Are indoor positioning systems mature for cartographic tasks?

Evaluating the performance of a commercial indoor positioning system

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ABSTRACT: Better indoor mapping are linked together with better indoor positioning. This paper gives a brief overview over existing methods for indoor positioning. To get an impression of how well a WiFi based commercial indoor positioning system works as an input to indoor real time visualization, a network of control points were established. Accurate coordinates for existing access points were also measured to see if these could improve the WiFi measured coordinates. Our experiment indicates that the geometry of the access points/mobile platform, the nearness to the access points and obstacles, as for example walls, are the dominating limitations when it comes to measure more accurate positions.

KEYWORDS: Indoor maps, indoor positioning, WiFi positioning

Introduction

When we talk about maps most people will imagine some kind of graphic representation of our outdoor environment. Maps have been made for hundreds of years, and in the last decade the amount of collected data and their representation and visualization on Internet based media has been growing in an accelerating tempo. A new trend is to extend the collection of data to include spatial environments inside the buildings. Google has for example recently extended the well known Google Street View to include indoor environments.

Multi-storey buildings represent new challenges in structuring, displaying and perceiving the indoor environment (Walton & Worboys 2009; Giudice et al. 2010; Raubal & Egenhofer 1998; Raubal et al. 1997). Cognitive integration of multi-storey buildings is different than outdoor environment. Additionally, the added vertical dimension introduces cartographic challenges that are not present in the outdoor environment in traditional cartography. Two dimensional floor plan maps is one of the most common map type used for indoor environments. The abstraction level range from architectural style, to high abstraction levels like airport and mall maps. New alternatives to regular floor plan maps have been suggested in the literature and in commercial projects. Some of which investigates possibilities of haptic representation for smartphones (Raja 2011), adaptation of metro maps (Nossum 2011) and “street view” photographic environments (Google Art Project 2012). Similar to all projects related to cartographic representations of indoor environments is that they either rely on accurate positioning or have a significant added value in the case of accurate position.

As GPS has been the key to success for outdoor location based services; indoor positioning is the key to success for indoor location based services. In most outdoor environments GPS is the technology that is most relevant for the "average man". However, when we move indoor, GPS is way more limited. Indoor GPS signals can be amplified by the use of **GPS repeaters** (Jardak & Samama 2009) and there exist high sensitive GPS receivers that, up to a certain limit, can be used indoors (Zhang et al. 2010). However, GPS repeaters are supplementary equipment that is not very widespread, and high sensitive GPS receivers are still quite limited in complex multi-storey buildings. For indoor positioning, other technologies exist which are based on local equipment as opposed to the use of global satellites. For example Liu et al. (2007) and Nordan (2011) gives a detailed overview over different systems: **RFID-systems** (*Radio Frequency IDentification*) is based on sensing passive or active RFID chips when it comes within the range of a receiver. With passive systems the sensors are typically placed at key positions such as doorways to enable room-scale positioning. **Ultrasound-based systems** work by transmitting ultrasound waves from tags, which are frequency modulated for identification and are picked up by dedicated receivers. Calculation of the position is based on measurement of the strongest signal, and since the ultrasound signal is hampered by walls etc., the technology is best suited for positioning on room level. There have also been some experiments using **infrared signals.** However, the necessity of a free line of sight between the transmitter and the receiver is a major drawback for this technology. All these technologies are based on a local infrastructure that includes sensor/transmitters of relative high density. This results in a dedicated infrastructure that needs to be installed solely for navigational purposes. Consequently, these are systems that are adequate when positioning is essential, and not for indoor positioning in general. **Cellular phone triangulation** is on the other hand based on the existing infrastructure for mobile communication. By comparing signal strength readings to known locations of cell towers the position of the hand-held equipment can be calculated. The accuracy of the distance measured from the transmitter to the receiver is in the first place poor. However, one advantage of this method is that the signals penetrate buildings, and Otsason et al. (2005) shows that by using fingerprinting techniques the method can be adequate for room-scale positioning.

WiFi positioning systems are one of the more promising techniques for indoor positioning. Wireless access points have become a natural infrastructure in buildings and some outdoor environments in urban areas, and the signals, which penetrate walls, can be handled by most handheld equipment like cell phones, tablets, laptops etc. Because this is an existing infrastructure, the cost for utilizing it for navigational purposes is low. It is also a fact that WiFi signals from each transmitter cover a much wider area than it is possible to obtain from for example infrared or bluetooth systems.

