RELATIVE NODES LOCALIZATION IN WIRELESS NETWORKS USING RECEIVED STRENGTH SIGNAL VARIATIONS

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Abstract: The geographical localization of entities in a wireless network is one of the most important issues of neighborhood awareness. A precise localization provides an advantage for the geographically-located services. However, the geographical localization within a wireless network should take into account the characteristics and the specificities of such environment. In this paper, we present a technique allowing a receiver to localize a sender within its range, without additional devices, as a GPS (Global Positioning System). We use only 3 RSSIs (Received Strength Signal Indicators) measurements, under the assumption that the sender sends messages with the same signal strength.

1 INTRODUCTION AND MOTIVATIONS

Wireless networks allows to connect a set of nodes in an efficient and fast manner, using limited infrastructure support or even without any fixed infrastructure as in ad hoc networks. The development of wireless networks is increasing, due to the emergence of new technologies and standards (e.g. 802.11[1], wimax[2]) and the exponential deployment of autonomous and advanced equipments and devices. Furthermore, the deployment of user-oriented services within wireless networks brought new issues and problems. One of the most important is the geographical localization.

Geographical localization within wireless networks provides important information, which can help in several applications:

- localization of users, clients or devices
- localization for eradication of radio interferences sources,
- localization of access points in a network,
- tracking of the motion of an entity in the network to facilitate the local guidance based applications …

Geographical localization techniques should take into account the characteristics of the wireless networks, such as mobility and dynamicity of nodes, low capacities in term of computation, bandwidth, energy and memory. Thus, the most suitable solution to deal with these requirements should not use additional devices, implying expensive overheads. In this context, we propose in this paper a relative localization technique within wireless networks, based on the received strength signal variations, without any knowledge about the environment (pre-established radio map). Our localization technique is dedicated to operate within wireless networks, composed of small number of nodes, even 2 nodes only, for low-speed oriented applications (eg. walking-speed oriented applications).

To present our contributions, this paper is structured as follows. Section 2 presents related works concerning geographical localization in wireless networks. In section 3, we describe our technique to locate a non mobile transmitter within LoS environment. In Section 4, we show how to calibrate the signal attenuation model within LoS environment, to produce the most exact RSSI measurements Section 5 presents the typical applications integrating our localization technique: a tracking mechanism of nodes within wireless network and a combined positioning technique using identified beacon nodes. Section 6 presents analysis and results, and finally section 7 concludes this paper and presents our future work.

[1]http://grouper.ieee.org/groups/802/11
[2]http://www.wimaxxed.com

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2 RELATED WORK

The GPS (Global Positioning System) (Hofmann-Wellenhof et al., 1997; Stoleru et al., 2004) is the most known localization technique. Each entity holds a sensor which receives and process signals from a satellite constellation, to define a 3-dimensional localization having an error margin evaluated to 10m to 20m. This localization method is widely used by mobile devices. However, it still expensive to deploy within wireless networks, in addition to the low reliability of the satellite signal reception indoors.

During the last years, were developed several localization techniques in wireless networks. We present in this section some of them, divided into two approaches: range free and range based techniques (He et al., 2003).

2.1 Range Free Localization Techniques

In these techniques also called topological techniques, no physical measurements are used. The localization is only based on the data links established by the node to situate, with its neighbors. Within these techniques, reference nodes called beacons are chosen, having self localization capabilities such as GPS. The mechanisms belonging to this approach are as follows:

- Centroid algorithm (Bulusu et al., 2000): a node that needs to localize itself, computes an average of the coordinates of the reference nodes that it receives. The obtained localization may have a large error margin.

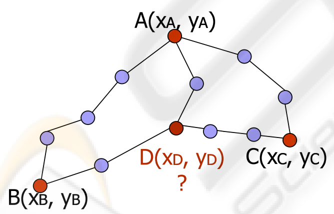

Figure 1: DV-HOP localization technique.

- DV-HOP (Niculescu and Nath, 2001b) each node estimates its position via the diffused coordinates of the beacons nodes, the number of hops to reach these nodes and the average size of one hop within the network. This average size is estimated by the beacon nodes and diffused within the network. Figure 1 illustrates this localization technique. The node D to situate, is at 2 hops from the beacon A (of size $average_A$), 2 hops from the beacon B (of size $average_B$) and 3 hops from the beacon C (of size $average_C$).

