

Optimizing Handover in Time-Sensitive Wi-Fi Networks through Machine Learning

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Abstract—Time-Sensitive Networking (TSN) plays a crucial role in ensuring determinism and low latency, vital for the demands of industrial applications. Integrating the benefits of wireless networks, including mobility, presents a significant challenge in such environments. In this study, we propose a novel solution to address this challenge by introducing handover capabilities into wireless Time-Sensitive Networking (W-TSN). Through real-world development and testing, we present an optimized approach for minimizing handover delay and leveraging machine learning to select the optimal handover time and space moment in a two-dimensional environment, with low effect on time-sensitive traffic. Our findings demonstrate that our mechanism reduces handover delay below 10 milliseconds and optimizes the handover moment selection, leading to improvements in critical network parameters such as bandwidth and jitter.

Keywords—wireless time-sensitive networking; IEEE 802.11; handover; ML; openwifi; UWB.

I. INTRODUCTION

In industrial automation, it is critical to efficiently utilize network resources, particularly for real-time and safety-critical applications. This is especially evident in collaborative scenarios involving robots, where precise communication among human operators and other robots is essential for synchronized operations and safety compliance [1]. In order to provide such high precision and predictability guarantees, and avoid network oversizing, especially in critical applications, a network paradigm has been introduced: time-sensitive networking¹ (TSN).

By combining several standards, including IEEE 802.1AS [2] for time synchronization, IEEE 802.1CB [3] for reliability, and IEEE 802.1Qbv [4] and IEEE 802.1Qav [5] for traffic scheduling, TSN effectively establishes the foundation for determinism over Ethernet networks. In addition to its well-established benefits in industrial automation, TSN brings numerous advantages in diverse applications, spanning automotive networks, smart grids, healthcare, Industrial Internet of Things (IIoT), audio/video streaming, and beyond [6]. The common factor in these varied domains lies in the essential

requirement for wireless flexibility. The integration of TSN into wireless systems, often referred to as Wireless-TSN (W-TSN), has emerged as a focal point of recent research, marking it as the next logical progression for TSN technology [7]. Nevertheless, the convergence of wireless, a technology known for its stochastic nature, with TSN, which promotes determinism, prompts several inquiries.

In our recent work, our research group has pragmatically tackled a number of these concerns, emphasizing areas such as management [8], association [9], application-network integration [10], and mobility, as introduced in [11], and extended in this current study. The stochastic nature of wireless communications poses a challenge in adapting and finding optimal configurations. To tackle this, the industry proposes paradigms like joint sensing and communication. One variable that has proven to be a convenient addition is localization [12]. However, until now, the dependency on extra infrastructure has reduced its usability. But this is changing thanks to vendors that are incorporating ultrawideband (UWB) modules into their Wi-Fi chips [13], [14]. The inclusion of sensing in wireless would inherently improve the global network vision, being a rich source of information; however, it would increase the complexity of the system.

The consideration of numerous variables, subject to change due to mobility, prompts the exploration of alternative solutions such as machine learning (ML), a pivotal aspect of this study. ML finds extensive application across various domains, including computer vision, robotics, and communications. In Wi-Fi communications particularly, ML has been proposed for enhancing Channel State Information (CSI) feedback compression, distributed channel access, multi-AP coordination, and handover improvements, aligning with the objectives of this study [15].

Within the realm of wireless communications, an essential operation is handover, facilitating seamless transition for wireless clients, or Stations (STAs) in Wi-Fi, between Access Points (APs) while preserving uninterrupted connectivity [16]. Despite its significance, standards for handover are notably

¹<https://1.ieee802.org/tsn/>

lacking. Existing standards do not offer a unified solution, and only a few vendors implement them, creating interoperability issues [17], [18]. This gap is further pronounced in the context of W-TSN, accentuating the necessity for a comprehensive approach. Mobility undoubtedly emerges as a pivotal aspect in the seamless integration of wireless and TSN. Consequently, the primary objective of the present work is to devise a practical, Wi-Fi-based solution, building upon the work presented in [11], in a realistic two-dimensional environment. This solution aims to empower applications to harness the performance guarantees of TSN while enjoying the flexibility of wireless communications.

The subsequent sections are structured as follows: in Section II, the incompatibilities of the current handover procedure and W-TSN are described. Section III reviews related work on W-TSN handover and the use of ML in handover. Section IV describes the proposed W-TSN handover procedure. Software implementation details are provided in Section V. Section VI presents findings on handover delay and moment selection in both uplink (UL) and downlink (DL). Finally, Section VII summarizes and concludes the study.

