An Improved Technique Based on Zadoff-Chu Sequences for Distance Measurements

G. Piccinni, G. Avitabile, G. Coviello
Electric and Information Department (DEI)
Polytechnic of Bari
Bari, Italy
{giovanni.piccinni, gfa, giuseppe.coviello}@poliba.it

***Abstract*—The paper introduces a novel method for distance estimation based on an OFDM signal combined with the Zadoff-Chu sequences. By exploiting the properties of these sequences, it is possible to evaluate the distance between two active nodes with a very good precision and accuracy. The technique effectiveness is demonstrated by measuring the distance between a single transmitter and a synchronized receiver connected through cables with different lengths. The mean final accuracy of 0.2 cm joint to a mean final precision of 0.65 cm with 100 MHz of bandwidth is achieved. The proposed technique can be advantageously used in indoor positioning systems design.**

I. Introduction

The development of a real time indoor localization system with a very high level of accuracy and precision poses several challenges. This paper introduces a different method for measuring the distance between two active devices. The method exploits an OFDM like signal in combination with Zadoff-Chu (ZC) sequences and extracts the distance measurements directly from the cross-correlation between the transmitted and the received signal, by exploiting the properties of these ZC sequences. The forthcoming sections briefly recall the properties of ZC sequences and, then, present a first experimental setup, reporting the results obtained to validate the technique.

II. Basic Theory of operations

In the proposed distance evaluation technique, an OFDM signal combined with a Zadoff-Chu sequence is transmitted (OFDM-ZC). ZC sequences are part of the family of Constant-Amplitude Zero Auto-Correlation (CAZAC) sequences in which circularly shifted copies of a sequence are uncorrelated [1]. Moreover, ZC sequences do not increase the transmitted power if compared, for example, to superimposed Pseudo Noise (PN) signals and, in addition, a ZC sequence is a ZC sequence even after a FFT or IFFT operation. These properties are often exploited in telecommunications systems for timing, frequency and symbol synchronization, where a ZC sequence is transmitted into a preamble of a OFDM signal or as pilot subcarriers [2]-[3]. In the proposed technique, a 52 symbol length ZC sequence was generated. The single values of the sequence were inserted in an OFDM symbol in frequency domain according to the pattern established by the 802.11a standard [4].

In Fig. 1, the simplified architecture of the distance evaluation system is sketched. Once the OFDM-ZC is generated, its samples are stored into a Look-up Table (LUT) and subsequently read through a digital clock and fed to a suitable DAC generating the baseband signal. Finally an I/Q modulator up-converts the signal to RF that is subsequently transmitted on the channel. At the receiver side, the signal passes through a Low Noise Amplifier (LNA) and it is down-converted at baseband frequencies by an I/Q demodulator. The two resulting channels (I and Q) are sampled by two independent Analog to Digital Converters (ADC) which feed the samples to a Field Programmable Array (FPGA) or a Digital Signal Processor (DSP). This last block processes the samples and reconstructs the received signal and, most of all, implements the algorithm for estimating the relative distance.

If we consider a numeric transmission system and assume x[n] as the transmitted sequence of length N and h[n] as the channel impulse response, the received sequence y[n] is given by the convolution of x[n] with h[n]. The cross-correlation of y[n] with a local copy of the x[n] is given by the convolution of the autocorrelation $R_{xx}[n]$ of x[n] and the channel impulse response h[n]. From the properties of Zadoff-Chu sequences, the autocorrelation R_{xx} of one of these sequences with a cyclically shifted version of itself is non-zero only at the time that corresponds to the cyclic shift, k. Hence, the cross-correlation function R_{xy} is given as:

$$R_{xy}[n] = \delta[n-k] * h[n], \tag{1}$$

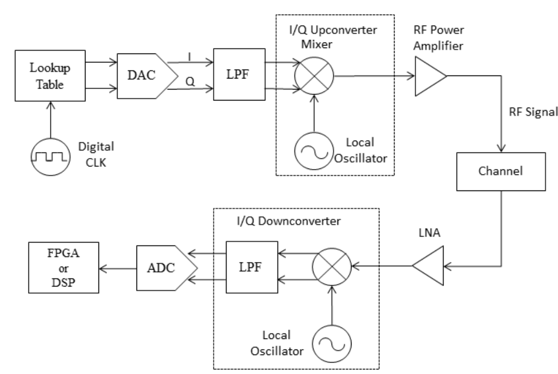

Fig. 1 Architecture of estimation distance system.

where $\delta[n-k]$ is the Kronecker function sequence, shifted by k samples according to the time delay τ_d between T_x and R_x signals. The distance between the transmitter and the receiver can be calculated extracting the value of k from the cross-correlation function and then, multiplying the corresponding delay times by the propagation velocity, v_p. In a radio channel, the propagation velocity is equal to c, the speed of light (3×10^8 m/s), while in other transmission media it is expressed as a percentage of c, in dependence by the dielectric ε_r and magnetic permittivity μ_r of the medium.

