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Distributed Localization Protocol for Routing in a Noisy Wireless Sensor Network

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***Abstract*—To be efficient, routing protocols in wireless sensor networks suppose to take into account local interactions, noise and collisions. In this work, we propose a routing protocol suitable for noisy environments. Using the Qualitative Localization Algorithm (QLoP [13]) in order to select sensors with a better signal-to-noise ratio, we build a logical topology on which we apply a routing protocol. We show that Received Signal Strength Indicator (RSSI) is not a good metric to evaluate proximity. In order to provide a better proximity metric, we introduce the Qualitative Localization Protocol: QLoP. QloP does not use any anchor or dedicated hardware like GPS. Each node builds a Qualitative Distance according to the 2-hop neighborhood information. Thus, this algorithm allows to determine coarsely the proximity of the neighbors which are classified as *very close*, *close* or *far*. We highlight the routing performances in a noisy environment and compare it to a classical routing protocol on a flat topology. Delivery rate, throughput and average distance reachable in those extremes conditions are appreciably enhanced.**

I. Introduction

Wireless Sensor Networks (WSN) are formed by hundreds or thousands of low cost and low energy sensor devices. Route data through those kinds of networks have become major research issues. However, classical routing protocols are not suitable for WSN in a real environment, due to the particular radio environment of such networks. Noise, interferences, collisions and neighborhood volatility lead to performances slump. In this work, we propose to use QLoP [13] to build a logical topology based on Relative Neighborhood Graph (RNG) [23] in order to provide a routing protocol favoring the very closed neighbors as relays: the smallest links, which are more robust to noise and to the non-stationary of the radio channel, are mainly used. In many papers, RSSI is used to provide a proximity information. we show, before introducing our proximity metric used in QLoP, that RSSI is unstable and an inaccurate measure for proximity of two nodes. QLoP is a localized algorithm allowing to each node of the network to localize their neighbors using only local information without anchor or GPS. The algorithm uses only local information obtained by exchanging neighborhood tables with classical hello packets to compute a **proximity index** for each 1-hop neighbor. The figure 1 illustrates the result of the algorithm: the neighbors of the studied node are classified in *very close*, *close* and *far* nodes.

The objective is to provide a routing protocol suitable for this kind of topology, resistant to interferences, collisions and to noise. In this aim, the virtual topology will favor the shortest links, and thus, will build longer routes in a number of hops, but more effective in terms of delivery rate and throughput. We show that by favoring the closest neighbors, we select the nodes with a more important signal-to-noise ratio while increasing the performances against noise, interference and collisions.

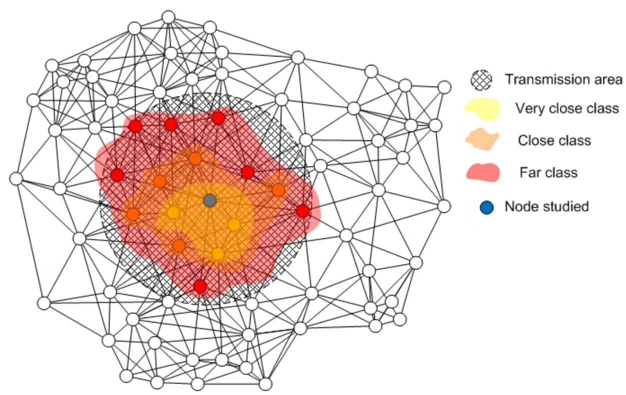

Fig. 1. Qualitative node proximity classification

The paper is organized as follows. In Section III, we present the qualitative localization algorithm and logical topology in section IV. Next, the assumptions we made and the results we obtained are discussed in section V. In Section VII some prior works about routing techniques are compared. We conclude with some future work directions in section VIII.

II. RSSI: a weak metric for proximity

In many papers, RSSI is used to provide a proximity information (RADAR [2], [14], [22], [19]). However, whole of these studies can't really establish a ratio between the distance and the received signal strength. [10] shows that the RSS is affected by three phenomena, the path-loss, the fading and the shadowing. Withal, for [20] the primary cause of unpredictable performance of RSSI is due to interference, and not to multipath fading. Moreover, in four experiments

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performed in three different environments (see Fig.2) which we won't detail in this paper, we underline that:

- the influence of environment on the stability and accuracy of RSSI (see Fig.3).
- the influence of angle: PCB antenna used in sensor chips are generally not perfectly isotropic.
- the influence of mobility inside the network (door, people, windows, etc.).
- the influence of received strength on the stability: more the signal strength is weak more RSSI is unstable (see Fig.4).

