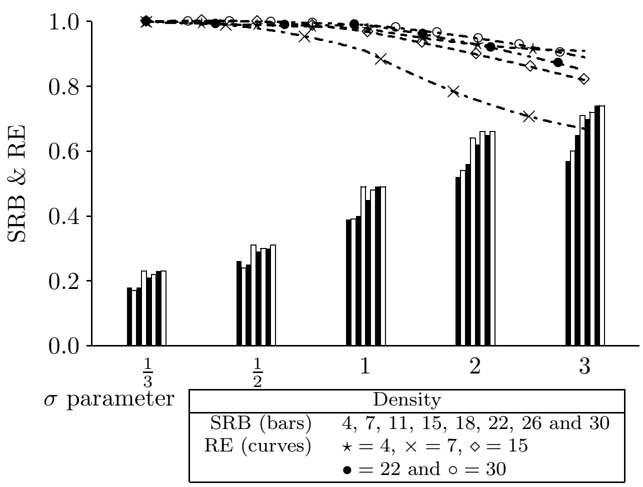

Figure 6: Border Retransmission Based Probabilistic Flooding (mode 3): parameter σ vs. reachability (shown in lines) and saved rebroadcast (shown in bars).

rebroadcast. The efficiency of the model seems good with the parameter $\sigma = 1$ or $\sigma = 2$ (more than 95% of reachability with SRB between 0.4 and 0.65). When $\sigma = 3$, the reachability is too poor (5% to 15% less similar than the solution with $\sigma = 1$ and when $\sigma < 1$, the results are close but with a lower saved rebroadcast messages (between $\sigma = 1$ and $\sigma = 0.5$ the percentage of saved rebroadcast messages goes from 45% to 25%).

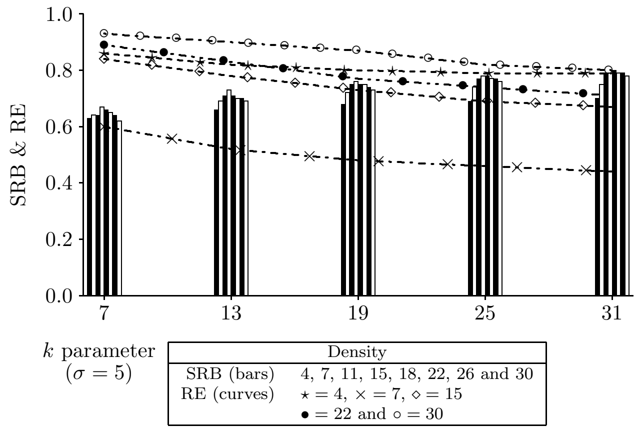

Figure 8: Density Aware and Border Node Retransmission Based Probabilistic Flooding (mode 4) with $\sigma = 5$: parameter k vs. reachability (shown in lines) and saved rebroadcast (shown in bars).

Fig. 7 and Fig. 8 presents the performance of the Density Aware and Border Node Retransmission Based Probabilistic Flooding, combined with local density (mode 4) when $\sigma = 1$, $\sigma = 3$ and $\sigma = 5$. The results shows the problem of the balance between reachability and saved rebroadcasts. Some results are very interesting and better than the previous modes. For $\sigma = 3$, you can reach more than 80% of the network with a SRB greater than 0.8. So, this scheme seems adequate for *partial broadcast*.

Table 1 and table 2 resume the trade-off problem inherent in all the precedent modes (mode 1, 2, 3 and 4): A good reachability give a worse SRB but a good SRB is obtained with a lower reachability. This seem to show that a combination of the probabilistic approach and a deterministic mechanism should help to reach "the last nodes".

Fig. 9 presents the performance of Density Aware and Border Node Retransmission Based Probabilistic Flooding with Neighbor Elimination (mode 5) with $\sigma = 1$ and $\sigma = 5$. The reachability is almost perfect (Table 3), whatever the σ value. Furthermore, the SRB becomes stable with the variation of density when σ increased (Table 4). The SRB is very good with $k \in [19, 31]$ and $\sigma \in [4, 5]$. For greater values of k and σ, the SRB decreased slowly. The neighbors elimination mechanism is not used to reach few nodes, but this is a part of the broadcast waves. Notice that if k is low,

