# LoWCA: Localization and Tracking Techniques Using a Wireless Sensor Network in Confined Areas - Study of the Impact of the Memory Size of Nodes

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***Abstract*—This paper proposes a generic solution called LoWCA for Localization and tracking nodes using a Wireless sensor network in Confined Area. This solution exploits the mobility of nodes to collect, transmit and pass around their knowledge. The knowledge used here is a collection of 'contact events'. Each contact event being a way to record the fact that a node has been in range of another node. A set of tag-nodes (fixed nodes) are used to indicate their position for the localization process. The scarce resources of the nodes and particularly their memory capacity lead us to define rules (filters) to determine which contact event must be stored, carried and forwarded in priority. Our generic solution is presented for a particular application domain: activities in confined environments such as mines. We study the effect of the memory size on the localization process through simulations. An experimentation step has been used to enhance our simulation model.**

***Index Terms*—WSN, DTN, Localization, Tracking.**

## I. Introduction

This article aims at proposes and evaluates a generic solution dedicated to Wireless Sensor Networks (WSN) called LoWCA (Localization and tracking using Wireless sensor network in Confined Areas). The application fields of the proposed solution deals with localization issues where the Global Positioning System (GPS) [1] is not operational. This solution is based on the exchange of atomic information called contact event noted *CE* which represents the recording of a meeting between entities in range. We assume that nodes carried by a mobile entity (a worker in a mine), must have a reduced size and weight, an extended lifetime battery, which means a limitation on computing capacities especially the memory size.

This new approach is inspired by the principle of 'store-carry-forward' of Delay-Tolerant Networks (DTNs) [2] and gives the opportunity for nodes to store contact events and send copies to other neighbours in range following certain rules. In our study, these rules may be applied by a node when it receives a copy of a contact event: filters can be applied to decide whether to keep this information or not [3]. The goal is to collect the greatest diversity of *CEs* but not a large number of replicas of a given *CE*.

We evaluate LoWCA through simulations to study the effects of the memory size on the quality of the knowledge collected at the collection point. With the aim to experiment our filtering mechanism in galleries of mines in the experimental site of CANMET (Québec), we have partially validated our solution by a local experimentation where mobile nodes are carried by students who move in the corridors of a building.

This paper is structured as follows. A brief state of the art in localization and routing protocols will be presented in Section II. Section III is dedicated to the presentation of the filtering mechanism and the first level of validation of our solution by simulations and experimentations. The evaluation of the effect of the memory size on the localization process through simulations will be developed in section IV. Finally, in part V, we end this paper with a general conclusion that highlights the main objectives achieved and suggests some perspectives for future research in the same area.

## II. Related Work

### A. Localization in Wireless Sensor Networks

The localization process in WSN is the way that nodes determine their position [4]. In other words, localization is a mechanism for discovering spatial relationships between objects. In a confined area, as in underground mining activities, the location of people or hazardous materials is a strong need, especially for security purposes. Addressing this need using positioning systems like GPS is impossible in underground environment. The objective of this project is to provide a tracking and localization solution independent of GPS system and based on zone or cell localization [5]. Tag-nodes (fixed nodes) are located at strategic areas and signal themselves to indicate their position. This position is used to locate mobile nodes a posteriori.

### B. Routing in Delay Tolerant Network

Traditional routing mechanisms in Wireless Sensor Networks are not directly applicable to DTNs because of the very low density of nodes and/or the intermittent connections. Two approaches are adopted in the literature to route packets in DTNs. The first approach is based on the network knowledge gathered by the nodes (e.g. topology, neighbourhood, routing table, ... etc.). Each node can store, share and propagate this knowledge [6]. The second approach is based on additional static and/or mobile nodes acting as a relay to collect information (e.g. Throwboxes [7]). When mobile nodes are used

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(e.g. data Mules [8]), the performance of this kind of solutions is very dependent on the movement of mobile nodes, it can be done randomly or done according to a predictable or controlled activity. The filtering mechanism proposed in this paper uses the model 'store-carry-forward' [6] by giving the opportunity to nodes to store contact events and send copies to other neighbours in range following certain rules and depending on the target application.

