CAPTURE – "Widening the Net" – Indoor Positioning using Cooperative Techniques

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***Abstract*— Context is fast becoming a fundamental requirement in modern day application development. Key to this requirement is the accuracy of the contextualized information being processed. Incorrectly interpreted context can lead to a missed opportunity or an inappropriate user interruption. Location is arguably one of the most significant contexts that can add value to an applications perceived intelligence. Timely and accurate knowledge of a user's position can vastly improve the precision of contextualized information. Many noteworthy systems have been developed that attempt to address the notion of localization in the indoor environment. With the use of a myriad of technologies and novel implementations these systems have somewhat overcome the issues surrounding the level of accuracy in indoor positioning. In actual fact, most of the research in the area of Indoor Positioning Systems (IPSs) has been primarily focused on solving the problem of positioning accuracy. All the time, an equally important issue of yield or coverage has been somewhat overlooked. Accuracy becomes somewhat meaningless, to an extent, in areas where even coarse positioning is unobtainable. It is the focus of this research to address the issue of coverage in IPSs. The concept is to utilize mobile devices to cooperatively locate devices that cannot be *'seen'* by IPS's in indoor environments. The methodology of such an approach is to use a cooperation of devices at the extremities of IPS ranges. These devices have themselves already been positioned, but can *'see'* beyond the IPSs current range and can, in concert, locate devices that they can *'see'*.**

Keywords- Cooperative Positioning; Collaborative Positioning; Self Positioning; Indoor Positioning Systems; IPS.

I. INTRODUCTION

The problem of locating people or devices in all areas of the indoor arena, is a challenge that, as of yet, remains unsolved. Many technologies and techniques have been employed in an attempt to find a solution, but none have effectively done so. It is the focus of this particular research to describe a framework and implementation whereby mobile devices can assist in a collaborative fashion to extend the capacity of an Indoor Positioning System, thereby adding to the body of research in this area to help in the effort to find a solution.

Access to location based information in mobile devices is becoming ubiquitous. Global Navigation Satellite Systems (GNSSs), such as the Global Positioning System (GPS) have the capacity to locate a mobile device with enough precision to provide adequate context to nearly any application purpose. More importantly, it has the coverage to do so at a global level, with 24 satellites offering an almost unobstructed view, providing the necessary infrastructure to deliver such vast yields. GPS, through its success, has quietly infiltrated most of our modern day lives. If you look just beneath the surface of most modern day systems, you will invariably find layers of GPS services. GPS controls key pieces of infrastructure such as, traffic management systems in modern cities. The atomic clocks on-board GPS satellites send extremely accurate timing information, which is used to synchronize traffic lights. GPS offers positioning estimates accurate enough to now automatically land airplanes and navigate emergency services directly to their destinations. The requirements to use GPS is becoming more and more trivial with advances in accuracy and the technological advancements in hardware. Unfortunately, GPS positioning signals do not have the strength to penetrate a buildings fabric, after making the near 22,000 km journey to earth. This makes its application as a Location Based System (LBS) in the indoor arena virtually redundant. A comprehensive solution to the provision of accurate position estimations and broad coverage in the indoor environment has, proven somewhat problematic to deliver. The reasons for this are wide ranging and cover a large area of research [1-6], identifying issues with reflection, refraction, absorption and diffraction. Any of these issues can introduce challenges when attempting to position using wireless signals, especially so in the indoor environment. But a fundamental problem is that one of the most commonly implemented indoor positioning solutions use existing Wi-Fi network components to locate devices within its range. Although this technique offers obvious economic rewards, utilizing a preinstalled infrastructure. These topologies were typically designed to provide network coverage to mobile devices rather than deliver an indoor location based solution. Large areas without coverage are commonplace in these networks, because network designers were not typically concerned with providing 100% coverage for mobile data. Furthermore, where a single Wireless Access Point (WAP) can adequately provide network access to mobile devices, three or more can be required to accurately position. Hallways, toilet areas or other general purpose areas that ordinarily would not require network coverage sometimes do not get dedicated WAPs. Transient users navigating these areas of the network can be un-locatable using this infrastructure. Moreover, the indoor arena is an especially noisy atmosphere, being home to other wireless devices such as Bluetooth Headsets, Cordless Phones and Microwave Ovens, which operate on the same frequency as a Wi-Fi signal [6]. Considering users spend more time in an indoor environment [7], the need for a solution is obvious. Outdoor

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localization has quite a few years' research and development on its indoor equivalent, this coupled with the aforementioned difficulties provides for a fertile research area at present.

