Radio Proximity Detection in a WSN to Localize Mobile Entities Within a Confined Area

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***Abstract*—To localize mobile entities within a confined area, a wired infrastructure is neither scalable nor cost-effective. An alternative solution consists in deploying a Wireless Sensor Network (WSN), made of energy-autonomous devices. In an environment where GPS is inoperative, we propose that the position of a mobile is given relatively to a set of tag nodes deployed in the zone of activity and signaling their position. In a symmetrical way, each mobile node is announced periodically thus allowing a mutual detection of radio proximity (tag-mobile or mobile-mobile). During the contact the nodes are able to share and store the information required by the localization application. This information is then largely scattered by using the mobility of nodes to carry data up to the application collection points.**

Then arises the question about the choice of the medium access method and its performances for the proximity detection in a cell covered by a tag node. IEEE 802.15.4 unslotted CSMA/CA being largely used in low power WSN, we study its performances according to the density of the mobiles and the load of the cell.

***Index Terms*—WSN, Contact, Localization, Unslotted CSMA/CA.**

I. Introduction

The objective of this research activity is to propose a model of self organized wireless networks to meet the needs of a monitoring activity by exploiting the radio contacts in a mobile population. The term contact refers to a situation of proximity between two entities, typically for a distance smaller than 10 meters. The basic idea is to use a radio device to detect the proximity between the two entities carrying these devices. During the contact, mobile entities exchange information related to the application. The movement of mobiles is used to transport the information exchanged to the application collection points.

The targeted applications are:

- The localization of people or equipment in a confined area (a building, a mine). The objective here is to be able to localize a mobile entity when GPS (Global Positioning System) based systems [1] are not possible or satisfactory.
- The storage of the contacts of a population within a geographical area (unit of care, exposure zone). For example, tracing the activity in a healthcare service can allow to find the origin of a nosocomial infection *a posteriori*.
- The simulation of a contagion process (a virus, a news, the buzz marketing). The objective is to define a system that allows an experimentation with available devices or a simulation with the tools of network engineering. The results obtained can then be compared with those of the existing analytical models in the field of health or sociology [2].

The goal of this paper is to meet these applicative needs by proposing a model for transparent and autonomous networking, without disrupting the activity of the mobile entities. Our architecture is built upon a WSN (Wireless Sensor Network) [3], composed of low-power, cheap communicating devices. The small size of such equipments allow them to be carried as a badge, or included in materials. This paper is organized as follows. In section II, we explain in details a scenario of "contagion" process. From this scenario, we then profile a network solution based on a WSN, and we give a state of the art on this topic. In the following we particularly treat the needs for localization in confined areas by taking as example the underground mining activity [4]. In section III, we describe the architecture of our solution which is our contribution. The section IV, deals with the evaluation of performance of the CSMA/CA medium access method [5] [6] in this context. We focus on the impact of the mobile density in a radio cell on the performance of the radio channel access method. Finally, we conclude our work and give the perspectives of this study.

II. Basis and purpose

A. *"Word of mouth" principle*

Figure 1 shows a situation which can be observed between mobile entities equiped with radio devices or classically modeled and simulated by using network engineering tools [7]. A transmitter transmits information to a receiver by an electromagnetic wave that is transmitted and received by antenna characterized by a lobe.

The mechanisms developed in this article are based on the principle of "word of mouth". When two mobiles

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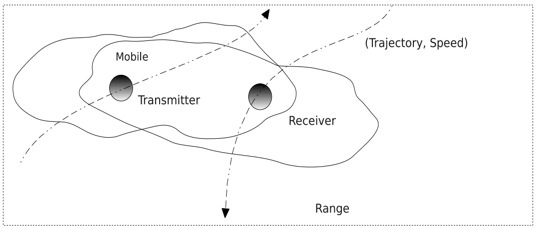

Figure 1. Mobile entities and range of contact.

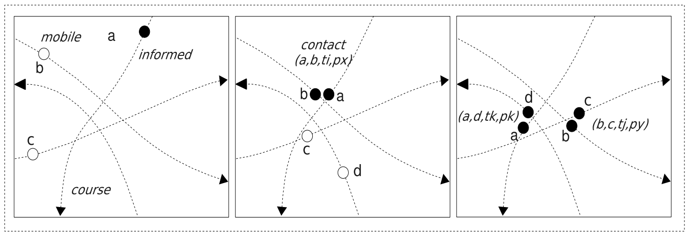

Figure 2. Propagation process.

