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An Energy Efficiency Figure of Merit for Radio Transceivers

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***Abstract*— Selection of an energy efficient wireless transceiver is an important step in the design of any low power wireless system, specifically wireless sensor networks or IoT devices. In this paper, a figure of merit (FoM) for evaluating the energy efficiency of wireless radio transceivers is proposed. Using this FoM, it is possible to easily compare the performance of transceivers built with completely different technologies, in term of energy efficiency. This FoM can be used as a practical tool for researchers and engineers to evaluate wireless transceivers and determine the state-of-the-art or select a desired transceiver.**

I. Introduction

The energy efficiency of wireless communication is a critical aspect in the emerging wireless systems, for instance, Internet of Things (IoT) or wireless sensor networks (WSN). These devices are usually powered by batteries or low power energy harvesters. Thus, for long operation time they have to consume minimum amount of energy.

One of the main building blocks in a wireless device is the radio transceiver. A radio transceiver is an electronic circuit (discrete, module, or integrated circuit) which is capable of transmitting and receiving radio signals. These circuits, usually consume a notable portion of the total energy that is consumed in a wireless device. Therefore, 'power efficiency' becomes one of the main criteria in evaluating the performance of a wireless transceiver.

There are many radio transceivers available on the market and new transceivers are appearing occasionally. Each of these transceivers might be compatible with different protocols (Bluetooth, SigFox, WiFi 60 GHz, or etc.). These devices may employ completely different frequency and modulation, which may provide totally different data rates or ranges, consuming different amount of power for the operation. For this reason, evaluation, comparison and selection of appropriate transceivers can be a very frustrating task.

Figure of merit (FoM) can simplify this process. FoM is a numerical quantity based on characteristics of a transceiver that represent its efficiency. In this paper an energy efficiency FoM for radio transceivers is proposed which includes the main required characteristics of a transceiver. It enables us to evaluate and compare the energy efficiency of different radio transceivers independent of the production technology, architecture, or the protocol they are designed for. Using an energy efficiency FoM in these fields will also facilitate the process of research and development.

Several attempts have already been made to define an energy efficiency FoM for radio transceivers. In [1-3] different metrics for energy efficiency of a wireless link for both: circuits and protocols, are proposed. However, the required information for the proposed criteria is often not available in the datasheets and is difficult to measure. Survey on energy-efficient FoMs is performed in [4]. However, these FoMs are better suited for transceivers and components used in cellular networks, and are less efficient to evaluate the energy efficiency of transceivers built for short-range digital connections.

The proposed energy efficiency FoM, covers the tradeoffs between power consumption, data rate, and communication range. The advantages of this FoM is that it is easy to be derived and interpreted. It is based on parameters which are normally present in datasheets and reports of transceivers.

II. Radio Link

Fig. 1 depicts the structure of a conventional radio link. The transmitter radio (TX Radio) is a circuit that converts the input data stream into a radio signal. The antenna in the transmitter side converts the radio signal into an electromagnetic signal. This signal propagates in space and transfers the message to the receiver. This signal gradually attenuates during propagation due to scattering or absorption. The receiving antenna side converts the electromagnetic signal back into the form of an electrical radio signal. The receiver radio then detects the received radio signal and reconstructs the original stream of digital data. The energy efficiency of such a system can be evaluated by three main characteristics as following:

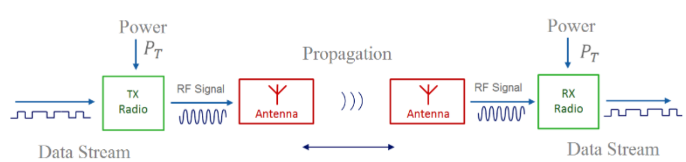

Fig. 1. A conventional radio link structure

A. Data rate

The data rate, or the speed of communication, is a critical parameter in the application of a radio link. It determines the amount of information which can be transferred for a certain period of time. The data rate of a radio connection can be determined by parameters such as the bandwidth and modulation scheme that is employed for the radio communication radio.

B. Communication Range

The communication range is the maximum distance between the transmitter and the receiver in which the transmitted signal can be reliably detected by the receiver. It determines how far the information can be transmitted using an specific transceiver.

