Poster: Switchable Directional Antenna System for UWB-based Internet of Things Applications

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Abstract

By enabling control of the direction of power radiation, directional antennas reduce channel contention, increase the communication range of nodes, and consequently increase the throughput and the energy-efficiency of low-power wireless systems. So far, most of the work on directional antennas has focused on narrow-band radios only. In this work, we present the prototype of a novel, low-cost, energy-efficient ultra-wideband switchable directional antenna system consisting of four planar antennas that can be electronically switched at high-speed.

1 Motivation

The large majority of low-power wireless systems in use today are based on *narrow-band* technologies. Most of the wireless sensor networks (WSN) and Internet of Things (IoT) applications developed in the last decade, indeed, operate in the license-free and globally available 2.4 GHz ISM band. Recently, the attention of academia and industry has moved to sub-GHz long-range technologies such as LoRA and SIGFOX because of their ability to communicate over long distances at low energy costs. However, both the 2.4 GHz and the sub-GHz frequency bands are narrow-band and are therefore severely affected by multipath fading and cross-technology interference [1].

Making the shift from narrow-band towards *ultra-wideband* (UWB) has the potential to tackle these limitations. In UWB the signal power is spread over a wide bandwidth ($\geq$ 500 MHz), which results in (i) a higher immunity to multipath fading[1], (ii) an improved interference mitigation, as well as (iii) a very good time-domain resolution allowing for accurate localization and tracking [9]. Since the commercialization of the first low-cost IEEE 802.15.4-compliant UWB transceiver, the DecaWave DW1000 [2], the research on UWB systems and their use for localization applications [4] has radically increased.

All commercial and academic UWB-based systems in use nowadays, however, use omni-directional antennas. The use of *directional* antennas could further reduce the multi-user interference and extend the communication range at no significant energy cost, as it has been shown for narrow-band radios. In particular, previous work has proven that directional antennas can reduce contention and increase throughput [7], reduce interference [3], minimize packet error rate, as well as improve energy-efficiency [5]. We expect similar results to hold true also for ultra-wideband systems. Moreover, directional antennas enable angular diversity, meaning that, in the case of a deep fade, the antenna can be switched in order to keep the quality of the communication link high. The already highly accurate localization performance of UWB systems can further benefit from directionality by suppressing interfering multipath and exploiting directional information [8].

To address the lack of directional antennas for UWB-based systems, we have designed and developed a prototype of an electronically-switchable directional antenna. As the focus of our work is on low-power UWB-based wireless systems used to build novel WSN and IoT applications, the following *requirements* had to be addressed in the design process: (i) low cost, (ii) small form factor to support large-scale networks, and (iii) low power consumption to suit battery-powered devices. Fulfilling *all* these requirements at once is challenging because achieving a high directionality while still maintaining nearly constant electrical performance over the large frequency range usually requires an increase in the antenna size.

We now present a comprehensive description of a prototype that fulfills these requirements in Sect. 2 and discuss the next steps as well as emerging research questions in Sect. 3.

2 Prototype System

The system we have developed consists of a DecaWave DW1000 RF transceiver, an ARM Cortex M3 host processor, an RF switching network, and four directional antennas. Fig. 1 shows the antenna section of the prototype system, consisting of the antennas and the switching network. The

[1] The high bandwidth makes it possible to distinguish between different multipath components (MPCs) and to make use of the multipath energy to enhance the reliability of the communication link. In narrow-band systems the signal is "smeared" by the channel and making use of multipath components is not relevant [6].

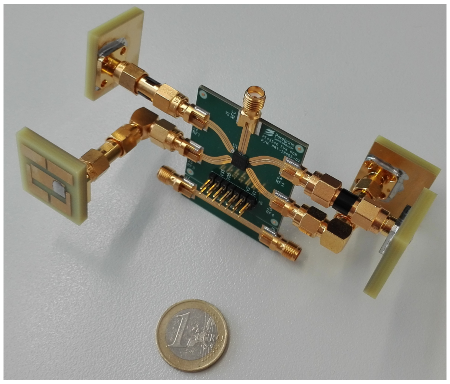

Figure 1. Antenna section of the prototype system containing four antennas and the RF switching network. On top is the port used to connect the DW1000 transceiver.

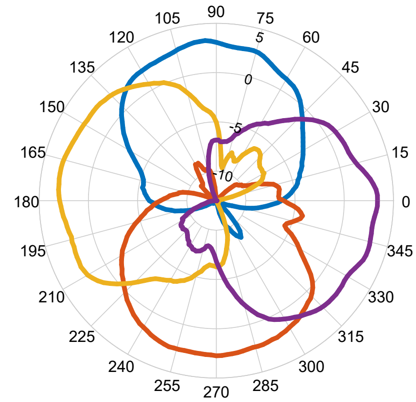

Figure 2. Measured antenna patterns of the prototype system at 5 GHz in polar coordinates (azimuth plane).

antennas are mounted in a way so that the main beam (orthogonal to the plane) is pointing at different directions with an angular shift of 90° between each other.

RF switching network. For seamlessly switching between different antennas, a high-speed RF switching network is necessary. In the developed prototype, we employ an UltraCMOS RF switch from Peregrine Semiconductor (PE42441), which consumes significantly lower current (90 μA) than traditional PIN diodes. Still, there is no significant degradation of the insertion loss in the desired frequency range (∼1-2dB@4.5-8 GHz). The switching time is 5 μs and the switch comes at a high-volume price of less than $3.5 (excluding PCB manufacturing). Two GPIO pins of the host processor are used to control the switching network and select the desired beam dynamically. Because of the low power consumption, there is no need for an external power supply and the antenna section can be seamlessly integrated in battery-powered devices. Please note that, due to the selected RF switch, the number of output ports is currently limited to four. In practice, the number of used antennas and therefore the number of radiating sectors can be expanded arbitrarily.

Low-cost planar antenna. The centerpiece of the proposed system is a low-cost directional ultra-wideband antenna. It has a planar structure and is based on a low-cost FR4 substrate, which results in a price of less than one dollar per antenna (in mass production). Also, the size of 25x23x4 mm is reduced to a minimum and ensures a small form factor for the system. The novelty of our antenna design is the small size while maintaining a stable behaviour over the wide bandwidth. The SMA connector is mounted directly on the antenna, so there is no need for an additional feeding line.

Antenna pattern measurements. Fig. 2 presents the results of the antenna pattern measurements in an anechoic chamber.

Table 1. Gain and HPBW of each sector at 5 GHz.

	Gain [dB]	HPBW [°]
Sector 1 (blue)	3.068 dB	88°
Sector 2 (purple)	3.380 dB	100°
Sector 3 (orange)	2.742 dB	98°
Sector 4 (yellow)	2.922 dB	108°

It was recorded in the azimuth plane (elevation=90°) with 2° resolution. As shown in the figure, four sector antennas are sufficient to have a proper coverage of the 360° horizon. The average gain over all four sectors is 3.028 dB and the half-power beam width (HPBW) is 98.5° (see Table 1). The results are exemplarily shown at 5 GHz, but the system is designed to be used up to 8 GHz and therefore covers all radio channels supported by the DW1000 transceiver.

3 Next Steps

As a next step, we plan to downsize the proposed system to a more compact and robust design and exploit its potential by tackling the following research questions: (i) Does exploiting directional information significantly increase the localization performance? (ii) What are the benefits in terms of energy consumption and throughput? (iii) How does the use of directional antennas affect the design of a location-aware UWB MAC protocol?

4 Acknowledgement

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5 References

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