# Indoor radio interferometric localization and tracking

## [Abstract for the Microsoft Indoor Localization Competition]

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## ABSTRACT

In a radio interferometric measurement a pair of wireless sensors produce a radio interference pattern by simultaneously transmitting pure sine waves at two close frequencies. Other wireless sensor nodes can measure the envelope (beat) signal of the composite interference signal as the received signal strength (RSSI). If two receivers measure the absolute phase of the beat signal at the same time, then the phase difference between the two measured absolute phases is the linear combination of four distances between the transmitter and receiver pairs modulo the wave length of the carrier. The radio interferometric measurement was introduced in [1] where centimeter precision localization error was achieved outdoors in a football field using the MICA2 wireless sensor nodes with the Chipcon CC1100 radio transceiver. The proposed localization technique of that paper had many technical and theoretical drawbacks which prevented the easy adaptation of it to indoor environments. In this short paper we overview our new results on addressing these technical and theoretical shortcomings and adapting the radio interferometric measurement to an indoor settings.

In the localization competition we plan to use COTS Unicomp Proton A wireless sensor nodes (very similar to the MICA2 but with the newer Atmega128RFA1 chip working at 2.4 GHz) with standard TinyOS software. We plan to use several infrastructure nodes and a fixed constellation of mobile sensors for static localization. On the other hand, if movement of the sensors is allowed, then we plan to use a single receiver with many infrastructure nodes.

## 1. INTRODUCTION

We assume, that the reader is familiar with the theoretical foundations of the (RIPS) radio interferometric measurement from [1]. The general procedure is depicted in Figure 1 where node $A$ and $B$ are the transmitters and nodes $C$ and $D$ are the receivers measuring the absolute phase of beat signal at a common time instant. Assuming free space propagation, the difference of the measured absolute phases satisfies the following formula

$$\varphi_C - \varphi_D \equiv 2\pi \cdot (d_{AD} - d_{BD} + d_{BC} - d_{AC})/\lambda \pmod{2\pi}$$

connecting the measured values to a function of the distances between the sensors. Note, that $\lambda$ is the wave length of the carrier signal, so for 2.4 GHz transmitters we have $\lambda =$ 12.5cm.

The original outdoor radio interferometric localization relied on several measurements (using different pairs of senders and receives) at several different frequencies. First, the $2\pi$ ambiguity can be resolved if we can change the carrier frequency in a wide range (the 400–460 MHz range was used in [1]). Second, we can use the non-linearity of the distances between the sensors to find an optimal configuration which best matches the measured relative phases. There were several theoretical and technical problems with this approach:

1. Multipath radio propagation changes the phase of the signals in an unpredictable way.
2. These errors also depend on the carrier wave length, and the original $2\pi$ ambiguity resolution does not work.
3. The transmitters had to fine tune their transmit fre-

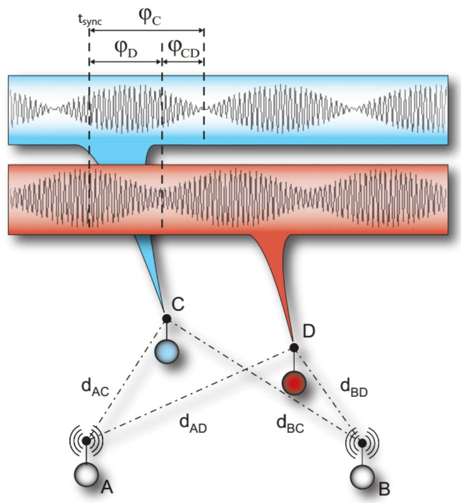


**Figure 1: The basic RIPS measurement**


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**Figure 2: The Unicomp Proton A mote**

quencies in order to bring the frequency of the beet signal down to a measurable 100–300 Hz range.

4. A single measurement took a lot of time (more than 250 ms) because of the slow radio, the collection of measurements was slow.

5. The schedule and orchestration of the measurement was not autonomous, it was hard to use the system.

Next we describe our solutions addressing these problems.

