Let’s Collide to Localize: Achieving Indoor Localization with Packet Collisions

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Abstract—A large fraction of indoor localization methods rely on anchor nodes that periodically transmit their coordinates using radio signals. Mobile nodes then use the received information to decode their own locations. For all these methods to work, the underlying assumption is that anchors should send their beacons at different times, i.e. the beacons should not collide. We propose a radically new approach for indoor localization: to overlap the transmissions of beacons (synchronized collisions). Our collision-based method leverages the capture effect, which states that when several radio signals collide, only the strongest (nearest) signal is detected. Compared to the state of the art, our simple change of perspective—from non-colliding to colliding beacons—provides two important advantages. First, the lifetime of the mobile nodes can be increased by three orders of magnitude (from days to years). Second, our method is more resilient to external interfering sources, such as WiFi stations. In this work-in-progress, we (i) provide a preliminary evaluation of our prototype, and (ii) describe the challenges that we are currently working on to produce a fully-fleshed commercial system. While indoor localization is a very active research area, to the best of our knowledge, we are the first ones to evaluate a collision-based approach.

Keywords—Indoor localization, radio signals, capture effect.

I. INTRODUCTION

Over the last decade, there has been several notable studies that have investigated the use of radio frequency signals for indoor localization [1], [2]. Most of these studies require received signal strength measurements (RSS) to decode the location of a node. Our method does not require RSS measurements, and hence, it does not fall into this category. Our study is more related to range-free methods. In these methods, upon reception of the beacons, mobile nodes determine their position by processing only the \((x, y)\) coordinates of the anchors (no RSS involved). The information received from nearby anchors can be processed following simple centroid techniques [3], which average the received coordinates; based on distance vector routing [4], which use off-line hop-distance estimations to obtain geographical coordinates; or using complex geometric calculations such as APIT [5], where an irregular deployment of anchors is required to derive triangular sections.

Novelty and basic idea. Our study differs from the state-of-the-art in range-free methods in a fundamental way: we do not require beacons to be sent at different times, to the contrary, our method requires a precise overlap of the beacons transmissions. These overlapping transmissions can leverage the capture effect to decode the beacon (coordinates) coming from the anchor with the strongest signal. Hence, in essence, what our method does is to divide the space of interest into a sort of Voronoi diagram, similar to the bottom part of Figure 4. The Voronoi cells are defined by the coordinates of the anchors and the specific characteristics of the environment, such as walls. Mobile nodes are then localized by closest-proximity: when a node is within a given cell, it obtains the coordinates of the corresponding anchor. While conceptually simple, our idea has several important implications, and—as we will observe—its implementation needs to overcome non-trivial technical challenges.

II. THE COLLOCAL APPROACH: LEVERAGING THE CAPTURE EFFECT

Our method, named Collocal, leverages a physical layer phenomena known as the capture effect. This effect is described in Figure 1. When two wireless signals collide there are three possible outcomes depending on (i) the relative strength of the signals, and (ii) their relative timing. If the strongest signal is received before the weakest signal, then the strongest signal is successfully decoded as long as the signal-to-interference noise ratio (SINR) is above a certain value, Figure 1(a). If the stronger signal arrives during the preamble of the weaker signal, then the SINR needs to be higher (than in the previous case) in order to decode the packet successfully, Figure 1(b). This is the capture effect. Finally, if the stronger signal arrives after the preamble of the weaker signal, then no packet is successfully received,
synchronization and (ii) data transmission. Both components
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be small (no big batteries allowed) and inexpensive. This
pose constraints in terms of size and cost, the tags should
without replacing the battery. Commercial applications also
is tracking goods in a building for five years, or more,
coarse granularity (localization within a few meters) and
one anchor to the other in steps of 10 cm. At each point,
the receiver collects data for 30 seconds (60 samples total).
in this simple scenario, the room is divided in two cells and
we want to localize the node in the right cell.

