Dynamically Extending the Reach of Wireless Networks in Determining Movement of Individuals Between Cells

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Abstract— **Location Based Systems are now a ubiquitous part of everyday life, seamlessly assisting us in everything we do from driving our cars to finding a cab, even preventing us missing our bus or train stop when oversleeping whilst on one. Global Positioning System (GPS) being the culmination of research in this area, and the technology of choice for outdoor location based systems today. Since then there have been significant inroads made in the development of Indoor Positioning Systems that attempt to mirror the success of its outdoor big brother equivalent. There are however some obvious barriers that currently stifle this aspiration, primarily the topography of an indoor location with its many walls, doors, pillars, ceilings and floors, distorting the signals to\from mobile devices and their tracking devices. The characteristically noisy behavior of wireless channels, Bluetooth devices, cordless phones, microwaves etc. can cause interference as they all operate in the same band as Wi-Fi devices, namely 2.4 GHz, while water and human bodies absorb RF signals at that frequency. Furthermore the limited range of tracking devices such as Wireless Access Points (APs), and the restrictions surrounding their positioning within a building further exacerbate this issue. This paper advocates a solution to some of these issues, proposing a method to extend the range of Indoor Location Based Systems using Mobile Devices at the extremities of Cells who 'know' their location, to determine the location of devices beyond the Cell range of the AP.**

Keywords- Localisation; Indoor positioning; Indoor localisation; geographical positioning; wireless; GPS.

I. INTRODUCTION

When Wieser [1] articulated his vision on the future of computing, he described a time where computers would be everywhere in the environment, and would be truly ubiquitous. His devices would communicate with the environment and each other to meet the needs of their users. Emphasizing that for these devices to be able to support their users, they would need to know where they are, and therefore understand their context, this led to the development of Context Aware Systems. Location Aware Systems are Context Aware Systems that utilize the location of the user to adapt the service accordingly [2]. Context Aware Systems employ different types of context in their applications, to support and assist users whilst also offering them a more enhanced experience. While systems for fixed PCs can also use context and even location, for example to select the closest printer; for portable and mobile computing devices with more mobility and ever-changing contexts, using context is a key technology [3]. Context Awareness was defined by Dey *et al.* [4] as: *"the ability to use context to provide task-relevant information and/or services to the user"*. The term *"Context Aware Computing"* was first mooted by Schilit *et al.* [5] in the early 1990's, but the Olivetti Active Badge System [6], developed in 1992, is widely recognized as the first Location\Context Aware System. Context is defined by Chen *et al.* [7] as consisting of location identity, activity and time, of these, location is the most used in Context Aware Systems, which has led to the current proliferation of Location Aware Computing, and Location Based Systems [8]. Literature from Yang [9] and Rowe [10] reflect that Location Awareness is rapidly becoming a fundamental requirement for mobile application development, which highlights the challenges posed for ubiquitous localization of devices. The main focus of this research is to develop a system that would augment an already installed and configured Indoor Location Based System, utilizing the Mobile Devices at the extremities of the Wi-Fi Network. These Mobile Devices will '*know'* their location, and can be used to expand the coverage area of the Location Based System to include Devices beyond the reach of its APs, a somewhat P2P (Peer-to-Peer) like location based solution.

Fig. 1illustrates a building with Wireless Access Points strategically placed to cover as much of the 'L' shaped building as possible, given the limitations of the range of the devices. The circular shape outlines the coverage of a number of APs and is used to illustrate the coverage area and the Black Spot, but should not be confused with a diagram of only 3 APs. A database of fingerprinting has been calibrated to

ISBN: 978-1-902560-26-7 © 2012 PGNet

determine the location of devices while they are within the range of the APs, so almost any device within the building can be located. The 'Yellow' triangle shaped area at the front of the building, labeled as 'Black Spot' is the one area of the building that is not covered by an AP, therefore Mobile Node X's position cannot be located using the APs. Mobile Node X will be referred to as the Blind Device as it cannot ascertain its location at this stage. Mobile Node A and Mobile Node B are located at the outer reaches of the APs and their positions are 'known'. Mobile Node A and Mobile Node B will therefore be referred to as Reference Device A and Reference Device B. The wireless cards on Reference Device A and B also have a range of signal and the Blind Device lies within that range.