The most common method for WiFi positioning is to measure the strength of the signals from several wireless access points, and use this information to triangulate the position of the mobile device. There also exist systems where characteristics such as time of arrival or angle of arrival of the signals are used to determine the location (Köbben 2007). This will however require the employment of additional hardware. Yeung and Ng (2007) introduces an algorithm where the signal strength from mobile device to the access points is measured together with signal strength generated by the access points. They claim to have improved the accuracy of the location estimation by between 12 and 38%.

Today there exist several commercial systems for WiFi positioning systems, and many authors have investigated the accuracy and precision of these systems. Zandbergen (2009) tested the accuracy of iPhone location by the use of Assisted GPS, WiFi and cellular positioning in natural environments. He concluded that the WiFi positioning system was far below expectations based on published performance by Skyhook Wireless. This is the system employed on the actual iPhone. Uneven distribution of wireless access points is assumed to be a reason for lower accuracy. The accuracy for WiFi positioning was however substantial better than the corresponding cellular positioning.

Gallagher and Kealy (2009) investigated the use of Ekahau Positioning Engine (EPE) and Skyhook Wireless Positioning System (WPS) for indoor environments. In their trials they found the EPE to have an accuracy of about 10-15 meters, while the typical error for the WPS was 30-60 meters. However, it seems like only the EPE was based on fingerprinting techniques in their trials.

Fingerprinting techniques, or calibration for the received signal, is used to store information about average strength of the received signal in various locations. When the mobile device receives signals from multiple access points the strengths of these signals can be compared to initial measurements stored in a database. Signal strength "profiles" can for example be stored for each room in a building to make room-scaled positioning better.

There is an abundant amount of related work which includes prototypes of indoor positioning in various manners (Ciavarella et al. 2004; Yang et al. 2007; Dahl 2006; Schrooyen et al. 2006; Huang et al. 2009). Most of the existing efforts have not included a rigorous evaluation method and measurements of accuracy and precision drawing on knowledge from the established field of land surveying. Surveys providing overview of different positioning methods and technologies are found in the literature as well (Mautz 2009; Curran et al. 2011; H. Liu et al. 2007). The different techniques available range from high precision and accurate laser positioning, commonly used in surveying to coarse IP geolocation, this paper focus primarily on available and non-dedicated infrastructures, which WiFi positioning is able to fulfill.

NTNU and Wireless Trondheim's WiFi positioning system

As described by Nordan (2011), the Norwegian University of Science and Technology (NTNU) uses the Cisco Mobility Services Engine (MSE) as a WiFi positioning system. The MSE is connected to the system of wireless access points that provides WiFi coverage to students and employees. Each access point is given a position based on a local coordinate system for each building. The coordinates are extracted from a drawing of the building, and due to the fact that positioning is a secondary task of the WiFi system, the locations of the access points are not necessarily optimized. The actual position of a handheld device is determined by signal triangulation from the access points to the device. Internally, one can, through the Wireless Control System (WCS), track any device connected to the network, while externally an API is exposed through a separate system named GeoPos.

The GeoPos system uses web services to connect to the WCS in order to extract the position information. GeoPos then adds value to the information by translating the relative coordinates to absolute coordinates. WGS84 longitude and latitude and UTM 32 coordinates are returned along with information about the actual building. The MSE/WCS system does not have any functionality for remembering previous positions of a device. Consequently, only the current known position of a device will be passed on. With a user account and appropriate cryptographic certificates, one can use the GeoPos system to track the position of devices with known MAC addresses. (This mainly limits you to track devices in your own possession.) The system is illustrated in Figure 1.

