

EWSN 2014: Posters and Demos

Welcome to Oxford, U.K., and to the Poster and Demo Session of the 11th European Conference on Wireless Sensor Networks (EWSN).

EWSN is a highly selective conference in the area of sensor networks and the Poster and Demo session provides an ideal platform to disseminate early research results and to showcase exciting demonstrations. In addition to the traditional Poster and Demo session, the authors of accepted submissions participate in a 1-minute madness session where they give a short pitch to all EWSN attendees.

This year we received a total of 43 submissions from authors in 20 different countries representing all continents, except Antarctica! Considering that poster and demos are aimed at disseminating preliminary work, the main criteria for acceptance was novelty. After an initial evaluation, submissions were divided into three categories: accept, borderline and reject. Most of the borderline submissions were discussed in detail among the three co-chairs. We accepted 29 submissions, 13 demos and 16 posters. The accepted posters and demos cover a wide range of topics, from traditional networking research such as routing, time synchronization and data fusion, to smart environments and novel localization methods.

The Poster and Demo session is an integral part of the EWSN conference and we want to express our gratitude to the General Chair, Niki Trigoni, the TPC Co-Chairs, Amy Murphy and Bhaskar Krishnamachari, and the members of the Steering Committee for their constant support.

We hope that you will enjoy the program and that you will strongly consider submitting poster and demos to future versions of EWSN.

Poster and Demo Co-Chairs EWSN 2014

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Contents

Applications	4
Demo Abstract: Data Center Monitoring on a Budget	
<i>Peter Haban, Faye Mitchell, and Cigdem Sengul</i>	4
Demo Abstract: Lessons Learned from a WSN Deployment for Precision Agriculture	
<i>Prashant A. Patil, Jabal Raval, Bhushan G. Jagyasi, Nilima Warke, and P. P. Vaidya</i>	6
Demo Abstract: Measuring Human Energy Expenditure with K-Sense	
<i>Kazi I. Zaman, Anthony White, Sami Yli-Piipari, and Timothy W. Hnat</i>	8
Demo Abstract: Demo Abstract: Object Recognition in Visual Sensor Networks. A comparison of two different operative paradigms	
<i>A. Canclini, L. Baroffio, M. Cesana, A. Redondi, and M. Tagliasacchi</i>	10
Poster Abstract: Sensor Network Based Surveillance System for Forest Protection	
<i>Gergely Vakulya, Gyula Simon, László Czúni, and Péter Z. Varga</i>	12
Localization and Tracking	14
Demo Abstract: Lightweight Continuous Indoor Tracking System	
<i>Zhuoling Xiao, Hongkai Wen, Andrew Markham, and Niki Trigoni</i>	14
Demo Abstract: Multi-Sensor Fusion for Indoor Pedestrian Tracking	
<i>Jan Medvesek, Andrew Symington, and Stephen Hailes</i>	16
Poster Abstract: A Case for Magneto-Inductive Indoor Localization	
<i>Traian E. Abrudan, Andrew Markham, and Niki Trigoni</i>	18
Poster Abstract: WiFi Sensors Meet Visual Tracking For An Accurate Positioning System	
<i>Savvas Papaioannou, Hongkai Wen, Zhuoling Xiao, Andrew Markham, and Niki Trigoni</i>	20
Poster Abstract: Robust Phase Estimation for RSSI signals	
<i>Gergely Zachár and Gyula Simon</i>	22
Poster Abstract: Robust Sensor Fusion for Radio Interferometric Tracking	
<i>Gergely Zachár and Gyula Simon</i>	24
Smart Buildings	26
Poster Abstract: Delivering Intelligent Home Energy Management with Autonomous Agents	
<i>Conor Muldoon, Michael J. OGrady, David Lillis, Tadhg OSullivan, Thomas Holz, and Gregory M.P. OHare</i>	26
Poster Abstract: Experimental Analysis of Environmental Perturbations on Wireless Sensor Network Operation	
<i>Mustafa Mousa, Ahmad Dehwah, and Christian Claudel</i>	28
Poster Abstract: Intelligent Building Management Systems Based on Cognitive M2M Communications	
<i>Manolis Surligas, Stefanos Papadakis, Vangelis Angelakis, Sofoklis Kyriazakos, Elias Tragos, and Di Yuan</i>	30
Poster Abstract: Secure Metering Communication in the Energy Smart Home Lab	
<i>Anton Hergenröder, Kaibin Bao, and Thomas Bräuchle</i>	32

Poster abstract: Robust Phase Estimation for RSSI signals

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Abstract—A distributed noise-tolerant and accurate phase-difference measurement scheme is proposed, which can be run on low end devices with limited computational power. The proposed algorithm can be used as a key building block in radio interferometric localization systems. The operation of the algorithm is illustrated by real measurements.