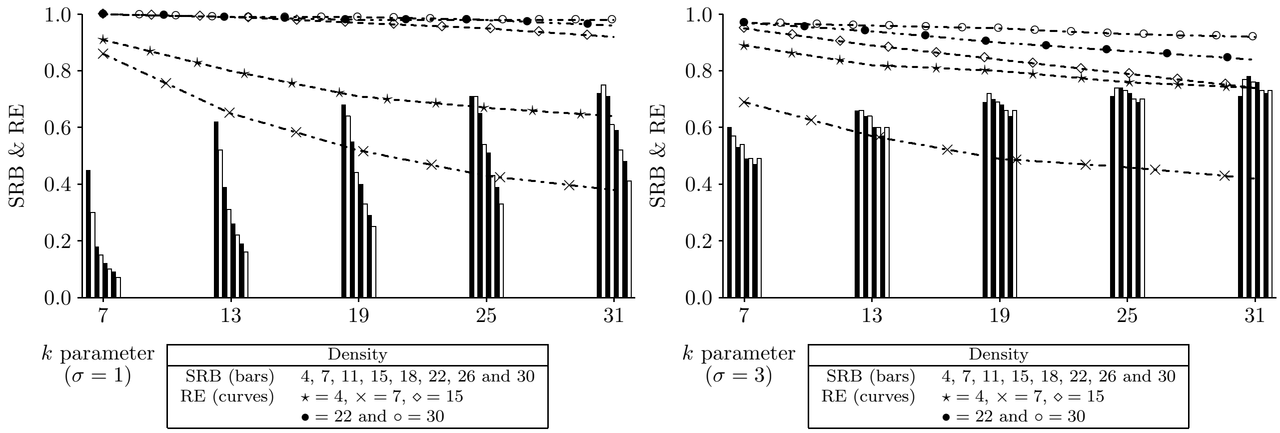

Figure 7: Density Aware and Border Node Retransmission Based Probabilistic Flooding (mode 4) with $\sigma = 1$ and $\sigma = 3$: parameter k vs. reachability (shown in lines) and saved rebroadcast (shown in bars).

Density	mode1 ($p = 0.7$)	mode2 ($k = 11$)	mode3 ($\sigma = 1$)	mode4 ($k = 19$,$\sigma = 1$)	mode4 ($k = 19$,$\sigma = 5$)
4	90.92%	100.0%	98.16%	71.36%	80.45%
7	82.09%	99.80%	90.56%	51.93%	47.94%
11	98.33%	99.81%	98.06%	90.62%	63.85%
15	98.77%	98.98%	97.90%	97.00%	72.69%
18	99.96%	99.72%	99.31%	99.36%	79.11%
22	99.46%	99.26%	98.95%	98.11%	76.76%
26	99.98%	99.06%	99.79%	99.93%	82.98%
30	99.70%	99.00%	98.98%	99.17%	86.68%

Table 1: Reachability for some configurations with mode 1,2,3 and 4

Density	mode1 ($p = 0.7$)	mode2 ($k = 11$)	mode3 ($\sigma = 1$)	mode4 ($k = 19$,$\sigma = 1$)	mode4 ($k = 19$,$\sigma = 5$)
4	0.263	0.000	0.390	0.678	0.676
7	0.287	0.059	0.391	0.642	0.721
11	0.293	0.167	0.400	0.549	0.750
15	0.299	0.417	0.490	0.437	0.755
18	0.299	0.428	0.453	0.395	0.749
22	0.297	0.534	0.480	0.334	0.746
26	0.296	0.605	0.488	0.292	0.744
30	0.296	0.651	0.490	0.246	0.733

Table 2: SRB for some configurations with mode 1,2,3 and 4

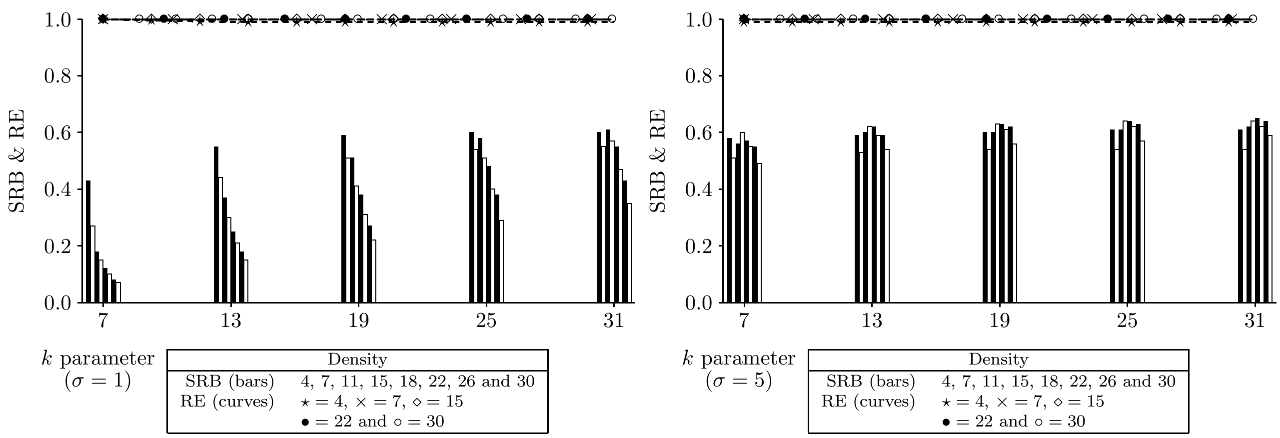

Figure 9: Density Aware and Border Node Retransmission Based Probabilistic Flooding with Neighbor Elimination (mode 5) with $\sigma = 1$ and $\sigma = 5$: parameter k vs. reachability (shown in lines) and saved rebroadcast (shown in bars).