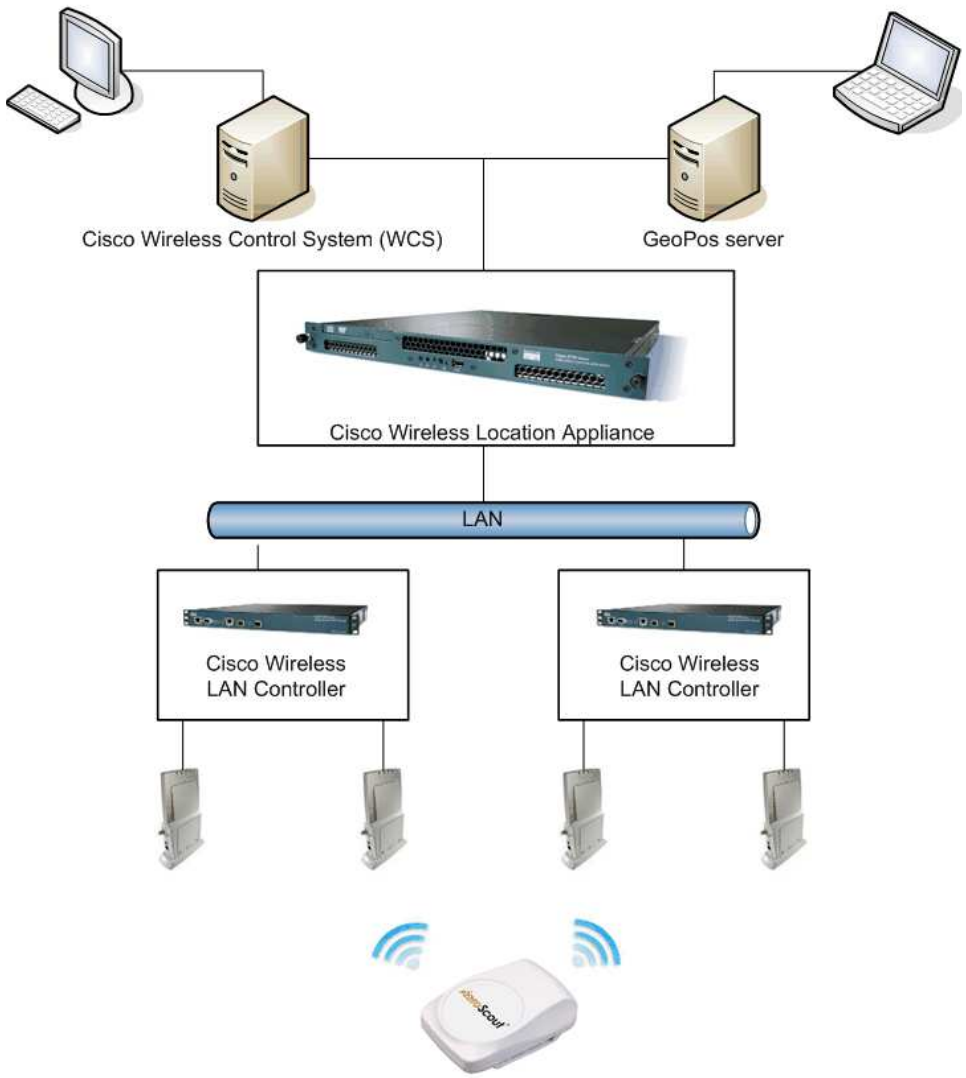

Figure 1: NTNU and Wireless Trondheim positioning system (Moen & Jelle 2007)

Investigation of the functionality and accuracy of the Cisco positioning system

Köbben (2007) presents a list of evaluation criteria for WiFi-based location systems. This includes factors such as accuracy, precision, calibration, responsiveness, scalability, self-organization, cost, power consumption and privacy. In this work we will primarily study accuracy and precision for the Cisco system at NTNU. We will also include calibration through fingerprinting methods.

Nordan (2011) completed an initial experiment where the accuracy of the actual WiFi positioning system was explored. His experiment was based on measurements both with and without fingerprinting techniques. He could not find any significant improvement by using the fingerprint information. Measuring 36 points he found the mean error to be 9.9 meters without fingerprinting techniques and 8.3 meters with, both with a quite high variance. The experiment in Nordan (2011) revealed however some problems regarding the measurement of precision and accuracy for the WIFI positioning at NTNU:

- The calculations of new positions are based on triangulation between access points and the wireless equipment. However, the wireless network is built for data communication, not for navigation. Consequently, the best geometry for calculations of the positions is not taken into consideration when access points are installed.

- For navigational purposes the access points need to be located in a reference system, either local for the building or a geodetic coordinate system. For wireless communication this is less important. The intention in Nordan (2011) was to run the experiment in a hospital building. However, when inspecting the data for the access points it turned out that most of the access points where given the same coordinate - in the garden outside the building. His experiment was consequently moved to a building with better configured access points. But even then the coordinates for the access points are picked out from sketches on maps, and the difference between the given and the real position can often be measured in meters.