## III. LoWCA

### A. Nodes and Knowledge Exchange

*1) Type of Nodes:* Our strategy of sharing knowledge requires to define three categories of nodes:

- Mobile nodes: play the role of data Mule [8] moving along a trajectory to collect and transmit data.
- Tag nodes: fixed nodes located at strategic areas. Their main role is to send periodic signals to indicate a position, but can also transmit and store data.
- Collector: generally a fixed node acting as a sink.

*2) Contact Events:* The three types of nodes broadcast periodically their identity in order to signal their presence. This allows nodes to detect that they are close to each other when they are in range. In this case, we say that they are in contact. When a node detects the fact that there is another node in range, a data structure, the contact event (*CE*), is created using the following structure: $MyID, PartnerID, \textit{NS}, T_1, T_2$. This structure consists of the address of the node that generates the *CE* ($MyID$), the address of the detected node ($PartnerID$), a sequence number (*NS*) given by the node that generates the structure and a time interval $(T_1, T_2)$ indicating the duration of the contact event. During this interval of time, nodes can exchange their knowledge (a set of contact events) to contribute to the passing around of the information needed by the application.

### B. Filtered-flooding Mechanism

Each node maintains a local knowledge of contact events that created or received by its partners. When the density and/or mobility of nodes increases, the number of events leads to combinatorial explosion and thereby, saturation of the storage space. It is necessary in this case to establish a filtering mechanism to decide whether to keep the information in memory or not. The solution proposed in this paper is to define a diffusion mechanism based on the following two principles: To avoid overloading the medium, during a contact between two or multiple nodes, the knowledge is diffused only once. Then, each partner applies one or more filtering policies to decide which knowledge it stores depending on the target application. The goal is to pass around contact events to the collection point that will be necessary for the chosen application in order to locate or trace all the nodes. Obviously, it is not necessary to have multiple copies of contact events representing the same contact. A first analytical study [3] developed a list of filters and investigated the effect of the number of mobiles on the localization process. The definition of these filters is given in what follows.

*1) Permanent Filters:* The main function of permanent filters is to eliminate duplications. Let $CE_a$ and $CE_b$ be two contact events with: $CE_a(Id_a, Id_b, NS_a, T_1, T_2)$ and $CE_b(Id_b, Id_a, NS_b, T_1', T_2')$ representing the same contact between two nodes $A$ and $B$. Note that for this contact, several forms of doubles may exist:

- DOubles Filter ($DOF$): Two contact events $CE_a$ and $CE_b$ in memory are considered doubles if they have the same identifiers $(Id_a, Id_b)$ and the same sequence number $NS_a$ or $NS_b$.
- DUals Filter ($DUF$): $CE_a$ and $CE_b$ are called duals if their duration, respectively $[T_1, T_2]$ and $[T_1', T_2']$ are equivalent.
- COncatenation Filter ($COF$): If two contact events $CE_a$ and $CE_b$ follow one another with a very short time interval for example: $T_2 \equiv T_1'$ and $T_1' - T_2 \leq \textit{threshold}$, then the contact event $CE_a$ is kept in memory by updating its duration: $CE_a(Id_a, Id_b, NS_a, T_1, T_2')$.

*2) Random Filter ($PRF$ with probability $P$):* Each node has the possibility to free memory places randomly with a probability $P$. This random parameter was introduced to avoid favoring the most recent contacts.

*3) Tag-node Advantage Filter ($TAF$):* A contact event involving a tag-node can be a crucial information for localization applications because this information shows a location for a given mobile. Indeed, each tag-node placed at strategic area of the mine has a unique identifier that will be used to create a contact event to record the fact that a mobile node has been in range of this tag-node. The identifier of the tag-node is used to locate mobile nodes a posteriori. When the memory of a node is saturated, contact events between two mobile nodes should be deleted first.

### C. Simulation Process

*1) Simulator Parameters:* All the simulation results given here are obtained using NS-2 [9] simulator. The medium access protocol used is IEEE 802.15.4 unslotted CSMA/CA [10] with a data rate of 250 Kbps for 10 mobiles. The ITU propagation model is used to take into account the role of the medium. Each simulation scenario has been replicated 25 times and each replication lasts 750 sec.