II. THE HANDOVER PROBLEM

Typically triggered by values of the Received Signal Strength Indicator (RSSI) falling below a defined threshold, as specified by IEEE802.11 and IEEE802.11f, the handover procedure can be segmented into three distinct phases: i) scanning, ii) authentication, and iii) association [19]. The STA initiates the scanning of neighboring APs through one of the two possible methods. The first method, active scanning, involves the STA switching to a specific channel, transmitting Probe Request frames, and receiving of Probe Response frames from APs. The STA then returns to its original channel. The second method, passive scanning, requires hosts to identify APs by scanning various channels and waiting a dwell time of typically 120 ms, on each channel to intercept broadcast beacon frames. Once a suitable candidate is identified, the STA disassociates from the initial AP and initiates an association and authentication procedure with the target AP.

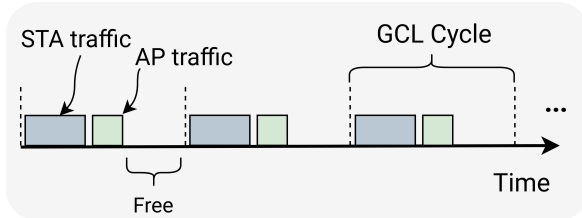


Fig. 1. Basic TSN Schedule

Analyzing the described handover procedure within the TSN framework reveals inherent incompatibilities. As illustrated in the basic TSN scheduling example of Figure 1, in TSN, traffic flows are assigned cyclic transmission timeslots based on their application requirements, such as those of the STA and AP in this basic example. A frequently utilized value for the cycle

time in machine control loops using common protocols such as PROFI-safe is often defined at around 10 milliseconds [20]. This cycle time serves as the basis for defining the node gate control list (GCL) cycle, as illustrated in the Figure. Returning to handover, the active scanning procedure, which includes channel switching delays typically in the order of tens of milliseconds, must fit within the available TSN schedule free space, utilizing valuable time resources. On the other hand, in the passive scanning case, it extends the required time significantly, reaching hundreds of milliseconds due to the dwell time, thereby making it incompatible with the transmission cycles of TSN. Furthermore, in both cases, while the STA is on a different channel, it will not be able to receive transmissions from its own AP.

In addition to the apparent incompatibilities in the handover procedure with TSN, it becomes imperative to optimize the handover process to minimize its impact on time-sensitive traffic. This optimization must aim to minimize handover delay and strategically choose the optimal moment for its execution. Handover delay is defined as time elapsed from the reception of the last frame from the current AP to the receipt of the first frame from the target AP, with no other intervening traffic [21]. Such an approach ensures the least possible disruption to time-sensitive traffic, aligning effectively with the specific requirements of W-TSN. Considering the identified constraints and available tools, the present study introduces the following contribution: a practical implementation of AP candidate determination in a two-dimensional space, reducing the need for channel scanning. This is accomplished through the integration of Ultra-Wideband (UWB)-based localization and RSSI measurements within a machine-learning model.

III. RELATED WORK

Currently, there's limited research on enabling mobility in nodes while ensuring time sensitivity in wireless systems. Notably, authors in [22] present a zero-delay handover approach, utilizing redundant communication over multiple radios per STA. Such an approach introduces complexity in TSN scheduling and handover delay management. The approach is evaluated in simulations as well as real-world experiments. While this approach would indeed enhance reliability, in our research, we demonstrate hardware-controlled optimizations that reduce handover delay while maintaining a single radio setup, simplify the procedure, optimize time resource utilization, and minimally affect time-sensitive traffic.

In [23] authors introduced a decentralized architecture where the STA initiates handover decisions, deviating from our centralized approach. This decentralized model relies on a single radio at the STA, posing challenges for achieving seamless soft handover due to TSN scheduling and channel switching speeds, often in the tens of milliseconds range. Thus, achieving true soft roaming without disconnections, as in cellular networks, remains challenging for real-world applications.

The Artificial Intelligence Machine Learning (AIML) Topic Interest Group within the IEEE 802.11 working group ex-

plores the application of AIML in IEEE 802.11 systems and devices, assessing technical feasibility. In their latest report [15], handover recommendations include adding weights to AP candidates based on handover probability predictions to prioritize channels in the scanning stage and predicting RSSI values to determine the optimal handover moment, facilitating STAs in initiating the scanning process at the right time. Given the absence of W-TSN conditions concerning channel scanning, these recommendations do not present a viable solution for time-sensitive applications. However, they underscore the importance of utilizing RSSI in the handover process.

