Enabling Location-based Applications through Integration of WSNs and Smart Phones

Francescantonio Della Rosa, Teemu Laukkarinen, Marko Hännikäinen and Jari Nurmi
Department of Computer Systems
Tampere University of Technology
Tampere, Finland
{name.surname}@tut.fi

***Abstract*— This paper presents the technical design of the TUTWSN Positioning Framework developed at Tampere University of Technology (TUT). The framework integrates Wireless Sensor Networks (WSN) and smartphones for data acquisition and positioning processing, short-range communications, and user applications. The main objective of the work is a proof-of-concept to drive location-based research towards real-life applications through the integration of heterogeneous technologies targeting at mass market.**

Keywords-WSN; Indoor Positioning; App;

I. Introduction

Wireless Sensor Networks (WSNs) are well known in the monitoring market nowadays, to be a set of densely deployed communication sensor nodes with high resource-constrained in terms of data capacity, processing power and energy [1]**.** WSN nodes (Fig. 1) are mainly adopted for sensing environment conditions and reporting the status through multiple hops and short-distance wireless communication links. Typically WSNs are able to self-organize and implement the main functionalities in a cooperative and efficient way [1]. The low cost of WSN nodes allows the monitoring of large areas, in a reliable and accurate way, by deploying a network of hundreds or even thousands of sensing nodes. The average cost of WSN nodes is steadily decreasing during the years, and it is expected to follow the same trend in the near future. In fact the basic node cost could represent a dominating factor in many applications, due to the number of WSN nodes deployed which might represent the major cost for applications like large scale in-building sensing [2]. A plethora of data of different nature can be gathered and collected depending upon the type of technology and specific network application [3]. In WSN, applications can be classified according to specific basic characteristics and application tasks which can be classified as [4]: *data logging*, where a node listening to physical phenomenon, periodically triggers measurements when a chang in the average behavior is detected; *event detection*, when a node monitors a specific event like motion detection; *object classification*, when a node identifies the target type by exploiting a combination of different sensor measurements; *object tracking* when a sensor is adopted to keep track of movements and path of a target object [4]. According to the aforementioned classification, it is clear how the location of the events is an important feature for WSNs and how sensed data without knowledge of the position and timing information can be considered useless.

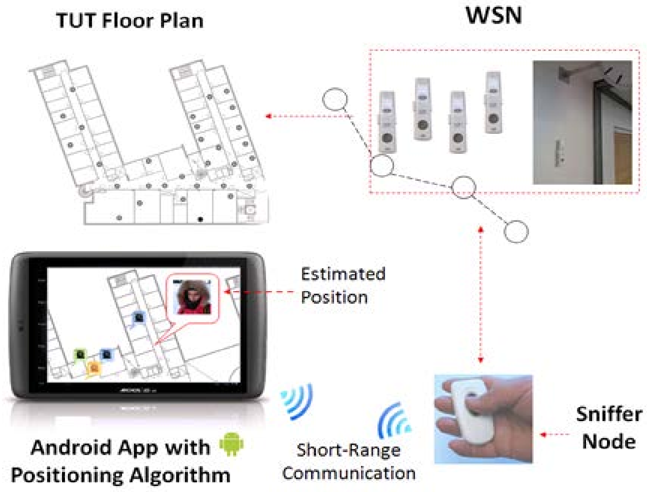

Figure 1. TUTWSN Positioning Framework

Currently, indoor positioning solutions available on the market are highly fragmented and do not offer an easily customized product meeting the real needs of the mass market, which might not have the economical disposability to full-fledged positioning solutions [5]. In addition, the indoor environment itself sets great challenges for location-based applications thanks to its intrinsic complexity which severely affects the accuracy of traditional systems [6], [7], from satellite-based (GPS, GNSS) to terrestrial-based (Cellular, WLAN), causing huge signal decay with unpredictable fluctuations [5]**.** In case of WLAN, which from a research-oriented point of view represents one of the most convenient solutions in terms of availability of an already existent deployed infrastructure, phenomena like shadowing, multipath, overlapping channels, objects, and sensitivity variations of heterogeneous wireless cards make it difficult to achieve accurate location-based solutions targeting at mass market [5]**.** For all the aforementioned reasons, the use of a WSN represents one of the best options among the available family of Signals of Opportunities (SoO) [5] for indoor positioning in terms of accuracy and reliability (Fig. 2) and a network deployment would represent the most appropriate choice in any