  The main disadvantage of this technique is that the average size of one hop in the network could not be determined precisely. To solve this problem, another technique called Amorphus Positioning (Nagpal et al., 2003) is deduced from DV-HOP, while taking into account the density of nodes in the network.

- PIT (He et al., 2003): each node within the network evaluates its position according to the formed triangles between the beacon nodes. Each result allows to refine the computed localization. This technique can produce only estimations of the node localization (cf. Figure 2).

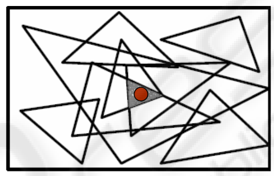

Figure 2: PIT localization technique.

2.2 Range based Localization Techniques

These techniques also called topographic techniques are based on physical measurements data, carried out for each wireless link established between the node to localize and its environment. The mechanisms belonging to this approach are presented in the following:

- Angle of Arrival (AOA): the localization of a node is computed by a triangulation using the angles of reception according to three beacon nodes (cf. Figure 3). The APS (Ad-hoc positioning system) (Niculescu and Nath, 2001a) technique uses the AOA localization within wireless networks. APS proposes a method for all nodes to determine their orientation and position in an ad hoc network, where a fraction of nodes have positioning capabilities (GPS) and under the assumption that each node has the AOA capability. These requirements make APS restricted to a specific context of wireless ad hoc networks.
- Time of Arrival (TOA): the localization of nodes is computed via the propagation times between the concerned entity and the beacon nodes. Both one-way propagation time and round trip time are used. The Cricket (Priyantha et al., 2000) technique uses the TOA localization mechanism, in addition to the combination of the RF and ultrasound hardware to enable a sensor, attached to each node, to compute the distance to beacon

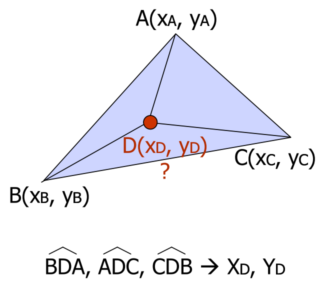

Figure 3: AOA localization technique.

nodes as follows: a beacon node sends information about the space over RF, together with an ultrasound pulse. A listener receives the RF message and then the ultrasound pulse, which arrives later due to the speed difference between RF and ultrasound waves. The time difference between the reception of the RF message and the ultrasound signal determines the distance to the beacon node.

- Time Difference of Arrival (TDOA): the localization of nodes within the network is carried out according to the relative moments of detection of a common event (such as ultra-sound message reception). This technique supposes a synchronization between the nodes, hardly applicable within wireless networks, due to their lack of fixed infrastructure. The Pushpin technique (Broxton et al., 2005) is a typical example of TDOA technique.
- Received Signal Strength Indicator (RSSI): distance between nodes is estimated according to an attenuation model of the received signal strength with distance. Path loss models represent the difference in dB in signal strength between transmitter and receiver via RSSI measurements. The most known model to evaluate the path loss is the Friis Free Space Path Loss Model (described in section 3).

The localizations techniques presented above allow a node within a wireless network to situate itself, according to reference nodes in the network (range free techniques), or to physical measurements carried out between the node and its environment (range based techniques). The majority of these approaches needs additional configurations or equipments which make them restricted to a specific wireless network context.
To deal with this inconvenient, we elaborate a fast and reliable localization technique based on the RSSI measurements, to operate within small wireless networks, without the need of any additional device or configuration (cf. section 3).

3 RELATIVE LOCALIZATION OF A NON MOBILE TRANSMITTER WITH LOS ENVIRONMENT

We propose in this section a technique allowing a mobile receiver to localize a fixed sender within its range, with only 3 RSSI measurements, in LoS (Line of Sight) environment and assuming that sent messages are with the same signal strength.

The path loss model we use to evaluate the distance between a sender and a receiver is the Friis Free Space Path Loss Model, which represents the signal attenuation when there is a clear line of sight between the transmitter and the receiver. This model stipulates that:

$$PLfs(d)[dB] = 20.log_{10}(4\pi d/\lambda)$$

Where:

- λ is the wavelength of the propagation wave. λ is evaluated as $\lambda = c/f$, c is the light speed (3.10^8 m/sec) and f is the frequency of the signal. For 802.11g (the dominating frequency is $f = 2.4Ghz$), $\lambda = 0.125m$,
- d is the distance between the transmitter and the receiver.