To summarize, in our point of view, the RSSI is not reconcilable with sensor networks because these kind of network are composed by hundred or thousand cheap sensors constrained in energy, deployed in dynamic and heterogeneous environments. Those constraints lead to the instability and the inaccuracy of RSSI. That's why we introduce a new metric based not on physical measures but on topological information (i.e. 1 and 2 hops neighborhood).

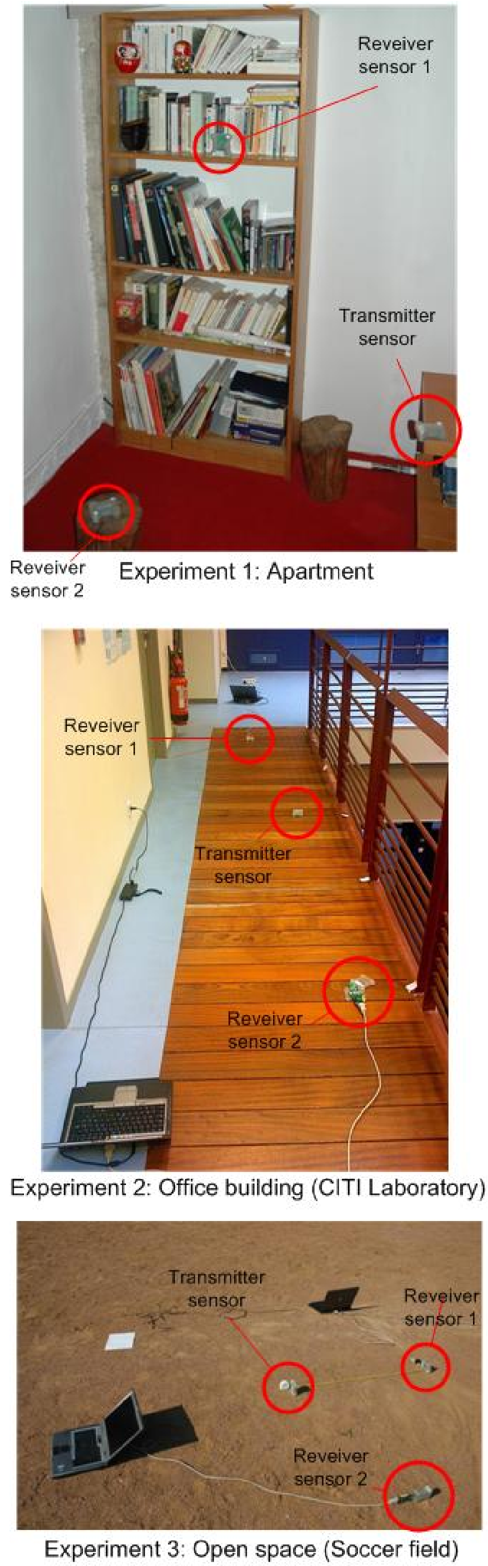

Fig. 2. The 3 different environments

III. QLoP: Algorithm overview

Several strategies may be used to localize a node precisely: time of arrival [5], time propagation difference of arrival ([17], [25]), the angle of arrival ([1], [18]) or a combination of TDoA and AoA [16]. All those protocols don't take into account the energy consumption and assume that each node is able to compute easily the time or the angle of arrival. Anyway, the anchor systems do not avoid the localization problem but reduce it to a subset of network nodes. Moreover other problems appear like the anchors placement in the network to allow a better localization of the nodes [4], [7].

Remember that the goal of QLoP algorithm is to determine coarsely the localization of the neighbors of a given node using only local information. This local information comes from the hello packets which are exchanged between 1-hop neighbors. The qualitative localization of a neighbor can be *very close*, *close* or *far*. Such coarsely location can be used to construct a reliable unicast routing protocol in noisy wireless environment with a high level of interferences: to choose the *very close* nodes allows choosing the nodes with a high C/I ratio as relays.

A node A calculates proximity index with his neighbor B in the following way:

$$PI_A(B) = (|V(A) \cap V(B)|) - \frac{max(|V(A)|, |V(B)|)}{2}$$

where $V(A)$ is the neighborhood of A and $|V(A)|$ is the cardinality of $V(A)$.

