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RNG RELAY SUBSET FLOODING PROTOCOLS IN MOBILE AD-HOC NETWORKS*

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ABSTRACT

In this paper, we study broadcasting protocols where nodes use some of their neighbors to forward messages. We propose a new protocol based on a variant of neighbor elimination scheme using RNG graph to ensure a full coverage of the network. The computation of RNG uses two kinds of distance: a geometrical one and and neighborhood-based distance that permits to use our protocol without positioning system. This protocol, called RRS for RNG Relay Subset, provides a self-selecting forwarding neighbor operating mode which guarantees a fair broadcast loading. In RRS a node v is a relay for a node u if and only if v is a neighbor of u and v has a RNG-neighbor which is not covered by u transmission. Moreover, experiments with 802.11-like MAC layer show that RRS is efficient.

Keywords: Broadcast, wireless networks, ad-hoc networks, localized algoritms, neighbor elimination scheme.

1. Introduction

A Mobile Ad-hoc Network (MANET) consists of hosts (that can be mobile or static) with a wireless radio interface. A node can directly communicate with its neighbors since one node can reach all its neighbors within transmission radius simultaneously, in a single-hop fashion. It can also find a route to the other nodes in the network by using multihop capabilities of the network: other mobiles 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.

In this paper, we are interested in network wide broadcasting which is the process in which one node sends a packet to all other in the network. Broadcasting is

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useful in mobile ad-hoc networks to disseminate information in the network or to generate route by using piggy-backing techniques for example. The basic protocol to achieve broadcasting is blind flooding: a node receiving the broadcasted message for the first time (message is identified by sequence number) retransmits it to its neighbors. This simple broadcast generates redundant transmissions and lead to a lot of collided packets in MAC layer. Several more efficient protocols have been proposed to minimize the number of retransmissions while trying to guarantee that a broadcast message is received by each node.

We distinguish two broadcasting protocol families: *source-independent protocols* and *source-dependent protocols*. In the first protocol class, the nodes which ensure the broadcasting task are always the same and are determined by topology configuration or node internal constants (node identifier for instance). As a result, these nodes are penalized and, moreover, if route discovery uses broadcasting, generated routes contain only such nodes (except source and destination). In this family, we can cite cluster-based and dominant set protocols [5, 14]. The family of source-dependent broadcast protocols offers a better *broadcasting load fairness*. Of course, this family includes probabilistic protocols [3, 13] but it contains *forwarding neighbor protocols* we consider in the sequel of the paper.

In forwarding neighbor protocols, each node has a relay subset composed of neighbor nodes. When a node transmits a broadcast packet, only nodes in relay subset will consider forwarding the message. There are two ways of determining whether or nor a node is in the relay subset: the emitting node computes the relay subset and gives the relay subset in the packet or the receiving node makes the decision by itself. Self-selecting forwarding neighbor method is preferable because messages are smaller and then induce fewer collisions than explicit relay subset scheme. We can notice that the contents of HELLO messages, used for presence detection, should also be considered. The extra length of explicit relay subset method can be removed by adding the relay subset in HELLO messages but additional collisions have to be considered. Multipoint relay (MPR) protocol [8] is an illustration of explicit relay subset protocol while location-based protocol [13] is a self-selecting forwarding neighbor protocol.

In order to reduce the total number of emitted packets, it is easy to see that it is not enough to reduce the size of relay subset. The relay subsets have to be sufficiently large to reach new nodes and to ensure network coverage in iterated process.

Neighbor elimination scheme (NES) [10] can be added over forwarding neighbor protocols. With NES, a relay node does not retransmit the message immediately but waits a given time window. If during this period all neighbors have been covered by other communication, the node cancels the retransmission of the message. The difficulty is to ensure that this deletion does not jeopardize the broadcast coverage.

In this paper, we propose a self-selecting forwarding neighbor associated with a variant of neighbor elimination scheme. This protocol is called RRS for RNG Relay Subset because it uses relative neighbor graph (RNG) [12] to guarantee the broadcast coverage.

The paper is organized as follows. Next section gives preliminaries and necessary definitions. Section 3 presents a short literature review. The RRS protocol is described in Section 4 and experimental results are commented Section 5. Finally, conclusion and perspectives are given Section 6.