The proposed system is called Self-Positioning & Range Extending Augmented Devices (SPREAD). The unique contribution of this work lies in the ability of utilizing Reference Devices A and B to determine the position of the Blind Device. This therefore extends the locating distances of any Indoor Location Based Systems, by utilizing the existing mobile infrastructure without the need for any further hardware.

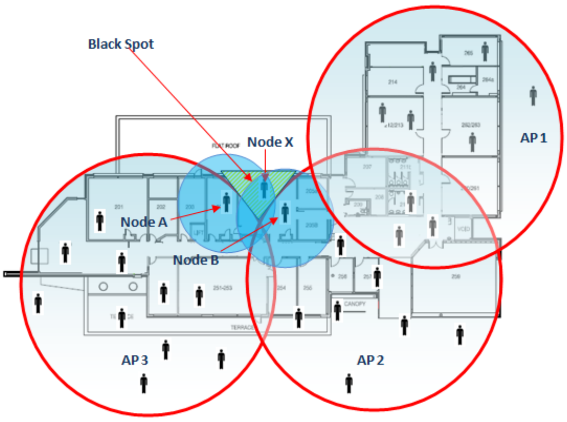

Figure 1: Fictional L shaped building with AP placed to cover most of the floor area

The remainder of this paper is organized as follows; Section II presents relevant background information and a review of related work, Section III presents the proposed detailed project, Section IV outlines work carried out to date, and finally a schedule for the project and conclusions are presented in Sections V and VI.

II. Location Based Systems

Localizations of devices in the outdoor arena have been around for some time. Devices that can determine exact location are relatively inexpensive. Indeed embedded GPS chips are being found in devices, from Mobile Phones to Cameras. GPS technology works through the use of a constellation of at least 24 satellites, each orbiting the earth every 12 hours, at a height of 20200 km [11]. These satellites broadcast their own location, and a very precise time signal. The reception of at least 3 of these signals enables the receiver to calculate the time of travel of the signals, and from this their own location. Standard GPS can provide accuracy of better than 7.8m 95% of the time [12]. This level of accuracy can be further improved with the use of assisted technologies to augment the GPS System in its estimation of a location [13], [14]. For example, Nationwide Differential GPS System (NDGPS) which is a ground-based augmentation system that provides increased accuracy and integrity of GPS information. High Accuracy NDGPS (HA-NDGPS) which is a further enhancement to this system, currently under development, argues that it will offer 10-15 centimeter accuracy [13]. Wide Area Augmentation System (WAAS) consists of approximately 25 ground reference stations that monitor GPS satellite data. Two master stations collect data from the reference stations and create a GPS correction message. This correction accounts for GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere. WAAS can provide accuracy of better than 3 meters 95% of the time [15]. Europe has also developed its own GPS System 'Galileo' which it argues offers better indoor coverage than standard GPS [16]. Augmented systems utilizing assisted technologies are also being employed in Indoor Location Based Systems to enhance the coverage and accuracy of its location estimation techniques [17], [10], [18].

The most common approach to developing an Indoor Location Based System has been via the utilization of the existing IEEE 802.11 network infrastructure, which are available in many public buildings and home environments. These proposed approaches can provide meter-level accuracy, which is sufficient for most location-aware applications, whilst also being cost-effective.

Ordinarily Wi-Fi location systems work in two stages. Stage 1 (Fingerprinting) the Offline Training Stage, is where a human operator carries out a site survey by sampling the Received Signal Strength Indicator (RSSI) from the Wireless Access Points (WAPs) located around the building. These samples are then loaded into a database which stores the Received Signal Strength Indicator (RSSI) readings of APs at different preordained sampled points. Stage 2 the online estimation phase, is where the mobile device's location is determined in real time by looking up sampled points on the database with the closest RSSI values to the mobile device. The Ekahau Location System is an example of an indoor location based system that employs this method [19]. There are however, environmental factors that can cause problems with this process, for example the following three dynamic factors have been observed to change frequently over time in the environment, thereby affecting the positioning accuracy.

