Bluetooth Direction Finding

N. Scolari, D. Nonaca

Localization is a hot topic and the recently released Bluetooth 5.1 specification adds a feature to improve it called "Direction Finding". It is based on the concept of Angle of Arrival and Angle of Departure (AoA/AoD) that provides information about the direction of the transmitted/received message. In the course of its continuous improvements, the icyTRx IP developed at CSEM has implemented this feature.

There are many techniques that can be used to localize a node inside a wireless network, such as the Time-of-Flight, phase calculation, etc. The Bluetooth SIG decided to use the AoA/AoD technique. In this case, the Transmitter node (Tx) or the receiver node (Rx), are intended to deploy an array of antennas. When the array is on the Tx side, we speak of the AoD, while if it is on the receiver, it is known as the AoA. During a transmission, the Tx or the Rx switches the antennas within a specific part of the packet. On the receiver side, the phase of the incoming RF signal changes between a chosen antenna and the phase difference is geometrically related to the angle formed by the RF signal propagation direction and pair(s) of antenna plane(s), as shown in Figure 1.

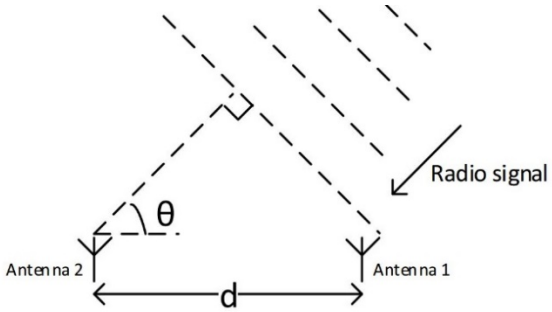

Figure 1: Angle of Arrival principle.

The Bluetooth specification does not define any particular configuration for the setup, number, or position of the antennas, in order to provide the flexibility and capabilities needed to configure the system for a wide range of use cases. In our implementation of the Direction Finding feature on icyTRx IP, we include as much as configurability as possible in order to enable the user to choose and program the antenna configuration. In particular, the number of antennas and the switching pattern are fully programmable (within the limits of the hardware implementation). Furthermore, the Bluetooth SIG does not specify any particular algorithm to perform the evaluation of the AoA or AoD. The task of finding the best solution is left to the customer. The digital baseband only needs to provide the signal samples from the receiver. The evaluation of the angle is then left to the network stack implementation.

The hardware changes to icyTRx consisted of modification of the packet handler in order to detect the optional phase sampling period, very precisely controlling the antenna switching pattern, and sampling the consequent data. Validation of the new hardware implementation was performed using an existing version of icyTRx as RF frontend, with the digital baseband implemented in a FPGA. The first measurements showed that calculation of the angle from the phase values obtained in the Rx is not straightforward: several issues due to phase ambiguity and multipath propagation need to be resolved in order to obtain a good estimate of the angle. Thus, in order to validate the principle of the AoA/AoD, a series of measurements have been performed in an anechoic chamber, in which a controlled rotating table is available, as shown in the Figure 2.

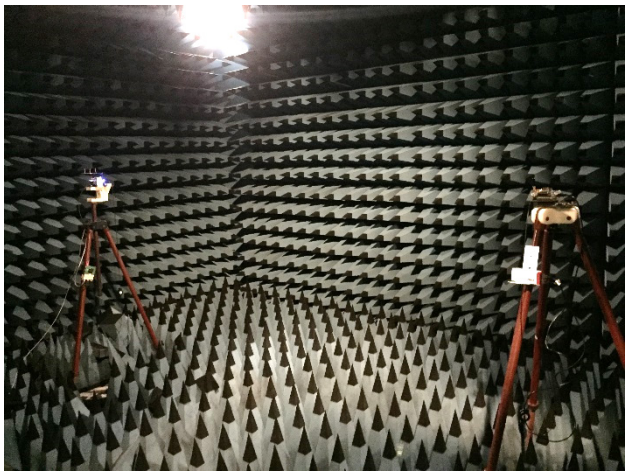

Figure 2: Measuring setup in the anechoic chamber.

For the initial tests, an array of 3 antennas was placed on an equilateral triangle separated by λ/2. The algorithm used to evaluate the angle was based on a brute force maximum likelihood principle. The results were nonetheless very encouraging, with a maximum error of 10° over the whole range of angles, as shown in Figure 3. It is interesting to note that some periodicity on the error measurements was found due to the antenna geometry, demonstrating that the angle calculation is not a trivial task.

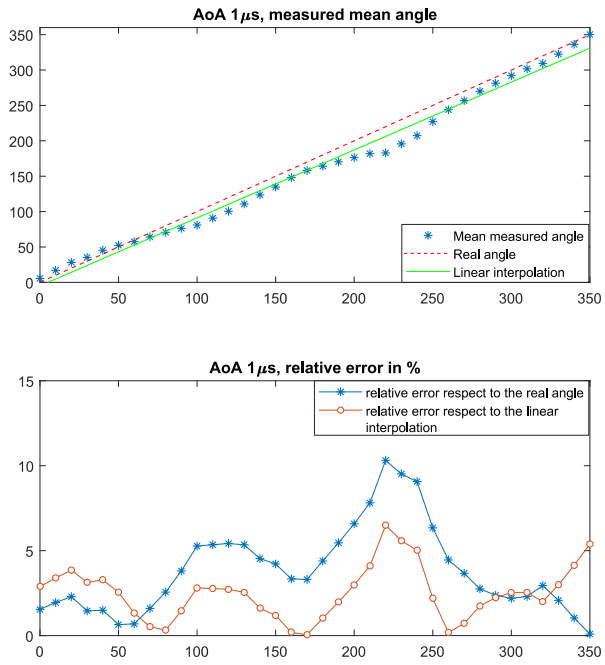

Figure 3: Measurement results for the AoA 1us.

The Direction-Finding feature of the Bluetooth Low Energy standard has been successfully implemented at a hardware level and a real silicon chip has been fabricated. The software aspects of the localization technique were found to be the most challenging; especially, due to the multipath propagation issue.