2. Preliminaries

A wireless network can be represented by a graph $G = (V, E)$, where V is the set of nodes and $E \subseteq V^2$ the set of edges of the available communications. A node u can send message to a node v if an edge (u, v) belongs to E. We define R as the maximum range of communication for all vertices and $d(u, v)$ as the distance between nodes u and v. The set E is defined as follows:

$$E = \{(u, v) \in V^2 | d(u, v) \leq R\}.$$

So defined graph is known as the *unit graph*, with R as its transmission radius. We also define the neighbor set $N(u)$ of the vertex u as $N(u) = \{v | (u, v) \in E\}$. The degree of a given node u is the number of nodes in $N(u)$. We also denote by $n = |V|$ the number of nodes in the network.

The relative neighborhood graph, denoted by RNG is a geometric concept proposed by Toussaint [12]. The relative neighborhood graph of G is denoted by $RNG(G) = (V, E_{rng})$ and is defined by:

$$E_{rng} = \{(u, v) \in G \mid \nexists w \in N(u) \cap N(v) \quad d(u, w) < d(u, v) \wedge d(v, w) < d(u, v)\}.$$

The condition is illustrated Fig. 1. The gray area is the intersection of two circles centered at u and v with radius $d(u, v)$. An edge (u, v) belongs to the RNG if there does not exist a node w in gray area. We can see in Fig. 2 the a unit graph (a) with its associated RNG graph (b).

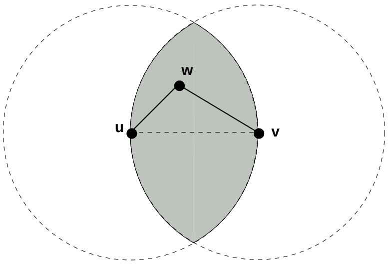
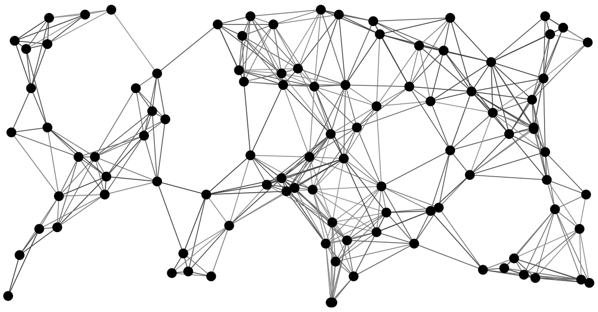


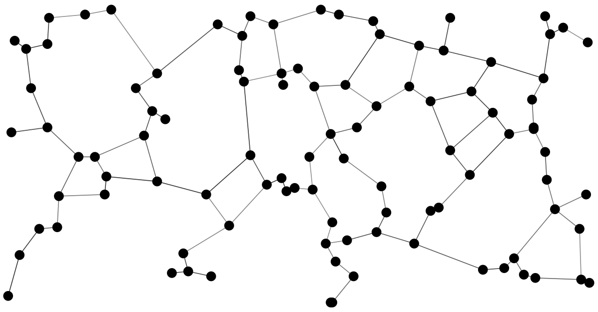
Figure 1: The edge (u, v) is not in RNG because of w.

The set of neighbors of a node u in the subgraph $RNG(G)$ is denoted by $N_{rng}(u)$.

The RNG graphs have interesting properties for ad-hoc networks [2, 9, 4] but the most important is that RNG preserves connectivity. It means that if there exists a path between two nodes in G, there still exists a path between these two nodes in $RNG(G)$. We can notice that the distance function d used in computation of RNG



(a) Unit graph



(b) RNG with Euclidean distance function

Figure 2: Example of RNG graph

can be replaced by any weight function. The advantage of RNG with Euclidean distance function is that neighborhood of a node u, $N_{rng}(u)$, contains closest nodes of $N(u)$. Moreover, the average size of $N_{rng}(u)$ for a randomly generated graph is about 2.5 whatever the degree of initial graph (greater than 2.5 of course).

