Relative Positioning of Mass Market Devices in Ad-hoc Networks

Francescantonio Della Rosa, Li Xu, Helena Leppäkoski and Jari Nurmi
Tampere University of Technology/Department of Computer Systems, Tampere, Finland.
Email: {name.surname}@tut.fi

***Abstract*—In this paper we present a practical approach to relative positioning of heterogeneous mass market devices using received signal strength. We propose a user-centric solution exploiting measurements from on-the-fly fixed reference points detected during scanning procedures. The technique implemented on mobile devices is able to locate neighboring mobiles, demonstrating to be a feasible and practical solution for sensing spatial social contexts in ad-hoc environments.**

***Keywords*—WLAN; Relative Positioning; Received Signal Strength**

I. Introduction

Next generation mobile applications are getting more and more social, ubiquitous and cognitive. With them also the need of automatically determine users' spatial social context with reliable sensing techniques is attracting the attention of researchers and applications developers. Such applications should be able to locate neighboring devices around, remotely control them, or simply locate and access the closest printer or sharing data with friends just by orienting the device towards them, sending messages and pictures [1], [2] or search for a wifi enabled car key. But this is only a short list of the potential applications that relative positioning can enable. Moreover, in order to enhance human interactions, the spatial cognition is usually considered more relevant than the absolute localization [2].

Existing solutions rely on deployed infrastructure or complex multi-hop strategies to determine spatial proximity of the user but they are limited in availability and accuracy [1][2].

Differently from location-based services based on the information obtained from fixed reference points with known coordinates, such as anchor nodes in Wireless Sensor Networks (WSNs) and Access Points (APs) in Wireless Local Area Network (WLAN) relative positioning does not require a fixed infrastructure. Extensive studies have been performed on positioning techniques based on Received Signal Strength (RSS) that can be used to estimate the position of a Mobile Station (MS) in a desired environment, outdoor or indoor. Wireless positioning using RSS approaches exploits the signal attenuation and distance-dependent properties of radio propagation using conventional or empirical path-loss models in order to provide valuable lookup tables of the measured RSS and the distance between the Transmitter (Tx) and the Receiver (Rx) [3][4] .

Relative positioning solutions presented in literature base their technique on the proximity range of pairs of devices, or to the actual distances between multiple devices and place them in a virtual map [1] using complex server-based positioning algorithms. Moreover, presented techniques are implemented on devices with the constraint of having the same software and hardware characteristics.

In this paper we present an experimental approach to relative positioning of heterogeneous mass market devices performed by using only the RSS coming from neighboring mobiles connected in ad-hoc mode.

The only hardware characteristic they have in common is the WLAN technology. Having WLAN available in all the smart-phones we show a practical method for implementing relative positioning with only ad-hoc peers performing passive scanning.

One application that has motivated our work is the detection of the spatial placement of users in close proximity for sharing data with, or even remotely control them. Basically it is like having a radar application exploiting the RSS in ad-hoc networks.

Our technique has been implemented on Nokia N900 mobile phones (but it can work in every mobile device with WLAN card) and makes use only of the passive scanning of WLAN from peer-to-peer communications to estimate the spatial location of neighboring mobiles in the absence of external reference systems.

The paper is organized as follows: Section II introduces a short survey of related works; section III describes the proposed relative positioning solution; finally concluding remarks and future works.

II. Related Work

Relative positioning approaches have been proposed in literature during the years. Several solutions refer to multi-hop measurements and communications. Extensive research can be found concerning simulations of scenarios with hundreds of nodes [5]. However literature lacks of practical solutions for mass market devices without the need of additional hardware. Several studies propose hybrid approaches combining technologies and sensors (e.g. Bluetooth, ultrasound, antenna arrays) referring to such techniques as peer-based localization.

For example node localization based on peer-to-peer interactions has been widely investigated in WSNs, where typically, RSS is exploited as the main range indicator. However, generally distributed localization in WSNs depends on a high degree of connectivity and an a priori knowledge of the anchor nodes positions.

Several proposed solutions define the proximity of pairs of devices and estimate distances between couples of