To achieve a better understanding of the wireless navigation system at NTNU, it was decided to carry out more thorough experiments to answer research questions as; does the system provide sufficient accuracy for turn-by-turn navigation in indoor environments, will improved positioning of the access point give better accuracy in the navigation, and does fingerprinting techniques implemented in the Cisco system improve the solution.

Though the network geometry still would be a limitation, the questions about more accurate coordinates for the access points and repeatable measurements were solvable. Consequently, it was decided to establish a permanent network of control points inside the Lerkendal building at NTNU. This network would be the frame of reference both for the investigation of the current wireless positioning system and for the measurements in another project that involves pseudolites for indoor GPS navigation. The network was also established in a way that made it possible to engage in future experiments involving new technologies. Development in accuracy and precision may then be studied.

The network was realized by the help of red enamel varnish and a custom/made tool for making permanent marks in the linoleum on the floor in the test building. 31 points were marked at different locations at first floor, while the second floor contained 9 points, and the basement 5 points in central areas (Figure 2). This gives 45 points all together.

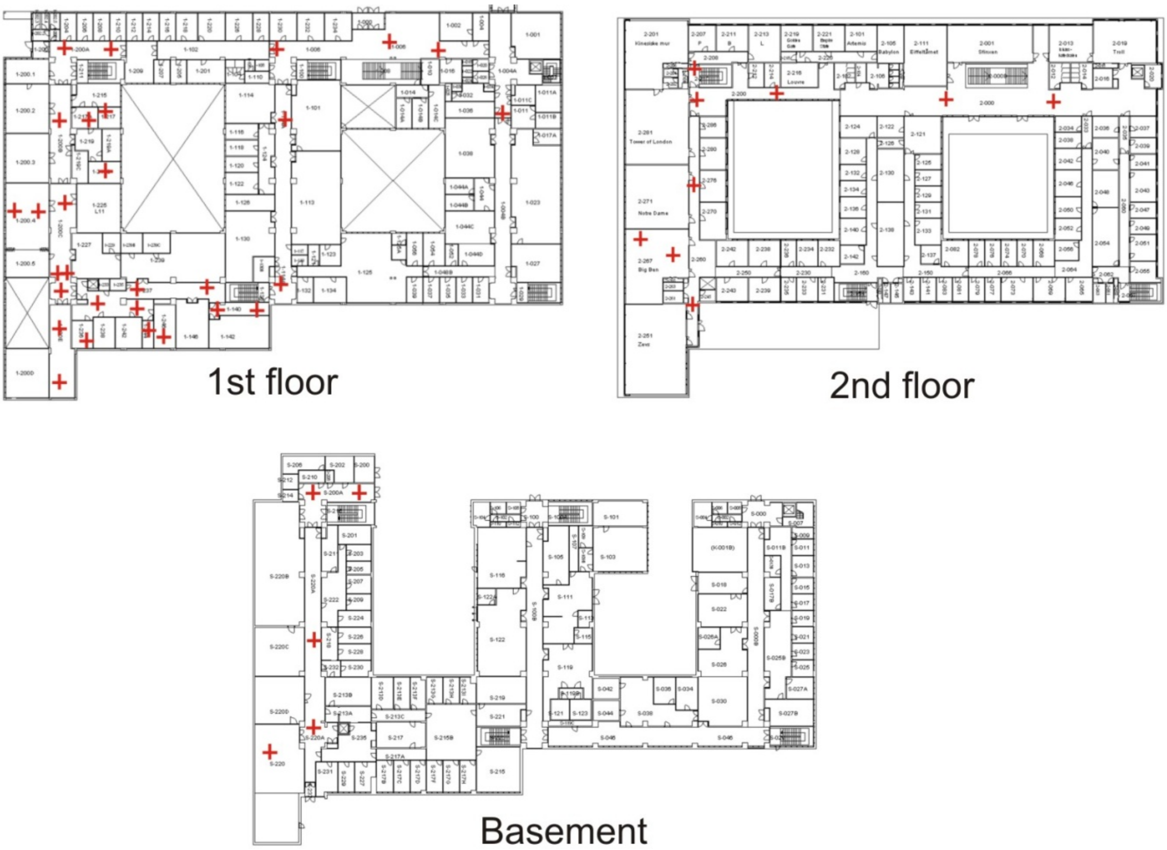

Figure 2: Control points established in the building.

