Distributed Qualitative Localization for Wireless Sensor Networks*

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Abstract. The use of localization mechanism is essential in wireless sensor networks either for communication protocols (geographic routing protocol) or for application (vehicle tracking). The goal of localization mechanism is to determine either precisely or coarsely the node location using either a global reference (GPS) or a locale one. In this work, we introduce a new localized algorithm which classified the proximity of the neighborhood for a node. This qualitative localization does not use any anchor or dedicated hardware like a GPS. Each node builds a Qualitative Distance Table according to the 2-hop neighborhood informations. Thus, the algorithm allows to determine coarsely the location of the neighbors which are classified as *very close*, *close* or *far*. The algorithm is analyzed on a regular particular topology and then we evaluate this accuracy on a random topologies. We apply this algorithm for a localized topology control and we show that these topology control algorithms remain effective even without GPS information.

Keywords: Localization, location, gps-free, wireless sensor networks.

1 Introduction

Many applications for wireless sensor networks, as vehicle tracking or environment monitoring, need location awareness to work successfully. Geographic or location-based routing protocols can be used without mechanism of route request packets flooded in the whole network and so, the energy is saved and the performances are improved. Moreover, in topology control protocols, where each sensor node needs to adjust its power transmission to minimize the energy consumption the algorithms must be location-aware.

GPS [HWLC01] solves the localization issue in outdoor environments. However, for large sensor networks where nodes must be very small, low power and cheap, putting a GPS chip in every device is too costly.

In this paper, we propose a localized algorithm that allows to each node of the network to localize their neighbors using only local informations. Our objective is to show that in a wireless sensor networks where special hardware or GPS cannot be used for cost reasons, there is a way to obtain coarse positions of

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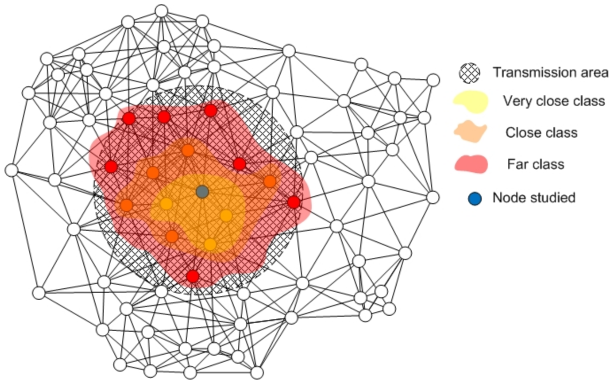

Fig. 1. Qualitative node proximity classification

the nodes. The algorithm uses only local informations obtained by exchanging neighborhood tables with classical hello packets to compute a **proximity index** for each 1-hop neighbor. We show that, despite the measurement errors, the algorithm is enough reliable and almost perfect on particular topologies (grid). The figure 1 illustrates the result of the algorithm: the neighbors of the studied node are classified in *very close* nodes, *close* one and *far* one.

The paper is organized as follows. In Section 2 some prior works about localization techniques are reviewed. The qualitative localization algorithm is presented in section 3. Next, the assumptions we made and the results we obtained are discussed in section 4. We conclude this work with some future work directions in section 6.

2 Related Works

Many localization techniques are proposed to allow nodes to estimate their location. We can distinguish two types of strategies of localization: fine and coarse localizations. The fine localization strategies determine precisely the coordinates of a node in the whole network whereas the coarse localization strategies specify a non precise area or introduce virtual coordinates, etc...

2.1 Fine Localization Strategies

The use of GPS system allows to localize a node precisely. However, it is expensive to install GPS receiver on each sensors. Some papers circumvent the problem and propose to use several anchors which are precisely located: each node can find its own position using triangulation or multi-lateration. For that, several solutions are proposed:

- The measuring from signal strength which is unrealistic because the radio signals can be disturbed by the environment,

- ToA (Time of Arrival) [CHH01] allows to compute the distance between two nodes by observing the time of propagation but this mechanism needs a nodes synchronization.
- TDoA (Time difference of Arrival) [WAH97], [NJ07]: two signals of different natures are used (ultrasound and radio for example) to improve the results of ToA.
- AoA (Angle of Arrival) [NN03], [AKBD06]: allows to determine the direction of a radio wave propagation.
- A combination of the TDoA and AoA [ML07] is also proposed to improve the accuracy and to adapt [CHH01] to 3D environments.