Density	$\sigma = 1$ $k = 7$	$\sigma = 1$ $k = 19$	$\sigma = 1$ $k = 31$	$\sigma = 5$ $k = 7$	$\sigma = 5$ $k = 19$	$\sigma = 5$ $k = 31$
4	99.56%	98.86%	98.52%	98.75%	98.41%	98.63%
7	99.95%	99.93%	99.87%	99.93%	99.87%	99.65%
11	99.98%	99.97%	99.98%	99.97%	99.97%	99.97%
15	99.99%	99.99%	99.99%	99.97%	99.78%	99.98%
18	100.0%	99.98%	99.99%	99.98%	99.97%	99.98%
22	99.99%	99.99%	99.99%	99.99%	99.98%	99.99%
26	100.0%	99.80%	99.99%	99.99%	99.99%	99.98%
30	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%

Table 3: Reachability for some configurations with mode 5.

Density	$\sigma = 1$ $k = 7$	$\sigma = 1$ $k = 19$	$\sigma = 1$ $k = 31$	$\sigma = 5$ $k = 7$	$\sigma = 5$ $k = 19$	$\sigma = 5$ $k = 31$
4	0.434	0.587	0.601	0.578	0.603	0.611
7	0.275	0.507	0.548	0.506	0.536	0.543
11	0.178	0.505	0.608	0.560	0.604	0.616
15	0.147	0.414	0.567	0.593	0.631	0.640
18	0.116	0.379	0.552	0.572	0.634	0.646
22	0.101	0.308	0.470	0.554	0.611	0.623
26	0.082	0.273	0.433	0.547	0.618	0.641
30	0.071	0.215	0.349	0.490	0.559	0.592

Table 4: SRB for some configurations for mode 5.

the neighbors elimination scheme is more used and hence it reduces the broadcast speed.

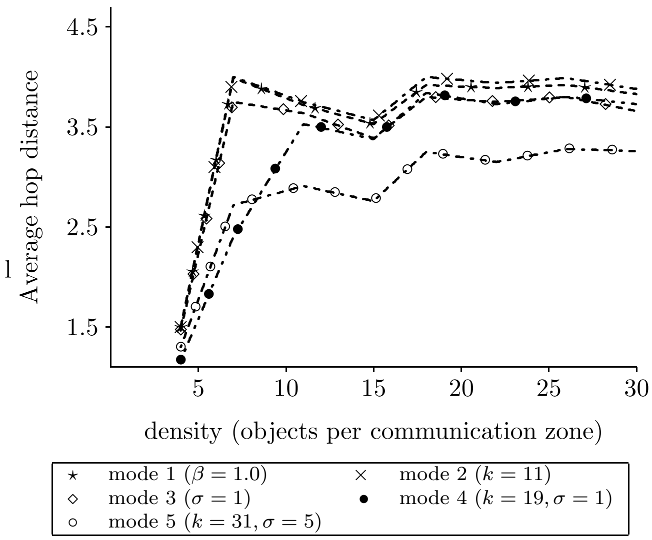

Figure 10: Density vs. average hop distance with the different modes.

Fig. 10 presents the average hop distance from the source for each model. One of the advantages of the approach is to favor (in probability) rebroadcast by the nodes that are near the border of the radio area. Hence shorter routes are discovered. The drawback is the eternal problem of stability versus rapidity: because the nodes are very close to the end of the radio area, they have more chances to be disconnected [12] (especially in moving environment, like ad-hoc networks). The modes 3 and 4 have an average distance hop lower than the first two modes because the nodes from the border of radio radius have more chance to reemit the broadcast. So they have more chances to diffuse to a large number of nodes. The mode 5 has the lowest average number of hop. This is due to the parameter used: $\sigma = 5$ and $k = 31$. These parameters only give priority to the extremity nodes, which have a good μ ratio. This offer good distribution during the first wave of the broadcast message (even if not all the nodes are reached) and good hop average for the first nodes reached. The second wave (launched by elimination scheme), joins the last nodes and propagate the good hop distribution to them.