The Cisco Wireless Location Appliance uses a local reference system for each building where foot is set as the unit. Since the primary task for this kind of equipment is network communication it is expected that the locations of the access points remain more uncertain. The actual coordinates are most likely extracted from a sketch of the building. To investigate this, the locations of the access points were measured using surveying equipment and well known surveying methods. These measurements showed that the internal accuracy for the access point locations was rather poor (several meters). Table *1* shows the difference between the existing and actual coordinates (accurate measurements) for the access points.

Table 1: Accurate coordinates and their differences from the coordinates picked from a drawing. All the values are in feet.

Acess point	Old X	Old Y	Accurate X	Accurate Y	dX	dY	2D diff.
A0-03	63,00	383,38	58,26	363,99	4,74	19,39	19,96
A0-01	54,13	280,84	58,37	270,34	-4,24	10,50	11,33
A0-02	59,06	333,01	57,98	320,86	1,08	12,15	12,20
A1-13	283,79	274,61	278,63	266,92	5,16	7,69	9,26
A1-14	262,80	339,24	261,40	329,95	1,40	9,29	9,39
A1-06	209,65	355,31	201,16	341,57	8,49	13,74	16,15
A1-07	170,93	285,43	162,16	277,94	8,77	7,49	11,54
A1-08	138,45	336,61	137,7	332,95	0,75	3,66	3,74
A1-11	230,64	251,64	230,25	244,57	0,39	7,07	7,08
A1-10	186,02	229,00	176,06	221,67	9,96	7,33	12,37
A1-09	117,45	228,02	114,52	221,6	2,93	6,42	7,05
A1-02	43,71	264,81	45,14	259,58	-1,43	5,23	5,42
A1-03	44,73	329,35	45,02	323,27	-0,29	6,08	6,09

A1-04	46,26	387,80	44,87	378,00	1,39	9,80	9,90
A1-05	109,58	370,41	98,92	357,62	10,66	12,79	16,65
A1-01	52,82	225,72	48,57	219,41	4,25	6,31	7,61
A1-12	276,25	230,97	270,64	222,93	5,61	8,04	9,80
A2-07	28,87	362,86	28,00	379,85	0,87	-16,99	17,01
A2-06	30,51	321,19	28,11	332,31	2,40	-11,12	11,37
A2-05	37,07	281,82	34,38	301,15	2,69	-19,33	19,52
A2-02	38,06	248,03	34,47	260,11	3,59	-12,08	12,6
A2-01	20,34	204,4	16,16	208,45	4,18	-4,05	5,82
A2-03	92,16	210,92	95,71	218,75	-3,55	-7,83	8,60
A2-04	164,36	212,34	166,69	224,57	-2,33	-12,23	12,45
A2-14	278,37	209,97	292,32	217,77	-13,95	-7,80	15,98
A2-11	201,42	329,68	206,58	343,35	-5,16	-13,67	14,61
A2-08	97,86	326,83	100,36	336,84	-2,50	-10,01	10,32
A2-09	145,34	291,34	153,78	303,85	-8,44	-12,51	15,09
A2-10	146,00	265,09	153,74	270,26	-7,74	-5,17	9,31
A2-12	250,66	295,60	266,25	306,93	-15,59	-11,33	19,27
A2-13	253,28	260,83	267,38	269,72	-14,10	-8,89	16,66

The access points were measured together with the network of indoor control points. Based on six first order outdoor benchmarks measured with RTK-GNSS, a high precision network was measured with a total station in a global reference frame. Estimated 3D standard deviations for access points in the measured global system were all in the magnitude of one centimeter. All the positions were measured in UTM, Zone 32N.

Using the two sets of plain 2D access point coordinates, the relation between the global and the local system were found mathematically, estimating the four unknown parameters in a conform plain Helmert transformation. Finally, a set of accurate, “corrected”, coordinates ensuring uniform internal geometry in the local system were determined, transforming the measured data set from the global to the local system.