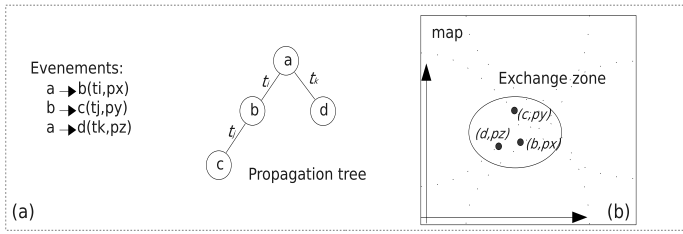

Figure 3. Events of contact analysis.

cross each other, i.e. when they are in range, they can exchange information during the duration of the contact. Based on the mobile movements and contacts, information can thus be propagated in time and space between the various entities of the network. That is why such mecanisms are also the foundations of the “Buzz Marketing or Viral Marketing”. When two people meet (or intersect), they can exchange information during this contact. This phenomenon is important in the reputation of a product or a movie but also in the distribution of news.

Figure 2 illustrates an example where information known by the person a is shared. Moreover, if the information exchanged is simple and atomic: “Fire!” for example, an analogy can be developed with the way a virus biologically spreads in a community activity [8].

In the network world of mobile stations communicating wirelessly, the mobile a carrying information communicates it when it passes near mobile b at time t_i at the position p_x, which in turn communicates to c at time t_j and position p_y.

The graph in Figure 3a is a way to represent the sequence of events in Figure 2 which led stations to exchange with each other. The map of Figure 3b shows an area where contacts are possible. Such places can be a crossroad or public transport, for example.

Let us focus now on the way in which the mobility of the minors inside a mine can contribute to the information diffusion, and on the particularly important collection of information for applications relating to security for example.

This form of exchange can meet various application needs, without the installation of an infrastructure to support communication since the transportation of information is ensured by the movement of the mobiles themselves.

By characterizing a contact with a date and a location, the retrieval of all these events can allow us to observe the temporal and geographical evolution of a process, and thus to reconstruct the path of a mobile or determine its last known position.

B. Extension of the activity monitoring and localization

The principle described above can be applied naturally to other application fields. For example, the fight against the nosocomial infections in a healthcare service unit is a major concern of public health. The reconstitution of the cares of the patients in terms of displacements and the contacts with personal and materials, can make it possible to target, or to raise the doubt, on the origin of the infection. In that case, the goal is not to model a viral transmission, but to store the contacts between healthy mobile actors and other carriers of an infection.

Another possible application relates to the study of the paths followed by visitors of an exhibition to propose a behavioral pattern [2]. For example, which artwork is the most observed? This type of application meets requirements identified in the field of social engineering.

C. Focus of this paper

The applications previously described need to collect information relating to trajectories of mobile entities within buildings and more generally in confined areas. These applications all refer to a geographical position.

In a underground mining activity, the localization of people or hazardous materials is a strong need, mainly as a security objective. However, responding to this need through the use of positioning systems such as GPS is impossible in an underground environment. In addition, the technologies that infer distances based on the measurement of the physical characteristics of the propagation of an electromagnetic signal, are inoperative because of the properties of reflection, diffraction and absorption related to the environment and the topology of the walls of the gallery [9] [10].

A less accurate solution but very satisfying in a mining area, is the localization by zone [11] [12]. The present article focuses specifically on the localization of mobile entities within a confined area, where GPS based systems are inoperative as underground mining galleries.

Deploying a network based on wired links in an underground environment is long and costly especially due to the deployment of power and communication cables, as well as their protection against the grubbing. This type of solution is not scalable in an environment that permanently evolves.

The WSN solutions are characterized by the use of light-weight devices with energy saving capability, but with computing and storage capacity limitations. The transmission consumes a few milliwatts or less and the communication range is of the order of a few meters.

D. State of the art

We are dealing with three complementary problems: a mutual proximity detection mechanism, the centralization of information concerning the positions of moving stations, and an *a posteriori* localization of mobile stations.

The interest of mutual detection and relative positioning of stations in a WSN is developed in [13]. The accuracy of the mutual detection mechanism is not our main objective, as the stations we use do not cover the whole area in which stations are moving. In the following, we describe the gathering of information and the localization mechanism.

1) Using mobile elements to collect data from a WSN: When the connectivity of the nodes of a WSN is poor or not permanently available, the use of data mule concept is a good solution if the application is tolerant to delay. For such Disruption Tolerant Networks, exchanges are governed as "postal-like" message delivery, the mule being the postman. The data mule concept is a (or several) mobile entity that travels through the wireless sensor network [14] [15] and collects data as it passes near sensors. It can be described by the way of a multi-tiered network structure as illustrated in Figure 4.

The multi-tiered structure shown on Figure 4 consists of three tiers:

- Sensor Tier. In our case it consists in static sensor devices acting as positioning tags and having constrained resources (memory size, energy autonomy).
- Mobile sink Tier. In our case it consists in workers carrying light-weight portable devices. These sinks act as relays for information gathering.
- Base station Tier. In our case it is a point of collection. Data carried by the mobile sinks is downloaded at this point.