I. INTRODUCTION

An emerging localization technique in sensor networks uses radio-interferometry [1]–[3]. In such applications precise distributed phase-difference measurements are necessary: two radio receivers detect interferometric radio signals (the envelope of which is the received signal strength, RSSI signal) at the same time (see Fig. 1). The localization and tracking algorithms use the difference between the phases of the two RSSI signals (see e.g. [1]). In this paper a robust and accurate method to measure such phase difference is proposed. The proposed method has low computational complexity on low-end devices and also provides fast and accurate measurements.

II. PHASE MEASUREMENT

In large scale sensor-networking applications, where a large number of nodes are utilized, the nodes are usually inexpensive devices with limited computational power. To perform distributed phase difference measurements on such devices, the phase estimation algorithm should fulfill the following requirements:

1. The processing requirements should be low enough to enable the utilization of the algorithm in devices with limited resources and processing power: the nodes used for measurement are based on an 8-bit microcontroller.
2. The processing should be fast, since the measurements should be done as frequently as possible.
3. The algorithm must handle the logarithmically-scaled sinusoidal signal form, since the RSSI values measured in the radio are provided on a logarithmic scale.
4. The algorithm must be robust to handle distorted and noisy signals.

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Based on the requirements a tailor-made algorithm was designed, which is using minimal resources on the devices.

To allow fast and still accurate processing, low-end devices use only integer calculus for intermediate results, while the final result is calculated on a host computer with floating-point arithmetic. Thus the measurement result can be more accurate while soft floating-point operations are avoided on the devices.

The operation of the proposed method can be seen in Fig. 2. First the RSSI samples are collected: the sampling frequency and the length of the record are determined so that at least a few full periods are present in the data record. Data recording is performed in a strictly synchronized manner: the two receiver nodes start the recording when a start message is received (using reference broadcast). Then in both data records reference points are searched for.

Note that the signal can be rather asymmetric, due to its logarithmic nature. Signal maximum or minimum points are good choices for reference, since their positions are invariant to the actual shape (see Fig. 1). The problem with these points is that the signal's slope is zero here, thus direct measurement is inaccurate in the presence of noise. Other reference points with higher slope (e.g. signal crossing a given value) would be easier to measure but they are not invariant to the actual signal's shape, resulting offset in the phase measurement. The proposed solution uses maximums as reference points but the estimation of these positions is done indirectly, resulting in an accurate and noise-resilient solution.

In the first processing step the average of the signal is calculated (red line). Then the upper and lower hysteresis

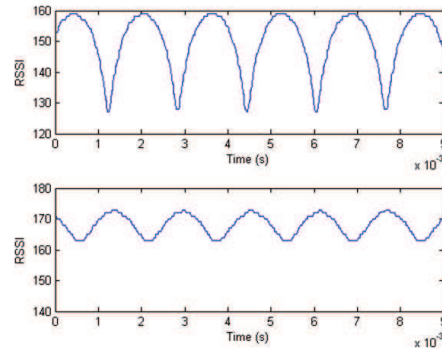


Fig. 1. Typical interferometric RSSI signal forms, registered at two receivers

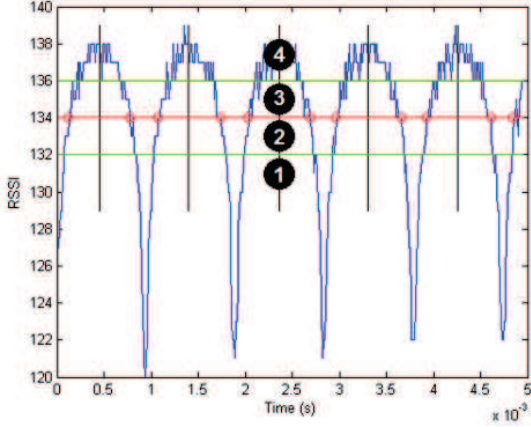


Fig. 2. Illustration of the phase measurement: red line: mean value, green lines: hysteresis limits, 1-4: amplitude ranges, red circles: 2-3 and 3-2 transitions, and black lines: estimated times of the reference points

limits (green lines) are determined, which have distances of Δ from the average, where value Δ is determined to be higher than the maximal noise level. The average and the two limits divide the amplitude space into four regions, as shown in Fig 2. The further processing of the signal is performed with a state-machine, which follows the signal through regions 1-2-3-4-3-2-1-..., in this strict order. When transitions 2-3 and 3-2 occur, the times of the transitions are marked (t_{23} and t_{32} , respectively, zero being at the beginning of the data record) and the time of the maximum of the signal is estimated as $t_{max} = (t_{32} + t_{23})/2$. (Notice that t_{23} and t_{32} themselves cannot be used as reference points, since their positions depend on the actual signal shape, see Fig. 1.)

