Radio-Frequency Handoff Strategies to Seamlessly Integrate Indoor Localization Systems

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***Abstract*—The widespread use of Location Based Services (LBS) drives the pervasive adoption of localization systems available anywhere. Environments equipped with multiple indoor localization systems (ILSs), require managing the transition from one ILS to another in order to continue localizing the user's device even when moving indoors or outdoor-to-indoor environments. In this paper, we focus on the handoff procedure, whose goal is enabling a device to trigger the transition between ILSs when specific conditions are verified. We describe the activation of handoff procedures by considering three types of ILS design and deployment, each with increasing complexity. Moreover, this work defines three handoff algorithms based on the proximity detection, and we test them in a realistic environment characterized by two contiguous ILSs.**

***Index Terms*—Indoor Localization, Handoff, Location-based Services, Cyber-Physical Systems**

I. Introduction

The potentialities of location-based services (LBSs) strictly rely on the assumption of being able to estimate the position of a target in a seamless way. This requirement represents a challenging task for a number of reasons. While for outdoor environment GNSS-based techniques are well established, for indoor environments it still exists the lack of a standardized technology and software interfaces enabling a device to self-localize or to be localized from the existing infrastructure [1]. Furthermore, the possible co-existence of heterogeneous Indoor Localization System (ILSs) gives rise to the problem of switching from an ILS to a different one, and changing the localization technology.

In this paper, we focus on the last issue we mentioned, namely the handoff (or handover) procedure that we introduce in [2], [3]. The handoff procedure can be defined as a software routine designed to keep connectivity with infrastructures enabling the provision of a localization service, while the user moves indoor and/or outdoor. We first propose a macro-distinction between vertical and horizontal handoff, then we define three possible scenarios describing how ILSs can co-operate and how such cooperation can impact the handoff procedure. We propose single, aggregated and managed scenarios according the cooperation level. This work proposes for the first time a set of three algorithms, designed to trigger the handoff procedure. They all rely on a proximity detection strategy, which is based on the analysis of the signal strength from a device that advertises an ILS: Signal strength, Relative Signal strength and Relative Signal strength with hysteresis. In our experiments, we adopt the Bluetooth technology to advertise the existence of an ILS. We reproduce about 70 ILS's transitions, and we compute the probability of an early handoff (p_{eh}) and the Time of Reaction (T_R). From our experiments, we observe that the three tested algorithms behave differently, with a minimum p_{eh} of 0.2 values of T_R ranging from a minimum of -4.8s to a maximum of 5.9s.

II. The Handoff Procedure

With the term *handoff*, we refer to a software procedure enabling a device to switch connection between different localization systems. When comparing the handoff localization with telecommunication systems, we immediately observe less stringent constraints. As a notable example, the handoff applied to telecommunication systems [4], [5] mandatory requires to keep connectivity across different base stations, so that to avoid any possible voice interruption during a call [6], [7]. Differently, concerning a localization system, a user during the transition from a system to a different one, could be temporary disconnected from a localization system. Another remarkable difference between telecommunication and localization systems is that base stations are deployed contiguously, maximizing the spatial coverage of the broadband signal. Differently, we cannot assume the same deployment for indoor localization systems. More specifically, we consider that at least at the initial stages, ILSs could not cover the whole indoor location, rather some regions might not be provided by any ILS. Consequently, when defining the concept of handoff for ILSs, it is important to take into account whether ILSs are contiguous or not.

We first distinguish the concept of *horizontal* and *vertical* handoff. In the first case, it exists a transition between localization systems that use the same standard. In the context of Information and Communication Technology (ICT), a standard refers to a set of guidelines, specifications, or protocols that are widely accepted and adopted within the industry. Standards provide a common framework or reference point that enables interoperability, compatibility, and consistency across different technologies, products, and systems. Therefore, even if ILSs use different technologies, for example UWB vs WiFi, if they adhere to the same standard they are to be considered instances of the same heterogeneous network infrastructure that enables indoor localization. Differently, the transition from a localization system to a different one that is not compliant with the same standard is to be considered a vertical handoff. In this last case, even the same technology is used, there would be no way to automatically interoperate, but specific adapters should be implemented to overcome the differences between the two systems. Under this respect, the transition from the outdoor localization in which there are already well established standard like Global Navigation Satellite System (GNSS) to whatever standard will be adopted for indoor environment is to be considered a vertical handoff.