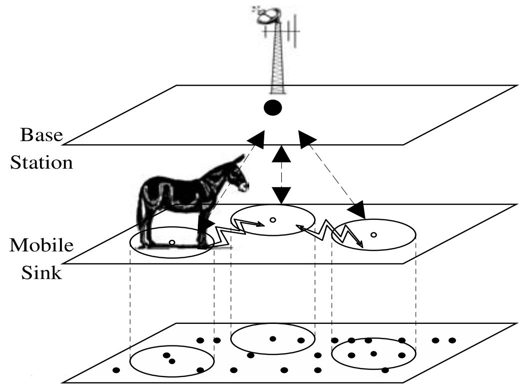

Figure 4. The MULEs three-tier architecture.

Such an architecture allows large scale deployment and provides a way to route information between stations that do not have a permanent connectivity.

Its benefits are [14]:

- to avoid complex multihop routing,
- to deal with non permanent connectivity (this is particularly important in our case),
- to spread the resource load better (no hotspots),
- to increase capacity (no bottlenecks near the data gathering point).

Its drawbacks are:

- to add large delays to sensor data gathering (few second to hours),
- mule devices need to recharge (extra delays),
- trajectories of mules significantly impact the performances of localization applications.

In [15], the authors are interested in data mule scheduling and address the problem of controlling a data mule such that it collects data from all the nodes in the minimal amount of time. They propose to control the movement of the data mule (path, speed) as well as its communication (i.e., which node it collects data from and at what time). In our case, the path selection of a worker in a mine is already fixed by its activity. We want to avoid particular constraints such as a particular moving speed or a job scheduling to collect data.

Another way to introduce such a concept is energetic autonomy of the network. This can be seen as a tradeoff beween data latency and the lifetime of the network. In [14] the authors suggest that the use of controllable mobile elements increases the lifetime of the network.

2) Mobile stations localization technics in a confined area: Existing indoor positioning approaches in a confined area give a good accuracy as long as the propagation conditions remain stable. Numerous papers try to locate stations by using RSSI (Received Signal Strength Indicator) measurements and a path loss model for the propagation conditions, even for confined areas. In

[16] the position calculation is based on a list of known WLAN (Wireless Local Area Network) access points and their location in the building. WLAN scans allow to detect these access points and an algorithm calculates the user position in terms of building section and floor number. In a mine gallery, it is difficult to preequip long corridors with a WLAN solution overlapping the whole area in which workers can be.

Another promising technique is the fingerprinting technology. This approach is also based on received signal strength measurements but requires a detailed radio fingerprint of the indoor area. The localization method needs a calibration: a fingerprinting database is created during a training phase and reference points are carefully chosen. In mine environnement the roughness of the walls greatly complexifies the propagation condition modeling [17] [7]. Furthermore, we are not looking for a high accuracy for the applications previously presented.

III. Functional description

Three types of nodes are defined :

- Tag-node: a fixed node which is associated to a particular location in the gallery. It is able to store information such as the list of mobiles that have transited in its area.
- Mobile-node: a mobile node is able to exchange information with other fixed or mobile nodes. The chronology of contacts with the tag-nodes composes a trail of the mobile node.
- Collector-node: a fixed node. When a mobile node crosses the covered area of the collector node, it empties its memory, or at least gives a copy of the gathered information.

Each node periodically broadcasts its identity. A node that receives this information produces an event of contact.

This architecture is a small variation of the three-tier architecture because the workers are indirectly the data MULEs in our mining application.

The memory capacity of mobile and tag nodes is limited. According to our main objective which is the most up to date location of a mobile entity, we consider the freshness of information as our metric.

Figure 5 gives a representation of a gallery at a given time with the communicating entities. Let us consider the following scenario. The mobile entities now in the activity area Y, have been traveling from the entrance of the mine to zone Y. The tag nodes along the way recorded their encounters. The same goes for the mobile entities now within the activity area X.

Here we suppose that none of these X mobiles met a Y mobile. Tag node i and j stored the contact with all

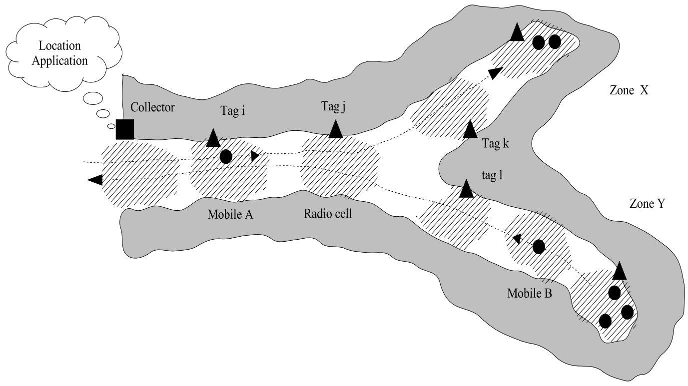

Figure 5. Example of scenario.

the mobiles, while tag node k stored only the contact with the X mobiles. Let us assume that mobile B is now leaving the mine from area Y and mobile A is coming from the entrance of the mine to the X activity area.