For the accurate and fast phase estimation, floating-point arithmetic is only used on the host computer. Therefore the low-end devices preprocess the signal using integer arithmetic, and transmit intermediate results to the host. These intermediate parameters $DSUM$, SUM and NUM are derived as follows:

$NUM = n$ is the number of the reference points in the record. First the device calculates the sum of the distances of the consecutive reference points:

$$DSUM = \sum_{i=2}^n P_{ref}(i) - P_{ref}(i-1) = P_{ref}(n) - P_{ref}(1) \quad (1)$$

where $P_{ref}(i)$ is the distance between the i -th maximum point and the beginning of the measurement. From these intermediate results the wavelength can be calculated on the host, using floating point operations as follows:

$$L = \frac{DSUM}{NUM-1} \quad (2)$$

The RSSI signal's phase is also measured using the reference points. A simple phase can be estimated as follows:

$$\vartheta = 2\pi \frac{P_{ref}(1)}{L} \quad (3)$$

where $P_{ref}(1)$ is the estimate of reference time delay (RTD). To decrease the effect of noise in the estimate of RTD, all of the $P_{ref}(i)$ values are used in the phase estimator, as follows:

$$\vartheta = 2\pi \frac{l}{L} \quad (4)$$

where l is a composite estimate of RTD.

Notice that the following equation holds:

$$P_{ref}(i) = P_{ref}(1) + L(i-1) \quad (5)$$

Let us define parameter SUM as the sum of the distances between the reference points and the beginning of the signal, as follows:

$$SUM = \sum_{i=1}^n P_{ref}(i) \quad (6)$$

Using (5) and (6), the composite estimate of RTD can be calculated as follows:

$$l = \frac{(SUM - \frac{(NUM-1)*NUM}{2} * L)}{NUM} \quad (7)$$

which can be simplified to:

$$l = \frac{SUM}{NUM} - \frac{DSUM}{2} \quad (8)$$

The estimated phase value can be calculated from the intermediate parameters at the host computer, using (8) and (4). From two phase values the phase difference can be calculated as follows:

$$\Delta\vartheta = (\vartheta_1 - \vartheta_2) \pmod{2\pi} \quad (9)$$

The operation of the algorithm is illustrated in a real measurement example where radio interferometric signals were generated with two transmitters, and the RSSI signals were measured and processed on two receiver nodes. All the nodes were placed to fixed positions, thus the phase difference should be constant. The distribution of the measurements can be seen in Fig. 3, where result of 1500 distributed phase measurements are shown, using the proposed algorithm.

III. CONCLUSION

A novel algorithm was proposed which is able to measure the phase difference between the RSSI signals of two radio receivers. The proposed method uses preprocessing on low-end devices with integer arithmetic, and post processing on a host computer, using floating-point arithmetic. This solution allows efficient utilization of scarce resources of low-end devices, allowing fast processing required in tracking applications [2]. The proposed algorithm increases accuracy using multiple reference points and averaging.

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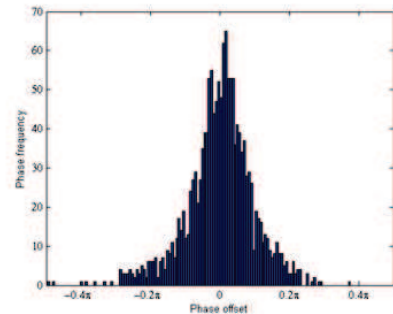


Fig. 3. Distribution of measured phase differences, using the 868 MHz ISM radio-band in disturbance-free environment

Poster abstract: Robust Sensor Fusion for Radio Interferometric Tracking

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Abstract—A new sensor fusion is proposed, which provides robust radio interferometry-based object tracking. The proposed solution utilizes redundant measurements and can efficiently handle noisy, erroneous, and missing sensor readings. The efficiency of the proposed fusion is illustrated by simulations and real measurement results.