The distinction between horizontal and vertical is analogous to that used in telecommunications, where horizontal handoff occurs when a connection or call is transferred from one cell or antenna to another within the same wireless access network. In other words, the transfer occurs within the same type of network technology, such as between two cells in a cellular network or between two access points in a Wi-Fi network. The handoff is generally managed by the network infrastructure in cooperation with the mobile device, using common standards and interfaces. While vertical handoff refers to the transfer between different network technologies, such as from a wired network to a wireless network or vice versa.

Both handoffs are important to ensure continuous and uninterrupted service for mobile users in different situations and environments. In our context, the goal of the handoff procedure is enabling a user to navigate *seamlessly* in the environments she/he is visiting. The objective is to minimize user intervention, who should not perceive differences in the transition between outdoor/indoor or indoor/indoor locations. In this work, we focus only on the horizontal handoff, assuming that the ILSs we are traversing adhere to the same standard we proposed in [2], [3] and we refer to as ILBS: Infrastructure for Location-Based Services.

In the next section, we recall the key concepts of this proposal to arrive to describe how the handoff procedure fits into the various phases of the navigation life-cycle that characterizes the devices interfacing with systems ILBS-compliant.

A. Navigation Life-Cycle

In order to overcome the heterogeneity of current ILSs and enable their interoperability the proposal key concept is that ILSs are required to advertise their existence both in the surrounding environment (local advertisement) and on the Internet (global advertisement), describing their functionality by means of a **discovery mechanism**. ILSs, designed on heterogeneous localization technologies and techniques, are self-described through a descriptor (ILBS descriptor), allowing the user's devices, e.g. a smartphone to discover the ILS (*local search*) and to adapt to the specific characteristics of the localization system. More specifically, this might involve turning on specific network interfaces like Bluetooth, UltraWide band, or WiFi. Furthermore, these environments must be able to be identified even remotely with a simple search on the internet (*global search*) in order to plan a route to reach them and to execute a vertical handoff at arrival. Some key elements available with the ILBS descriptor are: i) the **maps** of the indoor environment, ii) information about the available **ILSs** and **sensor infrastructures** with their interfaces and protocols and iii) the **services** provided by the indoor environment to end-users, such a tour or a booking services.

The main entities involved in this discovery process are:

- the System Agent (SA): it is a software process representative of the information system that announces the characteristics of the smart environment equipped with one or more ILSs;
- User Agent (UA): it is a software component running on the user' device and interacting on user behalf with the available ILSs/SA.

The Navigation life-cycle can be described by the states and transitions occurring to the UA as reported in Fig. 1. The *Initiation* state can be triggered in various ways, here

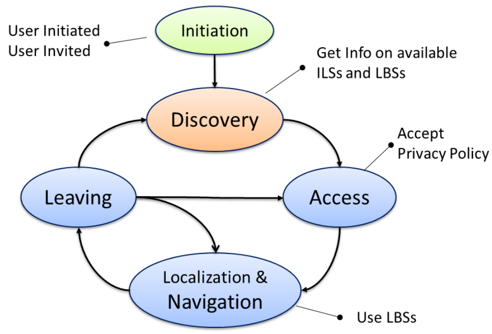

Fig. 1. Navigation life-cycle

we consider the case in which it is User Initiated, i.e. that it is the owner of the smartphone who wants to check if the environment, in which he has just arrived in, provides any location-based service. The user then triggers a search (local search) which marks the beginning of the *Discovery* phase. A local search requires that the UA scans the environment looking for some signals that indicate how to retrieve the ILBS descriptor. To this purpose, we can expect using Bluetooth's beacon messages based on the Eddystone format, which allow advertising URL. The Discovery phase ends when the UA retrieves the descriptor file. It can be implemented with a collection of metadata represented with a e.g. JSON or YAML syntax. The UA then moves on to the *Access* phase. During this phase, the UA requires to the user to accept/decline the privacy policies of the indoor environment [8]. The Access phase is determinant for the correct use of the localization services and it can determine a slowdown in the handoff procedure, as an explicit user's intervention is required. Once the Access phase concludes, the user can start using the available location-based services, namely the *Localization & Navigation*. The *Leaving* phase starts when the user exits the environment. At this stage, the UA releases the resources acquired during the visit. The leaving phase is closely related to the handoff procedure, as explained in Section II-B.