Other works, such as the one discussed in [24], delve into integrating machine learning into the handover decision algorithm known as ABRAHAM. This algorithm incorporates various decision criteria, including load, RSSI, and location. Machine learning techniques are employed to forecast these variables and facilitate proactive handover decisions. However, these predictions rely on gathered RSSI data, which is subsequently utilized for localization calculations. Although it presents a centralized approach, in contrast to our approach, this data collection method overlooks time-sensitive traffic interruptions, and the localization accuracy is notably inferior, with an error margin of approximately 3 meters. In contrast, our system leverages UWB-based localization technology, achieving precision levels as fine as 30 centimeters.

Our earlier research [11] laid the groundwork for this study, focusing on one-dimensional movement between two access points (APs). It utilized intersections of RSSI-distance curves to guide handover decisions. In contrast, our current study extends this work to two-dimensional movement with an additional AP. Here, we use intersections of surface models to more precisely determine handover areas. Our refined model adjusts better to real-world RSSI fluctuations, avoiding dependence on equation fitting and thereby increasing realism.

A significant divergence between our approach and existing methods is the emphasis on maintaining time synchronization and providing a transmission schedule, which is critical in time-sensitive networks. None of the current methods address the need to identify candidate APs for handover without disrupting time-sensitive traffic. Traditionally, the STA has been responsible for handover decisions. However, in W-TSN, which prioritizes determinism and enhanced network control, centralized handover decisions align better with its principles.

IV. W-TSN HANDOVER

Considering the reliability and latency constraints of TSN, along with the unique aspects of wireless communications in W-TSN, we have developed a process focused on minimizing the impact on time-sensitive traffic by strategically selecting handover moments. Before diving into the process, we will outline the involved topology, devices, and modules.

A. W-TSN Handover Architecture

Among the proposed configurations in TSN, as seen in Figure 2, we chose the centralized one due to its centralized network perspective and control advantage, key aspects in the

decision-making during handover. In this network architecture, the Centralized User Configuration (CUC) and the Central Network Controller (CNC) manage the computation and distribution of schedules across TSN nodes. The TSN switch forms the core wired part and is responsible for handling and forwarding time-sensitive traffic flows. The APs represent the wired network's edge, providing wireless communication for the STA.

An essential addition is the Handover Controller Module (HCM) at the controller and a Handover Agent Module (HAM) at the STA. These modules play an important role in handover management by detecting the need for handover and initiating the process. In addition to the wired and wireless time-sensitive links, a management and configuration network is presented. This network serves two primary objectives. First, it facilitates the HCM in gathering information concerning the STA link status. Simultaneously, it is employed to provide the STA through the HAM with the necessary handover information and it triggers handover, as described in the following section.

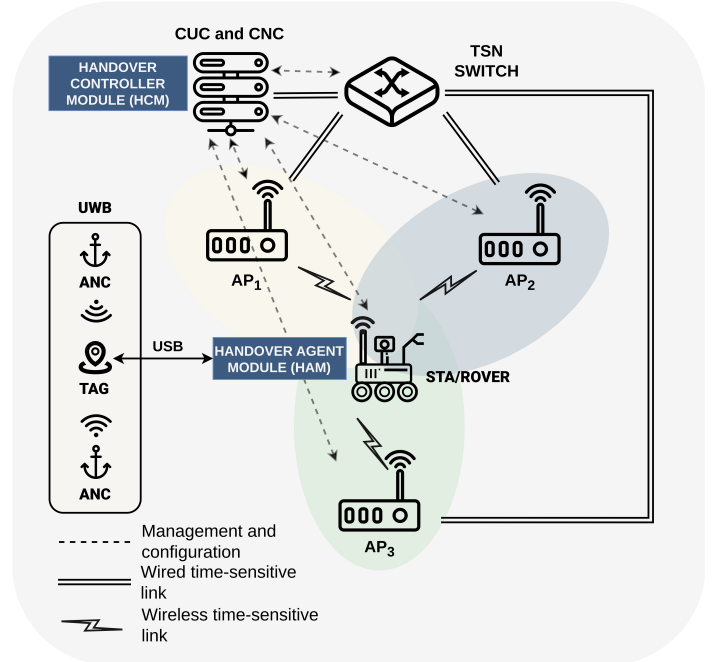


Fig. 2. Topology and testing setup

B. W-TSN Handover Procedure

Figure 3 illustrates our proposed state diagram for W-TSN handover. This section aims to offer a comprehensive overview of the handover procedure. However, for a more thorough understanding, detailed information on the procedure is available in [11]. To streamline the procedure, we have segmented it into four distinct states, outlined as follows:

- 1) Before HO: In this state, the STA is connected to an AP with a tailored transmission schedule, meeting its traffic demands. No handover is required in this state.

