# Real-time Indoor Localization with TDOA and Distributed Software Defined Radio

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***Abstract*—We present a system utilizing off-the-shelf hardware components and a software framework, which is able to perform radio frequency localization with high accuracy in the order of a few meters. The architecture consists of highly synchronized receivers that are utilized by a distributed software defined radio stack in order to obtain synchronized multi channel reception of the target signal. This includes transportation of the sampled baseband signals from the receivers over a backbone network and local signal processing at a fusion center. To overcome the large drifts in the synchronization signals provided by GPS, we permanently calibrate the system based on a stationary reference source. The implemented system framework enables us to perform research on localization algorithms and performance evaluation under the influence of various inherent noise and error sources.**

***Index Terms*—TDOA, Positioning, Localization, Synchronization, Distributed Systems**

## I. Introduction

Time based localization utilizing electromagnetic waves at high frequencies has been notoriously challenging due to its extreme demands on the system synchronization. The waves, propagating at the speed of light, are able to travel about 30 cm in a nano second. For a distributed system that wants to perform localization based on the time difference of arrival (TDOA) of such waves, the synchronization has to be in the same order to enable sub-meter accuracy. The technical challenges and high costs involved in the implementation of such systems is one of the major reasons hindering the research community from experimental work in the area. This has lead in many cases to focus on received signal strength or direction of arrival based systems, while evading to ultrasonic waves with a lower propagation speed in order to implement time difference based schemes. Nevertheless, in this publication we are going to demonstrate that recent developments in software defined radio (SDR) technology enable the implementation of real-time TDOA based localization systems with low costs compared to commercial systems used for spectrum monitoring.

## II. Theoretical Background

We consider a system of distributed receivers that are searching to localize a moving transmitter. In the literature, these receivers are also called anchor nodes, base stations or access points. The system is considered to be passive and has

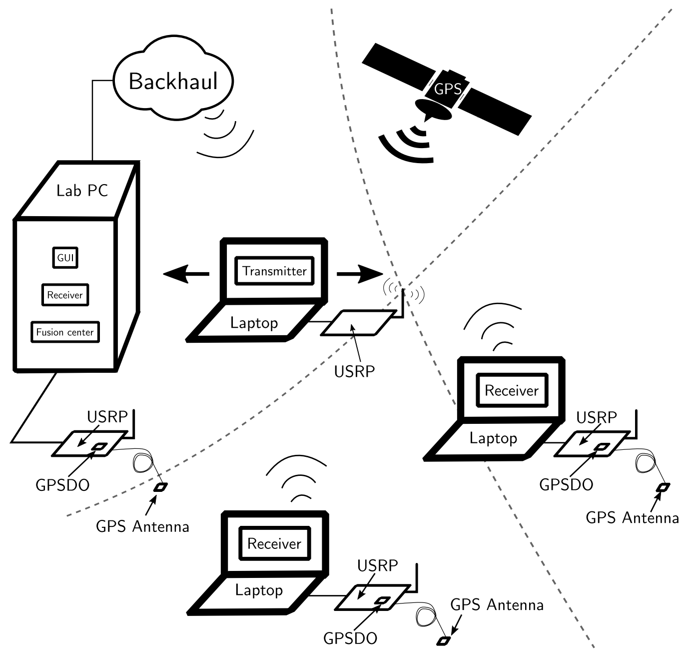


Fig. 1: Exemplary setup of the experiment. GPS antennas have to be placed close to or outside a window.

no communication from the transmitting target to the receivers for the purpose of the localization. For the sake of simplicity we assume a single transmitter, where the transmitted signal can be modeled as

$$y_r(t) = h_r s(t - \tau_r) + w_r(t),$$

where $w_r(t)$ is assumed to be an independent realization of a white Gaussian noise process and $\tau_r$ stands for the delay which is related to the propagation distance between the transmitter and receiver $r$. Then the TDOA based system is only able to observe time differences $\Delta\tau_{ij} = \tau_i - \tau_j$ between receiver $i$ and $j$. Based on that a solution for the location can be found, e.g., [1].These algorithms assume the TDOAs have already been obtained. Another way is to perform direct localization based on the signals as we have shown in [3]. As described in [4], this also enables us to incorporate a ray-tracing engine which can resolve multipath propagation. In our experimental