To generalize the previous equation with any distance d, we use the following path loss expression, which integrates a received power reference point (d0). We can choose $d0 = 1m$ without loss of generalization:

$$PL(d)[dB] = 2.PLfs(d0)[dB] + 10.n.log_{10}(d/d0)$$

Where n is the path loss exponent which represents the increase of path loss with increase in the distance between the transmitter and the receiver. For free space, n is equal to 2, but it would be better to calibrate this parameter, depending on each network characteristics.

Figure 4 illustrates a typical example where the receiver needs to localize the sender by determining the angle β between them. For that, the receiver starts by evaluating the received strength from the sender, at positions P_1 and P_2. The distance between these positions is L. Then, using the Friis path loss model, the receiver can evaluate the distances d_1 and d_2 at positions P_1 and P_2.

We suppose that the distance x between the receiver and the sender is equal to the average between the distances d_1 and d_2, where $d_1, d_2 >> L$.

$$x = \frac{d_1 + d_2}{2}$$

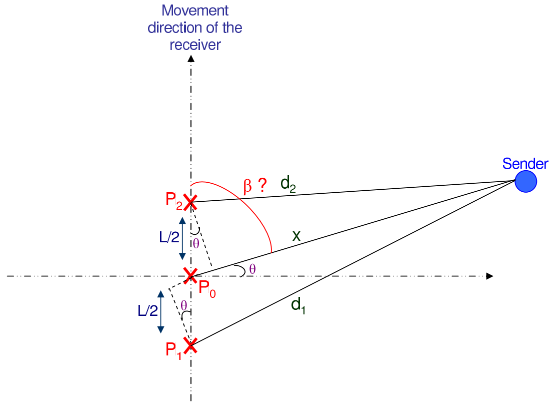

Figure 4: Evaluation of the angle between the sender and the receiver.

The following relations allow computing the angle β:

$d_1^2 = (x + L/2.sin\Theta)^2 + (L/2.cos\Theta)^2$
$d_2^2 = (x - L/2.sin\Theta)^2 + (L/2.cos\Theta)^2$
$\Rightarrow d_1^2 - d_2^2 = 2.L.x.sin\Theta$
$\Rightarrow sin\Theta = (d_1^2 - d_2^2)/2Lx$
$\Rightarrow \beta = arccos((d_2 - d_1)/L)$

Let the coordinates of the receiver at the position P_0 be (x_0, y_0), and the coordinates of the sender (x_s, y_s). Because of $cos(x) = cos(-x)$, two localizations of the sender are possible, verifying the equation $\beta = arccos((d2 - d1)/L)$. From Figure 5, we show that:

$x_s = x_0 + d.sin\beta$ or $x_s = x_0 - d.sin\beta$
$y_s = y_0 + d.cos\beta$ or $y_s = y_0 + d.cos\beta$

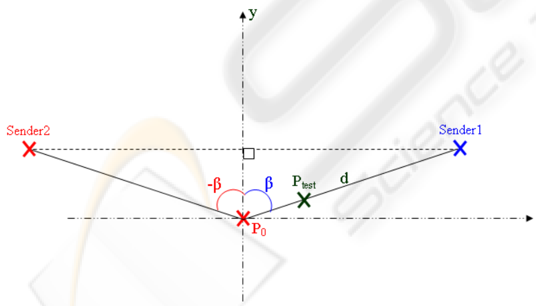

Figure 5: Localization of the sender using the angle β.

To be able to decide which position to choose for the sender, the receiver can measure the received signal strength from the sender, in the direction of one of the two localizations. Depending on the increase or the decrease of the received signal strength, the receiver decides which localization to choose for the sender. In figure 5, if the received signal strength increases at position P_{test}, the sender is at the localization 1; otherwise, it is at the position 2.

3.1 Advantages of Our Localization Technique

The main advantages of our localization technique are the following:

- No additional equipment has to be added to the wireless nodes to situate. Our localization technique uses only the history of received signal strength, to deliver a reliable and fast localization estimation.
- The node which wants to localize itself can move within the network and does not need to be fixed, as others localization techniques based for example on triangulation mechanisms.
- The higher is the number of measurements of the received signals strength, the more is the localization precision. Indeed, the measurements of RSSI can calibrate the path loss attenuation model used to compute the distance between the sender and the receiver (cf. section 4).
- Our localization technique can be integrated to other advanced mechanisms. We present in Section 5 a tracking technique of a node within wireless networks and a combined positioning technique using identified beacon nodes.