B. Handoff Operations and Scenarios

The Leaving phase begins when the user is about to exit the indoor environment. For this purpose, the UA must continuously check if the user is in proximity to an exit. This can be achieved by leveraging the user's position, proximity technologies, or a combination of these techniques. Therefore, the handoff procedure requires the UA to perform two high-level operations:

- triggering the handoff: this operation consists of detecting the conditions required for the UA to activate a vertical or horizontal handoff when approaching an exit;
- managing the handoff: this operation implements a set of steps required to: disconnect, connect and access from/to an ILS in order to switch localization system and resources.

We distinguish among three possible scenarios in applying handoff procedures: *Single*, *Aggregated* and *Managed*. Their underlying architectures describe the degree of cooperation between ILSs and they represent the natural way of deploying and interconnecting these systems over the time.

With the Single scenario, we assume that ILSs do not cooperate, rather each of them is an autonomous system. The user's device is required to discover an ILS as soon as it gets in proximity of it. The user has to accept, at least at the first visit, the privacy policy before to establish a valid connection. This is the case of ILSs deployed in various buildings of a city, and typically for these systems the focus is on seamless transition from an outdoor navigation to an indoor one. If there is no physical contiguity between the outdoor and indoor spaces, for example if the system is available only on a certain floor of the building, in addition to the coverage area, that is the spatial extent within which localization capabilities are operational and reliable, it is necessary to also provide a description of the proximity area, that is the information required to reach the coverage area: stairs, lifts and possible routes to reach the indoor space from the outside.

With the Aggregated scenario, we introduce a further complexity level. In this case, we assume that the description of different ILSs are aggregated in a unique ILBS descriptor and discovered by the UA at once. For example, this is the case of an wide shopping mall, equipped with 2 ILSs: the first covers the first floor, while the second provides localization services to the second floor. The ILSs may belong to different commercial entities, have been installed at different times and have different characteristics, but to provide a better user experience to the visitors who has just arrived at the large shopping centre, all the information of the area is provided during the discovery process at the main entrance.

We also consider a third scenario referred to as Managed. In this case, we assume the existence of an authority managing and coordinating the access to the indoor area. Similarly to the previous case, the user's device discovers all the ILSs at once, but a single authority is responsible for the localization policy. It authenticates and collects user consent, and provides an infrastructure for M2M communications between ILSs. This architecture is suitable for indoor environment in which it is required to control the access to specific areas for security reasons, e.g. an airport terminal.

State transitions occurring for the aforementioned scenarios are shown in Fig. 2. In the figure, we consider the UA moving from ILS_1 to ILS_2. In the case of single scenarios, the UA should start every time a new discovery process. Instead, in the case of aggregated or managed scenarios, some states can be skipped since the information is provided upon entering the area.

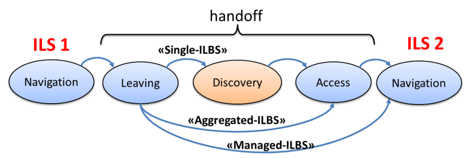

Fig. 2. Life cycle transitions in horizontal handoff

III. Radio-Frequency Handoff Decision Algorithms

We now propose three algorithms designed to implement the triggering operation defined in Section II-B. We show in Fig. 3 a user moving from ILS_1 to ILS_2. User's device is able to detect the proximity with respect to an ILS, through the signal strength analysis. In particular, the signal strength of ILS_1 decreases as the user moves away from it. Similarly, the averaged signal strength of ILS_2 increases as the user moves closer to it. Given the example reported in Fig. 3, we propose three possible algorithms to trigger an handoff procedure:

A1 - Signal strength: The device triggers an handoff only if the signal of the new ILS is sufficiently strong, i.e. greater than the threshold τ. In Figure 3, the handoff occurs at position C, if the threshold τ is set to R_{th1}. The general idea of this algorithm is avoiding an unnecessary handoff when the signal from a newly discovered ILS is still inadequate.