The communication range can be influenced by the environmental conditions, obstacles, or characteristics of the employed antennas. However, from transceiver point of view, the two main factors which determine the range of a communication are: the ratio of the output power of the transmitter radio and the input sensitivity of the receiver radio. A more powerful transmitter with a more sensitive receiver can provide a stronger link which in turn can establish a radio connection within a longer distance.

In some references this ratio is called "link-budget". In other sources this term is defined as the amount of attenuation of a signal in a channel. Here we define this ratio as "link strength" (*LS*):

$$LS = \frac{P_{Tx}}{S_{Rx}} \quad (1)$$

or

$$LS = 10^{(P_{Tx}[dBm] - S_{Rx}[dBm])} \quad (2)$$

where P_{Tx} is the transmitter output power and S_{Rx} is the receiver input sensitivity, which are normally presented in dBm. Both P_{Tx} and S_{Rx} have the same dimension (Power), therefore, *LS* is a ratio and has no dimension .

C. Power Consumption

Both the transmitting and the receiving radios consume considerable amount of power. A transmitter should provide energy of the transmitted electromagnetic radio signals and the receiver requires power for its low noise front-end amplifier.

Normally, a transmitter radio with a stronger output signal consumes more power. Similarly, a receiver radio with more sensitive input consumes more power. Therefore, the range of a radio link is expected to increase with the consumed powers also growth by the increase of the communication range. Also, normally, under the same conditions, the power consumption of both the transmitter and receiver radio rises by the increase of the communication data rate.

III. Energy Efficiency FoM

Radio transceivers are devices which can both transmit and receive radio signals. Therefore, one and the same such device can be used on both sides of a radio link. Consequently, the three characteristics (data rate, communication range, and power consumption) which are mentioned for a radio link, can also be defined for a radio transceiver device.

Based on what has been discussed, by dividing the production of the link strength (1) and the data rate by the total consumed energy of both the transmitter and the receiver, the *Energy Efficiency* can be defined as follows:

$$Energy\ Efficiency = \frac{P_{Tx}}{S_{Rx}} \times \frac{DR}{P_T + P_R} \quad (3)$$

where DR is the data rate, and P_T and P_R are the power consumption of the transmitter radio and the receiver radio respectively. Expiration (3) with dimension "bit / joule" is the FoM we propose.

To show the applicability of the proposed FoM, the FoM values of a set of transceivers available on the market are depicted graphically in Fig. 2. This set includes categories of transceivers, from long range Lora with less than 1 Kb/s data rate to the short range WiFi 60 GHz with more than 1 Gb/s. On this graph, we can compare completely different transceivers.

The line FoM = 1.68×10^{17}, depicts the state-of-the-art (SoA) on this data set. The devices closest to this line have the best power efficiency. These devices are also known to be very energy efficient. Note that, a single device might establish different FoM when operating in different modes (Fig.2-CC2642R). It shows that this device operates more energy efficiently in a certain mode, compared with the other modes of operation.

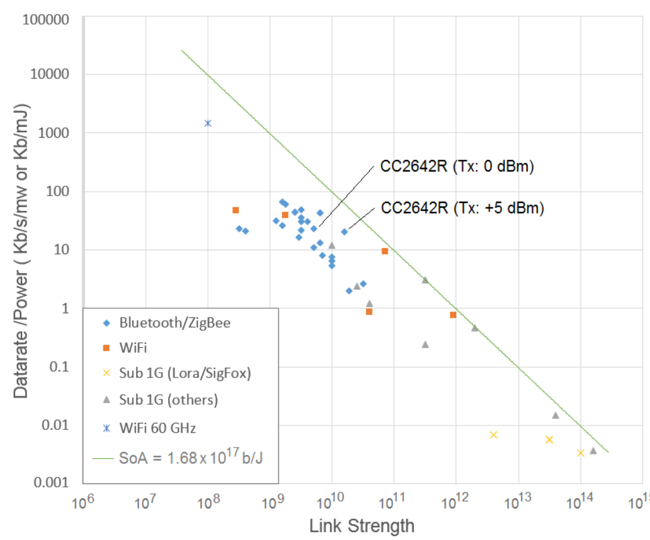

Fig. 2. Graphical presentation of the figure-of-merit (FoM) for different radio transceivers

IV. Conclusion

This FoM is obtained based on the main requirements of a user of a radio transceiver. The proposed FoM can be a tool to evaluate, indicate, and compare energy efficiency different transceivers and determine the state-of-the-art.

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