All those protocols don't take into account the energy consumption and assume that each node is able to compute the time or angle of arrival easily. Anyway, the anchor systems do not avoid the localization problem but reduce it to a subset of nodes of the network. Moreover other problems appear like the anchors placement in the network to allow a better localization of the nodes [BOCB07], [DT07].

2.2 Coarse Localization Strategies

Another strategy consists of finding approximate coordinates. If a non precise location of the sensor nodes is acceptable -depending on the application- several approaches are possible:

- The Active Badge system [HHB93]: each node is tagged and transmits a periodic hello packet every 10 seconds with a unique infra red signal which is received by dedicated sensors placed at fixed positions within a building, and relayed to the location manager.
- Location Estimation Algorithm [HE04] provides a probabilistic distribution of the possible node locations. According to both the prior location information and new observations from anchor nodes, impossible locations are filtered.
- The virtual coordinates [CA06]: each node determines its distance in number of hop to anchors and thus builds a virtual coordinates system. [WABDB07] shows that a routing protocol can be based only on virtual coordinates.

These protocols are not adapted to the sensor networks because either they require anchors connected to a fixed architecture or they require a centralized computation.

3 Algorithm Overview

Remember that the goal of our algorithm is to determine coarsely the location of the neighbors of a given node using only local informations. These local informations come from the hello packets which are exchanged between 1-hop neighbors. The qualitative location of a neighbor can be *very close*, *close* or *far*.

Such coarsely location can be used to construct a reliable unicast routing protocol in degraded wireless environment with a high level of interferences: to choose the *very close* nodes allows to choose the nodes with a high C/I ratio as relays. Applications in topology control or virtual coordinates for routing protocol are also possible.

A node A calculate 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 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 1). We calculate the class node in the following way:

Let $PI(x)$ the proximity index of neighbor x:

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

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

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 2 and table 3 show an algorithm application on a particular node for a given topology. Node 27 classifies its neighbors in 3 proximity classes. We can see in details values found by the qualitative localization algorithm in Table 3. Table 3 proposes also a comparison between the qualitative classification of neighbors of the node 27 according to the algorithm and the real classification based on the Euclidean distance. Note that, on this example, the network is parse.

The protocol is inexpensive in energy because it only uses informations necessary to many other protocols: self-organization (CDS-rule-k [WL99], CDS-MIS [WAF02],...) and pro-active routing protocols (OLSR [CJ03]) deployed in wireless sensor networks. Moreover, if the network is not very dynamic (low mobility, not many birth or death of nodes in the network [HV07]) this exchange of packets can be reduced and limited to the deployment phase of the network.

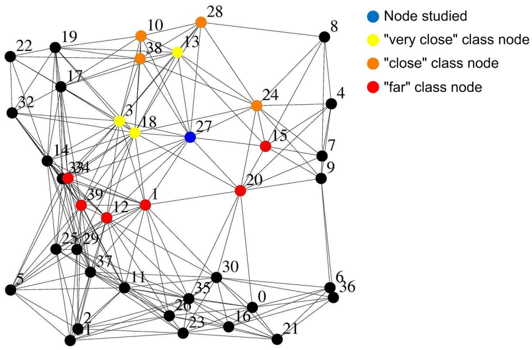

Fig. 2. Example of qualitative localization computed by the node 27

Neighbors nodes	proximity index	euclidean distance	proximity class	real class
18	2.0	50.067	very close	very close
3	1.0	65, 18	very close	very close
13	0.5	77, 01	very close	close
38	−0.5	83, 66	close	far
28	−0.5	103, 76	close	far
24	−0.5	66, 20	close	very close
10	−1.5	101, 18	close	far
1	−2.0	73, 09	far	close
20	−2.5	65, 96	far	very close
39	−3.0	115, 62	far	far
34	−3.0	115, 98	far	far
15	−3.5	68, 28	far	very close
12	−4.0	104, 40	far	far

Fig. 3. Comparison of the qualitative localization applied on the node 27. The classification obtained (*very close*, *close*, *far*) is compared to the classification obtained using a GPS with the Euclidean distance.

