Demo Abstract: Smart Antennas Made Practical: The SPIDA Way

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1. MOTIVATION

Smart antennas are a specific type of directional antenna able to *dynamically* control the gain as a function of direction. This contrasts with more traditional directional antennas, where the dynamic ability is missing, and with omni-directional antennas, which are designed to have equal gain in all directions.

Because of these characteristics, smart antennas may provide increased communication range by dynamically concentrating the transmitted power towards the intended receiver(s). This also reduces the contention on the wireless medium, as devices not involved in transmissions are less affected. Both features yield increased reliability at the physical level, an asset for network functionality such as routing protocols. Moreover, localization mechanisms may also take advantage of angle-of-arrival information [1].

However, applying smart antennas in real-world sensor networks remains an issue, due to the lack of practical prototypes that can be easily integrated with existing sensor network platforms. Some experiments are reported with prototypes that tend to be large, costly, or impractical because of the need of external power [2]. A few solutions also exist that require advanced signal processing techniques, which are generally difficult to implement on resource-constrained devices. As a result, most sensor network research involving smart antennas has been hitherto carried out in simulation.

Confronted with these issues, we design and build a smart antenna that is sufficiently inexpensive and practical to allow its integration with existing sensor network hardware. We also developed the software functionality to enable its use in a standard sensor network stack.

2. THE SPIDA SMART ANTENNA

We design the *SPIDA*[1] smart antenna to operate in the 2.4 GHz ISM band aboard a TMote Sky device, using a CC2420 radio. The current prototype is shown in Figure 1, attached to the sensor node through a standard SMA connector. We describe next the hardware/software characteristics, along with preliminary results on the antenna behavior.

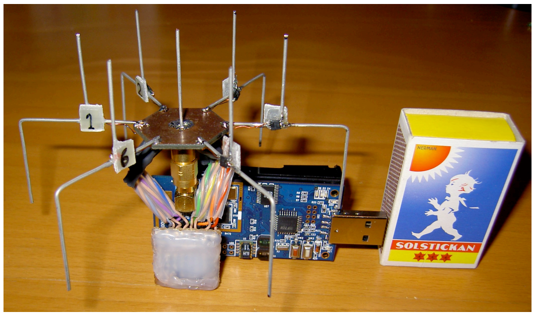


Figure 1: Smart SPIDA prototype.

2.1 Hardware/Software

The SPIDA is a *switched parasitic antenna* [3], i.e., it consists of a central active element surrounded by "parasitic" elements, which can be switched between ground and isolation. When grounded, they work as reflectors of radiated power, and when isolated they work as directors of radiated power. The central monopole is a conventional quarter-wavelength whip antenna. As shown in Figure 1, the SPIDA is equipped with six parasitic elements, yielding six possible "switches" to control the direction of transmission.

A distinguishing feature is the SPIDA's smoothly varying radiation pattern. The antenna gain is designed to vary as an offset circle from approximately 7 dB to -4 dB in the horizontal plane, without any significant side lobes even when using simplistic on-off control [1]. The antenna is straightforward to manufacture, and its most expensive part is the SMA connector costing about 5 ECU in single quantities.

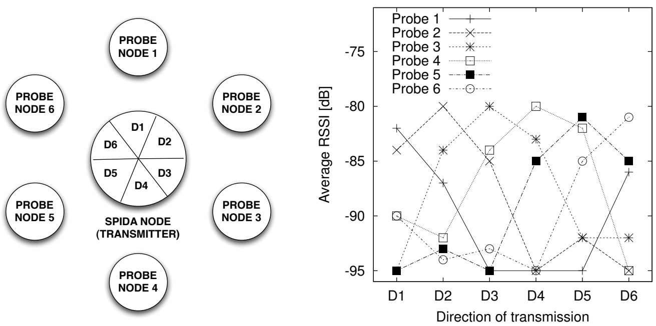
We design the control circuitry with a major aim of reducing interference and suppress noise from the sensor node digital circuitry. We use the available I/O lines on the TMote Sky to control the six parasitic elements, using two LC filters for each I/O line to prevent noise from entering the RF section. Each parasitic element is controlled by an ADG902 SPST RF solid state switch. The control circuit is soldered onto a stripboard with an attached 10-pin IDC connector that fits directly onto the TMote Sky expansion pins.