3. Related Works

The broadcast storm problem has been analyzed by Tseng *et al.* in [13]. They proposed five basic methods to reduce the broadcast cost: probabilistic, counter-based, distance-based, location-based and cluster-based. The probabilistic scheme decides to rebroadcast the message with a fixed probability. The counter-based scheme inhibits the rebroadcast if it has already received the message more than a given number of times. The distance-based scheme rebroadcasts the message if the distance between the sender and the receiver is further than a fixed threshold. The location-based scheme rebroadcasts the message if the additional coverage by the new emission is larger than a given bound. The cluster-based scheme selects gateways and headclusters to create cluster (with a cluster election algorithm like *Lower ID*). Thus, gateways and the headclusters are the nodes which rebroadcast. The location-based scheme given the best results but requires a positioning system.

We proposed the BRP (Border Retransmission Probabilistic protocol) in [3] to combine the probabilistic and the distance schemes. The approach has the advantage to be source-independent and to offer short HELLO messages. Firstly, a receiver node v evaluates the distance between the sender u and itself by comparing their neighbors lists. We define a "distance" function denoted by μ and defined by:

$$\mu(u,v) = \frac{|N(v) \setminus N(u)|}{|N(u)|}. \tag{1}$$

It is showed in [3] that this (non-symmetric) estimation of distance is good enough for broadcasting. The nodes with higher μ have better probability to rebroadcast the message, since they have not many common nodes with the sender (*i.e.* the receiver node is close to the radio border of the sender). More sophisticated solutions are proposed including introduction of a neighbor elimination scheme.

The neighbor elimination scheme (NES) [7, 10] is based on the following idea: a node does not rebroadcast a message if all the neighbors have been covered by previous transmissions. Hence, when a node receives a broadcast message, it can learn which nodes have been covered by the transmission (the neighbor list of the sender is included in the broadcast message). Then, the node can keep for each entry in the broadcast table a list of its entire neighbor contacted. When making rebroadcast decision, the node compares its neighbor list and the list associated with the broadcast entry. If not all the nodes in the neighbor list have been contacted, a rebroadcast operation is necessary.

A connected subset of a graph is "dominating" if all the nodes in the graph are either in the set, or neighbors of nodes belonging to the set. This idea can be applied in wireless networks: only nodes included in the dominating set are allowed to rebroadcast the message. Wu and Li [14] proposed a distributed deterministic algorithm for calculating a dominating set on a wireless network. Firstly, each node decides by itself if it is *intermediate*, *intergateway* or *gateway.* Let $N(x)$ denote the neighbors of x and $N[x] = N(x) \cup x$. Let suppose that each node has an unique identifier id number used as key. A node is intermediate if there exist two neighbour which cannot communicate directly. An intergateway is an intermediate node that is not eliminated by the following rule (called Rule 1): consider two intermediate nodes v and u, if $N[v] \subseteq N[u]$ and $key(v) < key(u)$ the node v is not an intergateway node. A gateway is an intergateway node that is not eliminated by the following rule (called Rule 2): assume u and w are two connected intergateway neighbors of an intergateway v. If $N(v) \subseteq N(u) \cup N(w)$ and $key(v) = min\{key(u), key(v), key(w)\}$ the node v is not a gateway.

To improve the previous model, it can be interesting to privilege nodes with many neighbors to be included in dominating set. Stojmenović *et al.* proposed in [11] to use the *degree* instead of the id of the node. When comparing the $key = (degree, x, y)$, nodes shall compare first their degrees. In case of tie, the coordinates (or the id if positioning service is unavailable) are used to resolve. The authors enhance the protocol with the use of a neighbor elimination and retransmission after negative acknowledgements schemes.

The MPR (Multipoint Relaying Method) protocol [8], proposed by Qayyum *et al.* is a deterministic method for reliable broadcasting. The algorithm selects a minimal set of one-hop neighbors that cover the same network as the complete set of neighbors. The authors proposed a greedy algorithm, since the computation of the minimal set is a NP-complete problem. Let us denote $MPR(x)$ the selected multipoint relay set of node x. Firstly, the heuristic adds 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 $N^2(x)$ not covered, select node in N(x) with a number maximal of not covered neighbors, and put it into $MPR(x)$. This protocol is the more significant example of explicit relay subset broadcast protocols. For each emitted broadcast message, the sender sends the relay subset in message.

