SILS: a Smart Indoors Localization Scheme based on on-the-go cooperative Smartphones networks using onboard Bluetooth, WiFi and GNSS

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BIOGRAPHY

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ABSTRACT

Seamless outdoors-indoors localization based on Smartphones sensors is essential to realize the full potential of Location Based Services. This paper proposes a Smart Indoors Localization Scheme (SILS) whereby participating Smartphones (SPs) in the same outdoors and indoors vicinity, form a Bluetooth network to locate the indoors SPs. To achieve this, SILS will perform 3 functions: (1) synchronize & locate all reachable WiFi Access Points (WAPs) with live GNSS time available on the outdoors SPs; 2) exchange a database of all SPs location and time-offsets; 3) calculate approximate location of indoor-SPs based on hybridization of GNSS, Bluetooth and WiFi measurements. These measurements includes a) Bluetooth to Bluetooth relative pseudo ranges of all participating SPs based on hop-synchronization and Master-Slave role switching to minimize the pseudo-ranges error, b) GNSS measured location of outdoors-SPs with good geometric reference points, and c) WAPs-SPs Trilateration estimates for deep indoors localization.
Results, obtained from OPNET simulation and live trials of SILS built for various SPs network size and indoors/outdoors combinations scenarios, show that we can locate under 1 meter in near-indoors while accuracy of around 2-meters can be achieved when locating SPs at deep indoors situations. Better accuracy can be achieved when large numbers of SPs (up to 7) are available in the network/vicinity at any one time and when at least 4 of them have a good sky view outdoors.

Keywords – Indoors localization; Smartphone LBS; Bluetooth localization; WiFi localization, GNSS

I. INTRODUCTION

Smartphones & Tablets, driven by mobile-services/applications are becoming very important to our communication, localization and information needs. Demands are huge for seamless outdoors to indoors navigation, and especially for accurate indoors localization. Examples of such LBS applications include tracking users (via telematics) for security and safety, find nearest restaurant/shop, and other Point-Of-Interest (POI) information [1]. Unless there is a pre-installed localization infrastructure of sensors in the vicinity that works with the current SPs, LBS Apps (eg. BLE-iBeconing) will be very restricted due to the weakened/limited GNSS signals reception indoors [2]. Most of the current solutions do attempt to hybridize multi-GNSS signals (GPS plus GLONASS) with cellular, WiFi, Bluetooth, as well as other inertial sensors on SPs to offer accurate/seamless location. However, on-the-go structure-less solutions, like our proposed scheme, are very challenging and not yet matured.

Fig. 1 illustrates a typical scenario used to describe SILS. It shows a cluster of cooperative Android based SPs outside our department building. We assume that these SPs use enhanced GNSS localization algorithms, such as Google's Map-matching to achieve accuracy to within 1 meter [3]. SILS first forms a smart Bluetooth network of these SPs. SILS will then calculate the relative pseudo-ranges between all SPs and compare that to the GNSS obtained location map to form a virtual localization map of this network. This map is shared with every SP in this network, and will also be shared with any new SPs joining the network. This map, as a third step will be used as reference points to synchronize all WAPs in the vicinity of our building. i.e. the WAPs clock offset will be calculated from the received Beacon signals from these WAPS, positioned at assumed altitude on every SP on this network, as shown in Fig.2 . This information may be required later for estimating initial position if any of the SPs in the network is in deep-indoors. Note that WAPs time is measured from the WAPs beacon signals that are generated at the millisecond level and received at the SPs in the MAC layer to avoid local interlayer nanoseconds delays. Once time synchronization is achieved with more than 4 SPs, the SPs then try to locate every WAP based on time-of-arrival (TOA) technique (one way measurement).