- 2) AP candidates determined: In this state, the HCM and HAM utilize a traffic flow impactless method, like localization, to assess link quality with potential APs. In case of the need for handover the next state follows.
- 3) Handover Prepared: In this state, the handover decision is finalized, and resources along the new path, including the transmission schedule, are prepared. Both TSN and STA are ready for the handover trigger.
- 4) Handover Done: The STA has transitioned to the target AP and can communicate with TSN using the new transmission schedule. STA then reverts to State 1.

Upon identifying the necessity for handover, driven by factors such as signal strength degradation, load distribution requirements among APs, or STA localization/mobility, the selection of candidate APs must be executed without disrupting time-critical traffic. To achieve this, we propose a combination of localization and telemetry. By using localization capabilities, the STA can precisely determine its location and relay this information to the HCM via the current AP using the management link. Hence, the HCM can discern one or more candidate APs suitable for handover, based on factors including the STA's position, AP locations, and telemetry data indicating signal quality for specific STA-AP pairs at different locations.

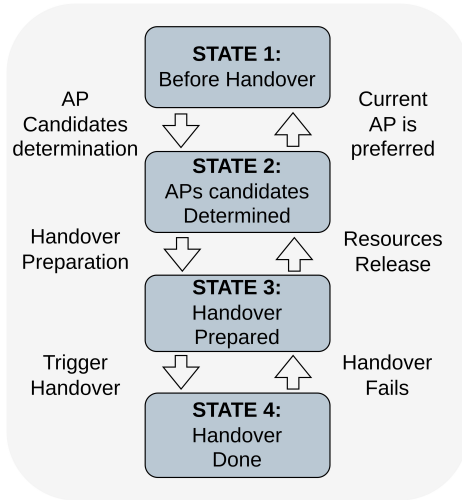


Fig. 3. Handover Procedure

Given that the description of other state transitions falls outside the scope of the present study, we will not dive into other state transitions. Nevertheless, it is important to mention that during handover preparation, the resources at the target AP as well as along the new transmission path must be prepared. Additionally, upon initiation of the handover process, information such as the updated transmission schedule or the designated time for handover execution must be communicated. In case of a handover failure due to issues like failed wireless association or unfavorable channel conditions, a contingency mechanism must promptly revert the STA to its previous AP. The primary objective is to minimize disruption to traffic flow(s).

V. W-TSN HANDOVER IMPLEMENTATION

In the described handover procedure, the handover delay and spatio-temporal moment selection methods are identified as critical processes. The handover delay predominantly affects the potential risk of frame loss, whereas the handover spatio-temporal moment selection is focused on optimizing variables like throughput and jitter, as substantiated by our results. This section will provide an exploration of these processes' respective functionalities and descriptions.

A. Handover Delay

Once the HAM within the STA receives instructions from the Controller's HCM, it starts the handover process from the user space. This process unfolds across four sequential steps. Initially, to prevent transmissions during handover, the Clear Channel Assessment (CCA) threshold is adjusted downward. Subsequently, both transmission and reception channel frequencies are aligned with the target AP channel frequency. Following this, the new transmission schedule is established, and ultimately, the CCA threshold is restored to its default setting. These specified parameters are typically configured directly from the driver, avoiding *netlink* communication delays between the user space and the driver itself. Consequently, direct register manipulation has been implemented using C code to mitigate these delays effectively.

B. Handover Moment Selection

The incorporation of UWB-based localization into W-TSN offers the advantage of eliminating the need for using time space to make handover decisions. Location information together with RSSI values are collected in HCM utilizing a telemetry mechanism. Nevertheless, as commonly acknowledged, in wireless communications, the correlation between STA localization and link quality may not be straightforward, varying based on the particular application and environmental conditions. Moreover, this relationship can evolve over time, presenting an additional challenge. Hence, these dynamic scenarios must be taken into account when formulating a solution. Following the previously described process, the subsequent approaches are formulated at the HCM. The HCM leverages the received information to make decisions based on one of the following specific algorithms:

- **Fixed polygon-based:** The first solution we propose does not fully consider the aforementioned challenges, however, it brings useful insights and a comparison point towards our next solution. Therefore, this approach involves dividing the space through which the STA navigates into fixed polygons, establishing well-defined handover borders. To mitigate the ping-pong effect, where the STA frequently switches between different APs along a border, a buffer zone is introduced. This buffer zone replaces the rigid boundary line with two distinct borders, effectively addressing the issue.