I. INTRODUCTION

An RF based positioning solution was proposed using radio interferometry [1]. A faster radio interferometric method was recently proposed which can be used for object tracking [2]. The tracking solution uses fixed transmitter and receiver infrastructure nodes to track the movement of a receiver node, when its initial position is known. Now a novel sensor fusion method is introduced, which provides enhanced and more robust position estimation for radio interferometric tracking. The proposed algorithm utilizes redundant measurements to enhance the accuracy of the position estimator and it is also able to self-correct measurement errors.

II. PREVIOUS WORK

Radio Interferometric Positioning [[1]] was proposed to provide low cost localization in wireless sensor networks, utilizing inexpensive off-the-shelf radio components. The method relies on radio interferometry and performs low-frequency signal processing of the interference signals, instead of high frequency signal processing. The method utilizes two transmitter nodes (A and B) to create an interference signal at two receiver nodes (C and D), as shown in Fig. 1. If the frequencies of the two transmitters are approximately the same ($f_A \approx f_B \approx f$) then the interference signal at the receivers will have a low frequency envelope, where the beat frequency is equal to the difference of the two transmit frequencies. This low frequency signal is the actual RSSI, which is available on most RF transceivers.

By measuring the phase difference ϑ between the RSSI signals detected at two receivers (C, D), a metric on the relative positions of the four nodes can be computed as follows [[1]]:

$$\vartheta(f) = 2\pi \frac{d_{AD} - d_{BD} + d_{BC} - d_{AC}}{c/f} \pmod{2\pi} \quad (1)$$

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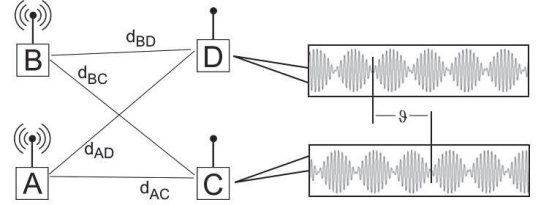


Fig. 1. Radio interferometric phase measurement

where c is the speed of light, and see Fig. 1 for distance notations. Note that this measurement does not provide conventional ranging, because (i) in (1) linear combination of unknown ranges is used, and (ii) only a 2π modulus of the phase is available in (1). The result of (i) is that possible solutions are on a hyperboloid surface, while the effect of phase ambiguity (ii) is that the solution will be a *set* of hyperboloid surfaces. The phase ambiguity can be resolved either by using multiple carrier frequencies and multiple $\vartheta(f)$ values, resulting rather slow processing [1], or by repeated measurements with phase unwrapping (using only one frequency) [2]. The proposed solution provides a more robust and fault tolerant fusion for the approach of [2].

III. PROPOSED SOLUTION

A. Measurement

Multiple fixed transceiver infrastructure nodes with known positions are used to track a moving transceiver node. In each measurement three infrastructure nodes and the tracked node is used, where two of the infrastructure nodes play the role of transmitters and one infrastructure node and a tracked node play the role of receivers, according to Fig. 1. Thus each measurement provides a phase difference value ϑ in the range of $[0, 2\pi]$. Using repeated measurements with the phase unwrapping technique proposed in [2], the solution of (1) results a single hyperboloid surface for each measurement.

In a *measurement round* multiple (n) measurements are carried out by changing the roles between the infrastructure nodes. Thus in each measurement round a set of independent solutions can be obtained in the form of n hyperboloids. Ideally the intersection of these hyperboloids provides the actual position estimator of the tracked object. However, due to phase measurement errors, the hyperboloids may not cross exactly the ideal position: (i) phase noise (in the range of $[0, \pi]$) causes small and random-like offset, while possible unwrapping errors of [2] (corresponding to phase error of $2k\pi, k = \pm 1, \pm 2, \dots$) may cause large and permanent outliers. The proposed fusion can handle both effects.

B. Basic location estimation

For sake of simplicity the method is discussed in 2D. In each measurement round n hyperbolas are calculated. The following error function is defined for a given point (x, y) :

$$err(x, y) = \sum_{i=1}^n d_i(x, y), \quad (2)$$

where d_i is the distance of point (x, y) from the i^{th} hyperbola. The estimated position (x_e, y_e) is defined as the point where the error function is minimal:

$$(x_e, y_e) = \operatorname{argmin}_{x,y} err(x, y) \quad (3)$$

Although the basic location estimator (3) performs somehow better than the estimator in [0], it still suffers from the effect of large and permanent phase unwrapping errors.