4 CALIBRATION OF THE EXPONENT LOSS FACTOR WITHIN LoS ENVIRONMENT

To avoid errors on the RSSI measurements, we should calibrate the exponent loss factor n used in the Friis Loss equation presented in section 3. With $d0 = 1$, we have $PL(d)[dB] = 80 + 10n.log_{10}(d)$. Thus, the distance d and the loss factor n are computed as follows:

$$d = 10^{(PL(d)[dB]-80)/10n}$$

$$n = (PL(d)[dB] - 80)/10.log_{10}(d)$$

To calibrate n, we use a second formulation of the Friis Model, which stipulates that: $P_r/P_t = (\lambda/4\pi d)^2$; where P_r is the received signal strength and P_t is the transmitted signal strength. For two successive received signals from a transmitter, we show that $P_{r1}/P_{r2} = (d_2/d_1)^2$. We thus have:

$$d_2 = d_1.\sqrt{P_{r1}/P_{r2}}$$

Our calibration algorithm, illustrated in Figure 6, consists of computing the distance between a transmitter and a receiver as the average between the two

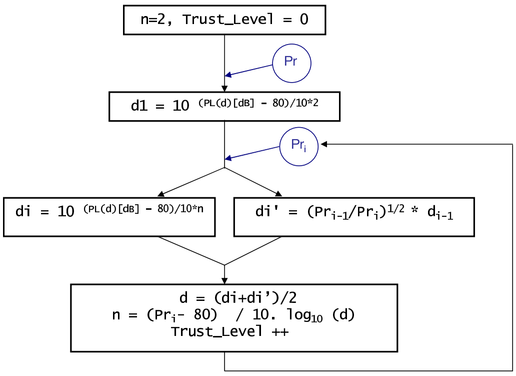

Figure 6: Calibration of the path loss factor.

values produced by using the two formulation of the Friis Loss equation. The exponent loss factor *n* is then computed as a function of the computed average distance. We add to our calibration algorithm a trust_level, which represents the number of calibrations carried out by a node in the network.

5 TYPICAL APPLICATIONS OF OUR POSITIONING TECHNIQUE

5.1 Tracking of a Mobile Node Within Wireless Networks

Our objective is to allow a mobile node A to track another mobile node B within the network, by only using RSSI measurements (cf. Figure 7).

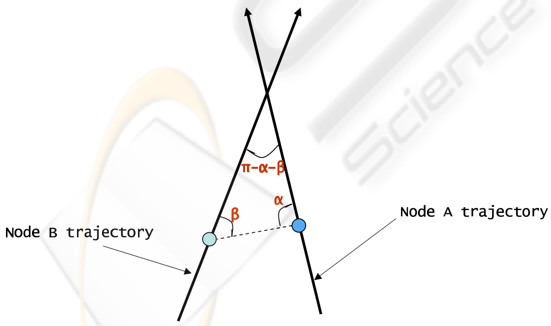

Figure 7: Tracking of a node in the network.

To compute the angle between two mobile nodes, we suppose that the flow of data sent by a node to an other is sufficiently high to consider that the motion of the two nodes can be divided into small sequential segments (each of the two nodes moves in its turn). We can thus use the localization technique described in section 3 to compute the angles α and β between the two nodes A and B.

Nodes A and B send periodically and mutually the angles α and β between them, as is illustrated in Figure 7, computed via our localization technique presented above. To track node B, the node A should deviate its direction by $\pi - \alpha - \beta$.

We are currently working on a two-nodes encountering application within a wireless network. This application consists of bringing together two mobile nodes, which periodically send to each other their localization information. Each node compute the angle between its direction and the direction of the other node and deviates its direction in order to encounter the other node, while decreasing the distance between them.

5.2 Combined Localization using Identified Beacon Nodes

We present in this section a technique allowing a node to identify its trajectory within a wireless network, where beacon nodes are chosen having localization capability by GPS (cf. Figure 8). The beacon nodes sends periodically localization messages to their neighbors in one hop (TTL=1). Each localization message contains the coordinates of the beacon node and the time of transmission.