Comparing the dominating set algorithm described in [11], the mode 5 offers equal reachability (close to perfect) with a better SRB for density lower than 15. The power of dominating set is to easily reduce the number of rebroadcast nodes in case of high density because it can detect mutually covered nodes.

About size of HELLO and broadcast packets, the results differ with the scenario model. For static scenario, dominating set will be better because it require only one HELLO message by nodes, so the overload is lower because BROADCAST messages contain only the ID of the sender. For high mobility scenario, I except than the model described in this paper could be very good because the number of HELLO messages is very high, so the associated overload is expensive for bandwidth occupation.

5 Conclusions

This paper presents improved probabilistic algorithms. Our experiments have demonstrated, through analyses and simulations, the efficiency of theses improvements with a significant reduction of the number of rebroadcasting messages. The combination of the probabilistic and distance schemes gives good results in term of reachability. Furthermore, because the nodes that rebroadcast the message are very close to the border of the radio area, the probability of getting an optimal distance is increased.

The algorithms are decentralized and present adaptability with the network topology. However, they are not *"reliable"* (in the sense described in papers [11, 8]). It doesn't guaranty a full coverage of the neighbors. But, with the mode 5, the global behavior succeed to join all the nodes with a very good ratio. So, the model can be used for broadcasting. We expect that the probabilistic approach can give good results to multicast routing discovery. In this case, probabilistic can offer good variety to generate multiple routes. Probabilistic Scheme give also better use of energy because they do not monopolise too much some nodes and offer an better average use of the battery.

In fact, one of the goal is not to have a full broadcast algorithm. It is more designed for route discovery: the protocol will be used in order to inform a part of the network of the research of correspondent and local searches will finish to establishes the route. However, it works fine as a full broadcast algorithm.

We believe that further saving may be achieved by improving the proposed algorithms in various ways. Firstly, trying to decrease the overhead by using some other criteria inspired from location-based, counter-based and dominating-set-based schemes [5, 9, 7]. Furthermore, the analyze of the algorithm with unidirectional links must be evaluated.

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References

[1] C.E. Perkins and E.M. Royer, "Ad-hoc on-demand distance vector routing," in *Proceedings of the Second Annual IEEE Workshop on Mobile Computing Systems and Apllications*, Feb. 1999, pp. 90–100.

[2] C-K. Toh, *Ad Hoc Mobile Wireless Networks: Protocols and Systems*, Prentice Hall PTR, 2002.

[3] C.E. Perlins, Ed., *Ad Hoc Networking*, Addison Wesley, 2001.

[4] I. Stojmenovic, Ed., *Handbook of Wireless Networks and Mobile Computing*, John Wiley & Sons, 2002.

[5] Yu-Chee Tseng, Sze-Yao Ni, Yuh-Shyan Chen, and Jang-Ping Sheu, "The broadcast storm problem in a mobile ad hoc network," *WINET Wireless Networks*, vol. 8, no. 2–3, pp. 153–167, march–may 2002.

[6] W. Peng and X.C. Lu, "On the reduction of broadcast redundancy in mobile ad hoc networks," in *Proceedings of the Annual Workshop on Mobile and Ad Hoc Networking and Computing (MobiHOC 2000)*, Boston, Massachusetts, USA, Aug. 2000, pp. 129–130.

[7] I. Stojmenovic, M. Seddigh, and J. Zunic, "Internal node based broadcasting algorithms in wireless networks," in *Proceedings of the Hawaii Int. Conf. on System Sciences*, Jan. 2001.

[8] A. Qayyum, L. Viennot, and A.Laouiti, "Multipoint relaying for flooding broadcast messages in mobile wireless networks," in *Proceedings of the 35th Annual Hawaii International Conference on System Sciences (HICSS'02)*, Hawaii, 2002.

[9] J. Wu and H. Li, "A dominating-set-based routing scheme in ad hoc wireless networks," in *Proceedings of the Third Int'l Workshop Discrete Algorithms and Methos for Mobile Computing and Comm (DIALM)*, Aug. 1999, pp. 7–14.

[10] Chunhung Richard Lin and Mario Gerla, "Adaptive clustering for mobile wireless networks," *IEEE Journal of Selected Areas in Communications*, vol. 15, no. 7, pp. 1265–1275, 1997.

[11] I. Stojmenovic, M. Seddigh, and J. Zunic, "Dominating sets and neighbor elimination-based broadcasting algorithms in wireless networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 12, no. 12, Dec. 2001.

[12] C.-K. Toh, "Associativity based routing for ad hoc mobile networks," *Wireless Personal Communications Journal, Special Issue on Mobile Networking and Computing Systems*, vol. 4, no. 2, pp. 103–139, Mar. 1997.