4 Simulation Results

All the results we provided here are computed using the simulator Java in Simulation Time (JiST) and Scalable Wireless Ad hoc Network Simulator (SWANS) [BHvR05]. The WSN topology is modeled as a Unit Disk Graph (UDG) and a CSMA/CA-like MAC layer is also used. Each node is motionless. The network cardinality varies between 50 and 700 nodes which are randomly and uniformly distributed in the simulation area except when we study the grid topology. The transmission power is used to control the average degree of network nodes. The objective is to investigate our protocol and observe its reliability to well classify the nodes.

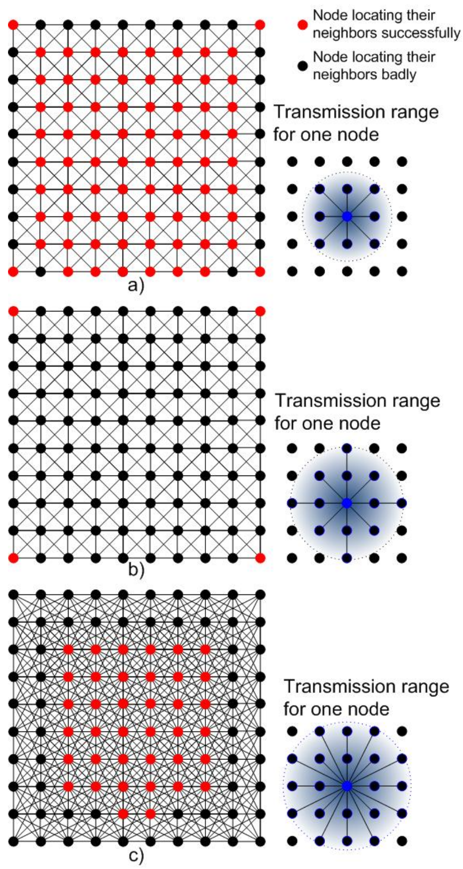

Fig. 4. Algorithm deployed on a grid

4.1 Qualitative Localization Protocol Behavior on a Regular Topology

We simulated a network of 100 sensors distributed uniformly to form a grid of 10x10 (see figure 4). Then, we increased the transmission power of each sensor and observe how our qualitative localization protocol reacts. Sometimes the vicinity of a node is not representative of the regularity of the whole network. In this case (Fig. 4, scenario b) or when the nodes are in the border area, the algorithm does not achieve to distinguish correctly the first two neighbors classes because of some incoherencies in the neighborhood. For other topologies, the neighbors classes can be determined without errors and the proximity index leads to the same classification that the euclidean distance. We can conclude that, when the topology and the neighborhood is almost uniform and regular, the qualitative localization is very effective and relevant.

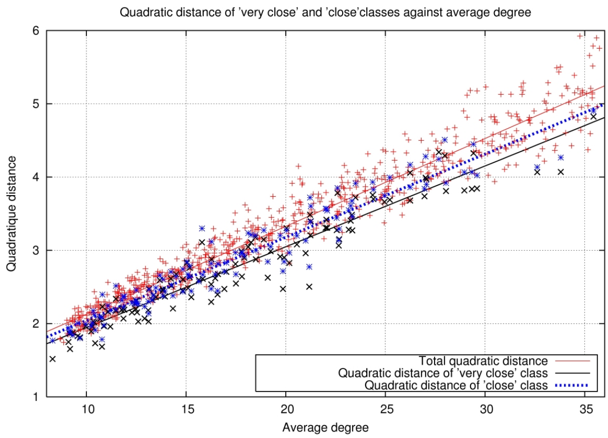

Fig. 5. Quadratic Distance in function of the average degree for each classes

4.2 Qualitative Localization Protocol Behavior on Random Topologies

But the sensor networks are seldom deployed with a regular topology. In order to measure the algorithm accuracy in more realistic environment we deployed, with a uniform and random distribution, 100 nodes and we varied the transmission power to increase the average degree. Then we calculated the quadratic distance between the neighbor nodes list classified using a GPS location and the same list classified using our algorithm.