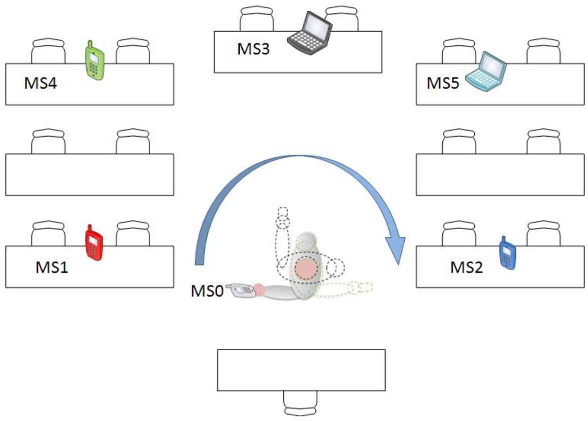

Figure 1. Experimental setup

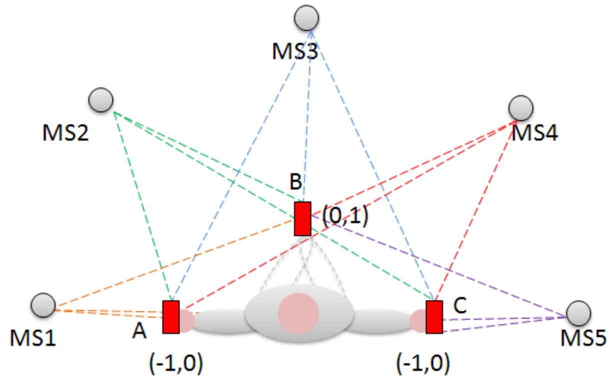

Figure 2. Semi-circular scanning with reference points referring to the position of hand.

neighbors placing them in virtual maps. In literature such proximity-based schemes [6] are known as the NearMe [7] which detects devices that are in a defined range among each others. BlueHoo [9] makes use of Bluetooth discovery to detect devices within the range achieved by such technology. Beep Beep [8], known for achieving high-level of accuracy with the use of sound limits the number of nodes at two. More interesting is Virtual Compass [1] which measures the distances among multiple nodes in close proximity through multi-hop communications having the scope to expand the area coverage and to spatially place the nodes relatively to each others on a 2D plane. Relate [2] makes use of ultrasound which is not available on mass market mobile phones. Spotlight [12], describes how to deploy nodes relative to each other in a multi-dimensional plane. Several other solutions [10], [11] make use of GPS units to locate subsets of nodes.

However all the aforementioned approaches exploit the interactions of several nodes in the network, with extensive amount of data exchanged, inter and intra-network communications (usually only simulated), localize only couples of devices in a 2D map, have connections to huge databases, representing the optimum solution only for their own systems and problem assumptions.

The scope of this paper is to propose a more general practical approach easy to be deployed in mass market devices. Specifically we propose a simple peer-based localization technique that: 1) works in the absence of fixed infrastructure or reference points; 2) works in both indoor and outdoor environments; 3) it is easy and fast to be implemented; 4) it is targeted for heterogeneous mass market devices; 5) does not require continuous data exchange between nodes; 6) is able to locate more than two nodes at the same time; 7) does not require any additional hardware.

Basically we propose a practical relative-positioning solution able to locate heterogeneous devices (such as smart phones, internet tablets, laptops), by exploiting only one technology: the WLAN in ad-hoc mode

III. The Relative positioning System

The main challenge when performing relative positioning, is the lack of fixed reference points since every node is mobile and the only known position is the center of the coordinate system (0,0) which is usually represented by the MS candidate to locate the relative positions of the neighboring nodes.

The scenario of our experiment takes place in a typical classroom as shown in Fig.1. The scope is to locate several heterogeneous devices placed around the user (representing the origin of the coordinate system) by estimating their relative positions. Several devices with different wireless cards have been used: two Nokia N900 (which we will refer as the MS0 and MS1), two NOKIA N810 Internet Tablet with embedded wireless card and OS MAEMO (which we will refer as MS2 and MS3), and two Laptops ASUS X51Lseries with Atheros AR928x Wireless Network Adapter (the MS4 and MS5),

The situation is here described: MS0 wants to estimate the relative positions of all the neighboring devices placed around; the only technology available is WLAN ad-hoc; all the devices are connected in ad-hoc mode; the final result is a map of the estimated relative positions on the device.

In order to accomplish our goal, a Python application has been implemented running on a Nokia N900 (Fig. 9). The application can measure and log the RSS, provide path-loss calibrations on-the-fly [3][4], convert the RSS into estimated distances, perform the relative positions estimations using the Least Square (LS) algorithm. Moreover, recorded data are stored into log files for post-processing and analysis of the results using Matlab. Different configurations have been performed by placing the devices from very close distances from MS0 (1m) to more long distances up to 15m and different cases of relative- positions estimations from 2 up to five neighbors have been performed.