As illustrated in Algorithm 1, this mechanism initiates by receiving the localization information of the STA. Subsequently, it verifies the belonging of the position

with one of the polygons. Finally, taking into account the current AP and circumventing the buffer zone, the decision is made.

Algorithm 1 Fixed Polygons

Input: $localization_coordinates(loc)$, $polygons(pol_i)$, AP_{now}

Output: AP_i

Initialization :

```

0: Receive  $loc$  {Localization coordinates are received at the
   HCM}
0: if  $loc$  is within  $pol_i$  then {Check if the space point belong
   to any of the provided polygons}
0:    $AP_i = pol_i$ 
0: else
0:    $AP_i = 0$  {When in buffer zone}
0: end if
0: if  $AP_i \neq AP_{now}$  and  $AP_i \neq 0$  then {Check if already in
   the AP and not in buffer zone}
0:   Handover to  $AP_i$  {Command HO using the HAM}
0:    $AP_{now} = AP_i$ 
0: end if return  $AP_{now} = 0$ 

```

- **Machine Learning online-based:** Acknowledging the challenges mentioned within a two-dimensional environment, we propose a machine learning (ML)-based modeling approach. This method continuously learns from the captured values of localization and RSSI. The mechanism involves two distinct stages:

- 1) The initial offline stage involves capturing channel information in tuples (localization, RSSI) to train the models. This is achieved by connecting the STA to an AP_i and relocating the STA over a specified duration, denoted as t . Subsequently, the acquired channel information is utilized to train an artificial neural network (ANN) model. This model is designed to predict the RSSI value corresponding to a specific STA position in relation to an AP_i . Hence, the number of models corresponds to the number of present APs.
- 2) Following the completion of the initial model training, the subsequent phase involves the online stage, as illustrated in Figure 4 and described in detail in the next steps:
 - a) Initially, the HCM receives localization information along with the RSSI from AP_i .
 - b) Subsequently, the decision to update the current model depends on the absolute difference between the sampled RSSI and the RSSI predicted by the AP_i model as seen in Equation 1:

$$|RSSI - RSSI_{model_i}| \geq u_{th} \quad (1)$$

Where $RSSI_{model_i} = AP_i model(x, y)$.

This discrepancy sets the update threshold u_{th} , a parameter that can be adjusted as required.

- c) If the condition specified in Equation 1 is satisfied, the sample (AP_i ; x, y ; RSSI) is stored in an update

cache of size u_{ch} . The purpose of the update cache is to promote batch updates of model(s) instead of individual updates, thereby minimizing the overall model update delay.

The model is updated using the online gradient descent method with a constant learning rate. Where the parameters of the network (weights and biases) are updated following Equation 2:

$$\theta_{new} = \theta_{old} - \eta * \nabla_{\theta} Loss \quad (2)$$

where, θ is the parameter, η is the learning rate and $\nabla_{\theta} Loss$ is the gradient of the loss with respect to the parameter [25].

- d) If Equation 1 is not met for the given sample, the subsequent step involves examining whether the sample belongs to a buffer zone. The buffer zone is created by identifying the intersection lines of the models and its purpose is to avoid the ping-pong effect.
- e) If the STA is not within a buffer zone, the subsequent step is to predict an RSSI value for each available model and compare them to identify the highest one.
- f) Finally, if the best AP model does not correspond to the current AP (AP_{now}), a handover command is sent to the HAM, specifying to which AP the STA should initiate the handover.

In summary, the outlined procedure shows adaptability to wireless environment fluctuations using STA localization and RSSI measurements. Importantly, enhancing the models could involve multiple STAs, not just a single one, which can improve accuracy. During the online stage, responsiveness depends on correctly setting η and u_{th} to manage RSSI changes effectively.

VI. MEASUREMENT RESULTS

In the following subsections, we will describe the measurement setup as well as results in terms of handover delay and handover impact in throughput distribution.