This paper is organized as follows. Section II, a description of the test environment is presented. Section III describes the CAPTURE framework. An analysis of the results found during testing are presented in Section IV and evaluated in Section V. Finally, Section VI offers a conclusion and some future implementations of CAPTURE.

II. TEST ENVIRONMENT

The main campus building at Letterkenny Institute of Technology (LyIT) was used as a live testbed for this research. The building itself consists of 3 floor levels and covers an area of approximately 20,000 sq. meters. It contains a variety of rooms and room sizes, ranging from computer labs, classrooms, lecture theatres, staff offices and toilets. The college uses a variety (CISCO 892w, CISCO Aironet 1140 Series and CISCO Aironet 2602e Series) of 802.11 Wi-Fi APs to provide network and internetwork connectivity to its users, which is primarily made up of staff and students numbering approximately 4000 in total. During the summer of 2015, a survey of the indoor positioning capacity of the Wi-Fi infrastructure of the LyIT campus was undertaken. The Ekahau Site Survey (ESS) [8] application was used to complete the survey. ESS is the industry standard for designing, planning and maintaining Wi-Fi network systems. The survey provided analysis of network connectivity and performance, which further proved our hypothesis that large areas of a building are not locatable when using existing Wi-Fi infrastructure. The Ekahau Site Survey 8.0 (ESS 8.0) system was used to perform a Throughput Site Survey, this survey measures throughput as well as jitter and packet loss to evaluate the Wi-Fi performance of a network at given locations. It collates data, which illustrates how the network is performing in that particular area of the building. ESS is most commonly used to assist with the designing and planning of new Wi-Fi networks, as well as troubleshooting issues with existing Wi-Fi implementations. It uses different observables to measure aspects of the wireless network infrastructure. These observables can measure range as well as Data Transfer Rates, Level of Interference\Noise, Signal Strength, Signal to Noise Ratio, Strongest Access Points and Ping Round Trip Time. These can then be analyzed to measure the suitability of a given area of a building to provide a level of service with a specific technology. For example, tests can be implemented and evaluated to highlight Wi-Fi blackspots or areas with low coverage or high levels of congestion or contention rates. The system generates heat maps of the surveyed area to illustrate issues relating to network or technology yield. An interesting facet of the ESS application is its ability to configure the output to measure Wi-Fi connectivity capacity of a given area, with a given infrastructure, while at the same time measure the infrastructures capability to position devices within that same surveyed area.

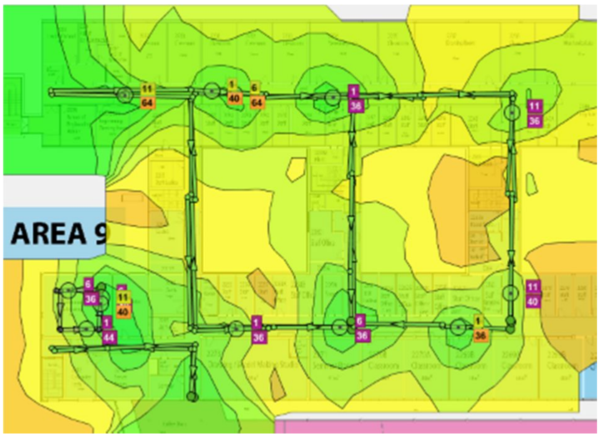

Figure 1 – Infrastructures capacity to provide Wi-Fi Connectivity

This provides the capability to clearly map the capacity of a currently installed infrastructure in any area within a building to effectively locate a mobile device. Fig. 1 Infrastructures capacity to provide Wi-Fi Connectivity, shows a sample area of the second floor of the West Wing of LyIT Letterkenny Campus, illustrating the infrastructures capacity to provide optimal connectivity to mobile devices within a Wi-Fi network.

Fig. 2 Infrastructures capacity to locate, is a heat map of the same area with precisely the same infrastructure but the representation for coverage differs dramatically. Large areas of the map cannot be used to adequately locate devices in this area of the building. These images graphically depict the challenges that designers face when attempting to implement an IPS using an endogenous infrastructure. IPS implementations can be classified as either exogenous or endogenous, endogenous is made up of infrastructure that has not been installed primarily for positioning reasons. Whilst utilizing an existing infrastructure, such as this offers many noble qualities, not least the reduced costs in procuring equipment to implement an IPS solution, the problems are obvious. Moreover, this emphasizes the hypothesis of this research and the need for a solution like CAPTURE to extend coverage into un-locatable areas of a network.