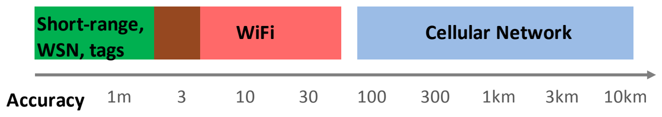

Figure 2. Accuracy in indoor environments

situation where there is a need for tracking specific targets [3]. In fact, as the peculiarity of WSN technology (Fig. 3) is to continuously send beacons to discover devices and to establish communications among them, these beacons can be captured with a passive sniffer device (e.g. an invisible node) (Fig. 1) and if the locations of the transmitting nodes are known, the sniffer position can be estimated through conventional positioning algorithms (e.g. trilateration).

At this purpose, this work presents the indoor positioning framework developed at Tampere University of Technology (TUT), namely Tampere University of Technology Wireless Sensor network (TUTWSN) Positioning System. The framework integrates WSN nodes and smartphones for data acquisition and positioning processing, short-range communications, and end-user applications. Specifically, we present the technical design and integration with mobile devices (e.g. tablets and smartphones) running Android OS, in pilot deployments (Fig.1) defined by: 1) Fixed/mobile location WSN nodes communicating in the 2.4 GHz frequency band; 2) Portable WSN sniffer nodes; 3) Location-based App exploiting short-range communications with the latter. The main objective of the work is a proof-of-concept to drive location-based research towards real-life applications while ensuring sustainable competitiveness of mass market requirements.

The paper is organized as follows: Section II and III describe the conceptual flow from Received Signal Strength Indicator (RSSI) to Transmitted Power variation in positioning together with user and market needs, laying the theoretical and technical requirements for the subsequent system design and experimental results shown in section Section IV and V respectively. Conclusions and future works are finally presented in Section VI.

II. Related Works

In wireless positioning different methods and techniques, based on SoO have been proposed in literature and adopted for experimental activities towards commercial location-based services [5]. Such methods can be divided into two main categories: mobile-based and network-based. While in the first a Mobile Station (MS) takes advantage of parameters gathered from fixed reference nodes to calculate its position, in the latter parameters from signals coming from the MS are sent to a centralized server which also performs the final position calculation. Displaying the sensed and collected data information in remote servers is sufficient for statistic and post-processing. However, with the increased processing capabilities of nowadays smartphones, it is convenient for the users to have the collected data processed in smart phones [3], in order to avoid continuous exchange of data with the network. Many works proposed in literature makes use of the RSS recorded from WSNs. In [9] a WCF is adopted to process the position estimation based on the RSS and achieving