The IEEE 802.11 specification adopts a radio frequency of 2.4 GHz, which is also the resonant frequency of water [10]. Hence an environment with a high Relative Humidity (RH) level tends to absorb more power from the radio signal than during lower RH levels. Since the human body is made up of 80% fluid, radio signals travelling around an empty hall will have a higher RSSI value that one during a busy period For example a college campus during the academic year will provide different RSSI values than outside the academic year, when no students are around the halls or rooms [17]. Doors by their very nature will open and close, ensuring that during the Fingerprinting process it can be difficult to predict which door will be open or even pieces of furniture (filing cabinets, suites of furniture, tables, or chairs) when the online estimation phase is attempting to locate a device at another date in time [20].

These environmental factors can affect the radio signal propagation from the APs to the target mobile devices, changing the RSSI and can incur location determination errors in the existing Wi-Fi based location systems that construct and maintain only one database signature of RSSI readings, because this single database signature is configured by the environmental condition at the time of site survey. When the environmental condition changes later this static database image may no longer accurately reflect the expected RSSI values in the environment.

Another method for estimating the location of a mobile device in an indoor environment is to input the collected RSSI values from a Mobile Device into a positioning algorithm. Positioning algorithms have evolved over time, mostly stemming from the research already carried out into them in the outdoor positioning arena.

III. RELATED WORK

Limitations in Indoor Location Based Systems stem from the inherent problems that arise out of the fluid nature of the indoor environment, in that it is ever changing and has so many factors that can disorientate a Location Based Solution. These problems have focused most current research into the area of positioning algorithms and the use of newer technologies to provide more accurate and robust solutions. There has been little or no investigation into using existing devices to augment or extend existing Location Based Systems as proposed in this paper, the following 3 literature reviews attempt to demonstrate and support this hypothesis.

The "Terminode (Terminal Node) project", Capkun et al. [21] propose a distributed infrastructure-free positioning algorithm whereby device (terminode) positioning is used by every terminode to obtain its position, utilizing a Self-Positioning Algorithm (SPA). The algorithm uses the distances between nodes to build a relative coordinate system from which the node positions are computed in two dimensions. The aim of this research is to demonstrate that where an existing infrastructure does not exist, and GPS cannot be used to resolve position there is still a way to obtain positions of nodes via distributed processing. Although this is described as GPS-Free positioning, it quite obviously could be 'Any Location Based System-Free' positioning solution, and therefore concurs with the SPREAD projects hypothesis that mobile devices can be employed to resolve the position of other mobile devices. The authors go on to prove, using simulated results, how this methodology will work by showing how it is possible to achieve a unique coordinate system by self-organization of the nodes. The Terminode project itself does not focus specifically on location based solutions and can be described more as a study and prototyping of large-scale self-organized mobile ad-hoc networks and has some inherent flaws in its attempt to build a Network Coordinate System. Here it utilizes the local coordinates of a device to become the network coordinates, forcing all other devices to compute their position relative to it, any motion of this device will cause all other devices in the system to recompute their position relative to it.

Shen, Wymeersch and Win [22] further investigate this cooperative paradigm, albeit in Wireless Sensor Networks in indoor and dense urban environments, the results of their findings are still significant and ad further weight to this papers hypothesis, that mobile device can be used to locate other mobile devices. They detail the problem with GPS being unable to penetrate most materials in these environments and propose a cooperative localization model using Wide Band or Ultra Wide Band (UWB) which can potentially offer high levels of positioning accuracy in cluttered environments [23], and the ability to penetrate obstacles [24], [25]. Agents (mobile nodes with unknown location), calculate their position using triangulation and time-of-arrival (TOA) ranging information from anchors (base stations) [26]. But in environments with dense obstacles (which is in most circumstances is the indoor arena), these agents find it difficult to triangulate their positions accurately because of the radio blockage to and from the base stations. The authors argue that when agents cooperate by taking ranging measurements from each other, and supplement this with the measurements provided by the viewable anchors that it can significantly improve the localization capability, in such a scenario. Shen et al., [22] go on to argue that they: "*show that agents and anchors are equivalent in essence, and anchors are just special agents with infinite accuracy in cooperative localization*".