As mentioned before in our system the only known position is the one related to MS0 which for which we assign the coordinates (0,0). Being available only one reference point if we roughly convert the RSS from the connection links MS1- MS0, MS2-MS0, MS3-MS0, MS4-MS0, and MS5-MS0 into distance using empirical

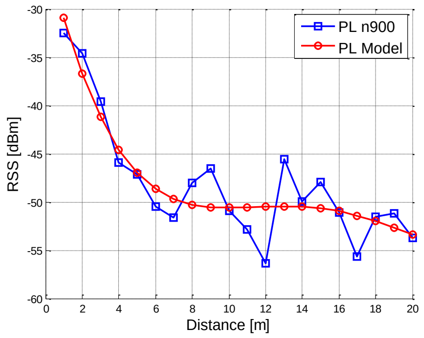

Figure 3. Empirical Path-loss Model

Figure 4. Short-range (2m) versus Long-range (15m) Measurements

path-loss models we can only obtain concentric circles centered at MS0.

Hence, inspired by the user-centric communication theory [3] in order to find at least 3 fixed reference points, we propose to make the user performing a semi-circular scanning by defining three fixed positions as described in Fig. 2: A:(-1,0), B:(0,1) and C:(1,0) belonging to the position of the hand. From each of the obtained fixed reference points the user's device can scan at the same time the RSS from all the neighboring MSs, convert it into distance, and estimate relative positions with conventional triangulation methods [3] based on LS.

A. RSS-to-Distance Estimations

The first step to perform is the calibration of the device under test in order to build an empirical path-loss model. Our path-loss model has been obtained by placing the MS0 at several distances from 1m to 20m respect to another device connected in ad-hoc mode, measuring the RSS and getting the most occurring value at each step. Fig. 3 shows the obtained empirical model (blue line), which has been filtered with a 4^{th} order polynomial approximation (red line).

B. Short-range measurements

Fig. 4 shows the RSS measurements detected in very close proximity (2m) and at long-range (15m). Measurements from 2m are much more reliable in the sense that they are more stable if compared with the ones recorded at 15m since they are less affected by fluctuations as expected [3][4]. Moreover the obtained empirical path-loss model clearly agrees with the theoretical in that the decay of the signal at closer distances is larger than at longer distances [3].

In [3][4] the benefits of exploiting RSS short-range measurements coming from ad-hoc links have been demonstrated by introducing the cooperative concept, a technique able to enhance the location accuracy in adverse environments where conventional selfish techniques fail. Being more reliable and less fluctuant than long-range RSS measurements from AP-MS links the short-range measurements offer the possibility to accurately estimate the distances between MSs deployed in the area.

C. Positioning on a 2D plane

In a bi-dimensional space each node position is determined by its own (*x*,*y*) coordinates giving the distance between nodes and fixed reference points (A, B and C). Once the relative distances of each detected node have been estimated, triangulation algorithms can be applied using a LS approach, as mentioned before.

In the first experiment we show how our simple technique is able to locate three devices placed around the MS0 and having coordinates in meters: MS1 (-3,2), MS2 (3,2), MS3 (0,3), MS0 (0,0). Results of the performed the user-centric semi-circular scanning (with MS0 facing MS2, MS3 and MS1 respectively) for detecting the RSS is shown in Fig. 5. The step-wise changes shown in the measurements are due to the position and orientation changes of the device as shown in Fig. 2. As mentioned before the close-proximity shows reliable RSS measurements accordingly to the path-loss model. Fig 6 shows the estimated distances for the three devices during the scanning. The estimated distances are the input of the LS algorithm and the final estimated positions are shown in Fig.7. Here the relative positions can be clearly distinguished and a potential range radar-looking for facing the devices can be drawn. Hence our technique is able to estimate the relative positions of three devices.

More complex is the case of 5 devices since different distances from MS0 have been used (Fig.8). However even in this more complex environment our simple technique is able to locate and map different neighbors' positions. Fig. 8 shows the averages of the estimated positions of neighboring devices, from which it can be observed that even with more devices placed at longer distances the relative positions are detectable.

CONCLUSIONS

In this paper we have presented a practical solution to locate different mass market devices connected in ad-hoc mode in short-range requiring only passive scanning of RSS. The technique is a feasible and practical solution for sensing the spatial social context of instant communities. In the extended version of the paper we are going to show limits and potentials of the technique with more complex configurations, distance-dependent accuracy of the results and details of a practical implementation of relative-positioning applications for smart phones.