*2) First Level of Validation:* The mobility scenario for a mine [3] is adapted in a university context where mobile nodes are carried by students who are moving in the building corridors. Figure 1 illustrates this scenario where the collector is located at the entrance of the corridor which is also the exit. Three tag-nodes are placed in classrooms.

*3) Evaluation Through Experimentation:* In this section, we will take a set of scenarios that will be used in two ways: for simulation results obtained by NS2 simulation process and for experimental results obtained with the help of students carrying TelosB motes [11] and following chosen trajectories. These scenarios are the same for simulations and experimentations in terms of trajectories, speed and number of nodes. Figure 2 shows the results obtained in simulation and those obtained by experimentation. In each figure the number

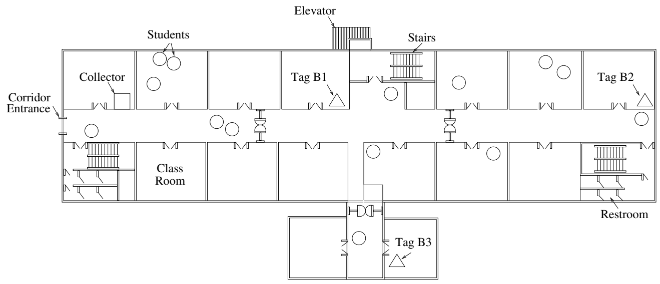


Fig. 1. University Corridors.

of theoretical expected contact event number which is the same for simulation and experimentation was added for clarity.

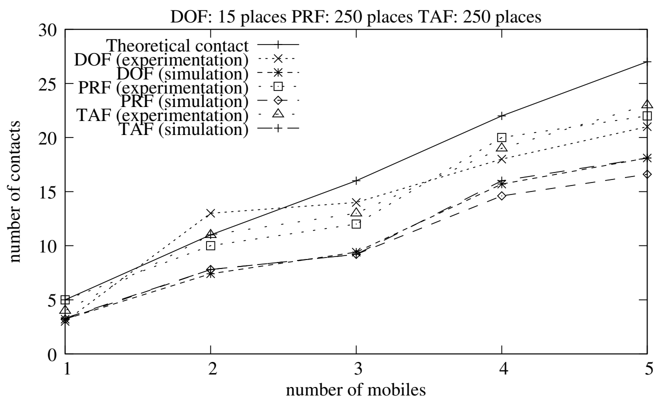


Fig. 2. Simulation and experimentation results with DOF, PRF and TAF filters.

Figure 2 also represents the results for the $DOF$, $PRF$ and $TAF$ filters. The number of places in the figure represents the number of contact events a node can store. To show the effects of those filters, 15 places are used for the $DOF$ filter and 250 places are used for both $PRF$ and $TAF$ filters. The simulated values are lower than the experimental data because experimentations create more false contacts compared to simulations. These false contacts are generated when nodes are in a border of a cell where connectivity is often unstable. The results also confirm the benefits of applying filters to have a diversity of contact events at the collection point to improve the localization or the tracking process.

## IV. Effect of the Memory Size

In order to evaluate the quality of the collection of contact events at the collect point (the collector), let us consider the ideal case for tracking applications. To be able to reconstruct any trajectory of a given activity we need to have at least one copy of each contact event of this activity. Replicas of a given contact event that reach the collect point are not useful. They can be assimilated as contact events repetitions that waste the forwarding capacity of our solution. In order to quantify the effect of filters and memory size on the quality of the collection of contact events we will use the following metric. First, we consider the number of different contact events gathered in the collect point, this score does not take into account the freshness of contact events and does not include repetitions because the $DOF$ filter is always applied, even with the other filters ($PRF$ and $TAF$). The metric is applied each time a node ends its activity and reaches the collection point. Then, to have an idea of the diversity of the collected contact events we decided to use the distribution of the number of contact events versus the duration of the activity (simulation). We assume that the distribution of all the contact events induced by this activity (called absolute contacts [1]) and the one of all the contact events gathered in the collect point are Gaussian distributions. In order to evaluate the diversity of this collection of contact events we consider the ratio of the standard deviation of these two Gaussian curves. The Gaussian function is defined by: $G(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(t-\mu)^2/2\sigma^2}$, where parameter $\sigma^2$ is the variance and $\mu$ represents the mean. To evaluate the diversity of contact events, we focus only on the variance $\sigma^2$ which can be obtained at the mid-height of the Gaussian curve. The diversity is therefore defined by the function: $R = \sigma_1/\sigma_2$ ($\sigma_1$ : for gathered contact events, $\sigma_2$ : for absolute contact events). The value of $R$ shows a good diversity when it is the closest possible to 1.