Chan and Hoang [27] propose an architecture for Mobile Ad-hoc Systems and Services (AMASS) with a vision to use both Mobile Ad-hoc Networks (MANETs) and peer-to-peer communication models to create temporal associations with resources in heterogeneous fixed line and wireless networks. Again, as with the other papers previously mentioned, their aspirations do not match completely with the goals of the SPREAD project, but certain aspects of the architecture outlined provide a strong argument that supports the hypothesis. Most notably is their desire to create a communication environment where any mobile node that knows its own location would share this location information with neighbouring devices, in an open fashion. This would then allow any device that did not know its location, to self-position itself by using this information supplied by mobile device that it can 'see'. Communication between these mobile nodes would be via IEE 802.15 Ultra-wide Band (UWB) or Bluetooth, they further envisage using roaming devices within the network to act as routers making forwarding decisions based on its location within the network relative to its nearest neighbour. Some initial findings from preliminary implementation on an experimental testbed, demonstrate a solid foundation for the framework although no concrete results were documented.

IV. SPREAD PROTOTYPE

The goal of this research is to evaluate the possibility of extending the range of an Indoor Location Based System using Mobile Devices that 'know' their location, irrespective of what Positioning Technology has been employed to resolve that location. These Mobile Devices that know their position shall be known as Reference Devices, which could theoretically be Mobile Phones, PDAs, Tablet PCs, or Laptops and would be located at the extremities of the range of the APs used to calculate their position. They could then be used to calculate the position of a device, which we will call the Blind Device (because it cannot determine its location) beyond the range of any APs but within range of the Reference Devices themselves. A Positioning Algorithm could then be used to determine the location of the Blind Device using the values received by the Reference Devices along with the already known location of the Reference Devices as input.

During the lifetime of this project, it is proposed that one of the .NET programming languages (most probably C#, or VB) will be used to design a client based application that will reside on all devices within a said network infrastructure. These clients will in conjunction, locate 'Blind Devices' using the union or overlapping of 2 or more of their respective wireless cell ranges. Therefore when 2 or more Reference Devices can 'see' the Blind Device, it can be ascertained that the Blind Device is located within the region of the overlapping of the cell range of the Reference Devices.

In an attempt to achieve as close to a real world scenario as possible in a simulation environment, while also ruling out problems with devices using different technologies, identical devices will be used during testing. 3 Acer Aspire S742Z Laptops, each with a P6100 Intel Pentium Processor an Atheros AR5B97 wireless Network Adapter and 3 GB of DDR RAM will be used to simulate 2 remote Reference Devices at the outer bounds of an AP in a Wi-Fi Network. Each will have preordained x, y coordinate values illustrated on a map, and 1 Blind Device that will take the known coordinate values of the Reference Devices and compute its location on the map relative to the 2 Reference Devices.

V. EXPERIMENTAL RESULTS

Some early development work was carried out to prove the concept that remote mobile devices could locate each other once they could 'see' each other. The application illustrated below in figure 2 portrays 3 remote devices at the extremities of a building; this was used to simulate a real world environment so that some rudimentary testing could be carried out. The application takes the coordinate information from each device and uses a circle of a defined radius to draw its apparent coverage area onto the screen.

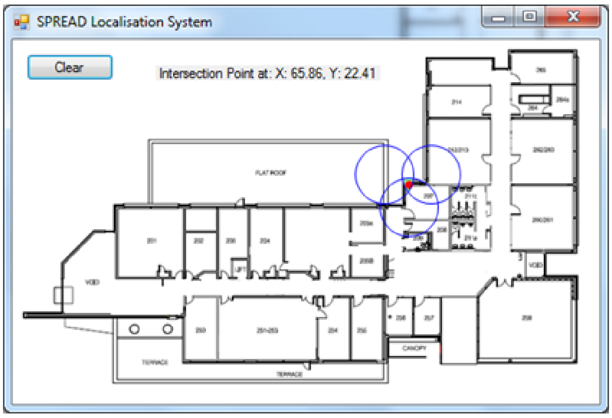

Figure 2: Prototype illustrating 'lost' device being localized.