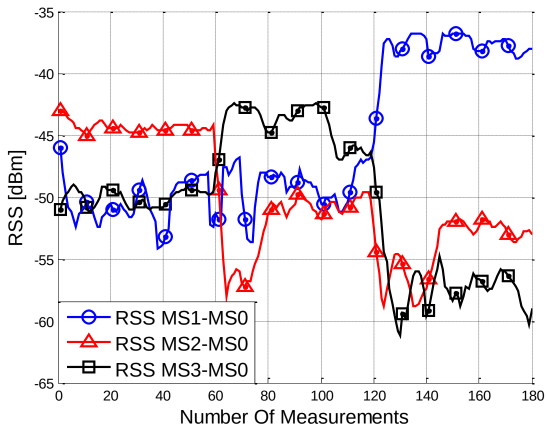

Figure 5. RSS variations for in positions A, B and C

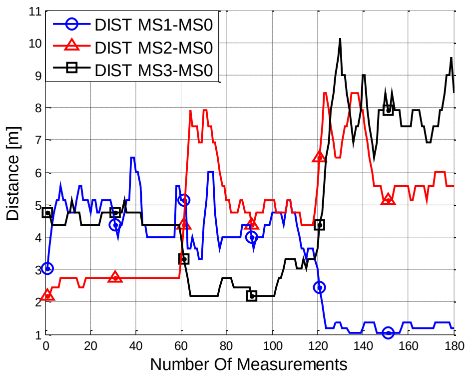

Figure 6. Estimated distances of fixed positions A, B and C

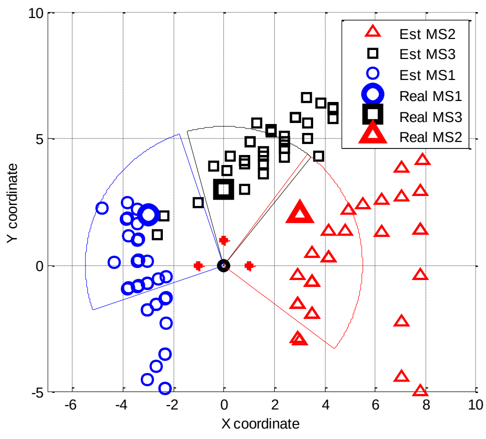

Figure 7. Estimated positions of three devices. Red dots represent the positions of the hand when performing the semi-circular scanning

ACKNOWLEDGMENT

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°227890 (GRAMMAR project), from the Nokia Foundation and TISE Doctoral Programme.

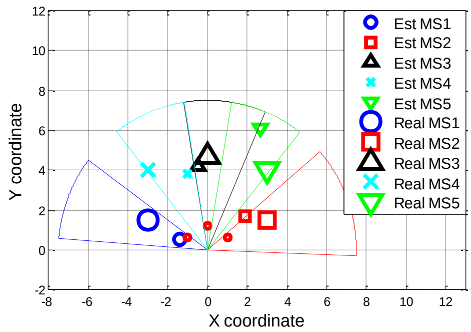

Figure 8. Estimated positions of five devices

Figure 9. Python Application Running on N900

REFERENCES

[1] N. Banerjee, S. Agarwal∗, P. Bahl, R. Chandra A. Wolman, and M. Corner "Virtual Compass: Relative Positioning to Sense Mobile Social Interactions" Microsoft Technical Report, MSR-TR-2010-5, January 2010

[2] RELATE: Relative Positioning of Mobile Objects in Ad hoc Networks http://eis.comp.lancs.ac.uk/?id=16

[3] Della Rosa F., Leppäkoski H., Biancullo S., Nurmi J., " Ad-hoc Networks Aiding Indoor Calibrations Of Heterogeneous Devices for Fingerprinting Applications", 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN), Zürich, Switzerland, September 2010.

[4] Della Rosa F., Leppäkoski H, Ghalib A., Ghazanfari L., Garcia O, Frattasi S. and Jari Nurmi "Ad Hoc Networks for Cooperative Mobile Positioning" IN-TECH. ISBN- 978-953-7619-X-X 2010

[5] D. Niculescu and B. Nath, "DV Based Positioning in Ad Hoc Networks, Telecommunication Systems, vol. 22, pp. 267-280, 2003.

[6] Holmquist, L.E., Falk, J., Wigstr¨om, J.: Supporting group collaboration with interpersonal awareness devices. Journal of Personal Technologies 3, 13–21 (1999)

[7] Krumm, J., Hinckley, K.: The NearMe Wireless Proximity Server. In: Davies, N., Mynatt, E.D., Siio, I. (eds.) UbiComp 2004. LNCS, vol. 3205, Springer(2004)

[8] Peng, C., Shen, G., Zhang, Y., Li, Y., Tan, K.: Beep Beep: A High Accuracy Acoustic Ranging System Using COTS Mobile Devices. In: SenSys (2007)

[9] Bluehoo, http://bluehoo.com

[10] Bulusu, N., Heidemann, J., Estrin, D.: GPS-Less Low-Cost Outdoor Localization for Very Small Devices. IEEE Personal Communications (2000)

[11] Guha, S., Murty, R., Sirer, E.G.: Sextant: a unified node and event localization framework using non-convex constraints. In: MobiHoc (2005)

[12] Stoleru, R., He, T., Stankovic, J.A., Luebke, D.: High-accuracy, low-cost localization system for wireless sensor network. In: Third ACM Conference on Embedded Networked Sensor Systems (SenSys SenSys (2005)