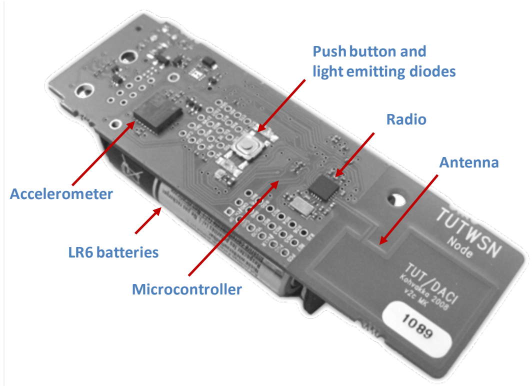

Figure 3. TUTWSN Node

approximately 3m of accuracy. In [10] authors propose CORTINA, a system based on wall-plugged sensor nodes, self-configuring, for tracking assets and people using small battery operated wireless tags collecting RSS measurements from nearby sensor nodes, hence adopting RSS maps and trilateration. In [11] authors propose a novel location algorithm based on hyperbolic positioning by using mean RSS values and Extended Kalman Filter (EKF). Only in 2005 a first attempt to replace RSS or RSSI with multiple varying power level beacon transmissions has been proposed in [13] for communications purposes. Moving towards our proposed technology, previous [14] presents a transmission power based ranging method, using a reduced amount of power level variation to replace the need for RSSI when performing coarse ranging activities. Finally, in [1], [15] the previous ranging method has been extended to estimate the positionin of WSN mobile nodes which opened the way to new appealing location-based capabilities and applications exploiting the potential of sensor nodes. In this paper we extend the idea introduced in [1] by proposing a straightforward integration of the WSN with mobile devices and describing the design of sniffer nodes acting as bridge and exploiting short-range communications between the WSN and the smartphones environment.

III. User and Market Needs

Despite the growing success of outdoor location-based services, it is now widely ascertained how people spend only 10% of their time outdoors, while all the rest is spent in buildings, shopping malls, airports, universities or museums, hence making indoor environments the main target for future Location-Based Services (LBS). Additionally a huge percentage of data connections comes from indoors [15]. This is the reason why in recent years we have been able to experience an increasing interest in indoor LBS together with position and location-aware applications spanning from indoor navigation to Ambient Assisted Living (AAL), from assets tracking to context-aware [15]. Unfortunately the aforementioned applications are very difficult to be enabled in large-scale due to the unavailability of valuable fixed reference points and signals which do not degrade inside buildings [15]. According to [16] in order to serve market needs, every sensor-based positioning technology needs to be

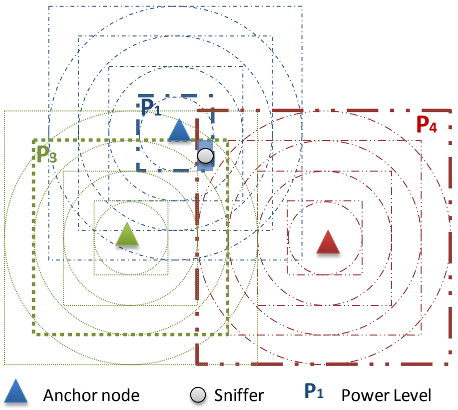

Figure 4. Positioning algorithm based on Cell-ID/Triangulation

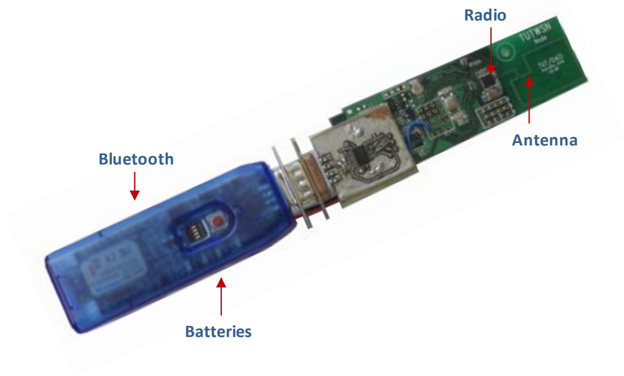

Figure 5. Sniffer Prototype

accurate, secure, low cost, low power, with low latency, small-sized seamless and non-intrusive. Additionally important technical factors include a minimal dedicated infrastructure with low time-consuming maintenance and security [17]. Moreover, mass-market applications for indoor positioning, in order to be successful, need to use devices already available on the market, without needing complementary components, requiring neither major nor minor modifications to the device itself. The positioning functionality should be as much transparent as possible to the user and extremely simple to be enabled. It is indeed worth to be mentioned that currently the positioning industry is highly fragmented and does not offer a customized product meeting the mass market needs to deliver to the users a seamless solution easily affordable for everyone anywhere and anytime, due to the immaturity of widely-available softwares to satisfactory support applications and integration of heterogeneous technologies with nowadays smartphones in a fully transparent manner.