C. Self-correcting position estimation algorithm

Since the calculated hyperbolas, due to phase unwrapping errors, can be far from the true tracked position, the estimator of (3) can have large bias. Note that (2) can be used to detect such situations. Assuming that the number of incorrect phase measurements containing unwrapping errors is much smaller than that of the good ones, the following algorithm can detect and correct these errors.

The idea of the algorithm is the following: in each measurement round an initial position estimator is calculated using (3). Then the possible outlier hyperboloids are tried to be compensated by $\pm 2\pi$, and (3) is reevaluated. If the error (2) is smaller after the trial, the associated phase value is permanently corrected, and the corrected value is used in the next measurement round.

The implemented process uses some restrictions to increase accuracy and to speed up the process. The maximum number of hyperbolas that can be moved is bounded by *check limit*. The error limit, below what no further enhancement is tried, is defined by *cost limit*. The pseudo code of the algorithm is shown in Fig. 2. Helper function *calc_error(P)* first calculates (x_e, y_e) from phase measurement set P , using (3), then calculates $d_i(x_e, y_e)$ and $cost = err(x_e, y_e)$, using (2), while *estimate_position* calculates (x_e, y_e) , using (3).

```

P0 = {p1 .. pn} // set of unwrapped phase measurements
Hchecked = {} // set of checked hyperbolas
[cost, d1..dn] = calc_error(P0) // see (2), (3)
WHILE |Hchecked| < check_limit &&
    cost < cost_limit DO
    i = argmaxi( d1..dn ), where i ∉ Hchecked
    P+ = (P0 \ pi) ∪ pi + 2π
    P- = (P0 \ pi) ∪ pi - 2π
    CHOSE Pnew ∈ {P0, P+, P-}
    FOR WHICH cost IS MINIMAL, WHERE
    [ncost, nd1..ndn] = calc_error(Pnew) // see (2), (3)
    cost = ncost
    d1 = nd1, d2 = nd2, ... , dn = ndn
    P0 = Pnew
    Hchecked = Hchecked ∪ i
END
[xe, ye] = estimate_position(P0) // see (3)

```

Fig. 2. Pseudo code of the self-correcting position estimation algorithm

IV. EVALUATION

The performance of the self-correcting position estimation algorithm was tested both using simulations and real measurements.

During the simulations a node was moved on a fixed trajectory and the ideal phase measurements were calculated using (1). To the ideal phase values we added normally distributed random noise with variance $\sigma = 0.3\pi$. The noisy phase measurements were processed by the unwrapping algorithm in [2] and then by the proposed self-correcting algorithm. In the test 6 nodes (and correspondingly, 15 hyperbolas) were used for tracking the moving object. The true and estimated trajectories of the object are shown in Fig. 3(a), with blue and green colors, respectively. For the same input the output of method [2] is shown for comparison (in red).

A real measurement result is shown in Fig. 3(b), where a node, carried by a person, was tracked by 4 infrastructure nodes, using 6 phase measurements in each round.

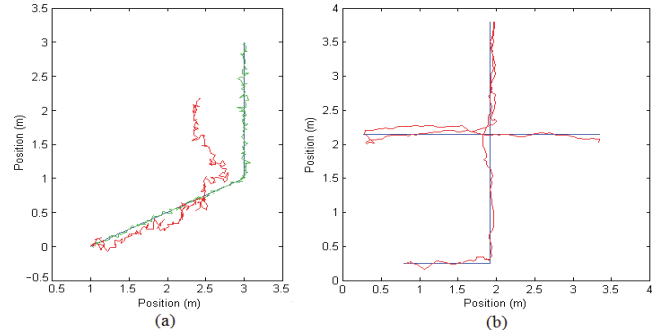


Fig. 3. Simulation and real measurement results. (a) tracking a simulated object with phase noise variance $\sigma=0.3\pi$ and using 6 infrastructure nodes. Blue line: ideal trajectory, green line: proposed method, red line: method of [2]. (b) real time tracking of a moving person. Blue: ideal trajectory, red: proposed method

V. CONCLUSION

A new sensor fusion algorithm was proposed for radio interferometric tracking. The algorithm utilizes redundant measurements to enhance the accuracy of the position estimator and it is also able to correct phase unwrapping errors, often present in real measurements. A novel positioning and self-correcting algorithm was introduced, the performance of which was evaluated using simulations and a real tracking experiment.

According to tests redundant measurements increased robustness and accuracy of the position estimate. Real measurement tests with 4 measurement nodes (and 6 phase measurements in each round) showed that the accuracy of the estimator was around 0.04m in average, with a maximum error of 0.12m.

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