The main idea is to give a high proximity index (PI) to the neighbor nodes having many common neighbors with the origin node (A) and few distinct neighbors. Indeed, we take into account the ratio between the number of common neighbors and the number of distinct neighbors. Effectively, close neighbors has a strong similar vicinity whereas distant neighbors will have much distinct neighbors. Thus, the

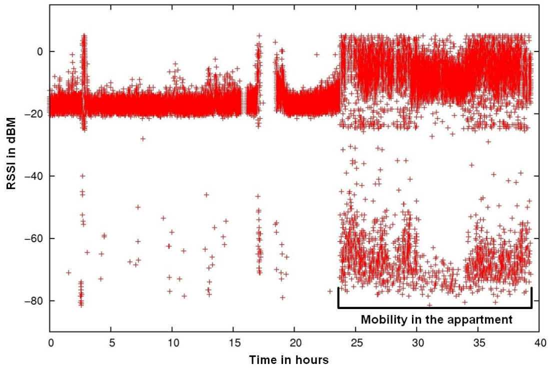

Fig. 3. RSSI evolution measured by sensor 1 during 40 hours

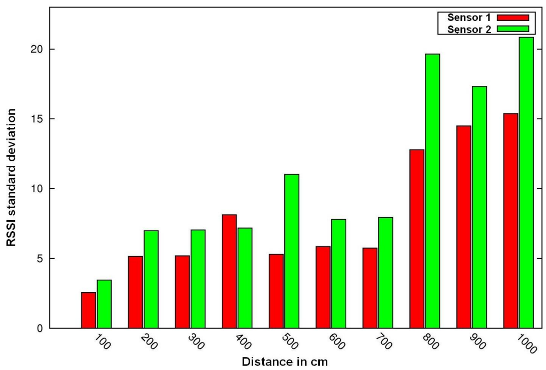

Fig. 4. Relation between RSSI standard deviation and distance for the two receiver sensors

proximity index is useful to represent the nodes which are *qualitatively* close. This logical proximity index is related to the geographical proximity in the case of dense and uniform networks. This mechanism allows to establish three distinguish classes among the neighbors: the *very close* class (or 1), the *close* class (or 2) and the *far* class (or 3) (see figure 5). We calculate the class of a node in the following way ($PI(x)$ denoted the proximity index of neighbor x):

$$inter = \frac{|max(PI(x_i)) - min(PI(x_i))|}{3}$$

$$class_x = \begin{cases} 1 & if PI(x) \geq max(PI(x_i)) - inter \\ 2 & if max(PI(x_i)) - inter > PI(x) \\ & \geq max(PI(x_i)) - 2.inter \\ 3 & if PI(x) < max(PI(x_i)) - 2.inter \end{cases}$$

Each node of the network computes a proximity index for each of its neighbors according to the local information received from its 1-hop neighbors. Each node maintains a table of his 1-hop and 2-hop neighborhood but diffuses only the table of its direct neighbors with periodic hello packets. Figure 5 show an algorithm application on a particular node for a given topology. Node 27 classifies its neighbors in 3 proximity classes. Note that, on this example, the network is parse.

The protocol is inexpensive in energy because it uses only hello packet with neighborhood tables. This kind of hello packets is necessary to many other protocols: self-organization (CDS-rule-k [26], CDS-MIS [24],...) and pro-active routing protocols (OLSR [6]) deployed in wireless sensor networks. Therefore, QLoP don't use any additional packet. Moreover, if the network is not very dynamic (low mobility, few birth or death of nodes in the network [12]) this exchange of packets can be reduced and limited to the deployment phase of the network.

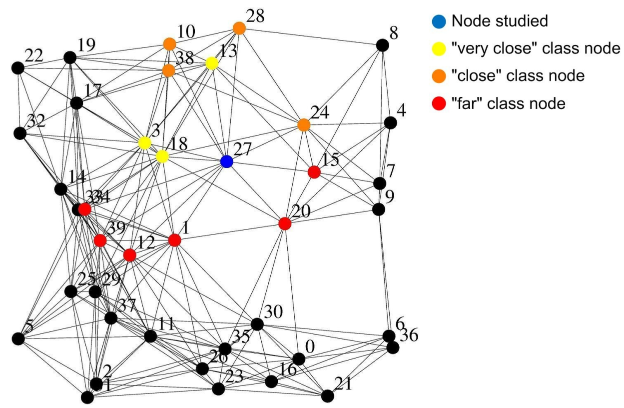

Fig. 5. Example of qualitative localization computed by the node 27.