When B crosses the mobile A in the area around tag j, B shares information on the known position of the group Y.

Thus, the mobile A that never crossed the group Y, knows the position of the mobiles in the area of activity Y. During exchanges with tag nodes i and j, the mobile B stores information about group X, which passed in front of the tags i and j respectively on dates t and t'. All the contacts gathered by mobile B, once posted in the collector, allow the location application to have an approximate position of the entities currently in the mine: the group Y is in the Y activity area, the group X is not on the path to the Y activity area, and mobile A was seen in the zone of tag j.

The accuracy of the location application depends on several factors :

- The validity of the collected information: it is the mobile entities that carry information according to their trajectory. The more nodes are mobile, the validity of the information in time is shortest, but the more information is spreading. The crucial point relates to the frequency of posting in the collector. This factor depends on the mobility model of the mining activity.
- The number and placement of tags nodes: naturally, the number of deployed tags determines the precision about the location of mobile (consider for instance a tag every ten meters). But the deployment strategy also helps to identify the path of mobile entities. For example in the junction of X and Y galleries, deploying 3 tags (1 for each segment), instead of one, leads the location application to deduce the direction of a mobile and the mobiles per segment, etc
- Storage capacity: we assume that the memory capacity of the network nodes is limited. As the mobility and the number of nodes (mobiles or tags)

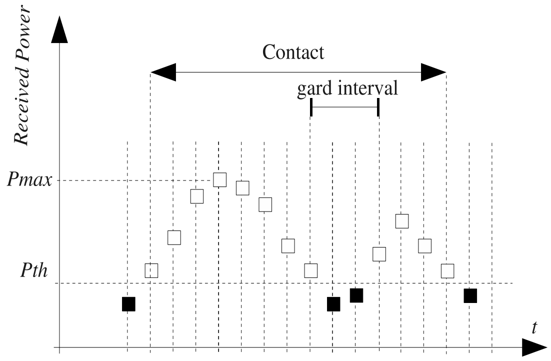

Figure 6. Event of contact.

increase the number of events of contact becomes larger. The limited memory buffers therefore impose a choice on the information to keep.

The points listed above are problematic in terms of topology, performance of protocols to access to the medium and energy management. At the application level, computing location of mobiles based on partial information dated by asynchronous clocks is also a major problem.

A. Description and event of contact

The contact between two entities is defined by a location, a time and a duration. Let us consider the case of a tag node.

In the same way as a beacon for naval signalling, the tag node indicates its presence with signalling frames at regular intervals. A mobile node passing in the area where the tag is visible, stores the position given by the tag and dates t_1 and t_2, interval during which the tag is visible, and the maximum received power of the signalling frames which allows us to approximate the distance from the tag.

Figure 6 illustrates an event of contact. Above a threshold of the received signal power P_{th}, transmitted frames can be interpreted. The first frame received from the tag triggers the start of the event. The time interval $[t1; t2]$ gives temporal information on the event and the maximum power P_{max} of the received signalling frames. The number of received signalling frames depends on the signalling frequency and the time during which the mobile is present within the covered area of the tag node.

Because of the instability of the medium, the topology of the environment, the transmission range, or the fading effect some frames are lost. Thus it is incorrect to consider that the mobile is out of the covered zone if a single frame is lost.

In addition, the event of contact should also be recorded by the tag. The mobile node must therefore report its own presence periodically. Finally several mobiles can be in the area covered by a tag node. This raises the problem of managing the contention for access to the medium between all these entities.

In WPAN (Wireless Personal Area Network) and WSN one of the most popular method to control the medium access is CSMA/CA [5] [6] [18] adequate for our study and, proven in wireless short-range networks. It is a random method that does not eliminate collisions. In our case the signalling frames are broadcasted and can be lost or delayed. A guard interval is necessary during which no reception of signalling frames does not mean the end of the contact event. If the time when no signalling frames are received exceeds the guard interval, the contact event is considered finished and t_2 is the date of the last received signalling frame.

Therefore the first step of this study is to analyze the behavior of the *CSMA/CA* method by simulation to determine the limits of this solution in the context of a mining activity.