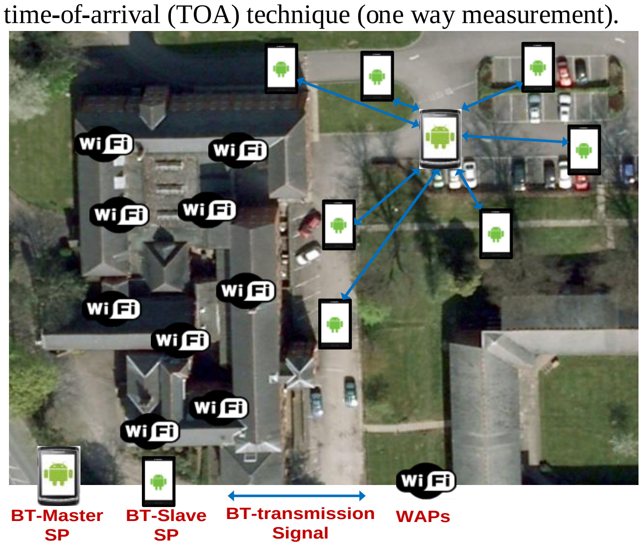

Figure 1. SPs outdoors network scenario

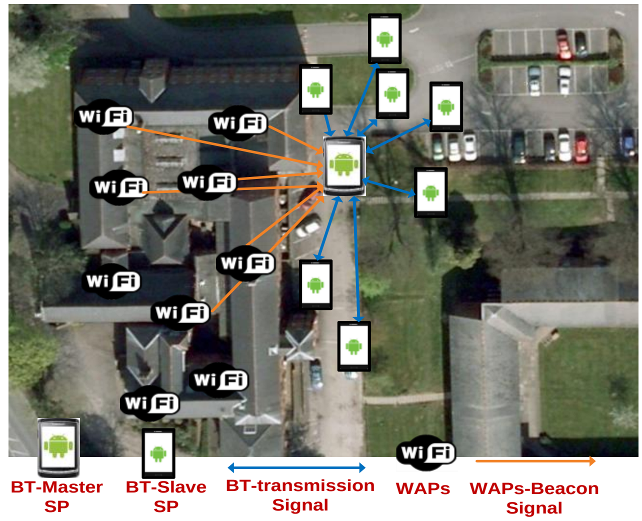

Figure 2. SPs outdoors network scenario showing available WAPs

We assume this SPs network is on the move all the time, and some SP's may be lost or new ones joining the network depending on the proximity of these nodes to each other (within Bluetooth coverage range). If any of the networked SPs enters indoors, as shown in Fig. 3, or if existing indoors SP join the network, with at least 4 SPs are still located outdoors with good sky view, then SILS will locate these indoors SPs to within 1 meter when at near-indoors and to within 2 meters when in deep indoors.

Our study concluded that pseudo-ranging estimation using timing measurements gets better accuracy than using Receive Signal Strength (RSS) measurements, since RSS has a non-uniform shadowing and so any pseudo-range estimation based on RSS would not be accurate [4]. Since Bluetooth communication is based on frequency-hop synchronizations, then counting the hops at precise GNSS time can help measure the time of flight (TOF) for each frame transmission accuretly.

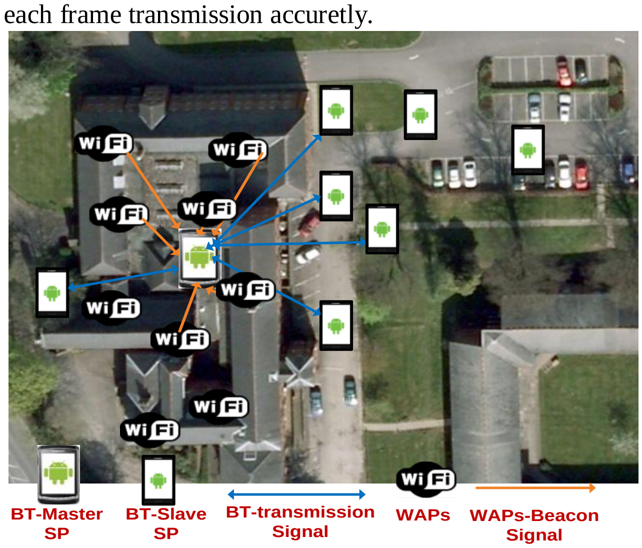

Figure 3. Collaborative SPs network to locate indoors SP using WiFi, Bluetooth, and GNSS

The bigger aim of our research is to propose a Smartphone based localization solution that will capitalize on existing infrastructure (with no need for special external hardware/sensors), yet offering high localization performance/accuracy at low cost. During the implementation and trials of SILS, we found that Android based Smartphones with on-board Bluetooth, WiFi and GNSS hardware have many challenges; including accessing functions implemented in Firmware. This has limited our trials breadth to validate all positive results achieved from OPNET simulation.

