

Link Budget, Power Trade-offs using Optimized Bluetooth 5 Transceiver IP

E. Le Roux, N. Scolari, N. Raemy

CSEM is continuously upgrading its icyTRX RF silicon IP [1] in accordance with the evolution of the Bluetooth Low Energy standard. For example, CSEM is currently implementing future direction-finding features. Bluetooth Low-Energy 5 introduced variable data rates for speed-range trade-off. Here, CSEM presents some figures, based on measurement and a propagation model, illustrating the potential impact of this trade-off on power consumption.

Bluetooth 5 introduced a variable data-rate to make a trade-off between communication range and speed [2]: in addition to the 2 Mbit/s data rate, Long-Range 500 kbit/s and 125 kbit/s rates are also now possible with the use of coding on top of basic 1 Mbit/s rate. As the rate impacts the energy per bit, this is also a trade-off between distance and product lifetime or battery size. Based on icyTRX measurements, CSEM presents a quantitative example of this trade-off and its potential benefits. For simplicity, and without loss of generalization, CSEM considers a symmetric communication between two icyTRX transceivers with 0 dBi antenna gains. The received power can be evaluated based on the following equation:

$$P_{Rx\ dB} = P_{Tx\ dB} + G_{AntTx\ dBi} - PathLoss_{dB} + G_{AntRx\ dBi}$$

For the purposes of making a relative comparison and understanding the tradeoffs, a simple propagation model is considered for the Path Loss [3]:

$$20 \cdot \text{Log}_{10} \left(\frac{4\pi \cdot 1m}{\lambda} \right) + 10 \cdot \eta \cdot \text{Log}_{10} \left(\frac{range}{1m} \right) + \mathcal{N}(0, \sigma^2)$$

$\underbrace{\hspace{10em}}_{1^{st} \text{ meter free-space}} \quad \underbrace{\hspace{10em}}_{\eta \text{ is path loss exponent}} \quad \underbrace{\hspace{10em}}_{\text{Normal distrib. } \sigma^2 \text{ variance}}$

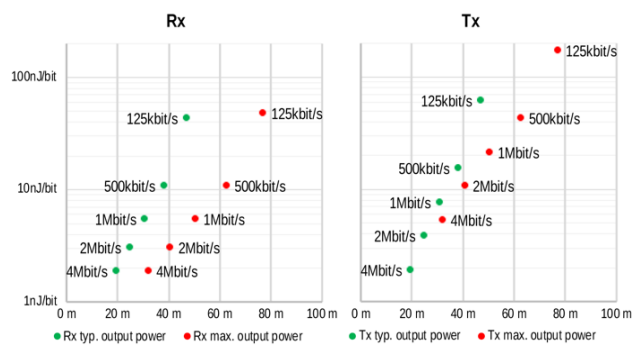
The η path loss exponent and σ standard deviation of Log-normal distribution are, respectively 2 and 0 for a free-space propagation context, 2.1 and 0 for a "corridor" Line-Of-Sight context, 2.9 and 6.1 for an "obstructed" Non-Line-Of-Sight context. Those parameters may vary quite a lot depending on real propagation context. The Log-Normal distribution is used to extract a $2.3 \cdot \sigma$ margin for a 99% connection probability.

Two different output powers are considered, with associated DC power consumption: the typical case is associated with the minimum 1.0 V supply voltage of the RF Power Amplifier (PA) and the maximum corresponds to the case of a 1.6 V PA supply voltage. The measured sensitivities associated with the selected data rates are also considered. In addition to the standard BLE cases, a proprietary 4 Mbit/s 4-FSK is considered for the purposes of comparison. A summary of the results for the various different cases is provided in Figure 1.

The best approach tends to be the maximization of data rate. When communication range is insufficient, the preferred

approach is to increase the output power before to reduce the data rate, if associated peak current can be supported.

Of course, additional considerations are associated with a specific application in which such a Bluetooth IP is implemented: possible asymmetry (typ. communication with cellular phone), packet overheads (including RF wake-up energy), antenna, interferer rejection, max. needed data rate, communication delay constrain or peak current that impacts the end-of-life voltage through battery internal impedance. A dynamic model of this impedance is preferred for simulations with currents profiles as battery-related time constants tends to be longer than packets duration.



Mode	DC Energy		Output power	Sensitivity @PER = 10 ⁻⁵	Communication range		
	Rx	Tx			Free-space	Corridor (LOS)	Obstructed (NLOS)
BLE 0.125Mbit/s	43nJ/bit	61nJ/bit	-0.7 dBm	-103.5 dBm	1345 m	327 m	47 m
BLE 0.5Mbit/s	11nJ/bit	15nJ/bit	-0.7 dBm	-100.9 dBm	997 m	246 m	38 m
BLE 1 Mbit/s	5nJ/bit	8nJ/bit	-0.7 dBm	-98.2 dBm	731 m	183 m	31 m
BLE 2 Mbit/s	3nJ/bit	4nJ/bit	-0.7 dBm	-95.5 dBm	535 m	136 m	25 m
4FSK 4Mbit/s	2nJ/bit	2nJ/bit	-0.7 dBm	-92.5 dBm	379 m	98 m	20 m
BLE 0.125Mbit/s	48nJ/bit	170nJ/bit	5.5 dBm	-103.5 dBm	2746 m	645 m	77 m
BLE 0.5Mbit/s	11nJ/bit	42nJ/bit	5.5 dBm	-100.9 dBm	2036 m	485 m	63 m
BLE 1 Mbit/s	5nJ/bit	21nJ/bit	5.5 dBm	-98.2 dBm	1492 m	361 m	51 m
BLE 2 Mbit/s	3nJ/bit	11nJ/bit	5.5 dBm	-95.5 dBm	1093 m	268 m	41 m
4FSK 4Mbit/s	2nJ/bit	5nJ/bit	5.5 dBm	-92.5 dBm	774 m	193 m	32 m

Measure of typical case Extrapolation with propagation model

Figure 1: Energy-distance trade-off (only Obstructed Non-Line-Of-Sight case illustrated in graphic).

[1] CSEM Scientific and Technical Reports (2012-2017).

[2] M. Wooley, "Bluetooth 5 go faster. Go further", Bluetooth SIG, <https://www.bluetooth.com/bluetooth-technology/bluetooth5/bluetooth5-thankyou>

[3] T. S. Rappaport, "Wireless communications: principles and practice (2nd Edition)", (2001).