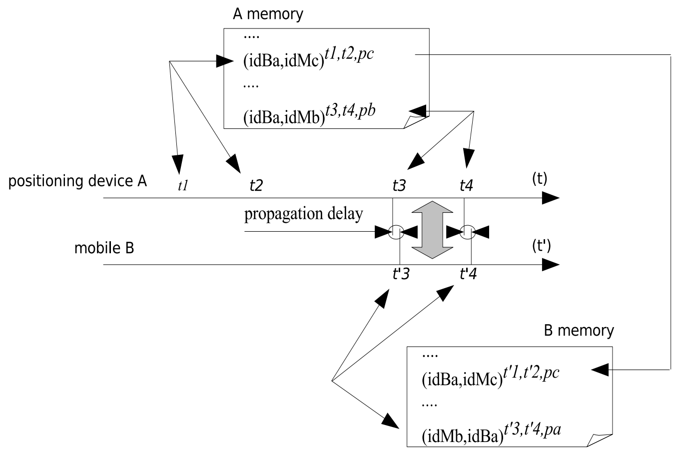

Figure 7. Contact event exchange.

B. Exchange and synchronization formalization

All contact events are formalized in the following manner:

$$(A, B)_{t_1, t_2, P_{max}}$$

Entity A met the entity B between dates t_1 and t_2 with a maximum power reception P_{max}. In the case of a location application, the sought information is the most up to date known position of a mobile entity. When the entity A or B is a tag node, information is obviously available. When neither A nor B is a tag node, their position can be approximated by comparing the history of their trail. So we have to be able to schedule in time all the contact events.

Consider the example shown in Figure 7. Let us consider the tag node A (idP_a) and the mobile node B (idP_b).

Between t_1 and t_2 this tag node saw in its coverage area the mobile C with a maximum received power of P_c. This contact event is recorded by A, by the mean of $(idP_a, idM_c)t_1, t_2, P_c$. Between t'_3 and t'_4 (local time of B), the mobile B is in contact with A. During the contact the two entities exchange their history of contact events. So A informs B about its contact with the mobile C.

As clocks entities are not synchronous, all contact events are dated in the receiver local time. To do that, all the nodes must send the current value of their clock, which can be done within the signalling frames and can be formalized by (A, $clock_A$). Thus, during the exchange of contact event historic the receiver can compute the offset clocks and can date contacts concerning other entities with its local clock. In this way the collector is able to schedule in time all the contact events posted by mobile nodes.

Finally, after t_4 and t'_4 respectively A and B record in their memory buffer the contact events they had just carried out, $(idP_b, idM_a)t_3, t_4, P_b$ and $(idM_b, idP_a)t'_3, t'_4, P_a$. The dates and powers recorded by each module are not the same because the radio link is not perfectly symmetrical.

IV. Simulation and results

A. Hypothesis

Results introduced here were provided by the means of NS2 simulation tools [7]. Table I shows simulation conditions.

Simulation Tool	NS-2 [7] version 2.32
Medium Access Protocol	IEEE 802.15.4 unslotted CSMA/CA [18]
Type of signalling Frame	Diffused frames
Data rate	250 Kbps
Frame length	15 Bytes
Number of mobiles within the coverage zone of a positioning Tag	N with $N \in [1; 200]$
Signalling frequency	$\frac{1}{T}$ $T \in [0.1\ s; 2\ s]$
Offrered Load in the coverage zone	$\frac{N}{T}$ signalling frames
Simulation duration	$10\ s$

TABLE I.
Simulation Conditions.

All the mobiles are signalling at a frequency of $\frac{1}{T}$. Each mobile uses its own clock taking into account a maximum time drift of 30 ppm. The transmission activity of these mobiles has to be non-correlated and quasi-periodical. In order to simulate this independency, each mobile starts asynchronously its transmission activity by respecting a random delay carried out according to a uniform law in a time interval of $[0, T[$. The positioning tag-node traps all the signalling frames it receives (i.e all the mobiles are in range of the tag-node). Then for each mobile the

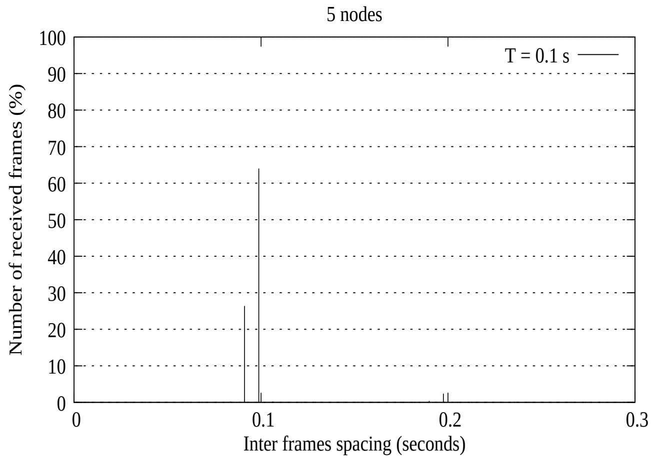

Figure 8. Effects of the mobile density with 5 mobiles.