A. Setup Description

The proposed W-TSN handover procedure has been implemented and evaluated using the openwifi IEEE802.11/Wi-Fi baseband chip/FPGA design [26]. As illustrated in Figure 2, the mobile wireless client features a Xilinx Zedboard, acting as the STA. This is connected via Ethernet to an Intel Next Unit Computing (NUC) end node to control a Rover Zero 3 robot. In our configuration, each AP utilizes a Xilinx ZC706 board. These APs are connected through Ethernet to a Qotom Q818GE Linux TSN Switch, which, in turn, is linked via Ethernet to another NUC, serving as the CNC/CUC.

The UWB localization system is composed of four Anchors (ANC) positioned at the edges of the testing zone, and a mobile TAG, which is attached to the STA board through a Universal Serial Bus interface. The UWB hardware is part of

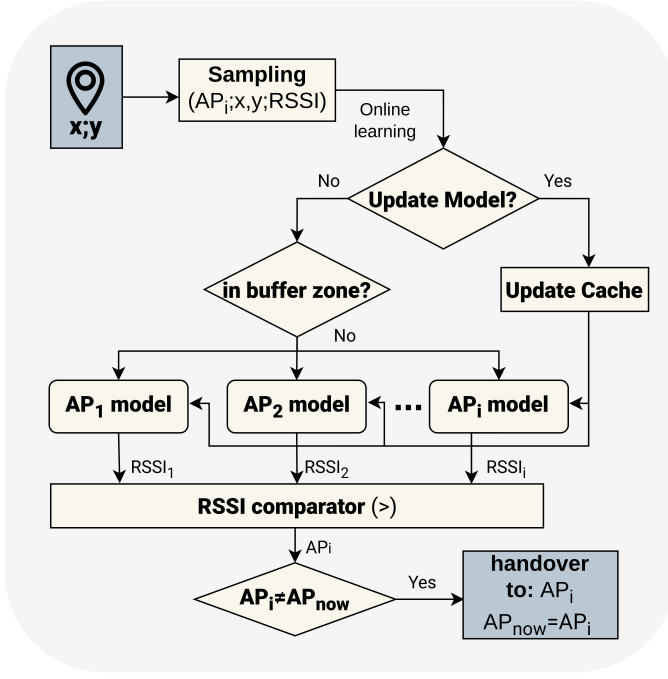


Fig. 4. ML online stage

the Wi-PoS platform, ensuring localization precision within the 5-centimeter range. This system is further augmented by a sub-GHz wireless infrastructure, facilitating seamless inter-communication, as detailed in [12]. The implementation and testing of this setup were conducted in a warehouse environment with metal shelves surrounding a 2x3 meter testing zone.

Finally, the management and configuration of the network are orchestrated through a ZeroMQ PUB/SUB model, enabling seamless message exchange between the HCM and HAM. The HCM can trigger an AP handover as needed, while the HAM communicates real-time coordinates and current RSSI values to the HCM.

B. Handover Delay

To measure handover delay in a real-world scenario, we utilized testing traffic comprising 100k ping frames generated every 1 millisecond, transmitted between the CNC and the mobile STA. At the receiver end, we measured the inter-ping arrival times to assess the impact of handover. Initially, a test without roaming was conducted in UL and DL directions to establish a baseline. Subsequently, tests involving continuous handovers were performed. Figure 5 shows handovers causing less than a 10-millisecond delay in frame reception for both UL and DL. These results include not only handover delays but also frame processing or transmission delays at various nodes, enhancing the realistic portrayal of handover delays from an end-to-end perspective.

C. Handover Moment Selection

To evaluate the handover moment selection algorithm, we utilized the topology illustrated in Figure 2. Table I provides a summary of the parameters employed for the testing. Figure 6

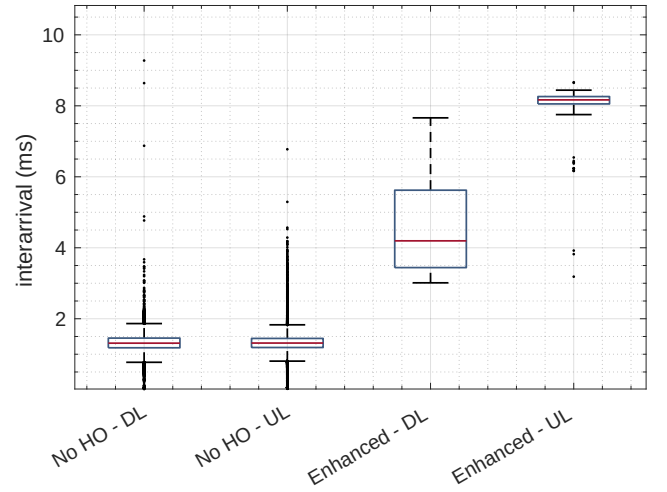


Fig. 5. End-to-end Handover Delay

depicts the TSN schedule utilized, where STA_i corresponds to the STA connected to the AP_i . In this schedule, the first timeslot in queue 0 is allocated for time synchronization via precision time protocol (PTP). Subsequently, queue 1 is dedicated to iperf testing traffic, while queues 2 and 3 in the final timeslot are designated for management and configuration traffic.