Figure 3 shows the number of different contact events passed around by mobile nodes to the collector. We also use the concept of useful knowledge (useful contact) which consists in counting the amount of contact events that the mobile nodes submit to the medium (network) during their activity. The collected contacts in the figure represents all the contact events collected at the collection point. The number of contact events does not significantly increase with the memory size because the $DOF$ filter deletes only replicas of contact events. We can explain these results by showing the distribution of contact events versus the duration of the simulation denoted $T$. Figures 4 and 5 show the distribution of contact events with 15 and 100 places for the memory size.

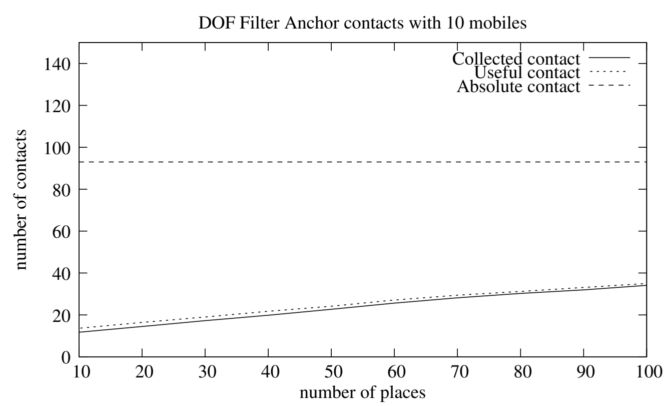


Fig. 3. Memory effect for the DOF filter.

Both figures show that the contact events collected by the collector represent the contact events created at the beginning of the activities. The ratio between the variance $\sigma_1$ (absolute

[1]The absolute contact represents all the contacts created by fixed and mobile nodes in the simulation and its value remains different from the theoretical contact.

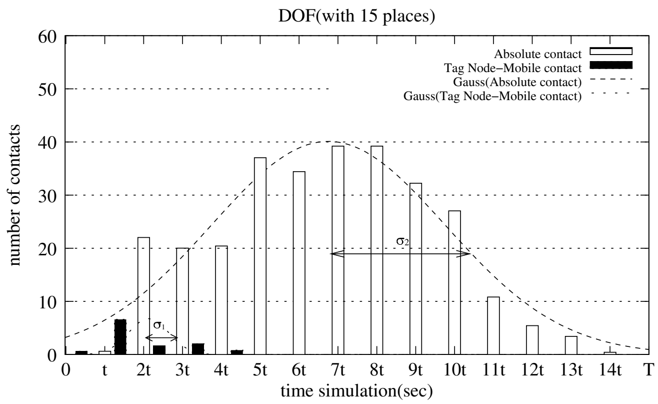


Fig. 4. Distribution of contact events for 15 places.

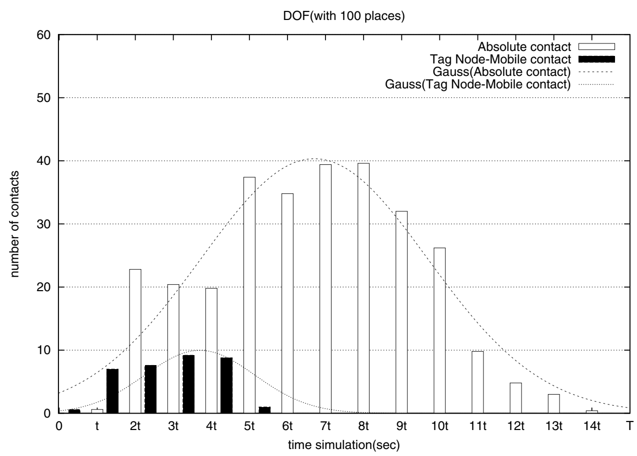


Fig. 5. Distribution of contact events for 100 places.

contact) and $\sigma_2$ (collected tag-node contact[2]) is $33\%$ when $15$ places are used and $50\%$ for $100$ places. We conclude that the $DOF$ filter is not sufficient for localization applications where the variety of information is a primary goal.