A2 - Relative signal strength: The device compares all the available ILS's signals, and it selects the strongest value independently from the actual signal's value. The target ILS is selected on an averaged measurement of the received signals. Referring to Fig. 3, the handoff occurs at position A. This algorithm avoids too many unnecessary handoff when the current ILS signal is still adequate.

A3 - Relative signal strength with hysteresis: the handoff is triggered only if the new ILS is sufficiently strong, given an hysteresis cut-off vale, namely h. In this case the handoff occurs at point B, as shown in Fig. 3. This algorithm prevents the so-called ping-pong effect between two ILSs [9], which is caused by fluctuations in the received signal strengths from the available ILSs.

We refer to Fig. 4 to describe our reference scenario. In the figure, we show two ILSs each covering a specific region: ILS_1 covers the orange region, wile ILS_2 the blue one. The transition between the two ILS is represented as a dotted-red line. We propose below a set of evaluation metrics for measuring the impact of the handoff:

- *Accuracy - A*: In the context of evaluating the performance of an handoff system in a classification task,

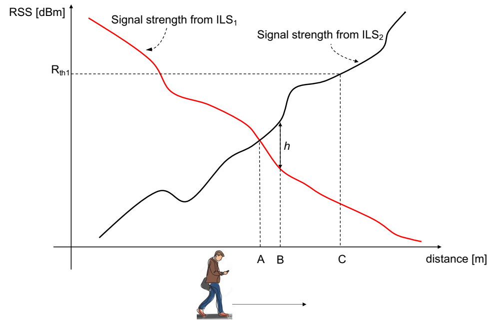

Fig. 3. Use of RSS with the handoff algorithms.

the accuracy metric measures the algorithm's ability to correctly determine the necessity of a handoff. It is calculated as the ratio of correct classifications to the total number of trials.
- *F1 metric* - F_1: Considers both the algorithm's ability to accurately detect the need for a handoff (recall) and its precision in correctly executing the handoff when necessary.
- *Probability of an early handoff* - p_{eh}: the probability that the algorithm returns an early transition with respect to the upcoming ILS. More specifically, given ILS_2 the localization system to which the users is approaching to, p_{eh} measures the probability that the algorithm returns ILS_2 even before the transition line (red-dotted line in Fig. 4;
- *Time of Reaction* - T_R: The time required by the algorithm to determine the ILS with respect to the transition line. This metric measures the triggering operation described in Section II-B. Given t_{GT}, the time of transition between two ILSs (red-dotted line in Fig. 4), and given t_{ET}, the time when the next transition is estimated, $T_R = t_{ET} - t_{GT}$. It is worth to notice that T_R can assume positive and negative values. On the first case, the algorithm is reactive, returning the correct ILS only *after* the user crosses the transition line. On the second case, the algorithm behaves in a proactive way, *anticipating* the ILS transition;
- *Time of Managing the Handoff* - T_H: The time required to manage the handoff procedure, as defined in Section II-B. This metric includes the steps described in Fig. 2. It is important to remark that, the time required to complete the handoff might be significant, therefore an algorithm anticipating the handoff procedure, i.e. a proactive algorithm, might mitigate the negative effect of significant values of T_H.

To further clarify the interconnection between the evaluation metrics, let's consider the following example. Suppose we have a system with $A = 1$, $F_1 = 1$ and $T_H = 3s$, indicating that: i)the algorithm successfully avoids unnecessary handoffs, ii) the procedure is accurate and iii) the handoff managing time requires 3 seconds. In this scenario, the optimal handoff procedure would be to have $p_{eh} = 1$, thus a fully proactive algorithm with a reaction time of $T_R = -3s$, thus compensating the managing time of 3 seconds. Indeed, setting $T_R = -3s$, the system becomes proactive and it initiates the handoff procedure 3 seconds ahead reaching the transition line. With $p_{eh} = 1$, the system consistently detects and predicts the need for a handoff, ensuring that all handoff procedures are completed precisely at the transition line.