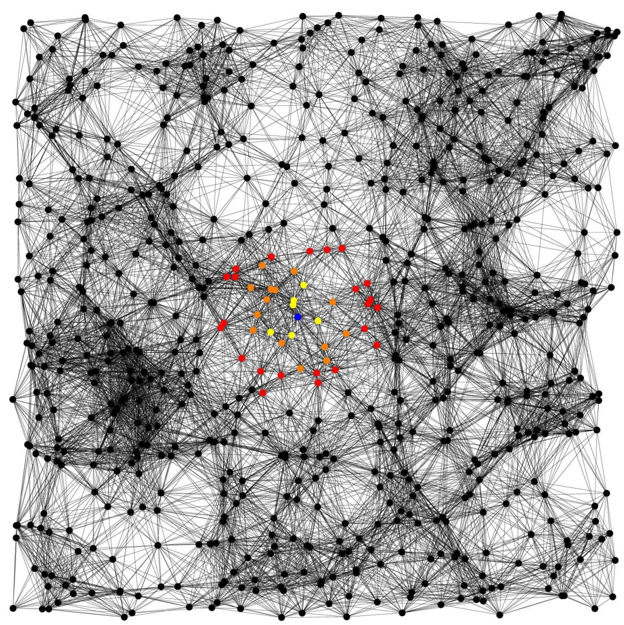

Fig. 6. Application of the algorithm in a random topology

In the case of dense topology (700 nodes, average degree: 40), the localization is very effective. We can see the localization into three classes on the figure 6. The yellow nodes are in the *very close* class, the orange ones in the *close* class and the red ones in *far* the class.

Each node allocates a class to its neighbors according to its proximity index. How evolve those classes when average degree increases? We can note (Fig. 7) that, when the average degree increases, the percentage of nodes of the *very close* class decreases, whereas the percentage of nodes of the *close* class increases. The *far* class remainder constant. That means that, more the density is large, more the proximity index is able to distinguish the really *very close* nodes.

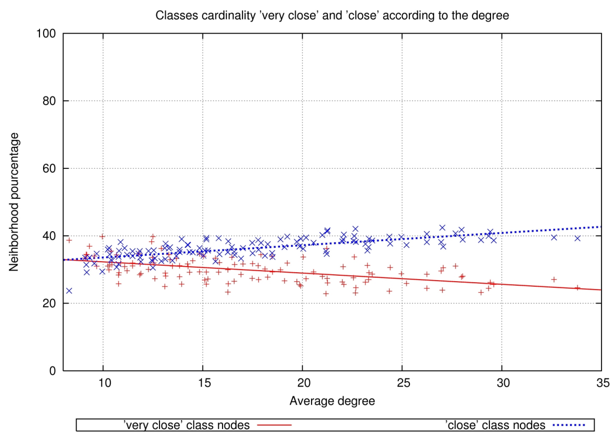

Fig. 7. Classes cardinality in function of the average degree

If we use this algorithm to know at which distance is a neighbor node, we should know if a neighbor selected as *close* or *very close* is indeed *close* or *very close* in the real world. We determined the number of neighbors belonging to the *close* and *very close* classes selected by the algorithm being indeed in the *close* and *very close* classes in a GPS-aware classification (red curve in Figure 8). Then we observe the number of nodes selected by the algorithm in these two classes and we note those which are not belonging to the GPS-aware classification *close* and *very close* (blue curve in Figure 8). More than 80% of nodes are well classified even for topologies with a low average degree. Again, when the density increases, the reliability increases too.

IV. Topology Control: QLoP-RNG

In dense sensor networks, it is often desirable to limit the vicinity to the closest neighbors: to stabilize the neighborhood and to select nodes with a less important level of noise or interference. Several topology control algorithms exist:

- Gabriel Graph [8]: an edge between u and v is selected if $disk(u,v)$ contains no another node inside.
- LMST [15]: Each node knows the location of its 1-hop neighbors and each node computes a MST in its neighborhood. The construction of the LMST topology is based on the construction of local MST by each node. An edge (u,v) is in the final LMST iif v is in the LMST(u) and u is in the LMST(v).