Figure 6 illustrates the memory effects when the $PRF$ filter is applied. The number of useful and collected knowledge in this case increases significantly by increasing the memory size. The distribution of contact events for $15$ and $100$ places (Figures 7 and 8) shows a better variety of collected contact events at the collection point when $100$ places are allocated to mobile nodes. The ratio $\sigma_1/\sigma_2$ confirms these results for $15$ and $100$ places as shown in Table IV.

TABLE I
DIVERSITY OF CONTACT EVENT.

| Memory size | $DOF$ | $PRF$ | $TAF$ |
|---|---|---|---|
| 15 places | 33% | 33% | 90% |
| 100 places | 50% | 90% | 90% |

We note that the best performances are obtained with the $TAF$ filter (Figure 9) which focuses only on tag-node contact

[2]We focus only on the counting of tag-node mobile contacts given their importance on the localization process.

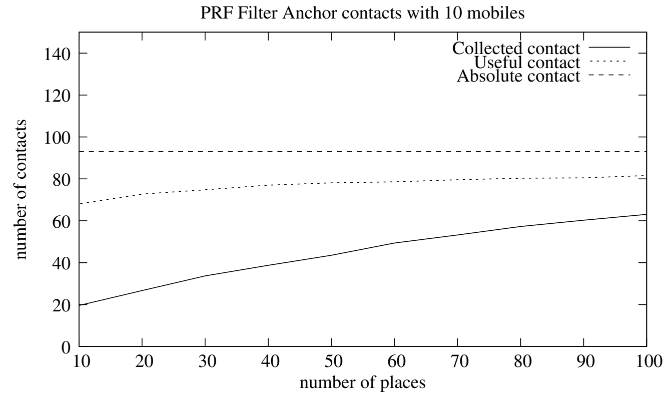


Fig. 6. Memory effect for the PRF filter.

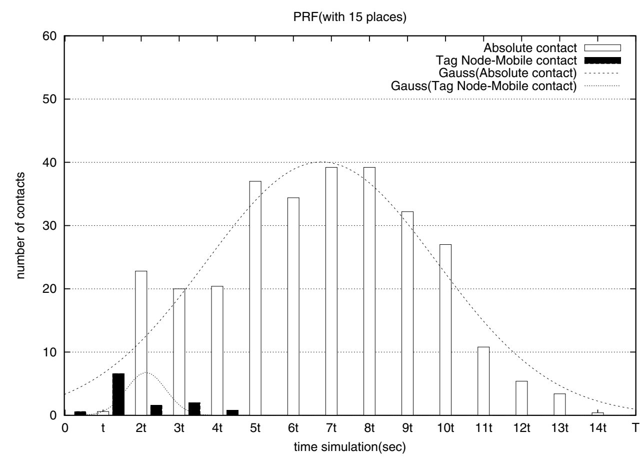


Fig. 7. Distribution of contact events for 15 places.

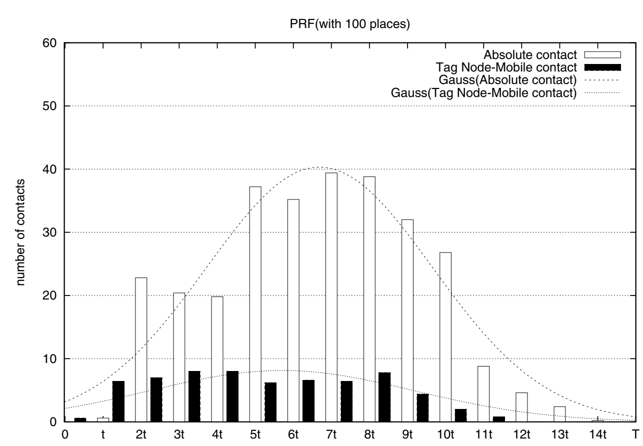


Fig. 8. Distribution of contact events for 100 places.

events. Another important point for this filter is for this scenario of 10 mobiles, when the memory size reaches a value of 70 places, the gain in number of collected contact events reaches an asymptotic behavior. The distribution of contact events for 15 and 100 places (Figures 10 and 11) shows also a large variety of collected contact events when 15 and 100 memory places are used. The diversity of collected contact events is improved even when 15 places are allocated. The value $\sigma_1/\sigma_2 = 90\%$ remains the same for 15 and 100 places showing the interest of this filter (Table IV).