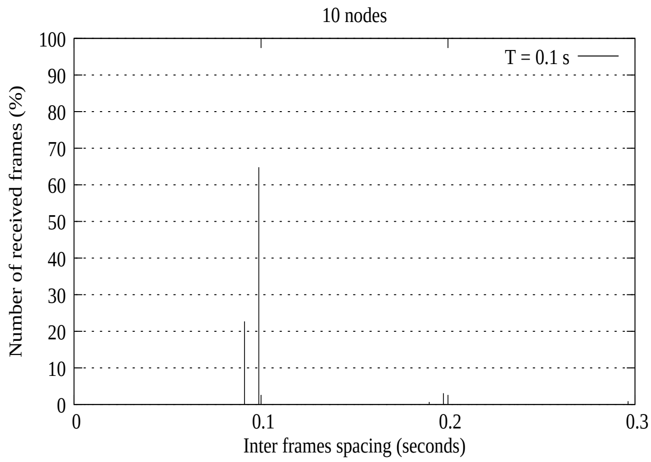

Figure 9. Effects of the mobile density with 10 mobiles.

distribution of the interframe time interval is studied in order to detect the end of a contact event.

B. Effects of the density of the mobiles

In this paper, distribution of signalling frame arrival is studied according to the offered load within the coverage zone of a positioning tag node. Let us consider the interframe distribution for all the mobiles in order to have an average behavior.

When N is low the distribution is mainly a peak centered on T (as shown in Figure 8). When N increases, two phenomenons appear.

The number of lost frames increases because the number of received signalling frames is smaller than the number of transmitted one. Distribution shows secondary peaks that correspond to inter-frames delays of $2T$ when a single frame is lost, of $3T$ when two successive frames are lost, and so on (Figure 9 and Figure 10).

When N becomes large, the cell of the tag-node becomes saturated, secondary peaks become numerous.

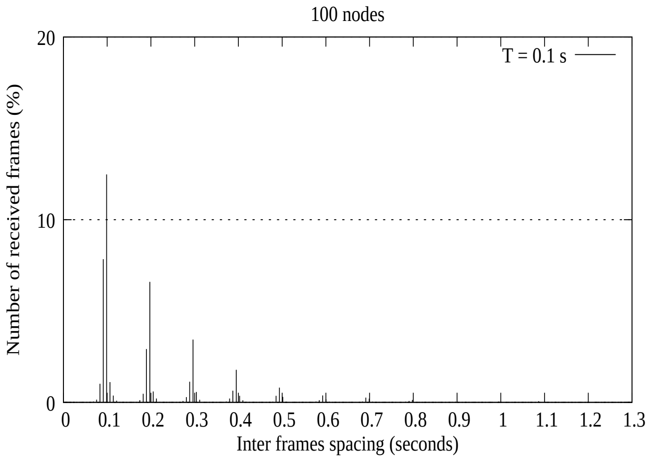

Figure 10. Effects of the mobile density with 100 mobiles.

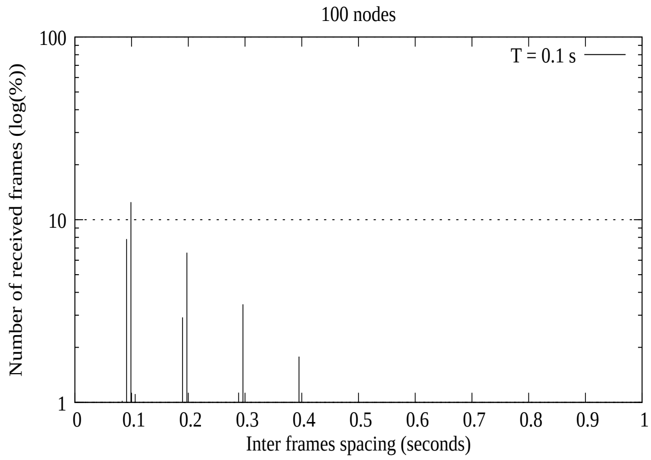

Figure 12. Effects of 100 mobiles

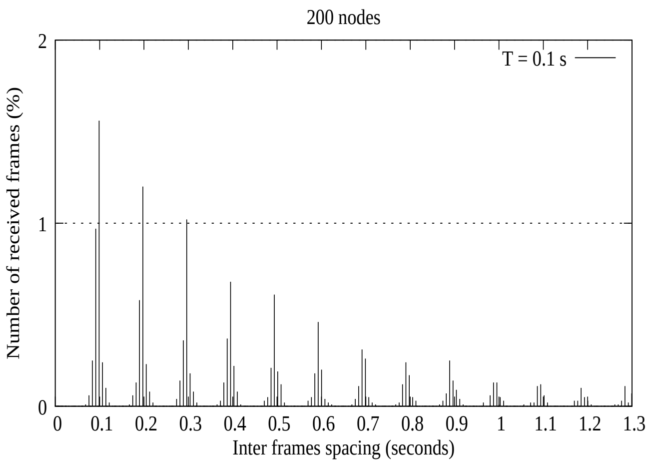

Figure 11. Effects of the mobile density with 200 mobiles.