Figures 2(b) and 2(c) depict the performance of the system
with and without a wall. A value of 100% indicates that
the 60 samples (60 overlapping collisions) were correctly
decoded into the right position. Collocal has three important
regions. First, the reliable regions [0, 60] and [140, 200],
where the signal of the strongest anchor is high enough
for the capture effect to take place. Second, the unreliable
region [60, 140], where there are no false positives, but the
relative strength of signals (SINR) is not high enough for
the capture to take place consistently. Third, the dead zone
region [100], where the strength of both signals are similar
and no detection is possible. Notice that the attenuation
causw by the wall, in Figure 2(b), reduces the variance
of the unreliable region.

A. Initial Prototype

Requirements. Our system targets applications requiring
a coarse granularity (localization within a few meters) and
a long lifetime. An example of this type of applications
is tracking goods in a building for five years, or more,
without replacing the battery. Commercial applications also
pose constraints in terms of size and cost, the tags should
be small (no big batteries allowed) and inexpensive. This
set of constraints require a system with very low-power
technology. To achieve these goals, Collocal needs to keep
the mobile nodes sleeping as much as possible.

The design of Collocal has two main components: (i) time
synchronization and (ii) data transmission. Both components
are built upon existing knowledge in the state of the art. The
novelty of our study is not on developing these components
but on analyzing collision-based localization, hence, due to
space limitations we only provide a brief description of our
initial prototype.

Hardware. We use the nrf51822 system on chip (SOC)
from Nordic Semiconductor. It is a 6x6mm IC that con-
tains a cortex-M0 processor and a 2.4Ghz transceiver with
a transmission rate of 2Mbps. With this hardware, the
time synchronization required to leverage the capture effect
should be less than 25 µsec. The radio transceiver has the
capability of reading RSS values. We do not use this
capability for Collocal, but we do use the RSS values to
provide an upper bound for the best performance that can
be expected from Collocal. This will be explained in more
detail in the next Section.

Time synchronization component. To achieve a high
level of synchronization with low power consumption, we
utilize a low-power low-resolution timer (32 KHz), in con-
junction with, the high-power high-resolution timer of the
processor (8 MHz). The low-resolution timer is always on,
while the high resolution timer is turned on only sporadically
– when a higher timing resolution is required. Overall,
Collocal achieves a time synchronization within 3.8 µsec,
which is vastly lower than the required 25 µsec.

Data transmission component. Besides sending localiza-
tion beacons, anchors may need to report back the location
of mobile nodes to a central repository (data collection), or
they may need to send other control data to the network
(data dissemination). To allow these data-transmission capa-
bilities, we developed a simple TDMA protocol that exploits
the well known concept of spatial reuse and Collocal’s high
level of synchronization. This basic TDMA protocol allows
new incoming mobile nodes to synchronize their timers
using a listening window of 31.25 ms, or a multiple of these
windows depending on the network’s configuration.

B. Advantages and disadvantages of Collocal

Our method provides two key advantages: a longer life-
time and higher resilience to interference. The main disad-
vantage of our method is its coarse granularity. These points
are described below.

Increased node lifetime. In traditional range-free meth-
of improvement after reducing their radio duty cycles such as wireless sensor networks, have also shown this level from days to years. Other low-power embedded systems, ≈ reporting period of one second, the duty cycle of Collocal is ≈ beacon i. Consider a receiver located at the same point as anchor 1, but not during the transmission of beacon j, the receiver would get an erroneous location. In networks exposed to the well-known burstiness of WiFi stations, this example would not be an uncommon scenario. A static node would show continuous “jumps” because its coordinates will be computed with different sets of beacons at every period; with the most inaccurate calculations corresponding to the instances where the nearest beacons are lost. In Collocal, resilience to interference is obtained by default. Since all beacons are sent at the same time, only two outcomes are possible. If the interference signal is lower than the strongest beaconing signal, Collocal is unaffected because the capture effect “filters out” this type of interference. If the interference signal is similar or higher than the strongest beaconing signal, no location can be decoded. Notice that in instances where the nearest beacons are lost. In Collocal, the key limitation of our method is that the number of cells is equal to the number of anchors. In other range-free methods, the number of cells is greater than the number of anchors because the overlap of the various transmission coverages dissect the space into smaller subregions.