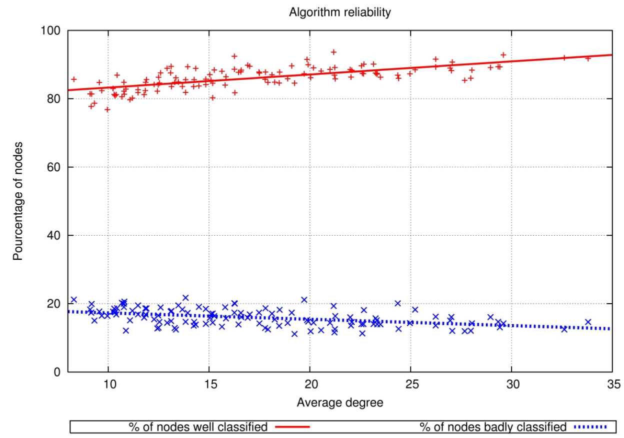

Fig. 8. Algorithm reliability

- RNG [23]: Thanks to the position of the 1-hop neighbors, a node removes the longest links in the following way: given two neighbor nodes u and v, if there is a node w such as $d(u,v) > d(u,w)$ and $d(v,u) > d(v,w)$ then the edge (u,v) is deselected.

Those algorithms are based on the knowledge of the exact position of sensors (GPS, antenna array, RSSI, etc...).

We applied our qualitative localization algorithm to build a Relative Neighborhood Graph (see Figure 9, denoted as RNG QLoP). RNG protocol guarantees the connectivity of the network. [11] shows that RNG is robust and that the disturbances due to the lost of a neighbor node are very limited and totally localized.

Thanks to the proximity index of the 1 and 2 hop neighbors, a node removes the longest links in the following way: given two neighbor nodes u and v, if there is a node w such as $PI_u(w) > PI_u(v)$ and $PI_v(w) > PI_v(u)$ then the edge (u,v) is deselected. In Figure 10, we observe the effectiveness of the logical structure created by observing the overall length of the selected links: more the overall length is low, more the algorithm is relevant because of the energy saved. This analysis highlights two points: the performance of RNG-QLoP algorithm is very close to the RNG using GPS and more the density is important and more the performances of RNG-QLoP are good. It is due to the information quantity increasing when the number of neighbors increases: it leads to a better precision.

V. DSR-like Routing on logical topology

A. DSR-like Routing

Dynamic Source Routing (DSR) is a routing protocol for mobile ad hoc networks than can be used for wireless mesh and WSN. It is a reactive protocol i.e. the routes are computed on-demand. A source node floods the network with a route request (RREq) packet and builds the required route from the responses it receives from route reply packet. In our

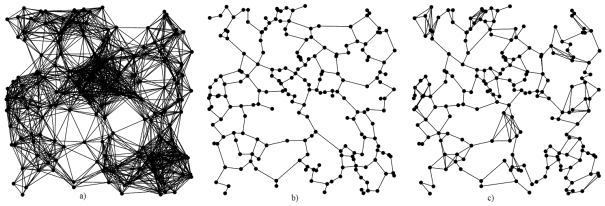

Fig. 9. a) Physical topology, b) Topology control (RNG, GPS) c) Topology control (RNG, QLoP)

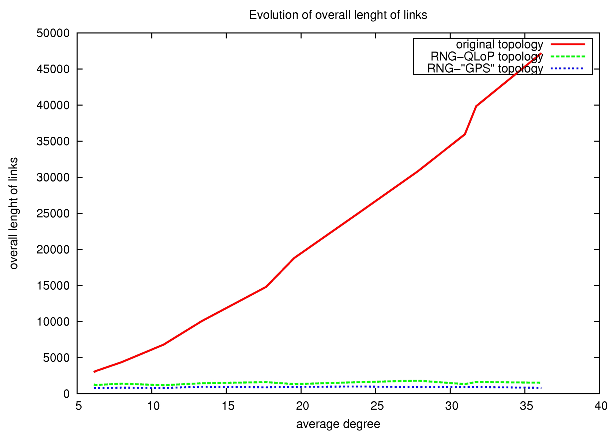

Fig. 10. Evolution of length of the topology links used

simulation environment, routes are an expiration date and must be refreshed periodically.