IV. Experimental Settings and Results

We now detail the experimental settings that we use to test the handoff procedures in a realistic use-case. More specifically, we focus on the Managed scenario described in Section II-B and on the triggering operation. Therefore, in our experiments, the proximity information of both the departure and arrival ILSs is known a priori.

In particular, the goal is to show how it is possible for an UA to trigger the handoff procedure. We focus only on the use of the Bluetooth technology to detect the entrances and exits of the environments. Thus, data to be considered already acquired is the MAC, the SSID and the position of the beacons that mark the exit and entry of the respective ILSs. Moreover, the threshold and hysteresis parameters of the handoff algorithms, can be considered suggested data included in the same descriptor file retrieved during the discovery.

We assume a user moves in an indoor environment in which two ILSs are available. Each system covers a specific region, ILSs can be discovered with a wireless short-range technology, such as Bluetooth tags. To this purpose, we select as testing environment our research institute, namely ISTI-CNR located in Pisa. We identify a 20-meters long corridor of 1.8 m width and 3.1 m height. The corridor is characterized by offices both on the left and right side, as reported in Fig. 4.

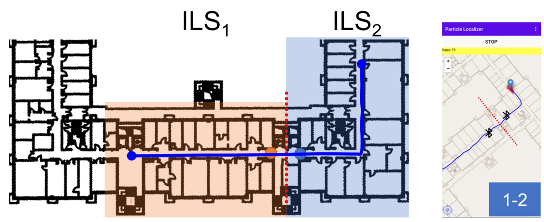

Fig. 4. Graphical representation of testing environment with two ILSs, the transition line is reported as red-dotted line.

ILS_1 covers the West side of the corridor, while ILS_2 covers the East side. The transition point between the two ILSs is a coffee area, and it is denoted with a red-dotted line in Fig. 4. The area covered by the two systems is delimited by Bluetooth beacons. In particular, we deploy 2 Bluetooth tags at 1.8 from the ground and 6 meters from the transition line reported in Fig. 4. Tags advertise iBeacon messages at $0dBm$ and $2Hz$ as advertisement frequency. Tags are small units powered with a CC2420 battery produced by GlobalTag.

A. Data Collection and Evaluation Metrics

Data are collected with a commercial smartphone, namely Google Pixel Pro 6 in which we install

`ParticleLocalizer`, an Android application designed to collect and log Bluetooth beacons. The app also estimates the user's position, showing the followed path, as reported in the right-side of Fig. 4. Tests are executed by a user holding the smartphone in hand and walking with a speed of approximately $1.1m/s$, the user acts as follows:

- she/he moves from ILS_1 to ILS_2;
- she/he moves from ILS_2 back to ILS_1.

The smartphone logs some information about the received Bluetooth beacons:

- timestamp of reception (Unix timestamp);
- MAC address;
- major and minor numbers;
- RSS value in decibel units.

Furthermore, we label the ILS's transitions (ILS_1 to ILS_2 and vice-versa) with the handoff Ground Truth (GT), namely the timestamp of a transition. More specifically, each time the user moves from an ILS to the adjacent one, we record the timestamp of transition. Such information can be used to compare the output of the implemented algorithms with respect to the GT. The format of the GT is the following: $< timestamp, ILS_x >$, where ILS_x identifies the destination ILS. On the right-side of Fig. 4, we show an example of the followed path testing the aforementioned transitions. The blue line shows the followed path, the pin icon shows the current user's position and the Bluetooth icon denotes the location of the Bluetooth tag delimiting the ILS. The figure also shows on the bottom-right corner the button to log the GT. In particular, every time the user moves from ILS_1 to ILS_2 or vice-versa, she/he logs the transition's timestamp pressing the button.