Table I
MEASUREMENTS PARAMETERS

Parameter	Value
Measurement time	150 s
APs distance (d)	3 m
APs channels	5955, 5975 & 5995 MHz
Data rate	26 Mbps
Bandwidth	20 MHz
iperf traffic	UL&DL at 5Mbps
Rover speed	0.4 m/s
t_s	40 ms

Cycle: 2048 us				
	512 us	512 us	512 us	512 us
AP ₁ :	PTP		iperf	C&M
AP ₂ :	PTP	iperf		C&M
AP ₃ :	PTP		iperf	C&M
STA ₁ :	PTP	iperf		C&M
STA ₂ :	PTP		iperf	C&M
STA ₃ :	PTP	iperf		C&M
	Q0	Q1	Q1	Q2/Q3

Fig. 6. Testing Schedule

The ANN employed in our study comprised five layers with 64, 32, 16, 32, and 1 neurons, respectively, utilizing a rectified

linear activation function, also an u_{th} of 10 dBm, and η of 0.0001 were used for the online training. Figure 7 illustrates the training measurements conducted with the mobile STA connected to each AP, along with the resultant models utilized in the offline component of the handover selection algorithm. As observed, the APs are positioned in a triangular formation. For the testing, the mobile STA was programmed to follow a fixed trajectory around the testing zone, ensuring that it crosses all three coverage zones. Another essential step in the algorithm's functionality is identifying the buffer zone during model updates. This is achieved through image processing tools, initially by delineating the edges of the APs' optimal coverage zones, as illustrated in Figure 8.

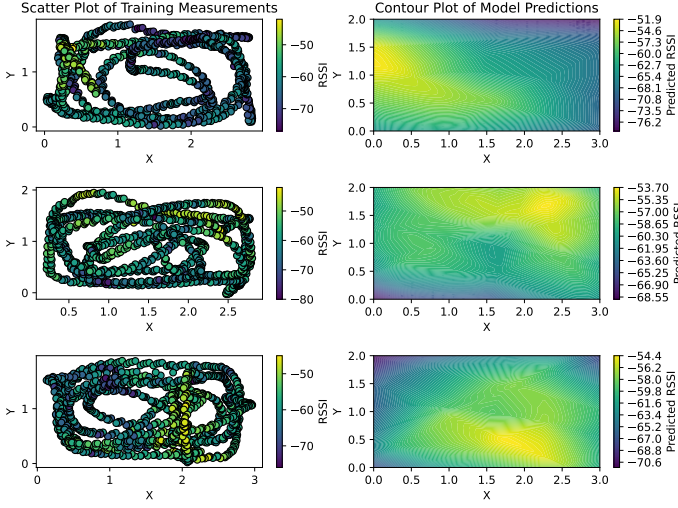


Fig. 7. Models offline training measurements and resultant predictions

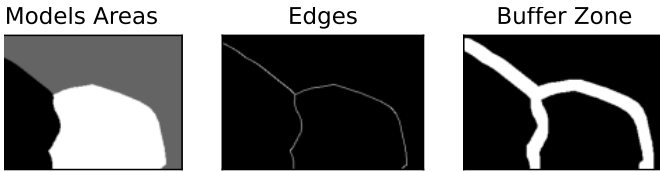


Fig. 8. Buffer zone generation

Figure 9 illustrates the throughput distributions of iperf traffic in three scenarios: no handover with the STA associated with only one AP, with the fixed polygon algorithm, and with the machine learning online algorithm for both UL and DL traffic. In the UL case, the distributions appear quite similar, whereas in the DL case, the online scenario seems to resemble the no handover and fixed polygon cases more closely.