B. Modeling and Simulation

All the results we provide here are computed using the WSNet simulator [3]. The simulator originality is an accurate PHY modeling. The range of a radio system is based upon the definition of a signal to noise ratio (SNR) threshold noted $\bar{\gamma}_{lim}$.

$$\begin{aligned} & l_{ij} : \Omega^2 \mapsto B = \{0,1\} \\ & (x_i, x_j) \mapsto l(x_i, x_j) = \begin{cases} 1 & \text{if } \bar{\gamma}_{ij} \geq \bar{\gamma}_{lim} \\ 0 & \text{else} \end{cases} \end{aligned} \quad (1)$$

To model interferences, WSNet replaces the SNR by a signal to interference plus noise ratio, SINR, which can be derived according to:

$$\bar{\gamma}_{ij} = h_{ij} \cdot \frac{P_i}{N_j + \sum_{k \neq i,j} h_{kj} \cdot P_k} \quad (2)$$

where h_{ij} is the path-loss and P_i and N_j are the transmission power and the noise level respectively. It should be noted that the assumption lead to a neighborhood instability and a coverage areas which is deformed as illustrated in Figure 11. We deployed, with a uniform and random distribution, 100 nodes and we varied the transmission power to increase the average degree. MAC layer 802.11 DCF is also used. Each node is considered as motionless.

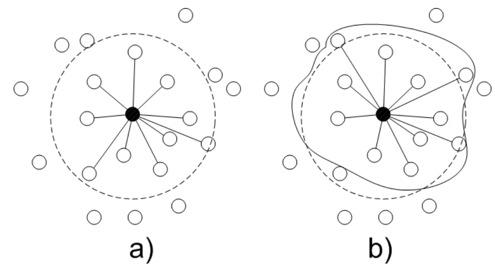

Fig. 11. Neighborhood with different radio range modeling: a) Perfect unit disk, b) Links with pathloss and shadowing

C. Results

The results are obtained with a constant transmission power and a variation of the ambient noise. We note a rupture of the network connectivity starting from a noise of -90 dBm. We compare the performances of following topologies:

- Flat topology i.e. the nodes communicate with their physical neighbors
- QLoP-RNG i.e. node construct locally a RNG structure using QLoP algorithm
- GPS-RNG i.e. node construct the classical RNG topology using geographic information.

Remember that QLoP-RNG and GPS-RNG do not modify the intrinsic connectivity of the network.

The Figure 12 shows the number of RReq packets retransmissions. These packets are essential for route discovery from a source node to a destination node. In a DSR-like protocol, the network is flooded. We observe a great disparity between flooding on a logical topology and on a flat one. In the case of flat topology and when the noise is weak, nearly 3 times more packets are forwarded by each node through the network. That results to overload the network and thus, favor the collisions. The second consequence is the waste of energy. QLoP-RNG and QLoP-GPS topologies strongly reduce the number of retransmissions.

However, this reduction of traffic has an impact on the probability of reaching a destination node (see Fig. 13). We observe a success delivery rate of RReq packets definitely lower for the routing protocol deployed on QLoP-RNG and GPS-RNG. When a destination node receives a route request packet, it returns a route reply packet in unicast mode. The route reply packets are also prone to the collisions, and interferences. That means that just few routes are built. On a flat topology, much of not reliable routes are built. These routes are based on opportunist links, not very robust and short-lived. On QLoP-RNG and GPS-RNG topologies, the built routes are based on more durable links.

In the following results, each node sends data periodically to a random destination node. We observe in Fig. 14 the delivery ratio. We saw that the process of route discovery