Our dataset comprises 64 transitions from ILS_1 to ILS_2 and vice-versa, with a total of 108.562 collected beacon messages from the tags positioned according to Fig. 4. Data collected with the smartphone are used to run the handoff algorithms. For the purpose of this work, we evaluate Accuracy, F1, the probability of an early handoff, p_{eh} and the Time of Reaction, T_R. We then analyze how p_{eh}, T_R are influenced by some algorithm's settings, as described in Section III.

B. Results

Experimental results are obtained by executing A1, A2 and A3 algorithm, with data obtained from the 64 ILS's transitions. Each of the algorithm analyzes the beacon values in a time window of t_w seconds, after which the algorithm outputs the corresponding result. The time window ranges in the interval 0.5s to 6s with a step of 0.5s. From our experiments, we obtain perfect Accuracy and F1 metrics (A = 1, F1 = 1) for the three tested algorithms, i.e. the algorithms always correctly trigger the handoff procedure. Concerning the p_{eh} and T_R, the results are reported in Fig. 5 and Fig. 6, respectively.

The probability of an early handoff is defined as the probability that the algorithm returns an earlier ILS transition, with respect to the transition point. Therefore, it measures the probability of anticipating the transition. From Fig. 5, we observe that t_w significantly impacts the performance of the three algorithms. More specifically, by increasing the time window t_w, the algorithms tend to reduce p_{eh}, thus they slightly postpone the ILS transition. This trend is evident for A3 algorithm (hysteresis-based). Indeed, as t_w increases, A3 triggers the handoff procedure by analysis beacon's values on a wider time period. The Time of Reaction T_R is defined as the time needed by an algorithm to return the correct ILS to which connect with, after the user crosses the transition line. In particular, when $T_R \leq 0$, then an algorithm is pro-active, while $T_R > 0$ implies an algorithm is reactive. From Fig. 6, we observe that t_w impacts the overall performance. The A2 algorithm is pro-active and it always anticipates the correct ILS to which connect with, the wider t_w, the earlier A2 anticipates the transition. Similar considerations also apply for A1 algorithm. Differently, A3 algorithm (hysteresis-based) is generally reactive also when varying the width of t_w.

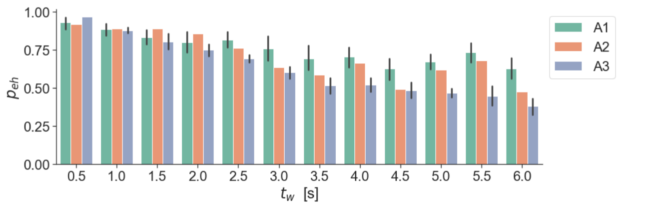

Fig. 5. Probability of an early handoff, p_{eh} by varying t_w.

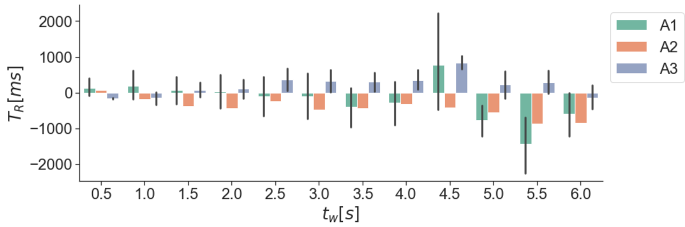

Fig. 6. Time of reaction, T_R by varying t_w.

We further investigate the performance of the handoff algorithms taking into account two settings: the threshold value τ (adopted with A1 Algorithm) and the hysteresis value h (adopted with A3 Algorithm). Concerning the threshold, we show in Fig. 7 the mean value of T_R ($\mu(T_R)$) and p_{eh} by varying: t_w in the range 0.5s to 6s and the threshold in the range -75dBm to -84dBm. The effect of the threshold is quite similar across different t_w values. More specifically, given $t_w = k$, it is always possible to observe a local minimum of the two metrics obtained with a specific value of the threshold. Concerning the hysteresis value, we show in Fig. 8 the results of T_R and p_{eh} by varying: t_w in the range 0.5s to 6s and the hysteresis in the range 1dBm to 10 dBm.

