Implementing Bluetooth Low-Energy 5 in icyTRX

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The Bluetooth Low-Energy 5 specification includes new features, notably a 2 Mbps mode and a Long-Range feature. The versatility of the icyTRX digital baseband, allowed us to implement the 2 Mbps mode without the need for changes. Implementation of the Long-Range feature required some modification of the baseband, but changes were minimized thanks to the modularity of icyTRX.

With the new Bluetooth 5 specification, the Bluetooth SIG intends to expand the number of use cases in which a Bluetooth radio can be deployed. In particular, the Low-Energy feature improves the data-rate and the range (distance). The first feature is realized by adding a 2 Mbps mode (the previous version of the Bluetooth Low-Energy (BTLE) supported only a 1 Mbps mode), while the second feature is implemented by adding a coding layer to the 1 Mbps mode. This coding layer enables us to keep the same analog radio front-end, and to add a simple coding/decoding layer to the digital baseband, extending the range. Two modes of operation are foreseen, one at 500 kbps and one at 125 kbps. Due to the convolutional codes, the gain in these modes is expected to be 4 dB and 12 dB respectively.

The icyTRX IP has a versatile digital baseband that already supports operation at a data rate of 1 Mbps, as well as other data-rates via different combinations of modulation and coding. Implementation of the BTLE 5 2 Mbps feature was straightforward: there was no need to modify the icyTRX radio, the analog or the digital parts.

As can be seen from Figure 1, bit-error rate (BER) sensitivity measurements performed at 2 Mbps demonstrate the excellent performance of icyTRX, which achieves a BER of 10-3 at about -95 dBm.

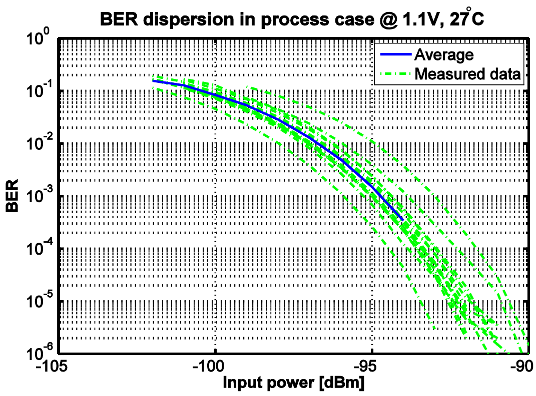

Figure 1: BER sensitivity at 2 Mbps measured over several samples.

The Long-Range feature is achieved by adding a coding layer to the 1 Mbps protocol. This coding layer is essentially composed of a rate 1/2 convolutional code combined with a coding pattern, similar to that of Manchester encoding. In the 500 kbps mode only the convolutional code is used, while the 125 kbps mode combines the two coding schemes. In either case, the access address of the packet is always coded at 125 kbps. Technically, both of these coding schemes were already implemented in icyTRX, so the change was straightforward and readily implemented.

On the other hand, this approach does not provide any major improvement in terms of sensitivity. In fact, the actual algorithms (e.g. the clock recovery algorithm) require a minimum SNR which is not compatible with the Long-Range feature. For this reason, it was necessary to implement additional algorithms in the radio in order to assure the synchronization. These algorithms use the redundancy present in the preamble and the access address in order to add some processing gain and hence to be able to detect signals with a signal-to-noise ratio (SNR) lower than 0 dB. In particular, the Viterbi decoding algorithm for the access address requires a correct initialization, which can be achieved only by pre-synchronizing the demodulator with a rough access address detection. For these reasons, a series of correlators have been implemented in order to detect the different parts of a Bluetooth Long-Range packet.

Figure 2 shows some simulated results of this algorithm. The output of the first correlator looking for the access address of the packet is shown. Such algorithms improve the sensitivity of the radio; however, they can be very expensive in terms of gate count and thus power consumption. Nonetheless, the modular architecture of the icyTRX digital baseband enables us to readily add the additional blocks required to improve the sensitivity with a minimal effort.

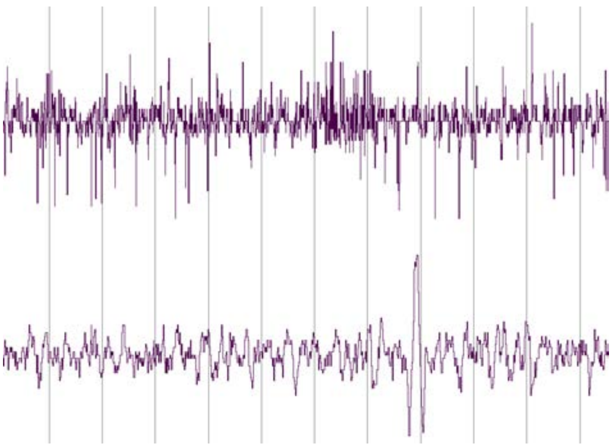

Figure 2: Simulation results of the correlation peaks obtained in the receiver: the first plot is the input signal, the second is the access address correlator output. The correlation peak is clearly visible.

The Long-Range feature has been tested on a setup composed by an icyTRX radio and an FPGA. In this configuration, the radio provides the output of the ADC to the FPGA, which performs the necessary demodulation steps. The preliminary results of this setup are promising; however a full silicon version is required to get rid of the limitations introduced by this setup.

The challenges introduced with the Bluetooth 5 specification have been easily met by the icyTRX platform, thanks to its flexible design.