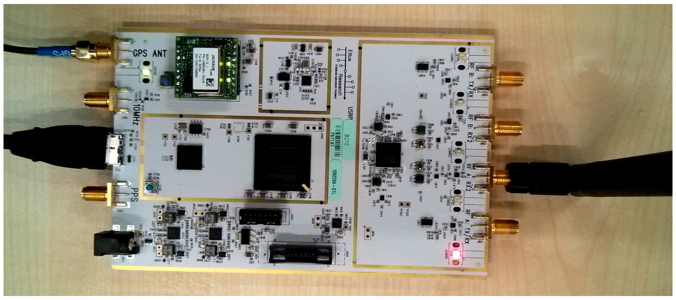


Fig. 2: The RF front-end including a GPSDO (upper left side) for time synchronization with other distributed nodes.

real-time localization system algorithms [1] and [3] have been implemented.

## III. System Architecture

The presented localization system is implemented based on the SDR methodology. This includes hardware for basic radio frequency and baseband signal processing and software to perform the major part of the digital baseband signal processing.

*1) Hardware:* The basic configuration of the system, as shown in Fig. 1, uses three receiver nodes and one transmitting target node that shall be localized. Each node consists of a radio front-end and a computer running the SDR framework. The radio front-ends are Ettus USRP B210, able to deliver complex samples at a rate of up to 56 million samples per second. In order to enable time synchronization the receiver nodes additionally need a GPS disciplined oscillator (GPSDO) that provides a clock signal for the front-end and a pulse per second (1PPS) synchronization signal. We evaluated two devices, namely the LCXO and the LTE Lite both manufactured by Jackson Labs Technologies. In order to make all the nodes mobile we use laptop computers. We are able to power the radio front-end as well as the GPSDO through the laptop battery. Furthermore, the system needs a backbone network in order to communicate the baseband samples of the receiver nodes. This is achieved either by standard Ethernet or 802.11 WLAN.

*2) Software:* The software part of the localization system consists of four components: transmitter, receiver, fusion center and GUI. A signal is created and transmitted by the transmitter component and the receiver component acquires the samples in a synchronized way. Those parts are implemented with the GNU Radio SDR framework [2]. For the transmitted signal we use BPSK modulated m-sequences as well as OFDM signals. Baseband samples are then sent from the receiver to a fusion center using the ZeroMQ library [5]. ZeroMQ is also used to communicate all necessary commands from the fusion center to the distributed receiver nodes. This communication is crucial for the initial setup and synchronization and to acquire samples exactly at the same time. After processing in the fusion center, all results are transmitted to one or more graphical user interfaces. All components can run independently on

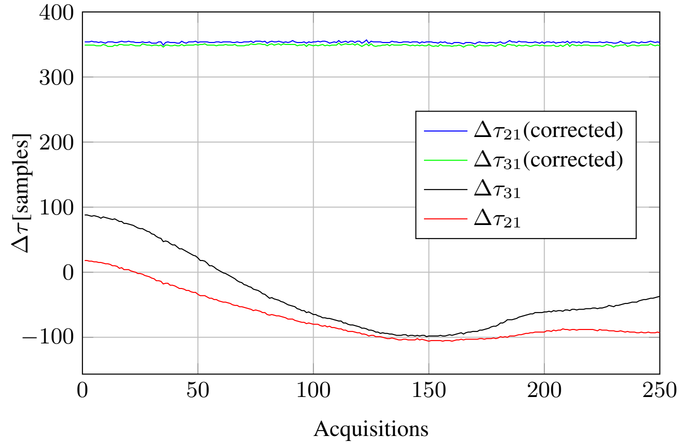


Fig. 3: Drift and correction of GPS based synchronization used for the distributed receiver nodes, shown for the TDOAs of a stationary target, sample rate 50 Msps, interpolation factor 10, signal bandwidth 5 MHz.

different computers in the network. The framework is able to obtain and process about one burst of 1000 samples, and thereby calculate one localization result per second.

### *A. Calibration of Time Synchronization*

A major challenge with the time synchronization of the distributed receiver system is a drift in the 1PPS signals obtained from the GPSDOs. In order to overcome this a signal from a local broadcasting station, e.g., FM, DAB, DVB-T, or a custom signal, is used to recalibrate the system before each acquisition. The results of the drift measured using the signals cross-correlation for a stationary target are shown in Fig. 3. It can be seen that the calibration algorithm is able to keep the synchronization error within about $\pm 2$ samples of the expected values.

## IV. Acknowledgments

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