Let two lists v and w in R^n be as follow: $v=(v_1, v_2, ..., v_n)$, $w=(w_1, w_2, ..., w_n)$. The quadratic distance dq is:

$$dq = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i - w_i)^2}$$

In this study we investigate the quadratic distance of the algorithm for the classes *close* and *very close* and all the classes (Fig 5). We observe that the quadratic distance increases but in a much slower way than the average degree. When the average degree increases, the number of neighbors to be located for each node increases. If the quadratic distance remains low that means that the precision increases. This phenomenon is explained by a higher number of informations and thus a high reliability. The various classes evolve in the same way. Nevertheless, we can observe a lower increase for the classes *very close* and *close*.

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? Will the *very close*

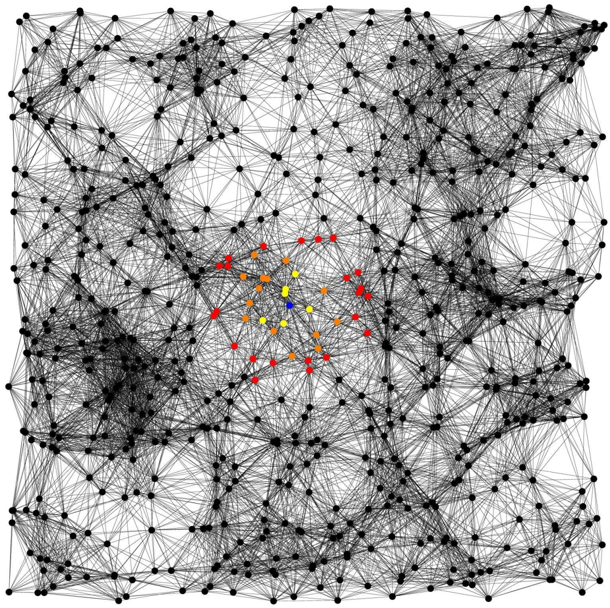

Fig. 6. Application of the algorithm in a random topology

class increases proportionally with the number of neighbors? We saw that the quadratic distance increased slightly when the average degree increased. However this metric is very sensitive to the length of the lists evaluated. Thus we investigate the average percentage of nodes selected in the *very close* class and in the *close* class (Fig. 7). We can note that, when the average degree increases, the percentage of nodes of the *very close* class decreases, whereas that of the *close* class increases. The *far* class remainder constant. This indicates that more