Section II of this paper reviews the literature on current cooperative localization solutions and evaluates the main drawbacks of them. Section III gives detailed explanation of the proposed SILS solution. This is then followed by a discussion of the experiments and scenarios performed to prove SILS in section IV. Finally, section V draws this paper's conclusions and outlines possible future work.

II. LITERATURE REVIEW

Independent of pre-installed localization infrastructure networks, on-the-go Seamless indoors-outdoors navigation, and vice versa, capability on Smartphones is an essential function for many LBS applications. Localization techniques are currently based on a hybridization of existing GNSS based localization with functionality from sensors onboard the Smartphone such as WiFi, BLE, Accelerometer, Gyro and Cellular technology (3G, LTE) providing access to geographical maps and localization databases. Current solutions still suffer from the lack continuity due to loss of GNSS signals when SPs go indoors, unless pre-installed localization sensor networks, such as those offered by BLE-iBeaconing [5] and WiFi fingerprinting [6], are specifically implemented to provide the SPs location while indoors in that particular vicinity. GNSS signals suffer from strong attenuation caused by building materials when the SPs enter indoors. i.e. the provision of semi-accurate indoors SPs location, on the go anywhere anytime, has proven somewhat problematic to deliver thus far.

Pre-installed Infrastructure localization network based on WiFi, Bluetooth, RFID, Zigbee and others will help tracking of SPs indoors to a good accuracy. The location errors in these solutions depend on how dense is the supporting fixed network nodes, how the concentration/presence of distractive signals emitted from other indoor equipment/devices that use the same air interface technology such as laptop's using the WAP or other BT networks, and on how the orientation of the transmitting/receiving device antennas at the time of the ranging calculation. The literature is rich with contributions based on such solutions (e.g. Wi-Fi Positioning System (WPS)-Skyhook, Real-Time Location System (RTLS)-Ekahau, BLE-iBeaconing) using schemes such as sound, vision, light and radio frequency waves based on various localization techniques including ranging (Trilateration/Triangulations) and RSSI fingerprinting. However, the scope of this paper is to focus on collaborative SPs solutions that can use existing infrastructure, such common WAPs on building, but does not require special hardware installation. i.e. Cooperation between various existing resources, such SPs and WAPs can offer enhanced localization indoors.

A GNSS based cooperative location optimization scheme has been proposed using a host server to fuse location coordinates supplied from onboard GNSS of any group of SPs to improve location accuracy. Then, pseudo-ranging estimation between the group SPs is calculated based on TOA technique using acoustic signal [7]. The server then, as a final stage, receives these pseudoranges and uses a complex optimization model to obtain further location accuracy improvement, within 1.2 – 4 meters. Obviously, this scheme needs to access a dedicated database/server to improve and share the location information among all these SPs which acceptable as a small overhead. Porting the task of the server into the SPs will eliminate the overhead of this server and its associated wireless connectivity, but we believe the optimization algorithm will take considerable resource and time that will drain the SPs batteries.

A skyhook WPS enabled SPs can obtain WAPs location in any vicinity. A group of such SPs can then use these WAPs as reference point to locate themselves within a claimed 10-20 meters when indoors. An improved location can be achieved if a GNSS position from an outdoors SP is shared with this group of SPs via a WiFi connectivity. This is achieved by applying "conditional prior probability" to improve the indoors SP location via probability distribution of the set of shared information (WAPs range, GNSS location of the reference SPs outdoors) [8]. The proposed "cooperative SPs localization" algorithm in this paper is based on four probabilistic methods namely Centroid method, Nearest Neighbour method, Kernel method and WAPs density method. Both empirical and simulation results claims that the WAPs density method provided more accurate results than the others, since WAPs density provides a function to distinguish the overlapped or the common shared WAPs information between the outdoors SPs and the indoors SPs. However, this location enhancement has resulted in 5-meter accuracy.