Application for running an indoor positioning experiment

A web application was developed to collect and store positions from the Cisco Wireless Location Appliance (WLA) throughout the experiment. The application was implemented as a web page with necessary server side functionality for requesting positions from the WLA as well as from HTML5 GeoLocation, and storing results in a database. The client controlled the positioning frequency and input parameters to the positioning system together with necessary information to store in the database. In an effort to get the most accurate positioning from the WLA positioning system, the client has the ability to do an HTML5 GeoLocation request. In Mozilla Firefox, the GeoLocation request is implemented to send out signals on present WiFi devices on all channels to all access points (Mozilla 2012). Requesting a position from the GeoLocation API results also in an additional position measurement based primarily on IP address and WiFi access point data which could be compared with the results from the indoor positioning system in question. To maintain security and privacy, the application was password protected and the communication between server and positioning system was encrypted. All requested positions and the complete result from the positioning system were stored in a SQLite database which could be accessed using a lightweight administration panel and an export application. The result from the positioning system consisted of coordinates in several coordinate systems including a horizontal local system, the UTM system and a geographic coordinate system – all in combination with a textual representation of the current floor. In addition the result included a confidence measure provided directly from the positioning system.

Measurements of positions by WiFi equipment

A custom-built "vehicle" was built to provide a stable and consistent platform for measurement of the coordinates provided by the wireless network (Figure 3). Since the position of the WiFi antenna inside a laptop is difficult to establish, it was decided to use an external WiFi unit that was connected through one of the USB connections on the laptop. This also made it easy to position the WiFi unit exactly over the control point on the floor and to keep the unit at a consistent height over the floor. Based on the expected accuracy of the positions provided by the wireless positioning system it might seem superfluous to arrange for precise placement of the equipment. It was however decided to avoid the inclusion of unnecessary incorrectness and to prepare for future analysis of future, more accurate, systems.

Figure 3: Movable platform for measuring control points.

10 control points in the first floor of Lerkendalsbygget were selected for further investigation. This included both control points in halls and open areas as well as points inside offices. In the selected locations there were variation in both the coverage of the wireless network and the geometry related to access points reached by the WiFi unit. The measurement campaign was accomplished in a period with few people present at campus (between semesters for the students and in the summer vacation for employees). Consequently, the general activity on the wireless network was low and stable.

The Cisco Wireless Location Appliance is equipped with calibration techniques, where the expected signal strengths in different locations are included in the calculation of the position (fingerprinting). In this experiment it was also interesting to study how fingerprinting (FP) influenced the determination of the various positions. Consequently, a series of measurements were carried out for all 10 control points both with and without FP. Since the accurate determination of both access points and control points provided new coordinates for these, the new positions for the access points could be implemented into the Cisco Wireless Location Appliance. To find if new coordinates had any effect on the position, new series of measurements were carried out both with and without FP.

For all the measuring series, each point was measured 5 times. After a study of auto correlation functions computed from representative time series measured in an early phase, it was decided to use at least 1 hour delay between the measurements of the same point to avoid time correlation. The coordinates were recorded as simple measurements to simulate a mobile platform moving around in the building. This gives no repeated measurement over time for each recorded point. eOur systems for recording of the data stored measured coordinates as local coordinates in feet as well as UTM coordinates processed through the GeoPos server. For the further study in this paper the local coordinates in feet were used.

During the measurement campaign we did some observations:

- If we were going to make several measurements in the same point it was necessary to disconnect and then connect the wireless network. Even then the system seemed to use the first coordinates in an algorithm for improvement of the position.
- It was always necessary to disconnect and then connect the wireless network between measurements in different control points, especially when the points were close. If not doing this, the coordinates for the previous point would be included in the calculation of the next.
- When doing the measurements we did not consider the orientation of the antenna to be of any importance.

Results

The measured coordinates for the control points are presented in *Table 2* and *Table 3*. In addition it can be mentioned that all the measurements showed the correct floor for the control points.

Table 2: True values and the mean values of the measured coordinates for the control points, dataset 1 to 4.

	True val.	Mean values			
Control point	**x** **y**	**1** **Old no FP**	**2** **New no FP**	**3** **Old with FP**	**4** **New with FP**
P-1	18 364,6	40,7 397,8	53,4 390,6	64,3 378,6	61,4 366,1
P-13	40,5 266,1	42,7 268,2	48,0 263,5	48,1 277,7	45,9 273,4
P-24	154,4 284,9	145,7 295,5	182,8 277,5	163,2 292,2	161,2 268,6
P-18	64,7 226,8	48,2 219,8	51,0 235,4	79,3 233,7	62,4 235,2
P-05	60,6 354,5	57,8 375,0	55,7 368,1	71,0 359,7	69,3 356,2
P-17	41,5 225,1	57,0 259,8	56,7 254,5	54,5 255,5	61,8 255,5
P-09	40,3 340,1	62,7 332,8	80,3 290,5	66,3 350,7	77,2 307,6
P-28	113,8 347,4	118,4 362,8	106,3 343,8	107,8 360,7	102,5 343,1
P-10	43,1 305,6	43,9 311,3	54,8 309,5	62,5 293,3	67,4 308,8
P-02	88,1 369,9	83,2 396,8	53,8 403,6	79,5 375,2	60,1 372,3

Table 3: Differences, standard deviation and variance in measured coordinates. Measurements with old and new coordinates for access points and with and without FP.