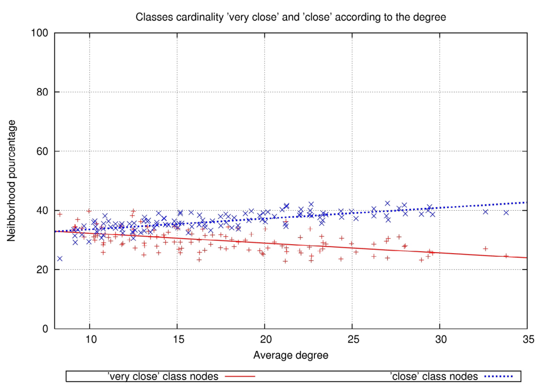

Fig. 7. Classes cardinality in function of the average degree

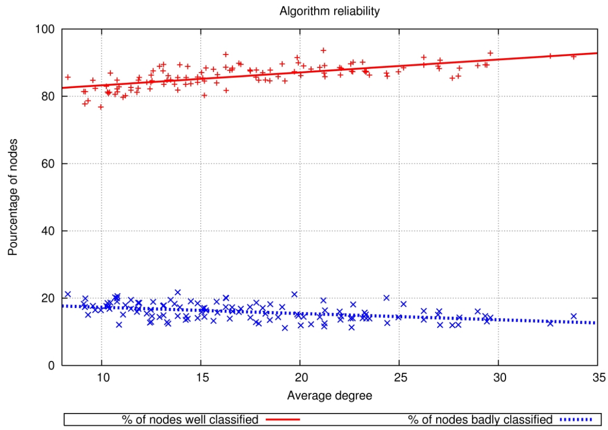

Fig. 8. Algorithm reliability

important is the density and more the index proximity able to distinguish the really *very close* nodes.

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. To answer this question, 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.

5 Algorithm Application on Topology Control

In dense sensor networks it is often desirable to limit the vicinity to the closest neighbors. Several topology control algorithms exist like:

- Gabriel Graph [GS69]: an edge between u and v is selected if $disk(u, v)$ contains no another node inside.
- LMST [LHS03a]: Each node knows the location of its 1-hop neighbor 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).
- RNG [Tou80]: 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.

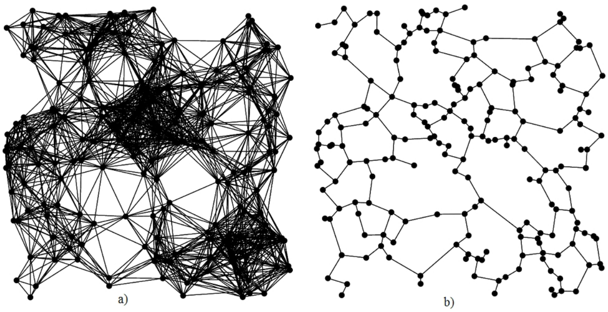

Fig. 9. a) Physical topology, b) Topology control (RNG, GPS) c) Topology control (RNG, Qualitative location)

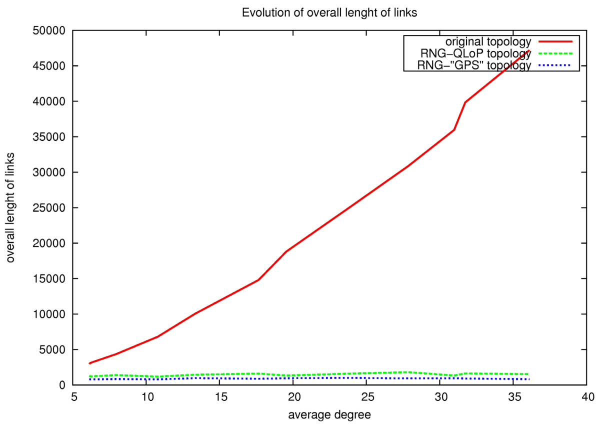

Fig. 10. Evolution of length of the topology links used

But those algorithms are generally based on the knowledge of the exact position of sensors (GPS, antenna array, RSSI, etc...). We applied our qualitative location algorithm to build a Relative Neighborhood Graph (see Figure 9, denoted as RNG-QLoP). 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 performance of RNG-QLoP is important too. It is due to the information quantity increasing when the number of neighbors increases: it leads to a better precision.

6 Conclusions and Future Works

In this work we propose a qualitative localization algorithm using only local information. Our proposition does not use GPS information or any anchor or dedicated hardware. Based on the local informations from its neighborhood, a node can classify its neighbors as *very close* or *close* or *far* nodes. We have illustrated the behavior of our algorithm on a regular topology and on random one. A quadratic distance is computed to highlight the relevant classification provided. We apply this qualitative location algorithm for topology control (QLoP). A Relative Neighborhood Graph is computed using QLoP: the performances are very close the performances obtained when an absolute location (GPS) is used. Next, we will apply this qualitative localization algorithm to provide unicast routing protocol suited to wireless networks with interferences. Our idea is to favor paths made up of small hops and thus, to use *very close* nodes as relays because of their important signal-to-noise ratio.

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