In a similar vain to SILS, an on-the-go (infrastructure independent) cooperative indoor localization using sensors onboard SPs (GNSS, inertial sensors such as accelerometer & magnetometer, and WiFi) has been proposed to locate indoors SPs to within 5 meters [9]. In this solution, a group of WiFi networked SPs, when outdoors, start a calibration process where estimated heading error is calibrated by GNSS heading estimation, and where pseudoranges error between these SPs is mitigated by detecting pedestrian-step trajectory using the onboard accelerometer. When indoor SPs join this network, shared location information will help establish initial position and the heading calibration process of these indoor SPs. Experimental results show that this proposed cooperative solution can achieve location accuracy up to 5 meter, if number of SPs is exceeds 40.

Our proposed SILS scheme does work without the need for pre-defined WAPs location or pre-installed localization infrastructure, and also does away with RSS-based technique. SILS is based on time-synchronization to GNSS-time of all participating devices and calculating pseudoranges based on time of signal flight; proven to offer accurate position calculation.

III. SILS implementation

We plan that SILS be implemented as a plug&play application on Android Smartphones (SPs). The scheme mainly access MAC level functions with the SPs onboard Bluetooth (BT) and WiFi transceivers as well as the GNSS receiver's firmware.

Our proposed scheme works in the following steps:

1. SILS will first detect and form a BT Piconet on the go with any SPs in the vicinity (for our purpose and scenarios, these SPs would be running SILS too and the required function voluntarily and cooperatively. Also, we do check if the SPs have a fresh GNSS location fix and so assume these are outdoors SPs. i.e. as the SPs are outdoors, they can obtain their geographical location easily and accurately using their GNSS-enabled receivers augmented by whatever necessary to obtain a coordinates fix within 1 meter accuracy, for example with Google's map-matching).

2. Synchronizing the clock time to GNSS time and defining the location of WAPs within WiFi range to this SPs network is done next. This done by using the various outdoors SPs as reference nodes for doing TOA calculation based on the Beacon signals of these WAPs. Previous research work [10] showed that this method could achieve location accuracy of less than 1 meter, depending on the number of participating SP's and their own position accuracy and geographical spread. That is, each of these SPs will calculate its pseudoranges to each of the reachable WAPs by comparing the timestamps of the transmitted and received WAPs beacon signals. The estimated pseudoranges are precise due to the highly accurate measurement of the WAPs clock offset and clock drift to within (±6 nsec) based on GNSS time.

3. The freshly calculated WAPs positions is shared between all SPs on the network. An optimization algorithm is applied to unify the position amongst the achieved positioning at regular intervals as desired. Currently, fresh position calculation is performed whenever a new SP joins the network. SILS will use this WAPs location information to help localization of indoors SPs that are at deep indoors with less than 4 SPs in the network outdoors.

4. When any SP moves indoors (from now on called SPm), SILS calculates SPm's position based on TOA Trilateration technique using the outdoor SPs (from now will be referred to as SPos) as reference stations. Three algorithms based on BT-to-BT connectivity are used to assure the location accuracy of SPm. These are described in the subsections below (A) BT-to-BT pseudo range measurements; (B) switching BT master-slave role to reduce error in the pseudo-ranging measurements; and (C) permutation reference points.

5. For an SPm that is happen to be deep indoors and there are only 4 or less SPos in the BT network, then we will use the WAPs as reference points to help in locating this SPm. Pseudoranges between such SPm and WAPs is calculated using time synchronized beacon signals in SP monitor mode. This location is now optimized with Pseudoranges calculated with SPos.