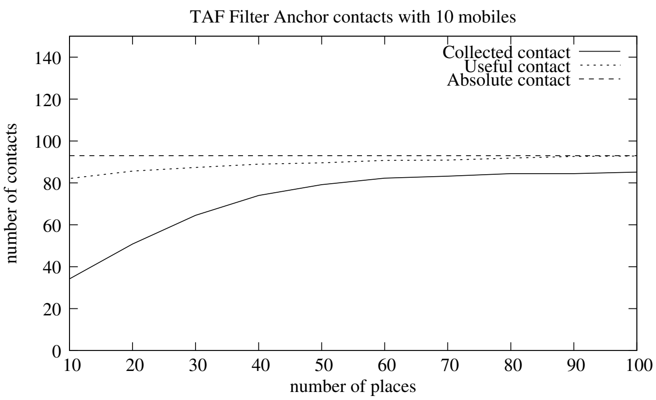


Fig. 9. Memory effect for the TAF filter.

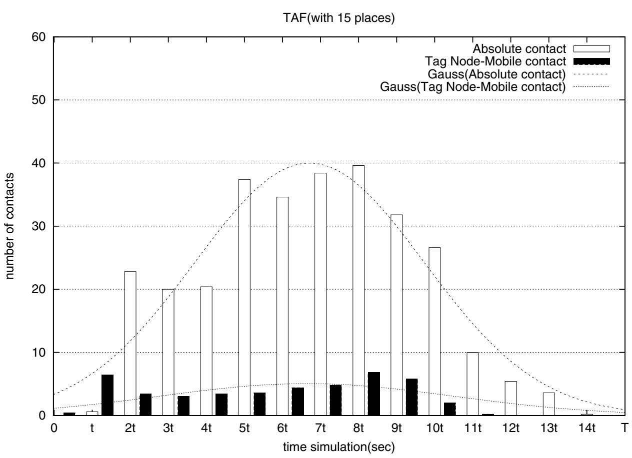


Fig. 10. Distribution of contact events for 15 places.

The simulation results given in this section show the importance of having a large variety of contact events passed around to the collection point. This diversity of knowledge can be beneficial for localization and tracking applications. In addition, the memory size of nodes can be set to a certain value depending on the number of nodes and the mobility scenario.

## V. Conclusion and Perspectives

The limited capacity of nodes in WSN, particularly in memory, leads to a limitation of the flow of data exchanged with the constant aim to preserve representative samples for the application. The filtering strategy of contact events proposed

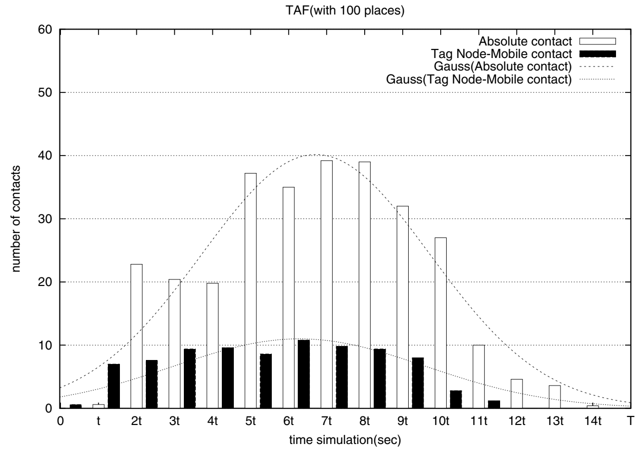


Fig. 11. Distribution of contact events for 100 places.

in this paper is based on the choice of filters that allow to select which *CEs* must be passed around to a collection point. We have given the simulation and experimental results for a generic scenario representing the activities of workers in a mine. We pointed out the importance of the choice of the type of *CE* filter and the memory size of the nodes. Experimentations on TelosB motes validated the feasibility of our filtering approach and we plan to test our solution in CANMET Experimental Mine in Québec.

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