# Time-of-Arrival Estimation using NI mmWave Transceiver System

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Abstract

**In this paper, we explore the configurations of National Instruments' millimeter-wave transceiver system (NI MTS) experimental setup for performing time-of-arrival (ToA) estimation. A 100-bit pseudo-random number (PN) sequence is modulated with binary phase shift keying (BPSK) and transmitted using a 28.5GHz frequency carrier. By logging the transmitted and received signals and then performing cross-correlation, we will demonstrate basic ToA estimation using physical millimeter-wave (mmWave) communication equipment.**

***Index Terms*—mmWave, Time-of-Arrival, National Instruments, mmWave Transceiver System, BPSK**

## I. Introduction

With the rise of 5G wireless communication and the development of 6G communication standards, research into increased millimeter-wave (mmWave) utilization has received increasing attention [1]. Among the features being developed, joint communication and sensing (JCS) and integrated localization and communication (ILC) are actively being researched [2], [3]. To this end, we discuss estimating the time-of-arrival (ToA) by first logging data using National Instruments' (NI) transceiver system and then performing a basic cross-correlation of the transmitted and received signals.

## II. Time-of-Arrival Measurement Methodology

In this section, we introduce the mmWave transceiver system (MTS) produced by NI used for testing. Likewise, we will explain our methodology for confirming the transmitted signal's ToA.

### A. Millimeter-Wave Transceiver System Equipment Setup

The measurement setup includes two PCI extensions for instrumentation (PXI), two antenna modules, two up-down converters (UD Box), two intermediate frequency-local oscillator module (IF-LO Module), an in-phase/quadrature (I/Q) digitizer, I/Q generator, analog-to-digital converter (ADC), and digital to analog converter (DAC) as shown in Fig. 1.

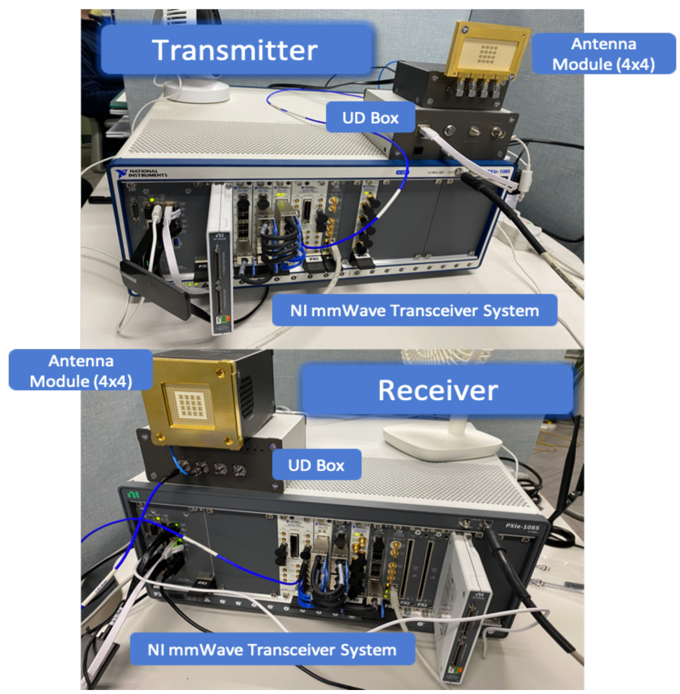



Fig. 1: Hardware setup

TABLE I: System specification

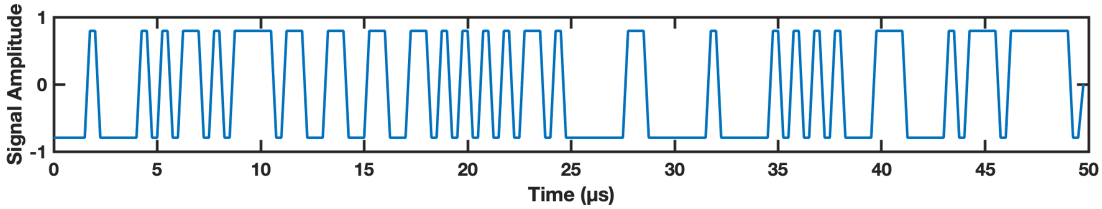
| Parameters | Value |
|---|---|
| Carrier Frequency | 28.5 GHz |
| Bandwidth | 50 MHz |
| Sampling Frequency | 4 MS/s |
| Modulation | BPSK |
| Antenna Size | Tx: 4×4; Rx: 4×4 |
| Symbol Rate | 2 MS/s |
| Transmission Length | 100 Symbols |

