# DIFFUSION BEHAVIOR OF IEEE 802.15.4 UNSLOTTED CSMA/CA IN A CELL OF PROXIMITY-BASED LOCALIZATION APPLICATIONS

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Abstract: This paper relates to a generic solution for localization and tracking applications using Wireless sensor network in confined areas where the GPS technology is no longer functional. The proposed solution exploits node mobility by allowing stations to come into contact with other fixed or mobile stations to collect, transmit and pass around their knowledge, which is a collection of 'contact events'. Each contact event being a way to record the fact that a node has been in range of an another node. This event can also refer to a geographical location. The amount of contact events that have been created depends on the effectiveness of the contact detection mechanism and on the performance of the *WSN* medium access method. This leads us to study the performance of IEEE 802.15.4 unslotted CSMA/CA when the offered load of a cell is only broadcast traffic. Frames are not always received because of collisions or of unsuccessful transmission attempts. This leads to a rupture of the current contact involving the creation of useless contact events for the same situation of proximity between entities. The results obtained by simulation, determine the capability of a cell in terms of number of mobiles and size of the exchanged frames for an acceptable rate of false contact detection.

## 1 INTRODUCTION

In this paper, WSN (Akyildiz and CanVuran, 2010) are used for proximity-based localization applications. Each mobile is equipped with sensors and collects data as it moves. When a mobile enters the cell of another node, the mobile can upload its data or download specific information about the area (for instance, a fine-grained map of the area). This communication is performed while both nodes are in range of each other. The key issue for such applications is the contact duration, which includes the delay required for the mobile to detect that it is in range of the other mobile, and for the exchanges.

The duration of a contact between two nodes is often computed by having the nodes sending periodic signaling frames, called beacons in the following. Each node can estimate the contact duration as the time between the first and the last beacon received. However, to determine which is the last beacon received is difficult because beacons can be missed due to changes in channel propagation conditions or due to an overload of the traffic at this particular location and at this particular instant. After having missed several beacons in a row, a node would wrongly assume that the contact is lost, although the node could still be in range.

Our contributions are three-fold. Firstly, we quantify the maximum number of mobiles such that the risk of false contact failures is bounded by a given threshold. Secondly, we show that in order to achieve the maximum throughput for diffused frames by using unslotted CSMA/CA (Lauwens et al., 2010), mobiles have to produce an offered load greater than the channel capacity. Thirdly, we propose a graphical way to estimate the cause of frame losses.

## 2 PROBLEM DESCRIPTION

### 2.1 Application Scenarios

This study is carried out in order to localize people or hazardous materials moving in a confined area where the use of GPS (Zheng et al., 2010) system is no longer possible. The solution we are dealing with can be summarized as follows. WSN devices can be spread over a confined area (such as mine galleries for example) according to their type:

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- Tag-nodes which are fixed nodes used to point out particular locations in the gallery and are able to store information such as a list of mobiles that have been in such areas.
- Mobile nodes are able to exchange information with other fixed or mobile nodes. The chronology of the contacts with tag-nodes can be used to deduce the trail of the mobile nodes.
- Collector nodes are usually fixed nodes. When a mobile node moves in its range, a collector can download a copy of the gathered information.

This is a similar version of the data mule concept (Bhadauria et al., 2011), where mobile nodes are mules, tag-nodes are mirrors and the collector node is a sink or a base station. Our objective is not to provide a fine-grained localization system but to determine if an entity is still in range or has been near a given location (typically the coverage of a small-sized cell of a particular tag-node).

## 2.2 Contact Definition

The three types of nodes broadcast periodically their identity in order to signal their presence (Baouche et al., 2009) (Baouche et al., 2011). This allows nodes to detect that they are close to each other when they are in range. We say that they are in contact. When a node detects the fact that there is another node in range, a data structure, called contact event, containing the addresses of the two nodes involved in the contact, a sequence number and the interval during which both partners are in range. 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.

## 2.3 Risk of False Contact Estimation

We focus now on the number of false contacts due to the overload of a cell. Let $p$ be the probability of missing one frame and $N_t$ be the number of frames lost consecutively. If, for example, $N_t$ equals 3 (three consecutive frames lost), the probability of false creation of contact event is $p^3(\frac{1-p^{n+1}}{1-p})$ (to take into account the losses of 4, 5, 6,...,n consecutive frames). This will be approximated by $p^3$ in the following.

Let us set the periodicity of beacon diffusion to 100 *ms* and let us suppose that it takes 100 *s* for a mobile to cross the coverage of the cell of a tag-node. During this time, 1000 frames must be received.

Let us assume now that we tolerate at most one false contact creation per node while it crosses the coverage of a cell. This can be approximated by $1000 * p^3 \leq 1$, that is to say $p \leq 10\%$.