Another crucial network variable, particularly for TSN, is jitter. Figures 11 and 10 present the jitter results of the aforementioned scenarios in both downlink (DL) and uplink (UL), respectively. It is evident the advantage of the online method compared to the fixed one. This advantage, observed in both throughput and jitter, stems not only from optimal handover moment selection but also from the reduction in the number

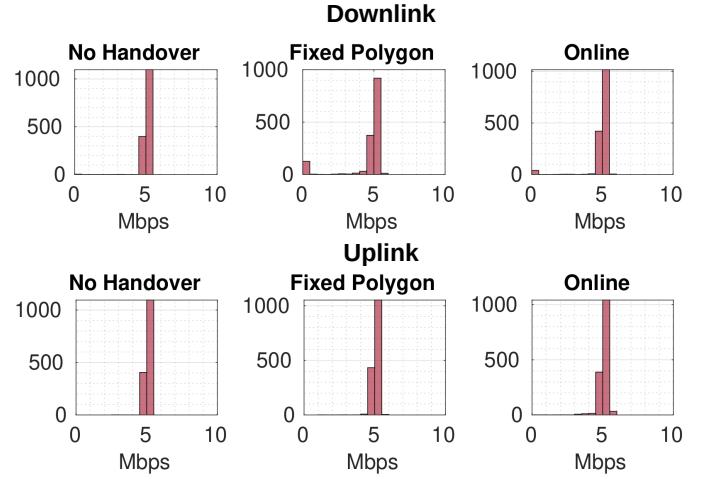


Fig. 9. Downlink and Uplink Throughput Distribution

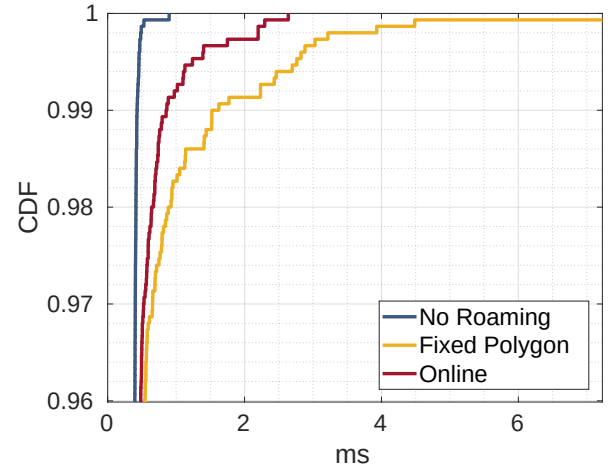


Fig. 10. Uplink Jitter CDF

of handovers due to updates in the APs' coverage areas. Specifically, in case of online learning method, the number of handover moments during one measurement decreased from 46 to 40 and from 46 to 38 for UL and DL measurements, respectively.

VII. CONCLUSION AND FUTURE WORK

Through the development of a state machine procedure tailored for handover within Wi-Fi-based Wireless Time-Sensitive Networking (W-TSN), along with optimizations aimed at minimizing handover delays, and the incorporation of a UWB machine-learning algorithm to predict RSSI variations across different locations for optimal handover timing while ensuring non-interference with time-sensitive traffic, a comprehensive handover solution has been realized. Empirical findings highlight the effectiveness of combining a rapid handover mechanism (< 10 ms) enabled by openwifi with a self-learning algorithm for selecting the optimal handover moment, leading

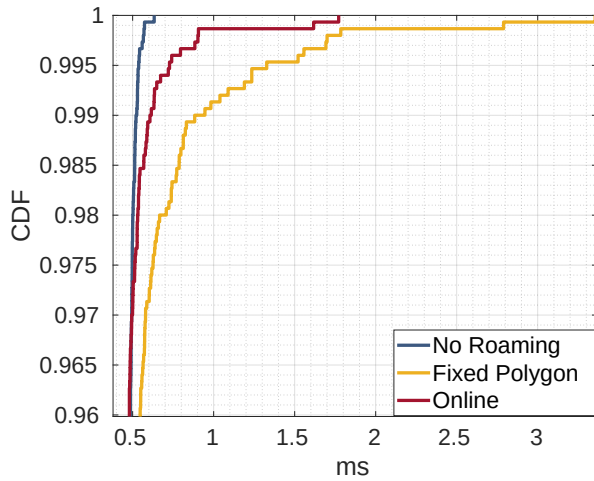


Fig. 11. Downlink Jitter CDF

to reduced jitter and improved throughput—essential factors for enhancing determinism in TSN. Future efforts will focus on assessing the models' stability during significant RSSI variations. Moreover, we will explore more computationally efficient online learning methodologies and their integration with other non-interruptive, time-sensitive traffic strategies and KPIs such as load distribution, packet loss, and jitter. This integration may occur in realistic environments with additional APs and STAs to enhance the solution's robustness and representativeness.

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