Adjih *et al.* proposed in [1] to combine the MPR and the dominating set approach. The MPR-Dominating set protocol has the main advantage to be source-independent (*i.e.* the nodes decide by themselves to rebroadcast or not). Each node computes its MPR and transmits it to its neighbors. From this MPR, a node determines if they belong to the "MPR Dominating Set" if it satisfies one of the following conditions:

- the node has the smallest *id* in its neighborhood,
- the node is MPR of the neighbor with the smallest *id*.

They prove the correctness of this algorithm creating a valid dominating set. They compare it to a simple MPR, and obtain close results. The protocol requires two-hop topology information, *i.e.* neighbors of neighbors and multipoint relay of neighbors. Contrary to Wu and Li's Dominating Set, MPR-Dominating Set protocol does not need synchronization or iteration.

The protocol RRS we propose is a forwarding neighbor protocol like MPR but is self-selecting forwarding neighbor.

4. RNG Relay Subset Broadcasting Protocol

The goal of our broadcast protocol is to minimize emitted packets while ensure full coverage of the network by using self-selecting forwarding neighbors. The protocol has also to be scalable and be efficient for small and high density networks. The location-based protocol [13] is interesting since it favors border nodes of the communication zone to relay the flooding. This principle is not scalable. Indeed, in low density network, nodes which ensure the connectivity two 2-hop neighbors are not only furthest nodes (see Fig. 3 where node G will never received the message). At contrary, for high degree graphs the location based protocol selects too many neighbors. Hence distance threshold has to vary with density network or at node level to local neighborhood but this adaptation does not guarantee total connectivity with 2-hops neighbors. In [3], this problem is lessened by introducing a probabilistic gradient which takes in account local density. But distance between nodes is not the only parameter to consider as illustrated above by Fig. 3. The first step of RNG Relay Subset is the construction of the relay subset.

Let $G = (V, E)$ be a connected unit graph. For each node $u \in V$, we compute a set $RRS(u)$ which is the RNG Relay Subset of u:

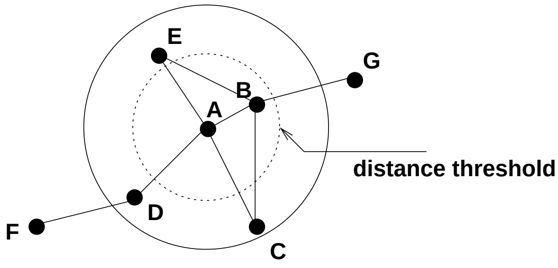


Figure 3: A low density example for location-based flooding protocol.

$$\forall u \in V \quad RRS(u) = \{v \in N(u) \mid N_{rng}(v) \setminus (N(u) \cup \{u\}) \neq \emptyset\}.$$

In other words, a node v is a relay for u if and only if v is a neighbor of u and if v has a RNG-neighbor which is not covered by u transmission. An example of relay subset is given Fig. 4. We see that a node in neighborhood of A is a RNG relay if it has a RNG edge which go outside of the communication area of A. The topology information brought by RNG assures that the iterated process can reach all nodes in the network. Indeed, let us consider the following algorithm:

- A node which wants to initiate a broadcast just sends its message without additional information except conventional heading like sequence number.
- On reception of a broadcast message from a node u, a node tests itself whether or not it belongs to relay subset of u. If the answer is negative, the message is dropped and in the other case, the node retransmits the message.

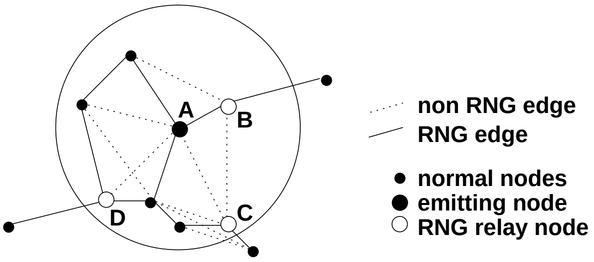


Figure 4: An example of RNG Relay Subset.

Let u be a node initiating a broadcast. We can notice that it is easy to build a graph such that the RNG Relay Subset of u does not cover the 2-hop neighborhood of u *i.e.* $N(R(u)) \neq N^2(u)$ (see Fig. 5). But it is easy to show that every node v of the network is reached by the flooding. It suffices to use induction on minimal path length in RNG between u and v.

