FIND: an SDR-based Tool for Fine Indoor Localization

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Abstract—An indoor localization approach uses Wi-Fi Access Points (APs) to estimate the Direction of Arrival (DoA) of the Wi-Fi signals. This paper demonstrates FIND, a tool for Fine INDoor localization based on a software-defined radio, which receives Wi-Fi frames in the 80 MHz band with four antennas. To the best of our knowledge, it is the first-ever prototype that extracts from such frames data in both frequency and time domains to calculate the DoA of Wi-Fi signals in real-time. Apart from other prototypes, we retrieve from frames comprehensive information that could be used to DoA estimation: all preamble fields in the time domain, Channels State Information, and signal-to-noise ratio. Using our device, we collect a dataset for comparing different algorithms estimating the angle of arrival in the same scenario. Furthermore, we propose a novel calibration method, eliminating the constant phase shift between receiving paths caused by hardware imperfections. All calibration data, as well as a gathered dataset with various DoA in an anechoic chamber and in a classroom, are provided to facilitate further research in the area of indoor localization, intelligence surfaces, and multi-user transmissions in dense deployments.

I. INTRODUCTION

The indoor localization problem has attracted much attention recently. For instance, various scenarios require positioning inside buildings, where conventional solutions, such as GPS, are not applicable. Recently, localization has become crucial for a novel paradigm of intelligent surfaces [1]. A possible approach to the indoor localization problem is to use Wi-Fi Access Points (APs), which are currently widespread. Many of them utilize antenna arrays to increase throughput with the MIMO transmissions. Information, e.g., the gain and phase difference, received by these arrays could be used to estimate the Direction of Arrival (DoA) of the signals from client devices. Afterward, such directions from several APs can be combined together to reveal the device location.

Several promising techniques, introduced in papers [2,3], including machine learning methods in paper [4], show excellent results with decimeter accuracy. However, the problem of the best DoA estimation is still open because of two issues. First, the existing approaches have never been compared with each other in the same scenarios. Moreover, they may rely on the different channel information. Some of them [3,4], operate with Channel State Information (CSI), while others [2] require IQ samples in the time domain. Unfortunately, there are no available datasets containing enough information to compare all the algorithms. Second, the existing approaches are implemented on various hardware platforms with different capabilities, often too poor. Many works [3,4] exploit Intel CSI Tool, providing CSI for 30 subcarriers out of a hundred of a 40 MHz frame, while the CSI values for the rest are skipped. A rare exception is a software-defined radio testbed [2] that employs only L-STF, the first field of the Legacy preamble, which is used for start-of-frame detection, for coarse frequency offset compensation, and for setting the receiver’s amplifier. Other fields remain unused, while the amount of information extracted from each frame directly affects the quality of DoA estimation.

To solve these issues, we present FIND (the tool for Fine INDoor localization), the 4-channel receiver based on NI USRP-2955, capable of capturing real Wi-Fi frames in the 80 MHz band. It retrieves CSI from all 242 subcarriers, as well as all time-domain IQ samples of the Legacy preamble, needed for backward compatibility, and VHT preamble, its extension for higher data rates. Fig. 1 shows an example of such information. Eventually, we introduce a dataset with all such information at different DoA, which can be used for comparing different DoA estimation algorithms under equal conditions. In addition, we provide supplementary data for calibration by our invented method detailed below. The developed prototype can be used not only for DoA estimation in typical localization systems and emerging reconfigurable intelligent surfaces. In addition, it can also be used for the investigation of the properties of the MIMO channel in Wi-Fi networks.