IV. SYSTEM DESIGN

The TUTWSN Positioning System (Fig. 6) is nowadays fully autonomous, with a network coverage and reliability strengthened by dynamic multihop routing. An energy-optimized protocol stack enables adding new wireless nodes freely and additional context to positioning services enabling social features. In the deployment, a passive WSN sniffer node, placed in the user's pocket, scans the WSN environment while delivering results to the targeted smartphone using Bluetooth (BT) technology (Fig. 5). The smartphone calculates the position of the sniffer which is in short-range communication with it, hence in very close proximity, through a positioning algorithm. The algorithm is based on a hybrid cell-id/triangulation concept augmented through a node priority ranking where, the transmission power of the transmitted beacons is rotated between different levels, allowing both floor and room-level localization. The positioning estimation to happen does not require any fingerprinting of signal strengths [5], neither pathloss models [5], which is crucial for easy deployments of the concept in real scenarios.

Moreover autonomous WSNs are easy to deploy, hence when exploited for indoor positioning services the technology can provide a real added value to e.g. building automation, AAL, security services, etc. In summary the proposed framework is implemented by:

- A WSN deployed in the campus area;
- A passive sniffer node with BT module;
- A tablet (or smartphone) running Android OS;
- A server for data gathering and social services.

A. *TUTWSN Technology*

The TUTWSN HW nodes platform [1],[17] is presented in Fig 3. It is based on a Microchip PIC18F8722 MicroController Unit (MCU), integrating an 8-bit processor core with 4 kB of RAM data memory, 128 kB of FLASH program memory, and 1 kB EEPROM. The TUTWSN consists of autonomously networking nodes constantly sending beacons on one specific network channel for discovering each other. The MCU is 8 MHz resulting in 2 MIPS performance [1]. Energy is provided through AA and AAA batteries. Wireless communications are performed by using a Nordic Semiconductor nRF24L01 2.4 GHz radio transceiver having data rate of 1 Mbps and 80 available frequency channels in the Industrial, Scientific and Medical (ISM) unlicensed radio band. The adopted platform is able to host different heterogeneous sensors integrated to the circuit board. These sensors include temperature, humidity, pressure, accelerometer, air flow, electrical measurements, and motion detection [17][16]. As the WSN is primarily not intended for positioning purposes it falls in the family of SoOs. Differently from WSNs proposed in literature the radio does not support RSSI. Alternatively, the transmission power of the beacons is rotated between four different levels and beacons are send every 500 ms. Nodes scan the network channel and use the transmission power of the received beacon for the communication between the receiver and the beacon sender. The TUTWSN consists of autonomously networking nodes constantly sending beacons on one specific network channel for discovering each other.

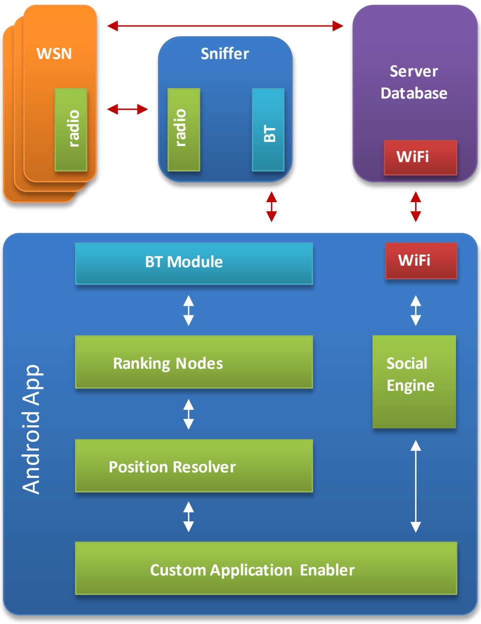

Figure 6. TUTWSN Positioning System

The overall campus wide WSN consist of 340 among fixed and mobile nodes acting as reference points for location-based service. In its history the TUTWSN has been used in over 20 field pilots with more than 1000 nodes between 2007 and present, organized with different research partners concentrating on specific monitoring applications, such as automation measurements, logistics, and personnel security [17].