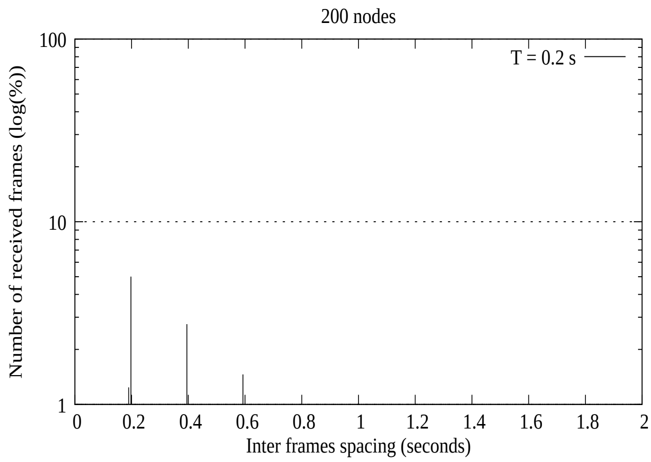

Figure 13. Effects of 200 mobiles.

This means that when the losses of successive frames are numerous, the peaks are not really identifiable any more, and the number of lost frames disables the identification of contact event. So when N is too high the offered load overloads the coverage zone of the tag-node, and the interval distribution is no longer useful (Figure 11).

Let us consider n_i as the surface of the peak i in what follows. If the surface of the peak $2T$ is corresponding to a number n_2 of frames that have been detected with an interframe delay of $2T$, this induces that n_2 frames have been lost. The number n_2 of such received frames has to be associated with $2 * n2$ transmitted frames. If n_3 is the number of received frames corresponding to $3T$ interframe delay, the surface of this peak has to be associated to $3 * n_3$ transmitted frames and so on.

We can deduce:
Nb of transmitted frames = $(\sum_{i=1}^{k}(i * n_i)) + N$
k: number of peaks
N: number of mobiles within the cell

N, the number of mobiles, is a correction factor introduced to take into account the fact that we are dealing with interval distributions. This formula is verified when the offered load is under overload conditions of the coverage zone of the tag-node.

C. Effects of number of the mobiles for a given offered load

A given offered load can be obtained by :

- N mobiles with a signalling activity period of T,
- $2N$ mobiles with a signalling activity period of $2T$.

Simulations have been done for :

- 100 mobiles and T equals $0.10s$
- 200 mobiles and T equals $0.20s$

Results are given in a logarithmic form in Figure 12 and Figure 13. We can notice that the distributions of inter-frame intervals are rather close but the surface of higher peaks is more important when the number of mobiles is 200. If we compare distributions for the same given traffic (Offered Load) produced by different number of mobiles, we find that a network is more quickly saturated when the number of stations is large [18].

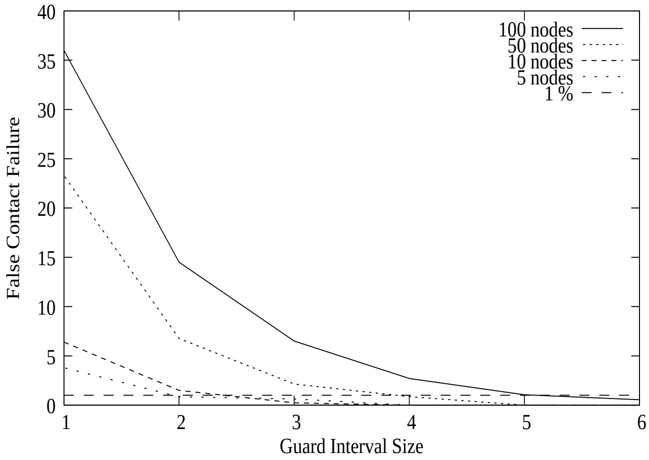

Figure 14. False detections of contact failure.

D. Effects of the offered load on false detections of contact failure

For the results of simulation given above, the loss of frames result only from the medium access method because all mobiles remain in range of the tag-node. Even for a small number of mobiles some frames are lost due to collisions. This is shown by the existence of secondary peaks on figures previously given (Figures 8 13). So the guard interval used has to be calibrated.

In our simulations, we are considering that the contact is permanent, the choice of a small guard interval induces false detections of the end of contact. Figure 14 gives the percentage of false detections caused by a received frame versus the length of the guard interval (given in number of signalling period).

