A new method for wireless synchronization and TDOA error reduction in UWB positioning system

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Abstract—**The clock frequency tolerance and instability have a big impact on positioning accuracy and precision in UWB localization systems. The paper deals with synchronization and TDOA error reduction technique relying on reference packets transmission. The method was implemented in the UWB positioning system. The paper contains description of the method, system architecture and results of performed measurements.**

Index Terms—**positioning systems, wireless synchronisation, UWB, TDOA error reduction**

I. Introduction

UWB (ultra-wideband) technology has lately become more and more recognized in the various wireless systems. It benefits from very wide frequency bands of transmitted signals (at least 50 MHz according to EU regulations [1] and 500 MHz to FCC regulations [2]), which lead to short pulse duration times. It allows for precise timing detection of received signals, high data throughput and makes system immune to multipath issues, since pulses can be easily distinguished.

What is more, devices using UWB technology can be small and are power and cost effective. All of the above makes UWB technology a great candidate for the localization systems, mainly indoor due to strict regulations. Positioning accuracy as good as a couple/over a dozen centimeters is something not-achievable with up-to-date systems based on e.g. WiFi or Bluetooth.

Most of the UWB positioning systems implement time measurement in order to get parameters such ToA (Time of Arrival) or TDOA (Time Difference of Arrival), which can be used for position calculation.

Typical localization system architecture contains some tags and an infrastructure. The infrastructure consists of the anchors spread around the area where localization is done and a control center. Two architectures can be distinguished, unilateral, where tags are receivers and anchors transmitters and multilateral, where the situation is opposite. In order for the system to work, all of the infrastructure's devices have to be synchronized, as precise timing is crucial for position calculation.

Two main issues can be recognized when it comes to synchronization [3]:

- device synchronization – done between the anchors, to maintain the same time-base,
- drift compensation – temperature and ambient changes can cause devices' clocks to drift for up to single microseconds.

There are quite a few methods for resolving mentioned issues. The easiest is to provide cable connections between all the devices. It is most commonly used in commercial systems [4][5]. However, deployment of the cabled infrastructure can be problematic in buildings or over the huge areas. Therefore, it is highly desirable to provide a wireless solution.

One way to achieve wireless synchronization in a unilateral localization system is presented in [3]. So called "zone supervisor" is introduced. It periodically sends packets. They are received by tags and anchors who note reception times. Independently, anchors sequentially transmit their own packets with a constant delay, which are received by the tags. All timing related data is gathered in the system controller, where position is calculated. Similar approach has been used in the EIGER system [6], with a main difference, that in EIGER tags calculate their position on their own.

In multilateral systems, a reference tag, placed in a fixed and known position can be used for synchronization. It would periodically send packets received by the anchors. As propagation times between the reference tag and the anchors are constant, packet arrival times at the anchors are synchronized. Such solution was described in [7][8][9].

Interesting approach has been presented in [10]. Authors proposed solution combining ToA and DoA (Direction of Arrival) measurements. No synchronization is needed, since the system infrastructure consists of one anchor with the antenna array.

Another approach is based directly on the impulse synchronization level. There are several algorithms working on the lower, non-system level. [11].

The paper is organized as follows. Section II describes proposed architecture and signal transmission scheme. Section III shows simulation results. In section IV performed experiment and achieved results are presented. Conclusions are discussed in section V.

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II. System Architecture

The localization system architecture developed within NITICS project is shown in Fig. 1. Anchor nodes measure time of arrival of packets transmitted by tags and the reference node. Results are send to the System controller over WiFi interface. The controller evaluates tag's position. The system implements TDOA positioning technique so the anchors synchronization is needed. The reference node distributes packets used for time synchronization and anchor's measurement errors reduction.

Implementation of wireless synchronization and WiFi links simplified the solution. The anchors do not need wired links neither for synchronization nor results transfer.

Every device shown in Fig.1, except from the system controller, has DW1000 chip on board [12]. It is 802.15.4a standard compatible UWB transceiver. Anchor nodes and tags are equipped with a DWM1000 module, which integrates DW1000 chip, crystal oscillator and antenna. Since reference node required better timing, DW1000 chip combined with TCXO (Temperature Compensated Crystal Oscillator) was used.