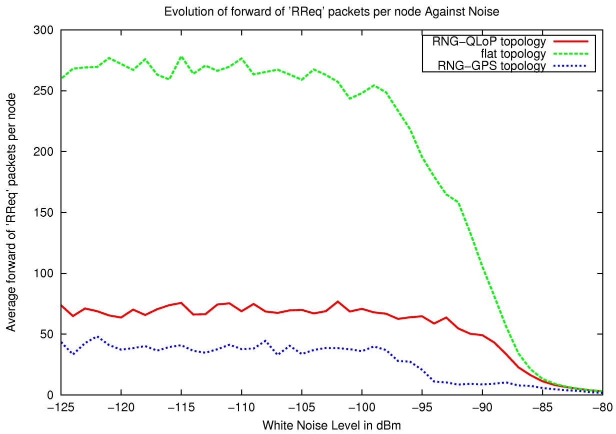

Fig. 12. Evolution of number of Route Request (RReq) packets forward per node

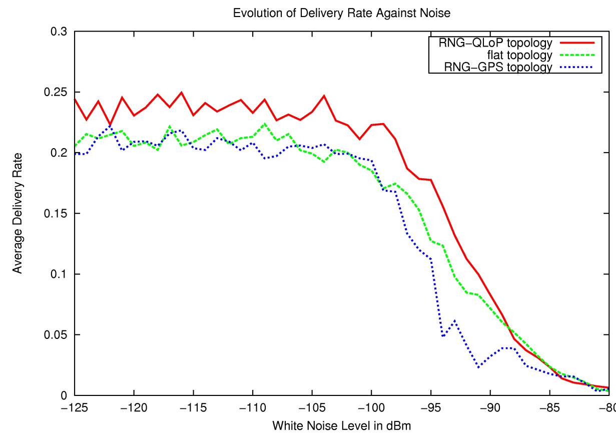

Fig. 14. Delivery rate against noise

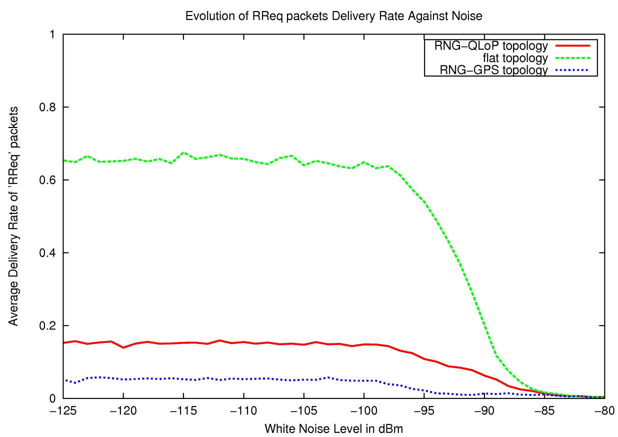

Fig. 13. Evolution of Route Request (RReq) packets delivery Rate

was different according to topology: whereas many routes are built on a flat topology, QLoP-RNG and GPS-RNG build a route only if it is reliable. QLoP-RNG obtains the best delivery rate. Even in the case of a strong noise, routing on this topology allows to transmit packets to destination. Here, the size of data packets allows only very seldom opportunist transmission, thus, routing on flat topology is less efficient. For GPS-RNG, the too drastic suppression of links prevents the communication instead of reinforcing it.

We note that in a network where communications are numerous and where the noise is important, only few packets of data arrive at destination. The path length covered in terms of euclidean distance plays a part: if the distance between a source and destination node is long, the delivery ratio is low. We see on Figure 15 which distance cover the received packets and the evolution of this distance according to the noise. The noise and the interferences impact, in an important way, the diffusion of the data packets. It is very difficult for a node to send its data beyond 20m in the case of a QLoP-RNG topology (the diameter of the network is of 141m approximately). That means that even when the network is viewed as connected, packets does not cross, on average, a certain distance. Here, the logical topology, even if it reduces the possibility of long hops, increases finally the average distance covered by a packet. That confirms the fact that the probabilistic transmissions, using long hops are negligible.

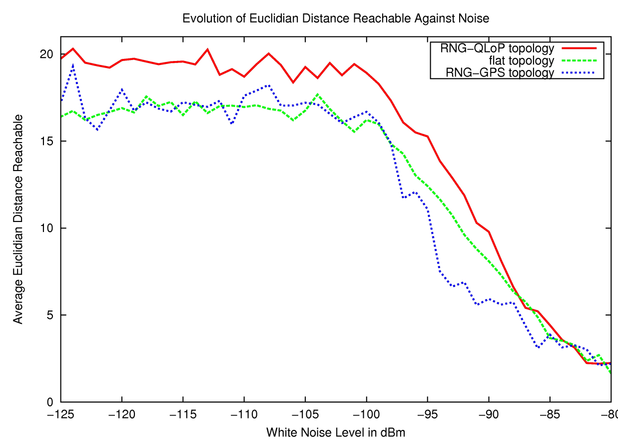

Fig. 15. Distance against noise

One of the differences between routing on logical topology and classical flat routing is the path length in terms of number of hops from a source node to a destination node. QLoP-RNG topology decreases the number of links in the network, to be based mainly on the shortest links and thus, the most reliable. In the case of long hops, the probability of successful transmissions is extremely weak and it is desirable ”to cut out” a great improbable hop into 2, 3 or 4 small probable hops. That is what the topology control based on QLoP does (see Fig.16).