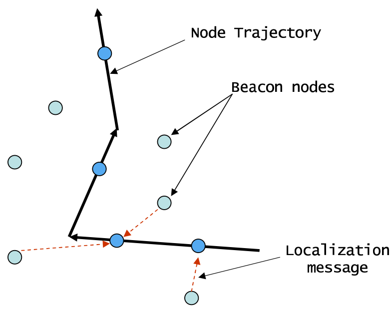

Figure 8: Identification of the trajectory of a node in the network.

The mobile node, moving within the wireless network, receives the localization messages sent by the beacon nodes allowing it to identify its trajectory according to the following algorithm:

while ()
Receive Localization-Message from beacon node i
if Receive 3 Localization-Messages from the same node i
Compute the localization according to the beacon node i
Store the localization within a positions history

end if
if Trajectory Identification
Linearization of the node trajectory using the positions history
end if
end while

To validate the applicability of our main contributions presented above, we present in the next section analysis and simulations we have done to calibrate the parameter L of our localization technique, simulate our calibration algorithm and finally evaluate the localization error margin depending on the different parameters of our approach.

6 ANALYSIS AND SIMULATIONS

6.1 Analytical Results

In the new localization technique presented in section 3, the parameter L should be well chosen to improve the reliability and the exactness of the results. Figure 9 (L = 10) shows the angle β, computed as a function of the difference between the two distances d_1 and d_2. We show for example that when $d_1 = d_2$, the sender is at 90^o from the receiver.

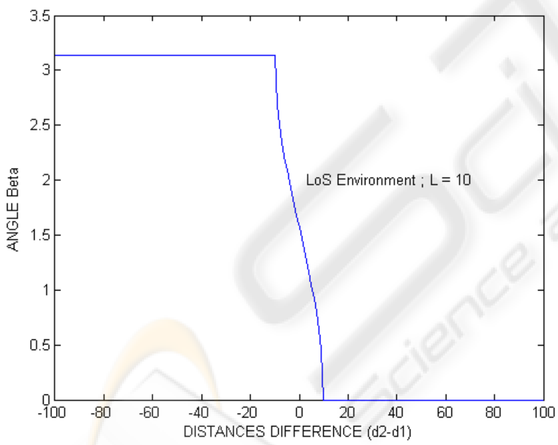

Figure 9: Angle β by (d2-d1) with LoS environment and L=10.

The choice of L is important to have a fast and reliable measurement of the angle β. Indeed, a large L compared to d_1 and d_2, allows more opportunities to measure exactly the angle β (the interval $[-L, L]$ is large). On the other hand, measuring the received signal with a small L is faster and easier.

From Figure 9, we show that to enhance the exactness of our localization technique, we have to ensure the following inequality: $|d2 - d1| < L$. Let's $T_{measure}$ define the time measurement period (the time between two RSSI measurements) ; and V is the maximum speed of the receiver. The distances difference ($|d2 - d1|$) should thus be limited to $V.T_{measure}$. Hence, the parameter L should be chosen as follows:

$$L > V.T_{measure}$$

For example, for $T_{measure} = 1sec$ and for $V = 10km/h$ (average walking speed), L should be equal to 3m.

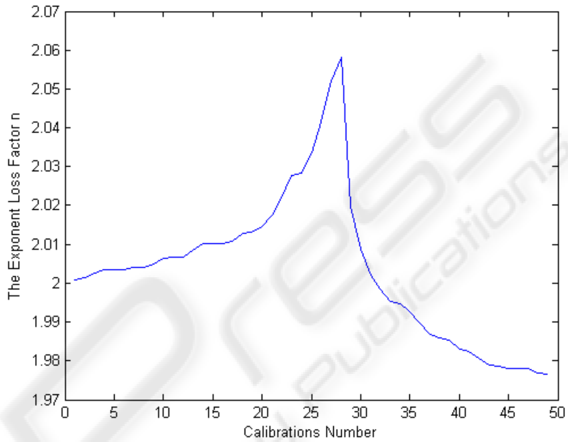

Figure 10: Calibration of the n loss factor.