B. *TUTWSN Sniffer Prototype*

The sniffer node (Fig. 5) is the key component for enabling the integration of the WSNs with nowadays mass market smartphones. It runs on a Microchip PIC18F8722 microcontroller and passively listens the deployed network by sniffing the network channel while recording received beacons. Every second (1s) it constructs an ASCII character packet of the received beacons power and the beacon transmitter Node IDs. Once received, the packet is delivered over RS-232 to a BT module further transferring the packet to an Android device using the standard BT Serial Port Profile. WSN nodes and sniffers use the 2.4GHz Nordic NRF24L01 radio chip for communications. The code enabling sniffing functionalities is implemented in C programming language. Entries in ASCII packet are simply constructed as "<node ID>:<beacon Tx power>" while multiple entries can be iteratively concatenated and the packet ends to a line feed and carriage return characters. The passive nature of the sniffer makes it completely invisible to the rest of the WSN hence it does not affect the WSN performances (e.g. throughput, latency, energy efficiency, reliability etc.) in any way, while gathering all the necessary information to the android device for performing localization service. Additionally, there is no limit for the number of sniffers in the network as there is the possibility to have hundreds of them on one square meter. Using the

Figure 7. TUTWSN Map

proposed sniffer dongle, the positioning can be brought to mass-market existing handheld devices without the need for calibrations [5].

C. *TUTWSN Positioning Algorithm*

As described in previous sections, in order to allow positioning capabilities, the TUTWSN anchor nodes deployed in the campus area make use of a transmit power level selectable, varying between -18 dBm and 0 dBm with 6 dBm intervals (Table I), hence four different power levels are detected by the sniffer and sent to the Android device.

TABLE I. LOOKUP TABLE FOR POWER-TO-DISTANCE CONVERSION

Tx Power [dBm]		Dist [m]
P1	0	2
P2	-6	7
P3	-12	12
P4	-18	20

The positioning algorithm adopted in our system (Fig. 4) takes inspiration from the Cell Identification (Cell ID) method usually performed in WLAN [5] or cellular-based positioning [1]. Specifically, a TUTWSN node radio range determined by a specific transmission power forms a cell [1]. The varying transmission powers determine variable sized squared cells where the minimum area bounded by the overlapping smallest cells represents the estimated location of the sniffer. Hence a TUTWSN node radio range is determined by a specific transmission power. The varying transmission powers are recorded together with the related node ID and sent to the Android App through BT.

D. TUTWSN Positioning App

The TUTWSN Indoor Positioning framework will let new users to locate simply using an Android app paired with a sniffer dongle. To put it simply, users can download the app from the website (or a centralized server in the campus area) using WiFi, turn on the sniffer and let it communicate with their android device through BT. The TUTWSN Positioning App allows users to estimate their position in the campus area at TUT, enabling the possibility to share it through a centralized server as reported in Fig. 6.

The application is implemented using Android SDK [18], which provides API libraries and development tools necessary to build, test, and debug the app for Android devices. The app itself is composed of modular code blocks which separate the physical positioning engine from the customized location-based App thanks to high-level classes encapsulating the overall positioning solution. The campus map (Fig. 7) is shown in a 2D image fashion representing the full area distribution of the WSN nodes and the final estimated position of the sniffer (hence of the smartphone itself). Zoom capabilities are enabled through Android classes.