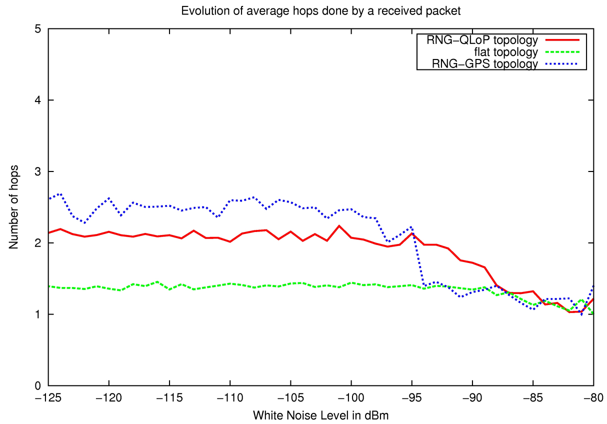

Fig. 16. Average number of hops per packet against noise

VI. What about energy consumption?

QLoP uses neither GPS, nor special equipment. The consumption of a receiver GPS is not negligible and if research to reduce GPS consumption exists, they require expensive additional equipment, like accelerometer as well as additional algorithms ([21]). QLoP uses only hello packets or "beacon" to inform its vicinity of its presence and to transmit its direct vicinity. QLoP is thus perfectly compatible with the sleep-mode protocols and self-organization protocols which are also based on hello packets. It is thus important to highlight that in most cases, QLoP uses only information already available and uses additional energy to compute proximity index for each of its neighbors. The computation of $PI_A(B)$ (proximity index of node B computes by node A) consists of an intersection of 2 sets. The complexity of this algorithm is thus O(n+m) where n is the number of neighbors of A and m the number of neighbors of B. It is thus extremely inexpensive in energy even if the density is very important.

VII. Related work

Routing protocol in noisy environment is rarely tackled. To our knowledge, there does not exist any paper which treats routing on logical topology, without geographical information and in a realistic physical environment.

[9] gives 18 reasons why the trade-off between routing over many short hops and routing over fewer longer hops is not as clearcut as is often assumed. The article admits the need for stable routes in the case of proactive routing but deals with opportunist routing i.e. geographic routing. It avoids the problem of route and neighbor discover and flooding problem.

[27] explores the trade off between Long-hop or Short-hop routing strategies and energy consumption. It determines an energetic cut-out to know at which distance it is more suitable to make one additional hop. This paper focus only on physical layer and when nodes can adjust their transmission power.

In these two papers, the case of concurrent communications is not approached. In the case of simultaneous communications, four communicating close nodes 2 to 2 can exchange data successfully (see Fig.17).

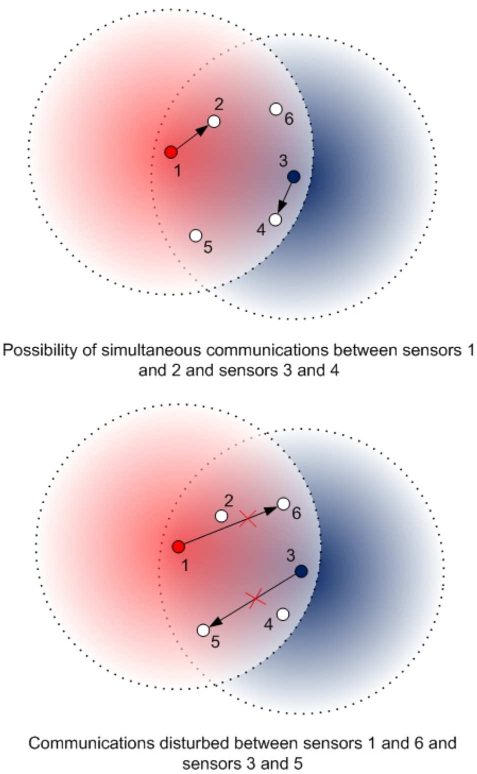

Fig. 17. Concurrent communications

VIII. Conclusions

In this work we propose a routing protocol suitable for noisy radio environment. It is based on a qualitative localization algorithm (QLoP) using only local information without any additional hardware or GPS.

We apply this qualitative localization algorithm for topology control (QLoP-RNG). A Relative Neighborhood Graph is computed using the proximity index computed with QLoP: the performances are close to the performances obtained with an absolute location (GPS-RNG).

Next we use this logical topology to provide a DSR-like routing protocol suited to wireless networks with interferences and noise. It favors paths made up of small hops and thus, to use very close nodes as relays because of their important signal-to-noise ratio. The QLoP-RNG topology reduces the cost of the route request flooding and constructs more robust route at the same time. It reduces the number of communications on the medium, the power consumption and robustness against noise. We believe that QLoP-RNG is a good trade-off between the too drastic link pruning GPS-RNG and no topology control.

The next step is to compare our solution to other routing algorithms under the same noisy assumption.

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