For high density, the size of RRS grows while the size of minimal relay subset size intuitively tends to a constant when density tends to infinity. For reasonable

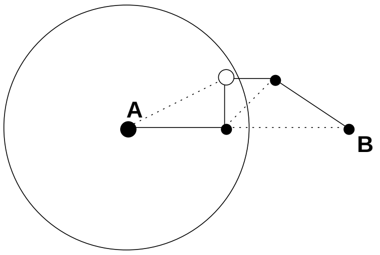


Figure 5: An example of RNG Relay Subset where $N(R(A)) \neq N^2(A)$.

density (less than 100 per communication zone) it is enough to consider a neighbor elimination scheme to limit number of retransmitting nodes. We propose the following algorithm:

- A node which desires to begin a broadcast sends its message.
- On reception of a broadcast message from the first time from a node u, the node generates the list of RNG neighbors which have not received the message: $list = N_{rng}(v) \setminus N(u)$. If the list is empty, the node drops the message and ignores later receptions. Otherwise, the node v set up a trigger for this message with a given timeout.
- On reception of an already received message from a node u, the list of remaining RNG neighbors is updated: $list = list \setminus N(u)$. If the list is empty, the message is dropped, next receptions are ignored and the trigger is cancelled.
- When the trigger is fired, the node retransmits the message since the list is not empty.

The computation of timeout is randomly generated in order to avoid that several RNG relay nodes send the message simultaneously. This random value is biased by distance to the sender for the same reason that location-based protocol [13] and border retransmission probabilistic protocol [4]. We propose to use the following formula where u is the sending node, v the receiving node, *max* is a constant of the system which represents the maximal timeout:

$$timeout = random(max/2) + max/2 * \left(1 - \frac{d(u,v)}{R}\right). \tag{2}$$

In our protocol, we suppose that nodes are able to evaluate distance between nodes in order to compute the RNG and the timeout. This can be achieved by integration of positioning system like GPS or signal strength measure. If the mobile is not able to evaluate real distance, we can use a software distance in the same manner than in [4] with the μ-distance (see Equation 1). But the function μ is not symmetric and cannot be used as distance function in computation of RNG (in this case connectivity preservation cannot be ensured). That is why we introduce the function ν to evaluate distance:

$$\nu(u,v) = \frac{|N(u) \setminus N(v) \cup N(v) \setminus N(u)|}{|N(u) \cup N(v)|}. \tag{3}$$

If nodes have a positioning system, they simply send their *id* and position in HELLO messages. Otherwise, nodes need to send list of neighbors and evaluated distance (physically measured or logically computed) to them. This is the minimum information needed to calculate RNG. For instance, we see in Fig. 6 the RNG graph computed with ν-distance for unit graph of Fig. 2.

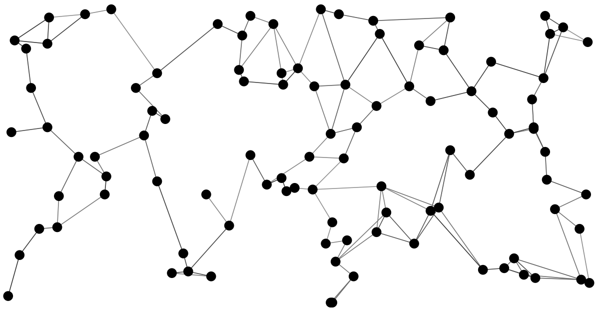


Figure 6: RNG graph using "ν-distance".

In next section, we give experimentation results of RRS and compare it to MPR [8] with 802.11 MAC layer.