III. Synchronization and TDOA Correction Method

There are two factors that have significant impact on positioning accuracy and precision: frequency stability and frequency tolerance. They both affect the time difference of arrival measurements. Results of period measurements performed with the system anchors equipped with quartz crystals can be an illustration of the problem. Devices measured period of packet transmission from TCXO driven transmitter. The anchors were installed in the room in which windows were opened for a few minutes. Difference between transmitted signal period and periods measured by anchors are shown in Fig. 2.

Offset results from different clock frequencies in all devices. Although DWM1000 modules provide means for clock frequency tuning the correction is not precise enough. Cooling the anchors (indoor - outdoor temperature difference was close to ten degrees) resulted in increase of measured offsets depending on the place of anchor location. Observed errors can seriously limit positioning system accuracy.

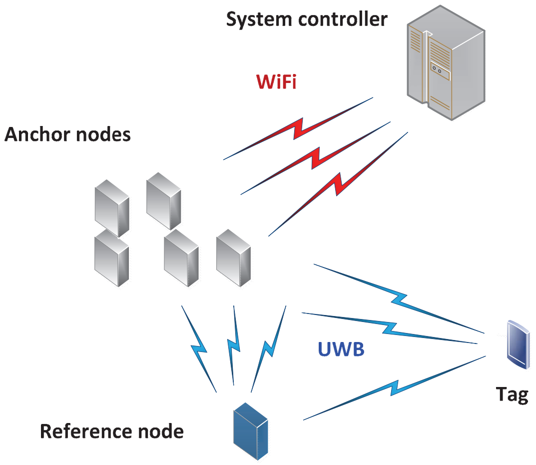

Figure 1. Localization system architecture

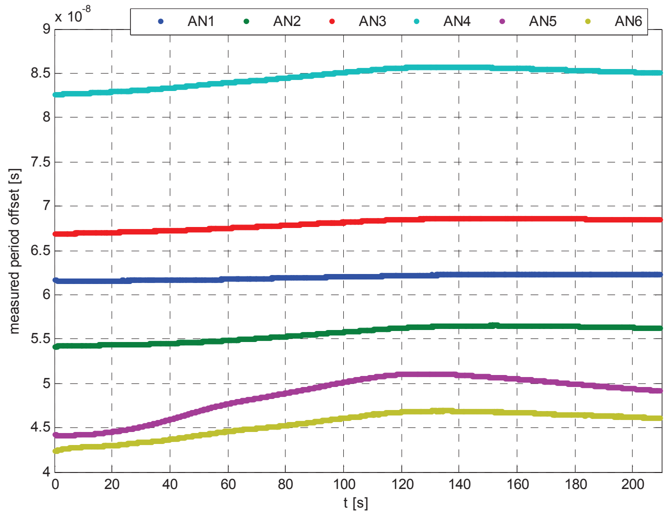

Figure 2. Transmissions in the positioning system

Therefore, a method for error reduction is required. The method implemented in the system relies on transmission of a pair of packets with a known reference interval by one of system nodes. The remaining nodes measure times of packets arrivals and correct results of their measurements.

The transmission scheme used in the system is presented in Fig. 3. The transmission is initiated by the tag. The tag's packet reaches the reference node and anchor nodes (only two anchors are considered in the figure). Reception of tag's packet triggers a timer in the reference node. After TD1 delay the node sends the packet (R1) and repeats the transmission after reference period Tref (R2). Signals from the reference node after propagation delays t2 and t3 reach both anchors.

Anchors measure time of arrival of all received packets, so they are able to calculate tm2, tm3, Tref2 and Tref3 periods. Two first results are used for TDOA calculation. Tref2 and Tref3 are used by the anchors for measured period correction.

The time difference of arrival for AN1 and AN2 anchors are calculated in accordance with the following formula:

$$TDOA21 = tp3 - tp2 = tm2 - tm3 + t3 - t2 \quad (1)$$

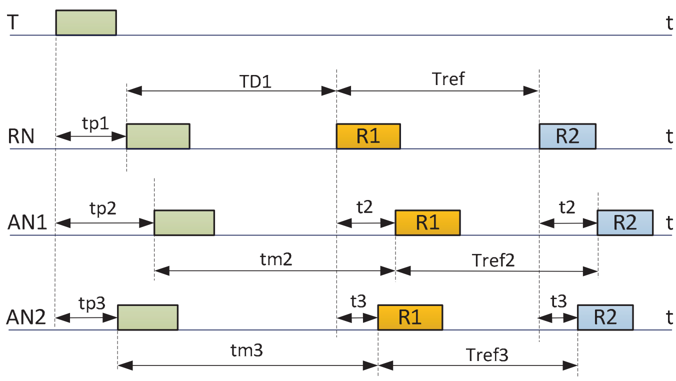

Figure 3. Transmissions in the positioning system

Both tm2 and tm3 intervals are corrected versions of intervals $tm2_m$ and $tm3_m$ directly measured by anchors. The correction consists in simple calculation:

$$tm2 = tm2_m * (Tref/Tref_n) \quad (2)$$

Due to reference period measurement errors correction deteriorates result precision. Therefore, the reference period was filtered using typical moving average formula:

$$Tref_n = Tref_{n-1}(1-k) + k * Tref2 \quad (3)$$

Current reference period value used for result correction depends on the previous value and current reference period measurement result (Tref2 in node AN1).

IV. Simulation

A. Simulation setup

Introduced averaging algorithm was simulated in the Matlab environment. Since reduction of random error component of the reference period measurement was tested, system consisting of a single anchor, one tag and a reference node was simulated. Random error component was modeled with Gaussian distribution with mean equal to 0 and standard deviation equal to 250 ps. Chosen standard deviation's value was based on the performed experiments.

Thirteen values of k coefficient (3) ranging from 0.01 to 1 have been used for simulation. In each case, 1000 test measurements were gathered. First 100 measurements were treated as a "training values" for building initial reference period. Standard deviation of the last 900 measurements was used for evaluation of system performance.

B. Simulation results

Standard deviations of reference period measurements for different k-factor values are shown in Fig. 4.

As seen, the smaller the k-factor, the smaller standard deviation of the results is. It conforms with theory, since smaller k coefficient implies that more measurement results are taken into account for averaging.

It is worth mentioning that for simulation purposes it was assumed that only clock jitter was present without any drift. In real-life scenario such statement would prove wrong, therefore experiment results may vary, however, an overall decreasing trend would be preserved.

V. Experiments

Several tests were performed in order to investigate the proposed TDOA error reduction method. Tests were carried out in the laboratory room. Anchor nodes and the reference node were located at positions shown in Fig. 5.

The TDOAs recorded for the tag worn by the person walking in the room are shown in Fig. 6. If the error reduction is not implemented (anchors do not use reference periods transmitted by the reference node) TDOA values are so different that proper localization is not possible.