C. Determining Threshold and Hysteresis Ranges

The effect of threshold and hysteresis settings on the evaluation metrics is remarkable for A1 and A3 algorithms. We discuss in this section an empirical approach to determine the threshold and hysteresis in a realistic environment. The approach we follow consists of collecting beacon messages in

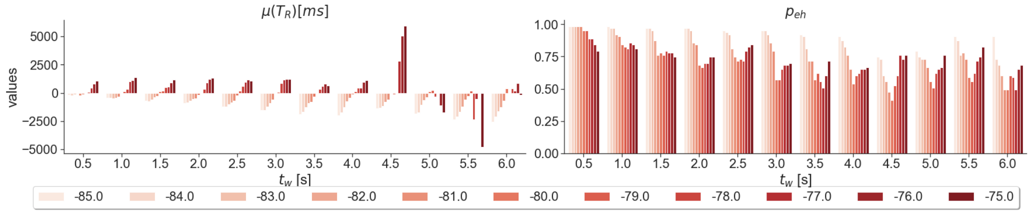

Fig. 7. Impact of the threshold values (τ from -85 dBm to -75 dBm) to T_R and p_{eh} for Algorithm A1.

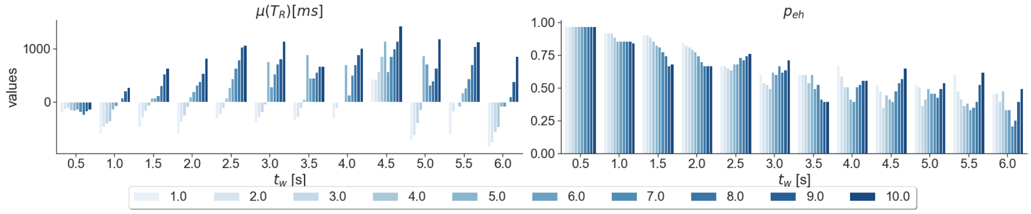

Fig. 8. Impact of the hysteresis values (h from 1 dBm to 10 dBm) to T_R and p_{eh} metrics for Algorithm A3.

the transition line. More specifically, we stay on the transition line for 30 seconds in each direction (east and west) and define τ as the average of the RSS measurements of the target ILS. While the hysteresis h is defined as the standard deviation of the collected RSS measurements. From the conducted tests, we measured $\tau = -78dBm$ and $h = 3dBm$. Given the time window $t_w = 3s$ (i.e., the handoff decision algorithm assesses whether to trigger the handoff procedure every 3 seconds), concerning A1 algorithm $T_R = 857ms$ and $p_{eh} = 0.65$, while for A3 algorithm $T_R = -190ms$ and $p_{eh} = 0.52$ (see Fig. 7,8) .

V. Conclusions

In our study, we focus on the handoff procedure, a software routine executed by the user's device to transition between localization systems when moving between indoors or outdoor-to-indoor environments. We propose a reference scenario coherent with a navigation life-cycle consisting of discovery, access, navigation and leaving phases. We test our approach in a realistic environment with two deployed ILSs and evaluate three handoff algorithms based on RSS analysis. We also introduce some evaluation metrics, designed to measure the performance of the triggering and managing operations of the handoff procedure. The experiments reported in this work only address the triggering operation characterizing the handoff procedure executed by the user's device. We plan to extend the proposed algorithms by taking into account other proximity techniques, such as the Time of Flight (TOF) and Angle of Arrival (AoA), in addition to incorporating position information. This multi-faceted approach aims to reduce power consumption due to radio listening. It is worth to notice that, at the current stage, a number of smartphones are already equipped with an UltraWide band (UWB) chipset. This technology allows a smartphone to estimate the distance from a tag (deployed in the transition area) more accurately than the use of commercial Bluetooth tags. Another line of investigation is to reduce energy consumption due to the radio listening. It is advisable to activate radio listening only when we are close to the exits, thus exploiting the position estimation offered by the ILS.

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