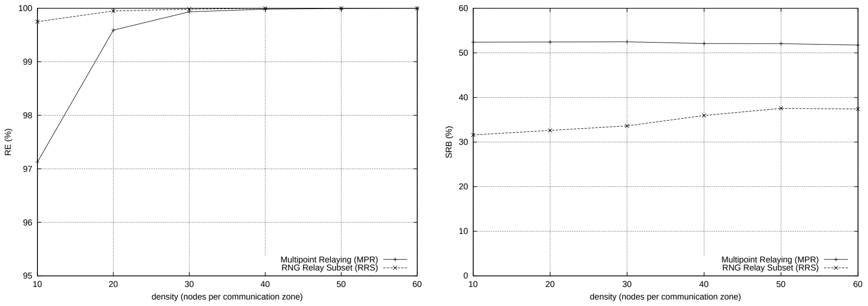
5. Experimental Results

In our simulations, we compare Multipoint Relay (MPR) and RNG Relay Subset (RRS) protocols. The first one, MPR, is an explicit relay subset protocol while the other one, RRS, is a self-selecting neighbor protocol. We use the following parameters in our simulations. We compute 1000 broadcasts for each measure. The area is a square with a fixed side size of 400 meters. The nodes are static, randomly placed in the area and their maximum communication radius R is fixed to 100 meters. The number of nodes n takes the following values: 50, 100, 150, 200, 250 and 300 (that correspond to density 10 to 60 nodes per communication zone). We retained only connected sets.

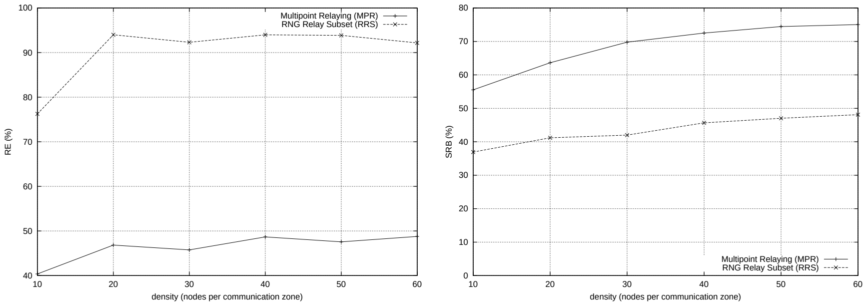
We use an 802.11-like MAC layer [6] that is a CSMA protocol. For RRS, the *max* parameter for timeout (see Equation 2) is 128 and the unit corresponds to DIFS duration (32 μs) which is the delay in MAC layer to determine whether or not the medium is free. Hence, the timeout is between 0 and 128 DIFS time slots (the maximum delay is about $4ms$). The size of the broadcasted message is about 512 bytes and an *id* requires 8 bytes (used to MPR to inform relays). According to MAC layer, the transmission of one message without relays information is about $1.5ms$ with a bit rate of 11 Mbps.

The observed parameters are the reachability and the saved rebroadcast. The reachability (RE) is the percentage of nodes which received the broadcasted message. The saved rebroadcast (SRB) is the percentage of nodes which have not re-transmitted the message. A good broadcast protocol is a protocol with reachability higher that 90% and a saved rebroadcast the higher of possible.

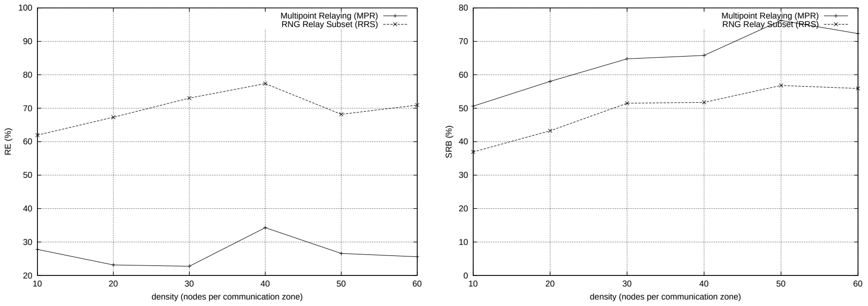
We run three scenarios: single flooding, five and ten broadcasts. In the first scenario, only one broadcast is launched (see (a) Fig. 7). In order to generate other network traffics, five and ten broadcasts are launcher simultaneously in the two other scenarios (see (b) and (c) Fig. 7).



(a) one single broadcast.



(b) five simultaneous broadcasts.



(c) ten simultaneous broadcasts.