II. FIND DESCRIPTION

In our testbed, we use NI USRP-2955 as a receiver connected to the laptop having LabVIEW 2020 software. This equipment allows data receiving and processing in an 80 MHz band from four channels simultaneously. It has an FPGA inside, facilitating the implementation of some parts of Wi-Fi
In an anechoic chamber

In a classroom

equal conditions. Unfortunately, due to hardware issues, it
estimation algorithms requiring different information under
signal-to-noise ratio. This data can be used for comparing DoA
all fields, CSI from all 242 subcarriers of VHT-LTF field, and
preambles, retrieving from them time-domain IQ samples of
the position of the antenna array in this case.

of our method since the phase shift is almost independent of
of multipath is reduced vastly. Fig. 2b confirms the advantages
as in paper [3], but in an anechoic chamber, where the impact
problems. We decided to perform calibration in the same way,
between channels in various positions in a classroom.

It can be seen from Fig. 2a, where we plot the phase difference
are non-identical even when antennas almost touch each other.
out that such phase shifts measured in different places in space
in which the effect of multipath is still significant. We found
channel here, we mean a combination of antenna, feedline,
and RF chain. Nonetheless, this phase difference is constant
in time and is caused solely by imperfections of components
mentioned above, as stated in paper [5]. Therefore, only one-
time calibration must be performed to eliminate its impact.

To remove such shifts, the authors of paper [2] proposed to
send a reference signal to all channels via splitter and measure
the phase difference between them. However, this procedure
does not take into account imperfections of feedlines and
antennas used in our case.

Another fruitful technique originating from paper [3] is to
deploy the receiving antennas at the same distance from the
transmitting one and measure the phase in this case. According
to the authors of the method, it is necessary and sufficient to
install the transmitting antenna closer to the receiving ones
in order to mitigate the impact of multipath in the indoor
environment. But it proved not to be the case in our scenario,
in which the effect of multipath is still significant. We found
out that such phase shifts measured in different places in space
are non-identical even when antennas almost touch each other.
It can be seen from Fig. 2a, where we plot the phase difference
between channels in various positions in a classroom.

Thereby, we proposed a new procedure to overcome these
problems. We decided to perform calibration in the same way,
as in paper [3], but in an anechoic chamber, where the impact
of multipath is reduced vastly. Fig. 2b confirms the advantages
of our method since the phase shift is almost independent of
the position of the antenna array in this case.

III. GATHERED DATASET

Currently, FIND works with 802.11ac Legacy and VHT
preambles, retrieving from them time-domain IQ samples of
all fields, CSI from all 242 subcarriers of VHT-LTF field, and
signal-to-noise ratio. This data can be used for comparing DoA
estimation algorithms requiring different information under
equal conditions. Unfortunately, due to hardware issues, it
operates at 2.4GHz instead of 5GHz declared in 802.11ac
standard. According to the specification, USRP-2955 has a
frequency range of up to 6GHz. In spite of this, we found
out that the amplifiers of the channels RX 0 RF 0 and RX 1
RF 0 do not work properly at 5GHz. Moreover, this problem
is observed in several different USRP-2955. However, in the
nearest future, we plan to solve these issues and expand the
capabilities of our tool for running at other frequencies and
with other preambles, such as HT, HE, and EHT [6]. We are
also going to carry out experiments in other scenarios, e.g., in
malls. As collected, the additional data will be included in the
new versions of the published dataset.

Fig. 1 illustrates the gathered information. It contains the
absolute value of time-domain IQ samples of various fields
of preambles mentioned above from one antenna (see Fig. 1a),
as well as the absolute value of CSI from the VHT-LTF field
on all four antennas, which is represented in Fig. 1b. These
absolute values are normalized to simplify the presentation.

With the devised testbed shown in Fig. 3, we collect data
from over 300,000 frames in a classroom and over 80,000
frames in an anechoic chamber. The receiver and transmitter
are placed in different positions in space, while the real DoA
is also tracked. We carry out experiments in semi-automatic
mode: we manually set the testbed to a certain position, then
the platform is rotated at a defined angle, where FIND receives
several frames, after which antennas are rotated to the next
angle. All gathered data is made open for further development
and testing of DoA algorithms.

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