A. Pseudo-range measurement via BT Signal

Our pseudo-range measurement via BT signals is based on time-measurements. Imperially experimenting with various methods to do the pseudo range measurements between two BT nodes, we have concluded that Hop-synchronization counting would the most accurate time measurement would be obtained by using. In a Piconet, when the connections between Master and Slaves have been made, both Master and Slaves generate a set of frequency sequences, which is called Hop-Sequence. These Hop-frequency values are generated based on Master's clock offset and MAC address. This means that Slaves can use the same Master's clock to count the hop-frequencies and then synchronize with that clock. Therefore, when a packet is being transmitted, both Master and Slaves shall hop from one frequency to next selected frequency at same time. As illustrated in Fig. 4, time stamping the epoch of all frequency changes shall be very precise when using accurate source time (like GNSS receiver time). Our pseudo-range measurement algorithm utilizes modified POLL-NULL packets to calculate the time of flight for every BT transmission. The Master broadcasts POLL packets to check the connectivity with his slaves, periodically and each connected Slave will respond by sending NULL packets to the Master.

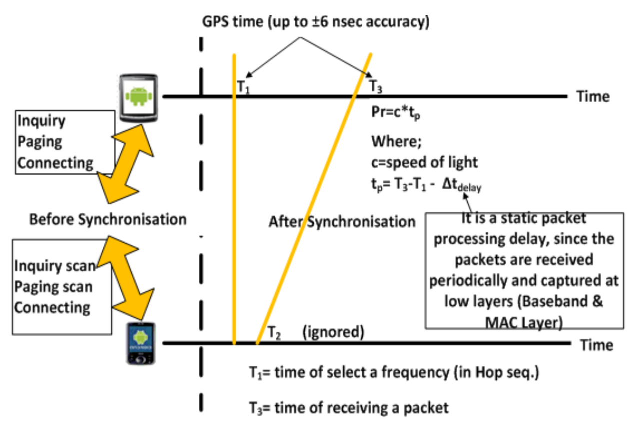

Figure 4. Pseudo-range measurement using Bluetooth hop-synchronization

In Fig. 4, Master generates T1 and T3 as timestamps during hop-frequencies and when receiving the NULL packets, respectively. To measure the flight time, T1 is subtracted by T3 and Δt_{delay} (time processing delay of the received packet). Then the pseudo-range between the Master and any Slave is equal to the time-of-flight x speed of light.

B. Proposed new switching master/slave role (SR)

In the following steps, SILS applies a new master/slave role-switching algorithm between all SPs in the Piconet to reduce the error of all pseudoranges measurement. To achieve this, SPm has to be the Master of this Piconet and will generates a database table, shared by all SPs, for storing several measurements described in the following steps:

1. As a preparation step, SPm first measures and stores its pseudo-ranges from all Slaves in the network based on the hop synchronization counting. It will then collects and stores all SPos GNSS position. These geographical coordinates are stored into the “reserved bits” of the NULL packets that is sent from the SPos to the SPm. Finally it will generate a list of master-slave switching sequence based on the RSSI from all SPos (in most cases, this guarantees that switching rotation will be based on nearest to furthest order). This information is then shared with all SPos.

2. The Master now surrenders his role to the first SPo in the switching list. i.e. the SPm becomes Slave and the SPo becomes the new Master.

3. The new SPo Master SP will measure and store its pseudoranges from all SPs in the network. This master will now surrender his role to the next SPo in the switching list, and so on until the order reached the SPm again.

4. The SPm, equipped with all the pseudo ranges from all switching master-slave sequence list, will now calculate its position, using a linear least squares fitting technique to enhance the SPm’s own pseudoranges measurements. Doing many experiments based on known SPs positions; we were able to achieve a 50% improvement to the accuracy of the SPm position calculation.

5. SPm will perform the Permutation algorithm described in next section (C) to enhance its calculated position.

C. Permutation reference stations (PR) algorithm

To elevate the error caused by Trilateration measurements when SPos are in bad geometry shape (DOP issues), we use the following permutation algorithm:

1. SPm will calculate an HDOP value for the current constellation of the network. This constellation is assigned two sets of weight values.