High resilience to interference. Nowadays, it is central to design systems that can cope with external interference. WiFi, Bluetooth, and a variety of electro-domestic devices operate, and interfere, in the ISM bands. The accuracy of traditional range-free methods depends on their ability to detect most (all) nearby beacons. For example, in Figure 2(a), consider a receiver located at the same point as anchor i. If there is interference present during the transmission of beacon i, but not during the transmission of beacon j, the receiver would get an erroneous location. In networks exposed to the well-known burstiness of WiFi stations, this example would not be an uncommon scenario. A static node would show continuous “jumps” because its coordinates will be computed with different sets of beacons at every period; with the most inaccurate calculations corresponding to the instances where the nearest beacons are lost. In Collocal, resilience to interference is obtained by default. Since all beacons are sent at the same time, only two outcomes are possible. If the interference signal is lower than the strongest beaconing signal, Collocal is unaffected because the capture effect “filters out” this type of interference. If the interference signal is similar or higher than the strongest beaconing signal, no location can be decoded. Notice that in

1 Most of this time is used to startup the transceiver, the message itself takes only 144 µsec

2 Other range-free methods could also be enhanced to reduce the duty cycling of nodes, but this would require (complex) coordination mechanisms to make sure that nodes receive the beacons from all anchors in range.

3 This is an “equivalent” RSS-method. Other methods, such as centroid calculations, would perform better (at the cost of using more energy and being more susceptible to interference).
dead zones and bit corruption. First, note that sample points 4, 8 and 12 provide no localization. This is because the RSS signals of two or more anchors are similar, and hence, the capture effect cannot take place. Second, and more importantly, at some points (2, 3, 6, 10 and 11), the performance of Collocal is significantly lower than the RSS method. The reason for this is that, in Collocal, the demodulation of the stronger signal is likely to lead to more bit errors because a one in a slightly weaker transmission can overwrite a zero in a stronger transmission. The result is something resembling a bitwise-OR on air of both messages, where a one is received instead of a zero. For example, if the strongest signal has the sequence 1000 and the weakest signal has a sequence 0010, the resulting sequence could be 1010. This effect leads to significantly higher bit-error-rates than the more traditional unsynchronized RSS methods.

In the next section we describe some potential solutions to overcome the limitations of Collocal.

IV. OVERCOMING DEAD ZONES AND BIT CORRUPTION

For Collocal to become a plausible commercial alternative, we need to overcome two key challenges: dead zones and bit corruption. We are currently evaluating three approaches two overcome these limitations.

A. Multi-Phase Transmission.

As shown in our initial evaluations, the dead zone problem is aggravated when the density of anchors is increased. To alleviate the dead zone problem, the anchor nodes could be divided in different groups, with each group transmitting their beacons at different phases. Figure 4 depicts the basic idea. First, when all anchors transmit, as in Figure 4(a), a node at point $M$ cannot detect its position because it is on a dead zone. Then, only anchors $i$ and $p$ transmit and the node assigns its location to $i$, Figure 4(b). After that, only anchors $j$ and $q$ transmit and the node assigns its location to $j$. After the three phases have finished, the node at point $M$ could correctly identify its final location to the middle area between $i$ and $j$. The bottom part of Figure 4 depicts how multi-phase can be used on 1-D (aisles) and 2-D (floor) areas. In aisles we can have three phases: all anchors, black anchors and gray anchors; while on floors we can have four phases. It is important to note that the multi-phase approach involves some trade-offs: nodes would need to listen longer (use more energy), perform more processing (to merge the information from the different phases), and its granularity would be susceptible to interference (if the information of some phases is lost, the granularity will be coarser).

B. Directional Antennas.

Another way to reduce the “density of signals” is to use directional antennas—which provide narrower coverages. In this way, neighboring anchors would interfere less with each other and reduce the extent of dead zones. We are currently evaluating multi-phase techniques and directional antennas and the results look promising. Our main challenge is bit corruption. Next, we explain a technique that we plan to investigate to ameliorate these effects.

C. Orthogonal Codes.

The high time synchronization of Collocal seems to create an on-the-air bit-OR operation. The overlapping at the bit level creates a higher bit-error-rate than usual. We want to explore more sophisticated coding schemes to overcome this problem. A possible direction is to use orthogonal codes to encode neighboring beacons. In this way we hope to decrease the cross-correlation of beacons. The trade-off for using complex coding schemes would be to increase the use of computing resources at the mobile node.

REFERENCES