The signalling period is $0.1s$ and the number of mobiles is varying from 5 to 200. If the offered load remains acceptable and if the length of guard interval can be adjusted to 2 or 3, then the number of false detections of contact failure is under 1% (for $N = 10$ mobiles and $T = 0.1s$).

V. CONCLUSION

The localization based on the technology of wireless sensor networks, easier to deploy in a confined area than a wired solution, with a long energetic lifetime, is an interesting topic based on the detection of proximity for monitoring the activity of a mobile population.

In an environment where the use of GPS is not possible, the location of a mobile is determined relatively to tag nodes periodically broadcasting their identity (their position) on the radio channel. The transit of a mobile device (itself signalling its presence) in a tag node radio area creates a contact event that is stored by each entity. This information is carried using the movement of mobiles up to the application collection point.

In the field of wireless sensor networks, the most commonly used technology refers to the IEEE 802.15.4. In this article our contribution focuses on the behavior of unslotted CSMA/CA medium access method on the proximity detection when a large number of mobiles are present in a tag node cell.

The simulation results enable us to conclude that this medium access method allows a tag node to support a sufficient number of mobiles in the radio cell. By setting a guard interval delay for a number of consecutive signalling frames lost, we can reduce to less than 1% unnecessary traffic generated by false contact failures. This validates the fact that a cell can support up to a hundred mobiles.

The prospects of this activity in the short term are to specify the exchange protocol of the historic of contact events stored by the entities, and the performances of the IEEE 802.15.4 access method with a payload greater than the simple signalling frames. Another challenge in the near future is to define mechanisms for saving energy in this context.

REFERENCES

[1] A. Srinivasan and J. Wu, "A survey on secure localization in wireless sensor networks," in *Encyclopedia of Wireless and Mobile Communications*, F. B, Ed. CRC Press, 2008.

[2] V. Uzunova, "Sociological modeling of the museum's virtual reality," in *Journal des anthropologues*, vol. no85-86, 2001, pp. 285–299.

[3] A. Bharathidasan, V. An, and S. Ponduru, "Sensor networks: An overview," IEEE Infocom 2004," SURVEY paper, 2002.

[4] C. Baouche, A. Freitas, and M. Misson, "A WPAN model to locate mobile entities in a mine gallery," in *ICWCUCA*, August 2008, pp. 183–187.

[5] L. Benoît, P. De Mil, I. Moerman, B. Dhoedt, P. Demeester, and N. Van Dierdonck, "Throughput and Delay Analysis of Unslotted IEEE 802.15.4," *JNW*, vol. 1, no. 1, pp. 20–28, 2006.

[6] L. Jin-Shyan, "Performance evaluation of IEEE 802.15.4 for low-rate wireless personal area networks," in *IEEE Transactions on Consumer Electronics*, vol. 52, August 2006, p. 742749.

[7] *http://www.isi.edu/nsnam/ns/*.

[8] G. Chalhoub, A. Freitas, and M. Misson, "A novel approach for simulating a bio-contamination process," in *BIODEVICES 2008*, vol. 2, January 2008, p. 123129.

[9] M. Ndoh and G. Delisle, "Propagation characteristics for modern wireless system networks in underground mine galleries," in *IWWCUCA 2005*, June 2005, pp. 129–132.

[10] ——, "Geolocation in underground mines using wireless sensor networks," in *IEEE AP-S 2005 International Symposium*, vol. 3B, July 2005, pp. 229– 232.

[11] P. Juang, H. Oki, Y. Wang, M. Martonosi, L. Peh, and D. Rubenstein, "Energy-efficient computing for wildlife tracking: Design tradeoffs and early experiences with zebranet," in *ASPLOS, San Jose, CA*, vol. 36, October 2002, pp. 96 – 107.

[12] L. Yihan, S. Panwar, M. Shiwen, S. Burugupalli, and L. Jong ha, "A mobile ad hoc bio-sensor network," in *ICC 2005*, vol. 2, May 2005, pp. 1241–1245.

[13] S. Antifakos and B. Schiele, "Beyond position awareness," in *Journal of Personal and Ubiquitous Computing*. Springer-Verlag, 2001, pp. 313–317.
[14] D. Jea, A. Somasundara, and M. Srivastava, "Multiple controlled mobile elements (data mules) for data collection in sensor networks," in *In DCOSS*, 2005, pp. 244–257.
[15] R. Sugihara and R. Gupta, "Data mule scheduling in sensor networks: Scheduling under location and time constraints," in *UCSD CSE Technical Report CS2007-0911*, 2007.
[16] M. Hermersdorf, "Indoor Positioning with a WLAN Access Point List on a mobile Device," 2006.
[17] F. Sottile and F. Bellifemine, "Design, Deployment and Performance of a Complete Real-time ZigBee Localization System," November 2008.
[18] "Zigbee Specification," ZigBee Standards Organization, Standard Zigbee 053474r13, 2006.

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