2. An iteration process will the start by omitting the GNSS position and pseudoranges of each of the SPos one at a time to calculate a new SPm location. New Weight values will be assigned for each iteration. This is achieved by a training process that will change the current Weight values based on mean/min-difference statistics associated with the each position calculation iteration.

3. The appropriate final position will be determined based on the resultant HDOP and weight set values.

IV. TEST SCENARIOS AND RESULTS

To prove SILS we have first simulated, using OPNET, a scenario where a group of 8 nodes start in the outside of our department building. One of these nodes will move indoors through light indoors area (signals are crossing 1 wall from the outside) and deep indoors (signals are crossing 3 walls deep inside the building). The movement of this SP is illustrated in Fig. 5 by trajectory line. The other 7 nodes has moved around but stayed outdoors.

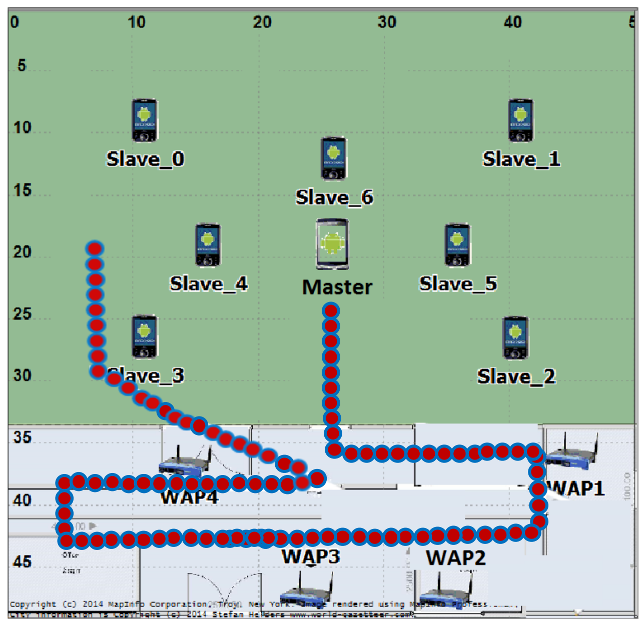

Figure 5. Piconet when Master moved from outdoors to indoors

In all the following experimental figures, three trials are conducted. For a trial where the indoor zone is a single wall is shown as a green line, the trial where the indoor zone is 2 walls is shown by the blue line, while the deep indoors 3-wall trial is shown by the red color. Fig. 6 shows the Signal/Noise obtained by the SP node that is labeled “master” as it travels from outdoors to deep indoors and back. Note that the Indoor zones in this scenario is based on the indoor path loss model of COST-231 [11] for both WiFi and Bluetooth signals. In addition, Fig. 7 shows the number of SPs connected in the BT network as the “master” nodes travels past extra walls.