## 2. TECHNICAL IMPROVEMENTS

We have selected to use a new COTS wireless sensor (Figure 2) based on the Atmega128RFA1 chip (an 8-bit MCU, 16 MHz, 128 KB ROM, 16 KB RAM). This chip has an integrated MCU and radio transceiver, so the access of the radio registers is much faster (no need for SPI). There are newer versions of this chip that operate at a lower ISM radio range (e.g. 433 MHz) which would be better for indoor localization. Some versions of the Proton sensors have an auxiliary radio chip, but we do not uses those and rely exclusively on the Atmega128RFA1 both for communication, synchronization, interference generation and interference measurement. We use the small blue ceramic chip antenna on the PCB.

We use the test modes of the radio chip to emit pure sine waves. This chip cannot fine tune the transmit frequency like the original CC1000 did, only the normal IEEE 802.15.4 channels can be selected. However, we can use a configurable trimming capacitor of the MCU to offset the clock frequency (which also drives the radio frequency synthesizer) so with some probability the frequency offset between the two transmitters is around 50-100 KHz. The sampling of the RSSI is running at 500 KHz. Currently one full measurement takes 1 ms (to change to test mote, set trimming, stabilize, do the transmission and RSSI sampling, and reset the radio).

We have implemented the digital signal processing algorithm on the wireless sensor. This calculates the start of transmission, period of the beat signal and the absolute phase at a fixed time instant. Unfortunately the resolution of the RSSI is very low (28 steps), but it seems to be enough for our purposes. The signal processing of the received RSSI signal takes around 0.7 ms.

We have developed a TDMA like scheduling algorithm that works reliably and minimizes the number of synchronization messages. The synchronization messages are also used to extract the measurement data to the base station for further processing. The scheduler is highly reliable and achieves a synchronization accuracy within 1 radio clock tick (62 KHz). The radio data transmission is further improved (eliminated all random delays in exchange of possible loss of messages). Depending on the schedule we can make around

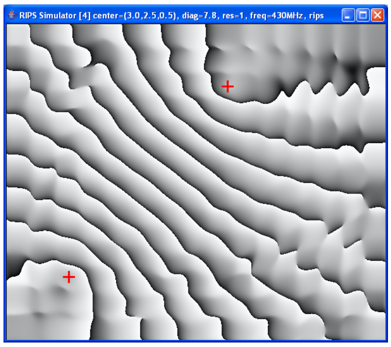


**Figure 3: The basic RIPS measurement**

500 measurements per second (one pair of transmitters and several receivers), which is two orders of magnitude faster than the original RIPS algorithm.

## 3. THEORETICAL IMPROVEMENTS

As can be seen on the simulated Figure 3, multipath changes the measured phase of the beat signal. Instead of trying to use the exact phase (which is distorted) we track the changes of this phase continuously. This way for a fixed pair of transmitters, a fixed receiver and a mobile receiver we can track how many contour lines the mobile receiver have crossed (where we jump between 0 and $2\pi$). This way we can have a rough idea on which hyperbolic line we are currently on. If we use several transmitter pairs, which give different sets of hyperbolas, we can get the position of the node with high probability. Unfortunately we also have an unknown integer ambiguity (just like for carrier cycle base GPS localization) but since our contour lines are not linear we can use the geometry to improve our estimate of the initial position. The technical improves sped up the measurement so much that we have enough data to track our position.

For a static localization algorithm we use a fixed configuration of receiver nodes at known distances relative to each other (the current number of nodes is being optimized). Then from our measurements with fixed infrastructure nodes we can find the likely position of the mobile configuration. There are several other improvements on the selection of transmission and receiver pairs not discussed here. Currently the localization algorithm is a brute force optimization running on the laptop computer, but even this seems to be fast enough.

The range of our localization technique is between 2–10 meters and we might get 10–50 cm accuracy. We did not experiment in larger halls yet, only in offices, but people can move around in the measurement arena. We would require regular tables (not metal ones) and maybe tripods for the fixed infrastructure motes. Currently we are evaluation our solution and experimenting at various locations trying to better understand the strengths and limitations.

## 4. REFERENCES


[1] M. Maróti, B. Kusý, Gy. Balogh, P. Völgyesi, A. Nádas, K. Molnár, S. Dóra and Á. Lédeczi, *Radio interferometric geolocation*, 3rd ACM Int. Conf. on Embedded Networked Sensor Systems (SenSys), San Diego, USA, 2005, 1–12.