The proposed technique performs the distance estimation in three main steps. First, the system collects a database of OFDM-ZC signals received from known fixed distances, then the cross-correlation between the previous collection and the signals received from the unknown distance is performed. Finally, a software algorithm calculates the distance between T_x and the R_x in the unknown position, from the measure of the Time Differential Of Arrival (TDOA) with respect to a receiver in a known fixed position.

III. Experiments and Results

In order to demonstrate the proposed technique effectiveness, an ideal channel without multipath has been implemented using a simple cable of known length. The architecture of the system, thus, comprises a single transmitter and a receiver. The baseband signal modulates a 2.4 GHz carrier with a 0 dBm amplitude. In this test bench, the algorithm is applied to extract the value of the time delay and to calculate the length of the cable connecting the transmitter to the receiver. In the whole set of measurements, the received signal was sampled with a frequency equal to three times the bandwidth of the signal. The software algorithm interpolated the data with an oversampling factor introduced in order to achieve a virtual rate of 10 Gsamples/s. A cable of 1.0 meter was used to set the reference distance and a batch of 100 measurements was performed. The cable lengths were previously measured for reference with a microwave network analyzer. In the measurements an OFDM-ZC of 64 sub-carriers was transmitted with a bandwidth ranging from 20 MHz to 100 MHz. Tab. 1 reports a subset of distance values calculated with the proposed technique, for a subset of different bandwidth values. The results demonstrate the validity of the proposed solution. In fact, the technique in ideal conditions, evaluates the length of the cables with a good accuracy and precision even with a narrow signal bandwidth. In fact, for a 20 MHz bandwidth, the mean accuracy is less than 0.9 cm, while it becomes 0.2 cm for a bandwidth of 100 MHz (Fig. 2(a)). In term of precision, as reported in Fig. 2(b), for a 100 MHz bandwidth a 0.65 cm mean value is obtained, while for 20 MHz its value is less than 0.9 cm.

IV. Conclusions

A novel technique for measuring the distance between two active nodes was introduced and experimentally validated. The method uses an OFDM signal within the Zadoff-Chu sequences and extracts the distance between a transmitter and a receiver with a software algorithm based on the correlation function.

TABLE I
Cables Lengths Measured vs Bandwidth

Network Analyzer [cm]	OFDM-ZC 20 MHz [cm]	OFDM-ZC 40 MHz [cm]	OFDM-ZC 80 MHz [cm]	OFDM-ZC 100 MHz [cm]
99.34	98,21	100,90	98.85	99.37
198.73	199,20	198,72	198.50	198.83
248.06	248,10	248,78	247.53	248.12
347.46	346,30	347,48	347.85	347.47
397.82	397,50	397,54	397.31	397.77
446.82	448.40	446.27	446.71	447.60

The capability of measuring the distances with a good precision and accuracy even with small value of bandwidth makes the proposed technique very powerful. A mean precision of 0.2 cm and an average accuracy of 0.65 cm with 100 MHz of bandwidth and a 64-OFDM-ZC signal has been experimentally reported.

References

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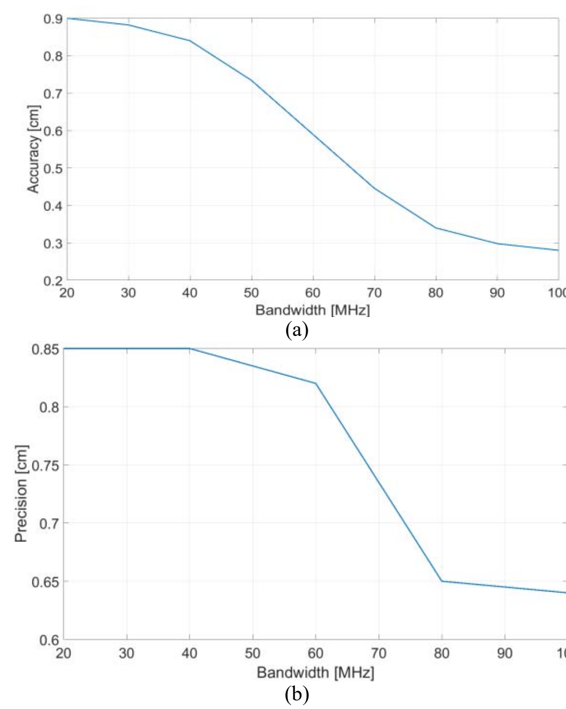

Fig. 2 Final mean accuracy (a) and mean precision (b) achieved, using the proposed technique vs Bandwidth.