Once more than one device has been added and these device coverage areas overlap, illustrating a scenario where a device in between them can 'see' both devices, the application calculates the center point of the intersection of these coverage areas, and paints a red dot to depict the lost device. The coordinate values of the lost device are also displayed on the screen at this point. Testing at this early stage of development was very basic, points were mapped on the screen and coordinate values were stored, then coverage areas were positioned so that the overlap fell on these positions to ensure that they matched. All tests carried out returned the previously mapped areas, adding more devices to the scenario allowed for more granular results, where the overlapped area becomes smaller in these cases. Since the estimation of the location of the lost device is calculated as the center point of this overlap, then the error rate of that calculation is also minimized.

VI. CONCLUSION

Research has shown that there is a requirement to investigate the limitations of indoor wireless location systems, and to provide solutions to some of the niche areas that would enhance this technology by extending its capability and range. This project aims to offer a means to capture the location of devices beyond the range of Wireless Access Points in a Wi-Fi network, thereby providing the ability to extend the range of these networks. There are still some issues that need to be address before any predictions of even a proposed solution can be lauded, for example the requirement that devices need to be at the extremities of the range of the Access Points and that these devices can reach the device that we want to locate. Furthermore as already highlighted there are quite a lot of issues already detailed in recent literature about the environmental variations that can affect RSSI values, considering we are advocating a solution that has as it reference points 'Mobile Devices' which are by their very nature nomadic, we are in fact exacerbating these issues further. With reference to future work, from a more practical aspect, the area of extracting RSSI values from Wireless Network Interface Cards needs to be investigated.

REFERENCES

[1] M. Weiser, "The computer for the 21st century," Scientific American, vol. 265, no. 3, pp. 94–104, 1991.

[2] E. Kaasinen, "User Needs for Location-Aware Mobile Services," Personal and Ubiquitous Computing, Vol.7 No.1, pp.70-79, 2003.

[3] J. Pascoe, N. Ryan, and D. Morse, "Issues in developing context-aware computing," First International Symp. on Handheld and Ubiquitous Computing (HUC 99), vol. 1707, pp. 208-221, 1999.

[4] A. K. Dey, and G. D. Abowd, "Towards a better understanding of context and context-awareness," Georgia Institute of Technology., Atlanta, Georgia, Tech. Rep. Atlanta, Georgia, Tech. Rep. GITGVU pp. 99-22, 1999.

[5] B. Schilit, N. Adams, R. Want, "Context-aware computing applications," in Mobile Computing Systems and Applications, 1994. Proc., Workshop on , vol., no., pp.85-90, 8-9 Dec 1994.

[6] R. Want, A. Hopper, "Active badges and personal interactive computing objects," Consumer Electronics, IEEE Transactions on , vol.38, no.1, pp.10-20, Feb 1992.

[7] G. Chen and D. Kotz, "A Survey of Context-Aware Mobile Computing Research TR2000-381," Dept. of Computer Science, Dartmouth College, Dartmouth, November 2000.

[8] G. Marsden, and M. Jones, 2006. Mobile Interaction Design. John Wiley & Sons, January 2006.

[9] F. Yang; D. Aoshuang, "A Solution of Ubiquitous Location Based on GPS and Wi-Fi ULGW," in Hybrid Intelligent Systems, 2009. HIS '09. Ninth International Conference on , vol.2, no., pp.260-263, 12-14 Aug. 2009.

[10] A. Rowe, Z. Starr, and R. Rajkumar, "Using micro-climate sensing to enhance RF localization in assisted living environments," Systems, Man and Cybernetics, 2007. ISIC. IEEE International Conference on , vol., no., pp.3668-3675, 7-10 Oct. 2007.

[11] G.M. Djuknic, and R.E. Richton, "Geolocation and assisted GPS," Computer , vol.34, no.2, pp.123-125, Feb 2001.

[12] K. Venkatraman, B. Amutha, K.T. Karthick, and S.R. Sankar, "A hybrid method for improving GPS accuracy for land vehicle navigation system," Emerging Trends in Robotics and Communication Technologies (INTERACT), 2010 International Conference on , vol., no., pp.74-79, 3-5 Dec. 2010.