At software level, we develop a simple API, shown in Figure 2, targeting the Contiki [4] operating system. The first

[1]SPIDA stands for SICS Parasitic Interference Directional Antenna.

Function	Input	Description
`spida_activate(int)`	1-6	Isolate one of the six individual parasitic elements.
`spida_deactivate(int)`	1-6	Ground one of the six individual parasitic elements.
`spida_set_direction(int)`	0-6	Configure all parasitic elements at once to set a specific direction of transmission. (0 causes the SPIDA to behave as an omni-directional antenna).

Figure 2: SPIDA API.



(a) Experiment setup. (b) RSSI at probes.

Figure 3: Direction experiment.

two functions serve to isolate or ground specific parasitic elements on the SPIDA, thus enabling individual fine-grained control. Nevertheless, we expect the common use of the SPIDA to involve only one isolated element at a time, to direct the transmission in one specific direction. The last function in Figure 2 configures all parasitic elements at once to enable transmission in one of the six possible directions. Giving `0` as input makes the SPIDA isolate all parasitic elements, leading to omni-directional behavior. For instance, this may be useful for neighbor discovery.

2.2 Preliminary Results

To check the correct functioning of our prototype, we use the setup in Figure 3(a). The node in the middle is equipped with the SPIDA and generates periodic broadcast transmissions. We deploy six nodes around the SPIDA, along the six possible directions of transmission. These nodes act as "probes" by logging the broadcast transmissions they hear, using standard omni-directional antennas. Every 10000 transmissions, the control software on the SPIDA node dynamically changes the direction of transmission.

The chart shown in Figure 3(b) demonstrates that the Received Signal Strength Indicator (RSSI) returned by the radio chip reaches a maximum when the direction of transmission aligns with the corresponding probe node. This reflects in better link quality and thus higher packet delivery. In contrast, the RSSI reading tends to be minimum when the direction of transmission is opposite to a given probe node. This shows that our prototype is able to direct the transmitted power in given directions while not involving other nodes. Nevertheless, we also carried out a more extensive assessment of the antenna performance [5].

3. DEMONSTRATION HIGHLIGHTS

To demonstrate the operation of the SPIDA, we design and build a supporting base plate equipped with six super-bright LEDs. We control the LEDs using dedicated circuitry interposed between the sensor node and the antenna. We turn an LED on when the corresponding SPIDA parasitic element is isolated, providing a visual indication of the current SPIDA configuration. We use a setup similar to Figure 3(a), connecting all nodes to a laptop for easier inspection of their internal states and visualization of the network topology. By controlling the radio output power, we may setup our demonstration on a 4 x 4 m table and still obtain a multi-hop scenario. However, a 10 x 10 m space would allow us to create a more realistic setting.

Using multiple experiment setups, we demonstrate different ways of taking advantage of the antenna's functionality:

- We show the increased packet delivery ratio in 1-hop unicast transmissions obtained by directing the transmission towards the target device. We compare this to using the omni-directional mode on the SPIDA, which emulates a traditional antenna.
- Still using unicast transmissions, we show the antenna's ability to change the direction of transmission by quickly alternating between the six probe nodes as target. This demonstrates the SPIDA's dynamic abilities.
- We show the impact of using the SPIDA with a traditional tree-based collection protocol. We use one of the probe nodes as sink, and let the protocol build a tree among the nodes in Figure 3(a). The SPIDA alternates between omni-directional mode for reception and neighbor discovery, and directional mode for transmissions to the parent in the tree[2].

We also plan to further involve the public by showing the various (disassembled) hardware components necessary for a SPIDA antenna, providing further insights into its construction process.

4. REFERENCES

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[2] In this demonstration, we assume the node location is known.