### B. System Specifications and Software Requirements

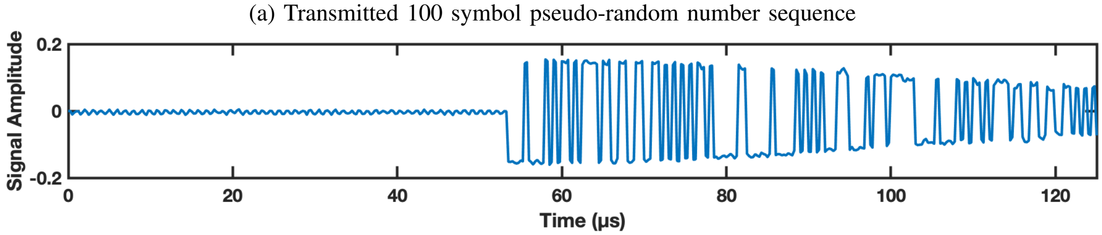
The two software packages we use for controlling the MTS system are Labview and TMXLab Kit. TMXLab Kit is used to control the antenna modules whereas Labview is used for programming the PXI. Labview provides simple and concise methodologies for controlling, configuring, and communicating between each field-programmable gate arrays (FPGAs) and host computers. The system specifications for the mmWave used during testing are summarized in Table I. MATLAB was also used to down-sample the transmitted signal as well as perform the cross-correlation analysis between the transmitted PN sequence with the received signal data.

### C. Time-of-Arrival Estimation Methodology

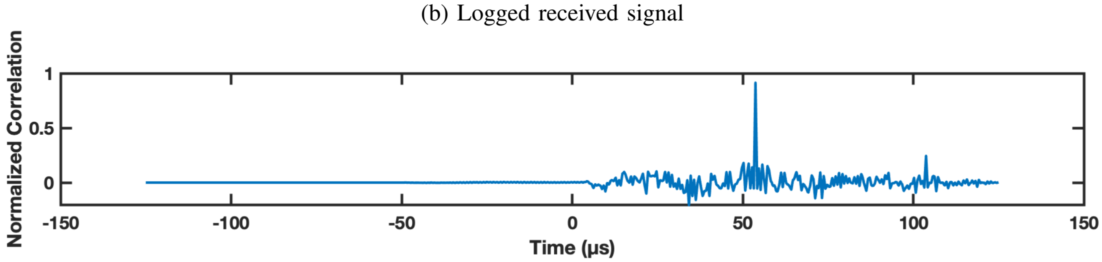
Experimentation setup and execution was done in the Fusion Tech Center on Hanyang University's campus in Seoul, South Korea. To estimate the arrival of a transmitted signal at the receiver, a simple pseudo-random number (PN) sequence of 100 bits is generated with binary phase shift keying (BPSK)




(a) Transmitted 100 symbol pseudo-random number sequence




(b) Logged received signal




(c) Cross-correlation of transmitted and received signal

Fig. 2: Transmitted 2MHz symbol rate pseudo-random sequence cross-correlated with received signal at a 4MHz sample logging rate

modulation. The receiver and transmitter are both triggered by the Windows OS host system clock to transmit and receive data for a 1 sec duration. During this time, the transmitter repeats the 100 symbol PN sequence without interruption. After the data is logged using technical data management system (TDMS) file format, a cross-correlation of the received signal and transmitted signal is performed in order to verify the periodic peaks occurred as expected.

Because NI MTS automatically collects samples at a rate of 3.072GHz in ADC Module, the total samples are down converted using the MTS's PXIe-7902R FPGA to a sample rate of 4 MHz before logging. The DAC Module also requires writing the transmitted signal at a rate of 3.072GHz, so the transmitted signal is down-sampled in MATLAB as well before performing the cross-correlation.

## III. Analysis on Time-of-Arrival Estimation Results

In this section, we show the results from the cross-correlation of the logged transmitted and received signals. The contents displayed in Fig. 2 show the results for transmitting a 100-bit PN Sequence using a 2MHz symbol rate. The transmitted signal in Fig. 2a was transmitted repeatedly but only the first iteration at the receiver and transmitter are shown.

The PN sequence was successfully transmitted as showed in Fig. 2b. As can be seen in Fig. 2c, the first peak in the cross-correlation occurred at the 53.75 $\mu$s mark indicating a successful ToA estimate for the first PN sequence transmission. It is important to note that the starting point at 0 $\mu$s at the receiver refers to the arbitrary start of the data logging not the signal's time of departure from the transmitter.

The symbol rate and logging sample rate were successfully increased to 32MHz and 64MHz, respectively, with periodic peaks in the cross correlation being observed. There were issues with buffer overflow and data completeness when the logging sample rate was increased past 64MHz. Therefore, more effort would need to be put into increasing throughput between the PXIe-7902R FPGA and host computer.

## IV. Conclusions

In this paper, we explore using the National Instruments mmWave transceiver system for collecting the time-of-arrival information needed for calculating the time-of-flight. Using this approach, we show that the transmitted PN Sequence can be detected using simple cross-correlation.

## Acknowledgment

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