This formula is used in order to define the number of mobiles that can move simultaneously within a cell while keeping the false contact risk under a given threshold.

# 3 EVALUATION

## 3.1 Evaluation and Simulation Process

In this section, we study the behavior of CSMA/CA 802.15.4 in a cell progressively loaded by broadcast traffic with a data rate of 250 Kbps. All the results given here have been obtained using NS-2 (Issariyakul and Hossain, 2008) simulator. Our approach is to consider the cell coverage of a given node: a tag-node for example. From 1 to $N_m (N_m = 100)$ mobile nodes are introduced within the cell coverage with a signalling frequency of $\frac{1}{T}$, $T \in [0,1]$ ($T = 100$ ms for the results given here). The offered load in the coverage zone is $\frac{N}{T}$ frames and each mobile starts its activity in a time interval of $[0,T]$.

The evaluation of the throughput is based on the computation of the average traffic received by each mobile node. This throughput is compared to the offered load within the cell, that is to say: $(N_m+1)*10$ frames/s, where $N_m$ is the number of mobiles.

These simulations have been carried out for different frame sizes: short (4 bytes) corresponding to a beacon, medium (60 bytes) and long (116 bytes) corresponding to beacons used to carry contact events.

We used $p = 10\%$ to identify the capacity of a cell. Our objective is to have real contact events rather than false contact events created by link failures due to the cell overload.

## 3.2 Throughput

The study of the throughput was carried out for the different lengths of frames. The results of the study are given on Fig. 1 and Fig. 2. Each figure is composed of three curves:

- The average traffic received by a node as a function of the submitted load to the MAC layer (denoted by to the mac). We can observe that the saturation of the medium (145 kbps, 28 mobiles) on Fig. 1 (long frames) is reached for an offered load greater than the maximum capacity of the medium ($G = 1$ for 250 kbps). This is due to the role of the MAC layer: a certain number of frames are dropped at the MAC layer after successive unsuccessful transmission attempts.

- The average traffic received by a node as a function of the submitted load to the physical layer (Fig. 1 by the phy). In this case, the saturation of the medium is obtained by an offered load smaller than the maximum capacity ($G \approx 0.8$).
- The asymptotic line represents the maximum theoretical throughput that can be obtained (*i.e.*, $S = G$). We use it in the following in order to calculate the number of collisions on the medium.

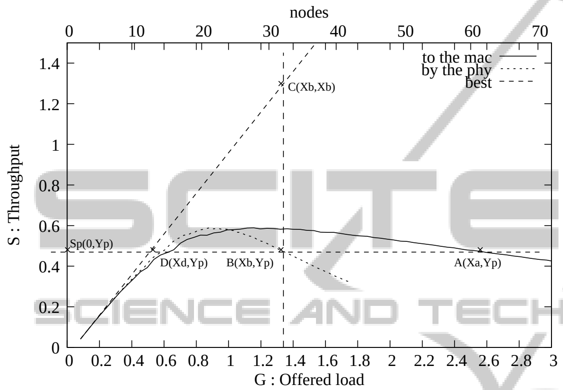


Figure 1: Long frames.

The same representation for short and medium frames is illustrated on Fig. 2. We note that the saturation of the medium for the short frames is reached with a throughput of 62 kbps for 96 mobiles ($G = 0.5$). The maximal throughput is obtained for the medium frames with 125 kbps for 42 mobiles ($G = 0.9$).

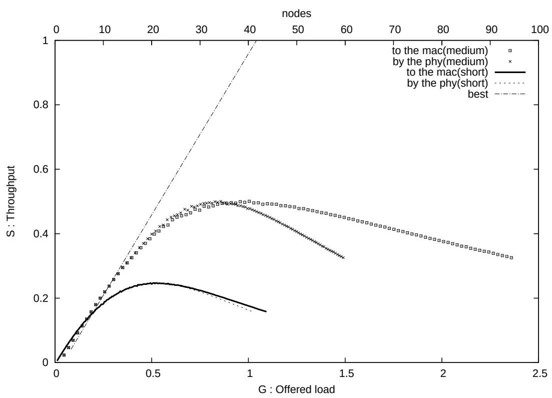


Figure 2: Short and medium frames.

## 3.3 Study of the Cause of Frame Losses

In the following, we deduce from the previous simulations (throughput vs. offered load) the number of drops at the MAC layer, and the number of collisions for broadcasted frames.

