# DiStAL: Digitally Steerable Antennas for Localization

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## ABSTRACT
We propose localization in real time using digitally steerable antennas. The antennas are based on Electrically-Steerable Parasitic Array Radiator (ESPAR) design that is digitally steered by a micro controller. The antenna is configurable to patterns that provide directional and omni-directional reception and transmission. The received signal strength is measured for distinct antenna configurations and the results are processed for an array of such antennas. The analysis produces the best location estimate of the transponder. This paper presents the operation and the needs of the proposed demonstration.

## 1. INTRODUCTION
Our approach is using a number of localization nodes that are equipped with a digitally steerable ESPAR antenna each [1, 2]. The nodes act as either transmitters or receivers with controlled directionality. The direction is changed over time to improve the localization accuracy. The targets for the localization are equipped with an active transmitter tag. The tag emits a control sequence over a radio channel using a range of transmission power values. The data received by the directional antennas is used for signal processing and multilateration that calculates the most likely positions of the objects to be localized [3, 4].

The following localization scenarios are possible:

1. The localization infrastructure nodes act as receivers scanning the area for objects with simple transmitters, then submit their data to the processing server that estimates the location of the objects. This case is better for small number of objects to be localized. When the number of objects increases, the probability of interference between the transmitters increases, unless TDMA or similar contention avoidance protocol is used.

2. The localization nodes act as spatial pattern transmitters (beacons) while the target objects are supplied with the receiver tags. The tags collect wireless signatures of the beacons and annotate them with timestamps. The captured information is sent to the base station for processing and analysis that estimates the location of the objects. This case scales better to larger number of objects, especially when the target localization needs to be time-synchronized. The tags still need to transmit the data either actively or as queried by the server to transport the data for processing. The beacon array may assist in delivering the data to the processing sink.

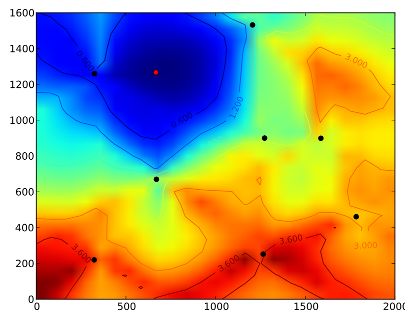


**Figure 1: Heatmap showing the estimated position of the transponder node.**

3. The objects to be localized are tag-free. The location is determined from the interference patterns created by the steerable localization beacons. The patterns are observed and captured by the rest of the steerable localization nodes and delivered to the server for analysis. This approach requires no instrumentation of targets, however has lower resolution for the location and does not provide the identity of the localized objects. Also, this approach does not scale well for number of simultaneous targets due to multiple obstacles, multi-path effects, reflections, and the complexity of data processing.

Our demo and entry to the competition will focus on the first scenario. Time and on-site performance permitting the second approach will be evaluated as well.

### 1.1 Position estimation
The target to be localized emits RF signal several times per second. The receivers measure signal power (`RSSI`) by applying omni-directional and three directional beam patterns to the antenna configuration. The measurements are filtered to reduce noise, aggregated and sent to the processing node. The signal analysis and data processing unit normalizes the directive signal strength using the unidirectional signal strength and creates signal power triplets $s_b, s_g, s_r$ for every receiver node.

Taking into account the positions and angular mutual orientation of the receiver antennas, the fingerprint maps of signal power triplets are calculated. The position of the emitter is calculated using maximum likelihood estimation.

Let $(x_i, y_i)$ be given positions of $N$ receiver antenna and

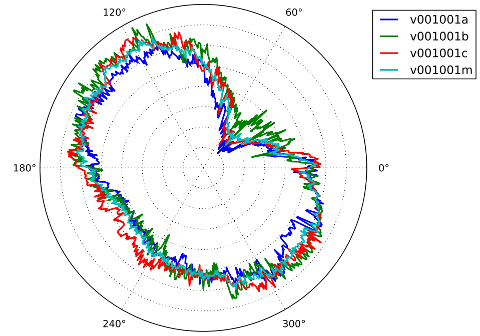


**Figure 2: Directionality of the SAntA antenna measured for a sample configuration.**

$\varphi_i$ their angular orientations. Received signal power triplets form $3N$ vector

$$\vec{s} = (s_{b1}, s_{g1}, s_{r1}, \ldots, s_{bN}, s_{gN}, s_{rN})$$

For the trial position of the emitter $(x_t, y_t)$, signal power triplets per receiver $w_b, w_g, w_r$ are calculated using measured and scaled directivity patterns and DoA to the receiver, $\Theta_i$

$$\Theta_i = \arctan \frac{y_t - y_i}{x_t - x_i} - \varphi_i$$

Calculated signal power triplets form $3N$ vector

$$\vec{w}(x_t, y_t) = (w_{b1}, w_{g1}, w_{r1}, \ldots, w_{bN}, w_{gN}, w_{rN})$$

The position of the emitter $(x, y)$ is calculated using minimization of difference between the measured and calculated signals $|\vec{s} - \vec{w}|$.

$$(x, y) = \arg \min_{x_t, y_t} |\vec{s} - \vec{w}(x_t, y_t)|$$

Figure 1 shows a heat map where a position is estimated using 8 nodes. As we are constantly evaluating and improving our mathematical solution, it may differ at the competition, however the hardware will stay the same.

## 1.2 SAntA beacon node

The directionality is achieved using ESPAR antenna design with one active element in the center and six passive elements around it. The antenna is embedded in plexiglass that has permittivity different from air and allows to reduce the size of the antenna. Another feature is using the active element at $\lambda/4$ while half of the passive elements are tuned slightly shorter and the other half are longer. This enables configuring the antenna as three 3-element Yagi antennas that have improved directionality. Finally, the antenna is configured digitally from a micro controller by selectively grounding or floating (enabling or disabling) the passive elements to customize the directionality pattern with no moving elements (Figure 2).

The steerable antenna array is controlled by the sensor node (named SAntA) (Figure 3) built using "Telosb" compatible "Tmote mini" module with MSP430 controller and 2.4GHz transceiver chip cc2420. The ESPAR antenna is controlled by six digital signals and attached to the node. There are six LEDs for user interface during the development and deployment. The node is programmable via USB port. The firmware is developed using MansOS operating system [5, 6]. The localization processing and analysis for

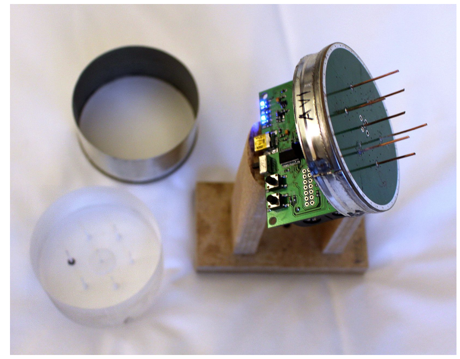

**Figure 3: SAntA components: the antenna dielectric medium (plexiglass), the antenna ground skirt and the ESPAR antenna with a the sensor node attached below.**

the server is written in Python, using NumPy and SciPy libraries.

## 1.3 Deployment setup

Our localization infrastructure will use battery powered SAntA beacon nodes either on camera-tripod or table top mounts. The setup has no moving parts. We expect to deploy up to 8 SAntA nodes depending of the layout of the test site. The localization target will carry a small, battery powered node as a transponder. A sink device will collect and analyze the real time data stream from the SAntA nodes and display the localization results on-screen.

# 2. REFERENCES


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