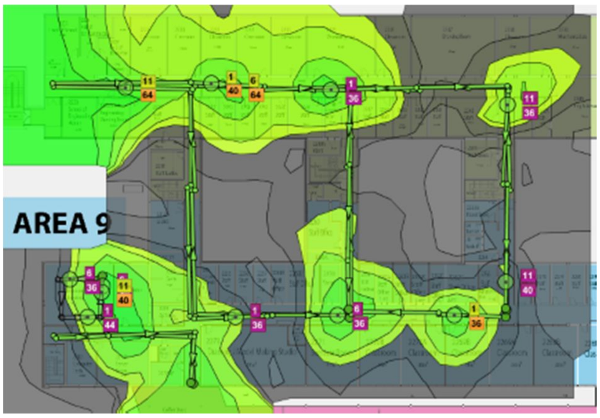

Figure 2 - Infrastructures capacity to locate

These blind spots are illustrated in the black areas in Fig. 2 Infrastructures capacity to locate, the green areas are areas where the endogenous infrastructure can adequately locate devices. Cooperative devices within the CAPTURE system that were at the edges of these green areas would already be located with the current IPS. These cooperative devices can see into these areas without coverage, in Fig. 2 Infrastructures capacity to locate, they could assist in locating devices within that area, thereby extending the reach of the IPS.

III. CAPTURE

The hypothesis of this research is that mobile devices at the boundaries of IPSs, who have themselves been located by an IPS, can assist in a cooperative approach to locate mobile devices beyond the range of the IPS but within range of the cooperating devices. CAPTURE attempts to prove this hypothesis in an augmented approach, using the Received Signal Strength (RSS) of both Bluetooth LE and Wi-Fi radio signals to ascertain range. A fundamental aspect of positioning and navigation in general, is the capacity to measure range. Range can be defined as a measurement of the distance between two points. One of the most popular ranging techniques used in indoor localization, is RSS. RSS is a measurement of the voltage that exists in a transmitted radio signal, which is an indication of the power being received by an antenna. When a signal first leaves a transmitting device, the power of the signal drops or attenuates, this is true of both wired and wireless transmissions. As a radio signal propagates through the air, some of its power is absorbed and the signal loses a specific amount of its strength, therefore, the higher the RSS value (or least negative in some devices), the stronger the signal. Knowing the amount of signal loss over a given distance provides a method to estimate the distance from a transmitting device, given a RSS.

CAPTURE then uses this RSS range observable as input for a positioning algorithm to determine the position of a lost device. The algorithm requires at least three reference devices to successfully position a *'lost'* device within a network. These devices must have *'a prior'* knowledge of their current position. That is, each of these devices have already been located by an in-house indoor positioning solution. During the tests Smartphones were used to position the lost device. RSS readings, both Bluetooth and Wi-Fi, were recorded from each device. The results of these tests are detailed in the tables in Section IV.

IV. RESULTS

The results of the experiments, which were carried out in a large campaign of measurements taken in the main campus area of Letterkenny Institute of Technology are detailed in Table 1 and Table 2. The mobile reference devices used in the tests to simulate the cooperative network were Sony Xperia Z1 C6943 Smart Phones running Google Android v5.1 (Lollipop) on a Quad-core 2.2 GHz Krait 400 CPU. Authors in [9][10] describe problems with varied RSS readings when using different phones, which most likely use different antennas. They describe the difference being up to 11.2 dBm when using disparate antenna in 25 meter tests. Lisheng et al, and Kaemarungsi and Krishnamurthy both describe these issues when testing using Wi-Fi, but because Bluetooth operates somewhat similar to Wi-Fi, it is expected that similar effects would happen with these readings when using different antenna types. Rappaport [1] also highlights issues with device orientation, which was also considered during the tests. All tests were carried out in a Line of Sight (LoS) environment offering a clear view of all phones during the tests. The average position error ranges from 0.16 meters to 65.14 meters when using Wi-Fi.

TABLE I. CAPTURE Wi-Fi RSS READINGS.

Wi-Fi RSS Readings				
Distance	**5 meters**	**10 meters**	**15 meters**	**20 meters**
Avg. RSS	-55.76	-63.16	-64.74	-64.93
Std. Dev	1.86	0.97	2.06	0.54
Avg. Position Error	0.16m	4.04m	2.62m	1.81m
Distance	**30 meters**	**40 meters**	**50 meters**	**60 meters**
Avg. RSS	-65.61	-67.67	-71.73	-70.68
Std. Dev	0.49	0.94	1.09	1.39
Avg. Position Error	10.03m	13.16m	2.72m	18.57m
Distance	**70 meters**	**80 meters**	**90 meters**	**100 meters**
Avg. RSS	-68.78	-69.14	-67.29	-69.68
Std. Dev	1.165	1.25	1.28	1.00
Avg. Position Error	39.50m	57.8m	65.59m	65.14m

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The positioning errors with Bluetooth range from 0.17 to 49.81 meters.