To do so, let us take again Fig. 1 giving the throughput ($S = F(G)$) for long frames. From each point $A$ of the curve 'to the MAC', an offered load $X_a$ (on the x-axis) and a throughput $S_p$ (on the y-axis) can be deduced. This particular throughput will be used to define three other points as shown in Fig. 1. Let us denote by $(0, Y_p)$ the coordinates of this point. If $A(X_a, Y_p)$ is the corresponding point on the curve called 'to the MAC', the same throughput is also used to obtain the offered load $X_b$ submitted by the physical layer to the medium. Let $B(X_b, Y_p)$ be the corresponding point of the curve called 'to the Phy'. It is also possible to define points $C(X_b, X_b)$ and $D(X_d, X_p)$ on the curve called 'best', this curve being $S = G$. Let us denote that the length of segment $BC$ and segment $BD$ are the same. These points are used in the following to evaluate the cause of the frame losses.

### 3.3.1 Frames Dropped by the MAC Layer

For each point $A$, it is possible to associate a point $B$. The difference of the x-value of these two points gives the number of dropped frames that have been queued in the MAC layer.

Let $F_1$ be a function of $G$ giving the number of drops: $F_1(X_a) = X_a - X_b$. (1)

Figure 3 shows the number of drops on the MAC layer for the four types of transmissions. We note in this graph that the shape of the curves depends on the length of the broadcast frames, so the highest number of drops of frames is obtained for long-sized frames.

### 3.3.2 Effect of Collisions

In our simulations, we use the free space model to model of propagation conditions, and all the mobiles in our scenarios are in range of each other. We consider that the frames handled and broadcast by the physical layer are either received or affected by a collision.

Let us take again the points defined previously: $B(X_b, Y_p)$ represents an offered load to the medium that gives $S_p$ as throughput. The curve denoted by 'best' gives us the throughput if all the broadcast frames are correctly received. The number of collisions is given by the difference between what is submitted to the medium and what is received (*i.e.*, the segment [DB]).

$F_2(X_b) = X_b - X_d$ (2).

Figure 4 represents the number of collisions for short, medium and long frames. We note that the number of collisions increases quasi-proportionally with the number of nodes in the network for the four types of transmissions. The effect of dropping mechanism can be clearly seen for long frames: only a part of the frames submitted to the MAC layer is sent.

### 3.4 Cell Capacity in Terms of Number of Simultaneous Mobiles

We now focus on the maximum number $max_{Nb}$ of mobiles; a cell coverage can support before having false creation of contact events. Our assumption is that we tolerate at most one false creation during 100 seconds ($p \leq 10\%$). To identify the value of $max_{Nb}$ for a given length of frame, we consider the intersection between the curve giving the throughput and a straight line $ET(x)$ representing what we are expecting: more than 90% of frames are received.

$ET(x) = 0.9 * (Ntx - \frac{t}{T})$. (3),

where $ET$ stands for expected traffic.

We deduce from this formula the values of 11 mobiles for long frames, 15 mobiles for medium frames and 21 mobiles for short frames.



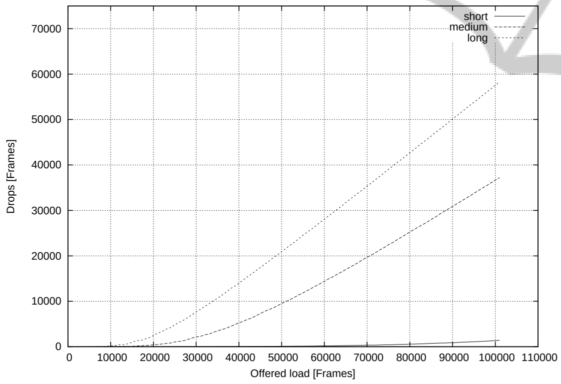


Figure 3: Number of drops.

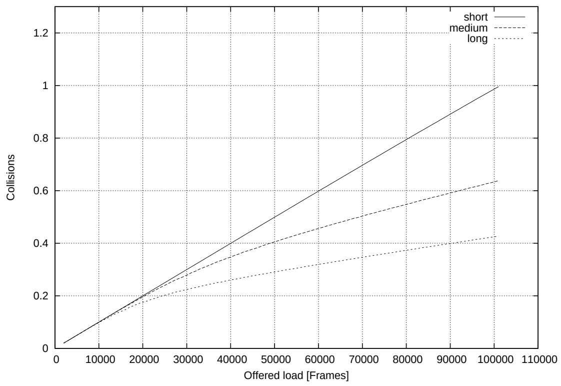


Figure 4: Number of collisions.

## 4 CONCLUSIONS

The particular point which is tackled in this paper is the estimation of a contact duration, when fixed and mobile nodes are in range of each other. This time is used by nodes to exchange information about previous contacts for example. The risk of successive frame losses leads us to evaluate the maximum number of mobiles that can be accepted in the coverage of a cell in order to avoid a false contact duration estimation. The method we proposed provides also a way to estimate throughput and the effect of the discard process of the MAC layer of IEEE 802.15.4 standard.

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