[13] National Coordination Office for Space-Based Positioning, Navigation (NAVCEN), and Timing and the Civil GPS Service Interface Committee., "Augmentation Systems," Coast Guard Navigation Center, 15 March 2012. [Online]. Available: http://www.gps.gov/systems/augmentations/. [Accessed 11 April 2012].

[14] National Coordination Office for Space-Based Positioning, Navigation, and Timing (PNT). The U.S. Coast Guard Navigation Centre., "U.S. DEPARTMENT OF TRANSPORTATION," U.S. Department of Homeland Security, 2012 March 15. [Online]. Available: http://www.navcen.uscg.gov/?pageName=ndgpsMain. [Accessed 11 April 2012].

[15] Federal Aviation Administration (FAA), "Navigation Services - Wide Area Augmentation System (WAAS)," Federal Aviation Administration (FAA), [Online]. Available: http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/waas/. [Accessed 11 April 2012].

[16] M. Quinlan, "Galileo - A european global satellite navigation system," New Developments and Opportunities in Global Navigation Satellite Systems, 2005. The IEE Seminar on (Ref. No. 2005/10810) , vol., no., pp.0_9-1/16, 24-24 March 2005.

[17] Z. Yang, Z. Sun, L. Jiang, and Y. Xie, H. Kishida, "An area zoning based WLAN location system," Wireless Mobile and Computing (CCWMC 2009), IET International Communication Conference on , vol., no., pp.437-440, 7-9 Dec. 2009.

[18] J.R. Guerrieri, M.H. Francis, P.F. Wilson, and T. Kos, L.E. Miller, N.P. Bryner, "RFID-assisted indoor localization and communication for first responders," Antennas and Propagation, 2006. EuCAP 2006. First European Conference on , vol., no., pp.1-6, 6-10 Nov. 2006.

[19] Ekahau , "Ekahau Real Time Location System (RTLS) Overview," Ekahau , [Online]. Available: http://www.ekahau.com/products/real-time-location-system/overview.html. [Accessed 02 November 2011].

[20] C. Y. Shih, and P.J. Marrón, "COLA: Complexity-Reduced Trilateration Approach for 3D Localization in Wireless Sensor Networks," in Sensor Technologies and Applications (SENSORCOMM), 2010 Fourth International Conference on , vol., no., pp.24-32, 18-25 July 2010.

[21] S. Capkun, M. Hamdi, and J. P. Hubaux, "GPS-free positioning in mobile ad-hoc networks," System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on , vol., no., pp. 10 pp., 3-6 Jan. 2001.

[22] Y. Shen, H. Wymeersch, and M.Z. Win, "Fundamental Limits of Wideband Cooperative Localization via Fisher Information," Wireless Communications and Networking Conference, 2007.WCNC 2007. IEEE , vol., no., pp.3951-3955, 11-15 March 2007.

[23] L. Joon-Yong, and R.A. Scholtz, "Ranging in a dense multipath environment using an UWB radio link," Selected Areas in Communications, IEEE Journal on , vol.20, no.9, pp. 1677- 1683, Dec 2002.

[24] M.Z. Win, and R.A. Scholtz, "On the robustness of ultra-wide bandwidth signals in dense multipath environments," Communications Letters, IEEE , vol.2, no.2, pp.51-53, Feb. 1998.

[25] M.Z. Win, and R.A. Scholtz, "Characterization of ultra-wide bandwidth wireless indoor channels: a communication-theoretic view," Selected Areas in Communications, IEEE Journal on , vol.20, no.9, pp. 1613-1627, Dec 2002.

[26] S. Gezici, T. Zhi, G.B. Giannakos, and H. Kobayashi, A.F. Molisch, H.V. Poor, "Localization via ultra-wideband radios: a look at positioning aspects for future sensor networks," Signal Processing Magazine, IEEE , vol.22, no.4, pp. 70- 84, July 2005.

[27] J.C. Chan, and D. B. Hoang, "Service architecture for integrating MANETs with heterogeneous IP networks," Wireless Communications and Networking Conference, 2005 IEEE , vol.4, no., pp. 2270- 2275 Vol. 4, 13-17 March 2005.