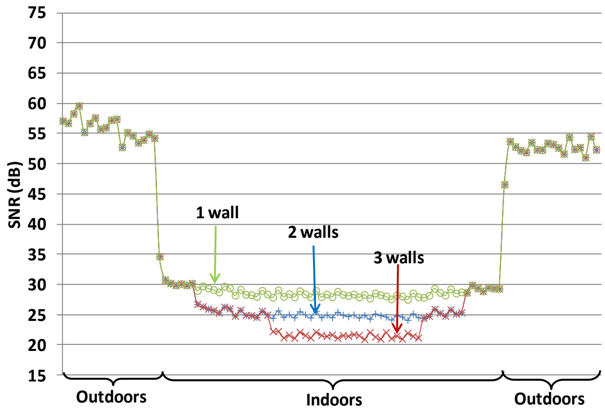

Figure 6. SNR measurements from outdoor to indoor

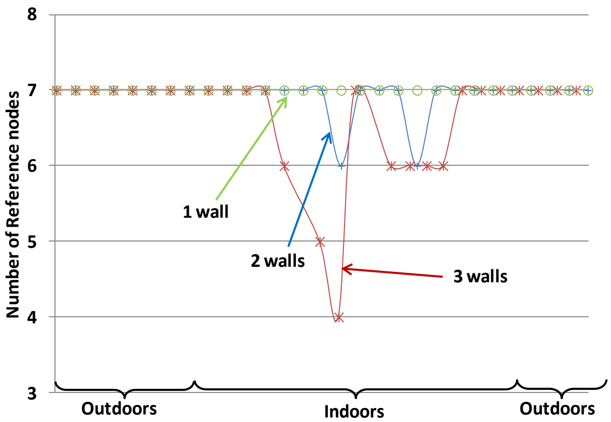

Figure 7. Number of SPs connected in the BT network

The following experiments are chosen to demonstrate the achievements of the various algorithms implemented in SILS:

1. Without adopting the master-slave switching algorithm, Fig. 8 shows the error obtained, using basic hop synchronization only, for locating the "master" node through the scenario path can be as high as 3.5 meters when the trial is for 3-wall deep indoors, and 2.5 meters for 2-wall deep trial.

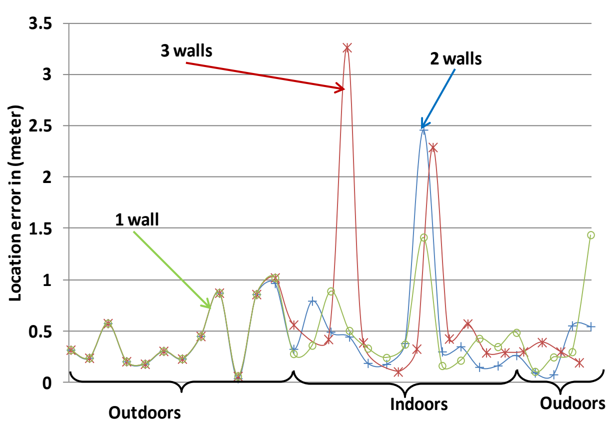

Figure 8. Location error from outdoors to indoors without switching master-slave role

2. Fig. 9 shows the error when the master-slave switching and permutation algorithm are applied. It can be seen that for the 2-wall trail, the location error of the "master" SP being reduced to just over one meter. Also table 1 display the pseudoranges enhancement in comparison to the basic hop synchronization only measurements. However, SILS has failed to locate the "master" when 3-wall deep indoors. This is due to the restriction placed by the Permutation algorithm that restricts fixing when the BT network has 4 or less SPs connected. This issue has been solved as shown in the next experiment.

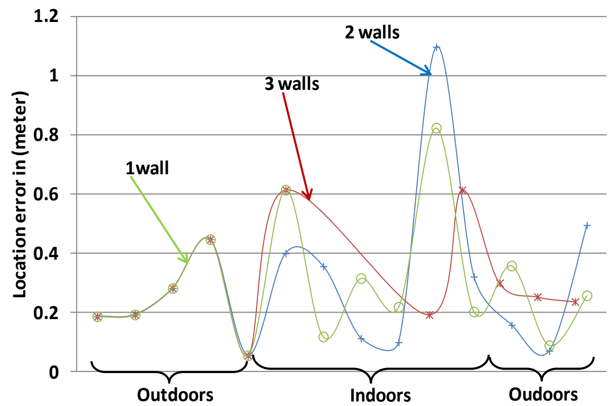

Figure 9. Location error during development of the SILS without WAPs

TABLE 1. PSEUDORANGES MEASUREMENT COMPARISON

Trial number	Pseudorange measurements		
	TRUE	Hop-sync (only)	Hop-sync and Switching M/S role
1	58.83	62.94	55.91
2	50.75	48.34	49.35
3	52.39	49.99	51.67
4	60.09	63.3	59.95
5	73.09	75.07	74.32
6	97.18	99.22	96.5

3. Fig. 10 shows how the error of 3-wall deep indoors trial has now been improved by including the WAPs as reference points to help locate the "master" when the BT network is less 4 SPs. Furthermore, the error for this trial has been reduced from 3.5 meters to just over 2 meters.