Table II CAPTURE BLUETOOTH RSS READINGS

Bluetooth RSS Readings				
Distance	**5 Meters**	**10 Meters**	**15 Meters**	**20 Meters**
Avg. RSS	-71.54	-73.86	-75.56	-74.42
Std. Dev	3.73	3.71	3.06	3.12
Avg. Position Error	3.7 m	2.19m	0.56m	8.78m
Distance	**30 Meters**	**40 Meters**	**50 Meters**	**60 Meters**
Avg. RSS	-79.10	-82.63	-83.64	-82.70
Std. Dev	6.12	3.81	3.75	4.60
Avg. Position Error	4.08m	7.92m	0.17m	16.51m
Distance	**70 Meters**	**80 Meters**	**90 Meters**	**100 Meters**
Avg. RSS	-82.04	-81.70	-82.15	-87.91
Std. Dev	4.70	2.87	3.29	3.02
Avg. Position Error	20.40m	40.30m	49.81m	7.85m

V. CAPTURE RANGE

Another important question this research posed was just how far could CAPTURE extend an IPS? Hypothetically speaking, there is nothing to stop a device that has been located using CAPTURE, to in turn cooperatively assist in the location of devices beyond the devices that located it but within its range. With the errors rates that are currently being recorded, this would seem problematic, especially considering the error propagation that would occur with each hop. Again, hypothetically speaking, it is still plausible within the scope of the CAPTURE framework. It is accurate to say however, that any positioning system, that uses range to position, is constrained in coverage, primarily by the technology employed to measure range. The current implementation of CAPTURE uses Bluetooth and Wi-Fi to estimate range, each of which have theoretical boundaries of 200 meters. In experiments implemented in the test environment described previously, to establish the limitations of CAPTURE, RSS values were recorded for Bluetooth at a range of 173 meters and Wi-Fi at a range of 175 meters. These experiments were carried out in a LoS environment, which would reduce dramatically in a Non-LoS situation. Furthermore, the evaluated range using the recorded RSS values in these tests was 137.56 for the Bluetooth 173-meter test – a 35.44-meter average positioning error and 129.45 meters for the Wi-Fi 175-meter test – a 45.55-meter average positioning error. Although these error bounds are very high, it still nonetheless proves the fact that CAPTURE can extend into those areas by that distance. Considering the nomadic nature and resource limitations of the collaborative devices employed to implement CAPTURE, it would be nigh on impossible to equal the accuracy levels achieved by custom designed IPS's. But then, without CAPTURE these devices would not be found at all.

Although the error bounds found using this implementation are very high, the concept of CAPTURE is still nonetheless proven. That is, that a mobile device that can see another mobile device, can help in positioning it. Without CAPTURE in the test scenarios described, the lost devices would never be found. To just be able to say that these devices that cannot currently be seen by the in-house IPS can be seen when using CAPTURE, albeit with a high error bounds is still noteworthy. If the lost device was a wheelchair in a hospital, or a passenger in an airport, that a LBS used the IPS to find, it could, conceivable, be anywhere in the world. Using CAPTURE, it could be located within a certain vicinity, providing a coarse position estimate. It is not perceived that CAPTURE would be used in scenarios whereby accuracy levels were required to be within a number of feet. Nor was it ever argued that CAPTURE would be able to offer the accuracy levels that an IPS could offer with its custom designed and powerful infrastructure. But it is the authors' opinion that CAPTURE has a role and that it can fulfill that role, to allow IPS's to use mobile devices to cooperatively extend their range.

VI. CONCLUSION

The motivation behind the development of CAPTURE was to provide a technique to provide better coverage for Indoor Positioning Systems. The live tests carried out to date on CAPTURE prove that it is in fact possible and that the use of cooperating devices is key to this. The accuracy levels of CAPTURE in its current manifestation makes it unviable currently as a solution. More work is required in the area of filtering of data to remove errors and outliers as well as looking at other technologies to enhance the current implementation. Round Trip Time (RTT), could be integrated with the current version of CAPTURE to offer more accurate position estimates. Most implementation of position solutions use a hybrid of solutions to solve the positioning problem. It would be considered common practice today to use a combination of ranging techniques in a hybrid solution, in most situations to establish a more accurate ranging estimate. It is hoped that a future version of CAPTURE could incorporate such a hybrid or augmented approach.

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