Differently from many indoor positioning solutions proposed in literature, the database does not represent a big issue in our case. In fact usually the database size is a crucial architectural issue [16], [5] due to many aspects mostly related to synchronization, maintenance and splitting [16]. The main drawback is indeed represented by the potential large amount of data do be created or downloaded by the users, hence transferred to the terminals with huge costs in terms of bandwidth and computation. The storage itself together with the control logic is becoming a real challenge due to the limited possibilities of the terminals [16]. In the proposed solution only the coordinates of the fixed reference points are needed to be downloaded into the android device, and no previous fingerprinting or constantly updated RSS calibration measurements are needed.

As previously mentioned, the TUTWSN Positioning App is developed for Android OS, hence it has the potential of running on a plethora of mass-market devices. It follows the mobile-based architecture, having two desirable peculiarities. On one hand thanks to the invisible nature of the sniffer respect to the network environment the user can keep his privacy level very high, on the other end network congestions are completely avoided as no data transfer is needed for the positioning service to happen. A typical LBS scenario to be applied can comprise three fundamental steps. For example a user can enter an indoor environment, such as a university covered by several WSN nodes monitoring the environments, grab the sniffer node dongle at the entrance and pair it quickly with short-range communications, download and install the app. At this point he can already enjoy the automated touring guide in the all campus area.

V. Experimental Activity

The experiment took place in typical floor with office rooms, at Tampere University of Technology, in Finland. Test devices (sniffers and tablets) were positioned in different places to perform the position estimation by periodically

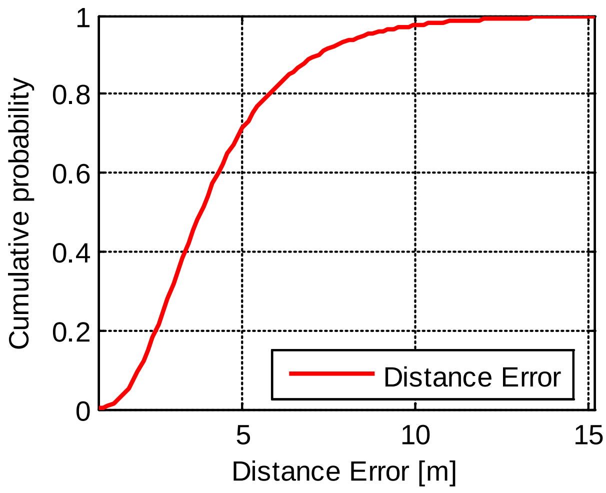

Figure 8. CDF of the distance error

scanning for detecting the presence of anchor nodes deployed in the campus area. A total of 100 test points where carried out, taking measurements and positioning estimations every second (1s). Fig. 8 shows the post processed accuracy results expressed in the form of Cumulative Distribution Function (CDF), clearly providing evidence of the localization capabilities of the case. In order to evaluate the proposed positioning solution, the results are shown in terms of absolute distance error between the centre of the obtained square (from the three overlapping squares) and the real position of the sniffer. To evaluate the localization performances, the absolute error in terms of distance between the real location and the estimated location has been calculated for every point.

VI. Conclusions

In this work we have presented the technical design of the integration of WSN technology targeting location-based services. The key benefits of the TUTWSN Positioning System framework include but are not restricted to: a very intuitive, modular way to add new nodes in the system, a total absence of user's device calibration needs, no additional HW installations or modification to the user's terminal required, automatic floor and room-level position estimation, quick installation of the app (only the .apk file is needed), cost effective scalability enabled by initial small deployment of WSNs mobile nodes easily expansible as the number of nodes increase, a software-based solution exploiting short-range communications with a sniffer dongle, an accurate and cost-effective solution to maintain over time and exploit in public indoor spaces. Hence the proposed TUTWSN Positioning System stands out from the competition by offering a straightforward integration of WSNs and Android smartphones through passive sniffers, together with a simple, scalable, and reliable indoor positioning approach so pervasive and affordable to become a default feature for existing populated indoor environments, like shopping mall, museums and university campuses. In future work, we are envisioning the integration of hybrid algorithms combining position estimations from heterogeneous technologies (WLAN, WSN, INS) in order to enhance the positioning accuracy of the proposed framework.

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