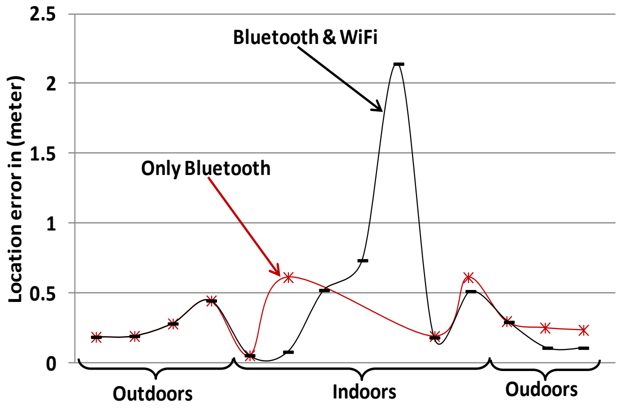

Figure 10. Location error for full SILS functionality

A. Trials Experiments

Android-based SPs (two Samsung Galaxy-mini III, two Samsung Galaxy-4 and one Samsung Galaxy III) are used to form various trials to confirm the performance of our OPNET simulations. We were able to prove that our BT-networking master-slave switching does improve the location error by 50% in the same way as our simulation results, see Fig. 11. However, due to lack of access to accurate nsec time functions on the Firmware of the GPS receivers on these SPs, we are unable at this point to conclusively demonstrate the rest of SILS functionality.

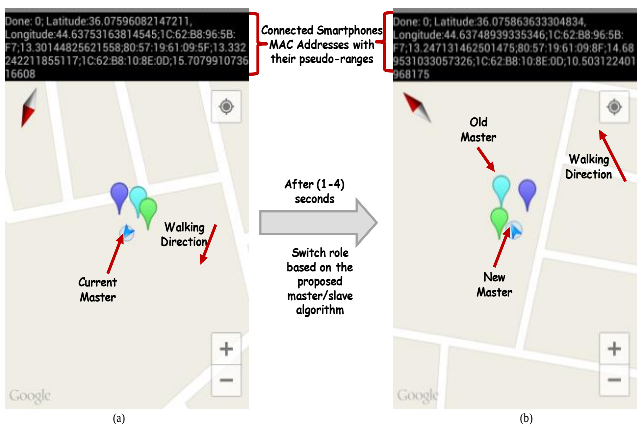

Figure 11. Switching master/slave role between Android-based SPs

V. CONCLUSION AND FUTURE WORK

This paper presents SILS scheme to offer seamless outdoors/indoors Smartphones positioning achieved from hybridizing onboard SPs GNSS receivers with Bluetooth and WiFi transceivers. Our proposed scheme does not need any pre-installed and calibrated localization infrastructure (works on the go) or prior geographic surveying, thus enabling SILS to be viable for use as low cost solution for various LBS. Hop-synchronization with GNSS time can be used as an accurate method to measure time of flight between Bluetooth nodes. The proposed scheme uses master-slave role switching and permutation reference nodes algorithm to improve location accuracy..

With the advancement of processing and memory onboard Smartphones has made such scheme as SILS a strong candidate for enabling any SP to locate itself indoors. We do make many assumptions regarding the cooperation of other SPs in the vicinity to make this possible and believe this is a realistic scenario for future solutions.

We have hoped that we crack some of the hardware implementation issues such access to accurate timing from/to the sensors used in SILS onboard off-shelf SPs. However, this proved to be very difficult since most manufacturers have little time for researchers in academic capacity. We have managed to prove by trials the main algorithm used in SILS; however, we have not yet completed the full trials we planned. Irrespective, and based on simulation results, we have enhanced the indoors localization accuracy when compared to recent contributions in the literature. Our simulations showed that accuracy to within around 2 meters is possible for 3-walls deep indoors trials.

Our further research focus will also include overcoming the signal interference issues at deep indoors.

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