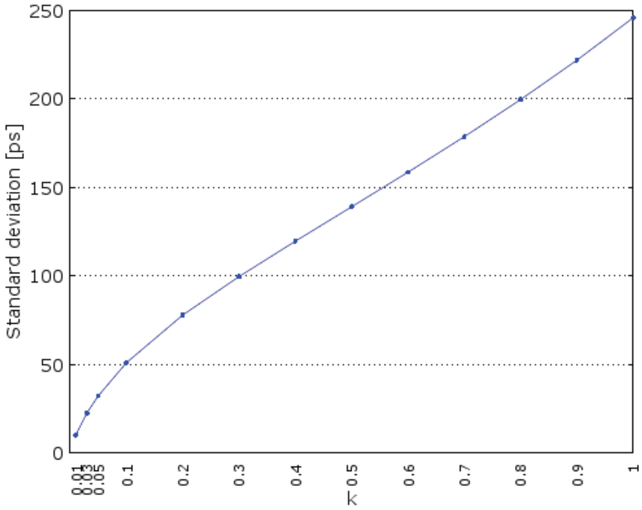

Figure 4. Standard deviation of the measured reference period vs. k coefficient

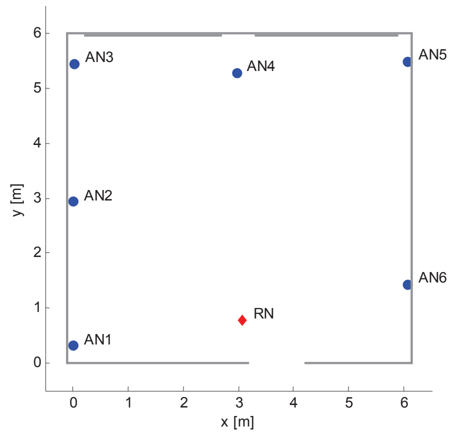

Figure 5. Anchors and the reference node location

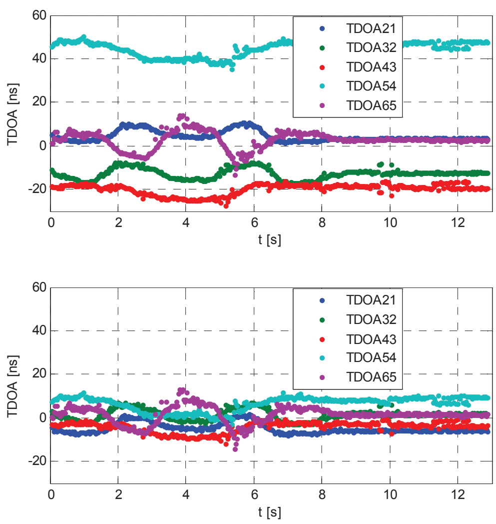

Figure 6. TDOAs before and after correction

Next tests were focused on evaluation of the reference period correction efficiency. The test depended on localization of a single tag placed in the middle of the room. The raw measurement results (times of arrivals and reference period measurements) were recorded in conditions described in section III (anchors clocks were changing during the measurement).

The measured times of arrivals were corrected as described in Section III using different values of k coefficient in moving average algorithm. Calculated TDOAs were used for tag position calculation with Extended Kalman Filter based algorithm. The algorithm fused all TDOAs delivered by the system.

In order to evaluate positioning precision, the Circular Error Probabilities (CEP) were calculated for 68 and 95 percents of raw positions. Obtained CEP values for different k coefficients are shown in Fig. 7.

Increase in the number of averaged measured reference periods results in a fall of both CEP values. The trend is reversed for k<0.05 because averaged period does not reflect relatively faster changes of internal clocks frequencies caused by temperature changes.

Moreover, a positioning error defined as a distance between point location and obtained results was evaluated. Fig. 8 presents Cumulative Distribution Function (CDF) of positioning errors for chosen k coefficients. For not averaged measured reference periods almost 70 percent of points was determined with accuracy better than 20 cm. After averaging that ratio can be increased even to 95 percent.

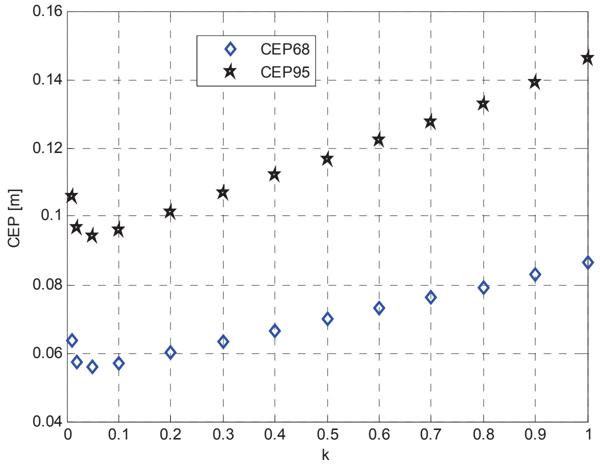

Figure 7. Circular Error Probabilities vs. k coefficient

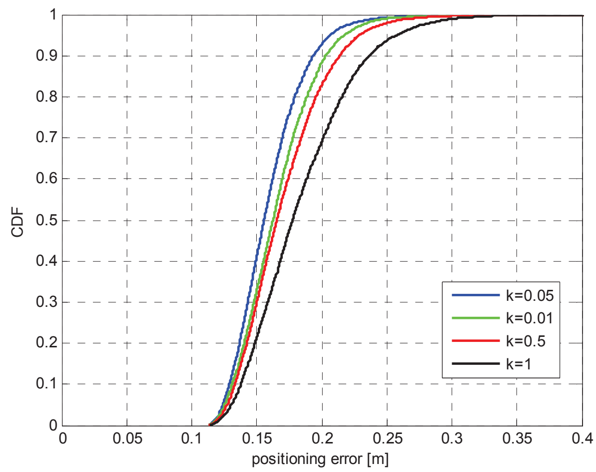

Figure 8. Cumulative distribution function of positioning errors for chosen k coefficients

VI. Conclusions

The paper contains description of the method providing wireless anchors synchronization and reduction of measurement errors in the ultra wideband positioning system. Wireless synchronization simplifies system installation. Proposed technique can be used in systems where anchors are equipped with low stability clock oscillators. Investigation of the method implemented in the system proved its efficiency. By averaging results of reference period measurements precision of obtained results can be significantly improved.

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