Figure 7: RE/SRB vs. density

We can see that with no other network load, MPR and RRS are both efficient with reachability above 97%. But the protocol MPR is more economical with an

SRB above 50% against an SRB below 40% for RRS. With five and ten broadcast, the reachability of MPR falls significantly while RRS stays above 60%. This distance is due to the extra-length added in broadcasted message in MPR: the list of relay nodes. This is not the only reason as illustrated in Fig. 8. In this figure, we give the reachability of MPR and RRS for a number of broadcast varying from 1 to 10 with a constant density of 15 nodes per communication zone. We test with two kinds of messages: empty data *i.e.* only headers and with packets containing 512 bytes of data. If shorter messages lead to higher reachability, it cannot explain the difference of coverage network between MPR and RRS.

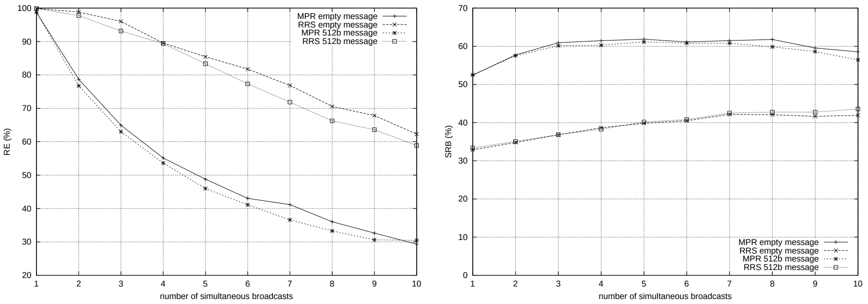


Figure 8: RE/SRB vs. number of broadcasts with empty messages and 512 byte messages with a density of 15 nodes per communication zone.

One of the main advantages of RRS is the self selection mode combined with neighbor elimination scheme. The number of relays in RRS is greater than in MPR (it is the optimization criteria) and hence the relay redundancy is better in RRS in case of collided packets. This relay redundancy is illustrated Fig. 9 where we give the average number of relays of MPR and RRS against the density.

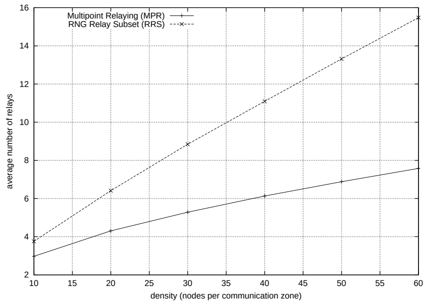


Figure 9: Average number of relays vs. density.

At last, we have compared performance of RRS with Euclidean distance (denoted simply RRS) and with ν-distance (denoted by ν-RRS) — see Equation 3). We give results with a single broadcast and we can see that the loss of SRB is trifling.

6. Conclusion

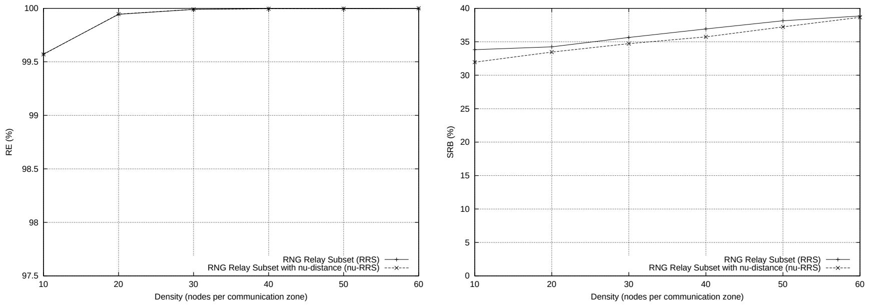


Figure 10: RE/SRB of RRS and ν-RRS.

In this paper we give a new broadcast protocol called RNG Relay Subset (RRS). The advantage of RRS is that neighbors of a broadcasting node decide by themselves to retransmit or not. This allows to reduce the size of packets and then to reduce contention in MAC layer. Moreover, the redundancy of relays combined with a full neighbor elimination scheme (based on RNG neighbors) lead to a good behavior with overloaded medium.

We compare our self-selecting forwarding neighbor flooding protocol to explicit forwarding neighbor version of MPR. That signifies that MPR put *id* of relays in messages. Furthermore, we have ignored network traffic generated by HELLO messages. In future works, we want to consider new protocols such that version of MPR where relays are transmitted in HELLO messages and dominating set based protocols [1, 10, 14].

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