In a second step of our analysis, our objective is to verify our calibration mechanism of the n loss factor n, presented in section 4. We choose a simulation example, in which we start initially by $n = 2$, the received signal strength $Pr = 150w$ and the signal loss $PL = 70w$. We calibrate the n loss factor 50 times according to the algorithm presented in Figure 6. At each calibration, we add a random value (between 0 and 1) to the value of PL. The result of our verification example is presented in Figure 10. We show in this Figure how the exponent loss factor can be adjusted depending on the RSSI measurements.

6.2 Simulation Results

In this section, we use the network simulator NS2[3] to simulate our localization mechanism, described in section 3.

Our simulation parameters under NS2 are as follow:

- channel type: wireless,
- propagation model: Free Space,
- MAC protocol: 802.11,
- antenna model: omni-directional,
- number of nodes: 2,

[3]http://www.isi.edu/nsnam/ns/

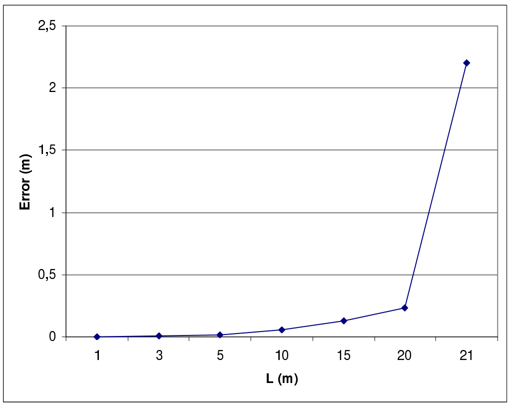

Figure 11: Localization Error by L ($d = 180.27m$).

- traffic: node 1 sends a CBR traffic to node 0, which receives these packets, evaluate their RSSIs and compute the distance to reach node 1.

We carried out simulations to evaluate the localization error of our approach. In a first step, we evaluate the localization error according to the distance L between the two positions P_1 and P_2, the distance d is fixed to 180.27 (cf. Figure 11). Then, we evaluate the localization error according to the distance d, while fixing the L parameter ($L = 3m$) (cf. Figure 12).

We show in Figure 11 that the localization error is strongly dependant on the parameter L. The smallest the parameter L is, the smallest is the localization error. For $L = 3m$, the localization error is equal to 0.0043m. However, we cannot decrease indefinitely the parameter L in order not to distort the RSSI measurements.

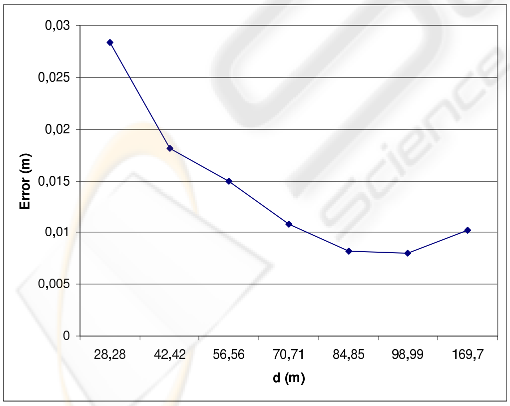

Figure 12: Localization error by the distance d ($L = 3m$).

Figure 12 shows that the localization error is dependant on the distance between the sender and the receiver, with a fixed L. We conclude that to have a small localization error, the parameter L should be much smaller then the distance d. In addition, we have used this hypothesis to compute the angle β between the sender and the receiver (cf. Section 3).

7 CONCLUSIONS AND FUTURE WORK

We presented in this paper a new localization technique, based only on the RSSI measurements. This technique allows a mobile node to compute the position of a fixed node in the network, by evaluating the variation of the received signal strength of three messages sent by this node. In a second step, we presented a calibration mechanism of the Friis attenuation model within LoS environment. This mechanism consists of calibrating the exponent loss factor n at each achieved RSSI measurement. We deduced from our positioning technique a tracking mechanism and a combined localization technique using identified beacon nodes.

To validate our contributions, we carried out analysis and simulations to calibrate the different parameters of our localization technique. We showed that the choice of the parameter L is very important to minimize the computed localization error.

The establishment of secure communications within wireless networks remain a key issue because of the characteristics and the vulnerabilities of such environment (Bouassida, 2006; Bouassida et al., 2006). In this context, other research works in our team are dealing with the assessment of security of messages using signal characteristics. We envisage to adapt our technique in order to obtain a ”distinguishability” degree between two nodes by analyzing strength variations. This will contribute to detect sybil nodes created by a malicious one.

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