Control point	Difference from true value				Standard deviation				Variance			
	1 Old no FP	2 New no FP	3 Old with FP	4 New with FP	1 Old no FP	2 New no FP	3 Old with FP	4 New with FP	1 Old no FP	2 New no FP	3 Old with FP	4 New with FP
P-1	22,7 33,2	35,4 26,0	46,3 14,0	43,4 1,5	19,2 6,0	12,2 11,9	12,4 3,8	13,7 7,1	370,5 36,1	148,1 142,2	154,1 14,4	187,0 50,6
P-13	2,2 2,1	7,5 -2,6	7,6 11,6	5,4 7,3	1,5 10,2	2,5 9,5	2,6 10,1	0,7 16,4	2,3 103,9	6,1 90,0	6,9 102,7	0,5 268,9
P-24	-8,7 10,6	28,4 -7,4	8,8 7,3	6,8 -16,3	28,2 19,2	28,0 19,0	7,3 9,2	4,9 9,5	796,4 367,4	781,3 362,4	53,6 84,1	23,9 89,6
P-18	-16,5 -7,0	-13,7 8,6	14,6 6,9	-2,3 8,4	31,2 15,9	28,6 22,5	21,7 7,8	2,5 8,7	973,0 254,2	817,4 505,1	471,2 61,6	6,4 75,4
P-05	-2,8 20,5	-4,9 13,6	10,4 5,2	8,7 1,7	10,5 11,8	10,3 12,7	6,5 15,8	11,2 21,6	110,8 139,7	105,6 161,6	42,8 248,7	124,6 466,3
P-17	15,5 34,7	15,2 29,4	13,0 30,4	20,3 30,4	13,2 11,0	10,8 22,5	6,5 15,4	8,2 11,5	173,0 121,1	115,9 507,5	41,7 237,9	67,8 132,7
P-09	22,4 -7,3	40,0 -49,6	26,0 10,6	36,9 -32,5	11,6 24,6	18,3 26,5	12,7 25,2	4,4 14,8	135,2 602,8	336,6 702,4	161,7 634,1	19,6 217,8
P-28	4,6 15,4	-7,5 -3,6	-6,0 13,3	-11,3 -4,3	10,9 9,9	15,6 29,5	5,8 5,9	5,1 5,1	119,0 97,8	243,5 872,3	34,2 35,1	25,9 26,5
P-10	0,8 5,7	11,7 3,9	19,4 -12,3	24,3 3,2	11,1 26,5	16,1 44,9	6,5 13,6	8,7 13,2	123,9 704,7	258,2 2015,8	42,2 185,3	75,2 173,3
P-02	-4,9 26,9	-34,3 33,7	-8,6 5,3	-28,0 2,4	19,9 17,1	26,0 11,1	16,0 2,3	4,6 0,8	396,7 292,7	675,0 122,4	257,5 5,5	20,8 0,6

A brief study of the results indicates that there are poor improvements by introducing more accurate coordinates for the access points. It also seems like the fingerprinting calibration, as it exists in the system today, has little effect on the positions measured by WiFi. However, the results show, with some exceptions, that the variances for the measured control points are lower when fingerprinting is turned on. It is also interesting to notice that the differences between WiFi measurements of the control points and the true values have a tendency to depend on the location of the actual control point. With some exceptions this location seems to be more vital for the calculation of the coordinates than the precision in the location of the access points or the fingerprint calibration.

Looking closer into the data sets we found a high correlation between coordinates measured in the same points but with different parameters. These large correlations can possibly be explained by the identical obstacles around the points, independent of which series that are measured. The geometry between the mobile platform and the access points was also similar for each point.

Table 4: Correlation coefficients computed between the x-components, dataset 1 to 4.

	X1	X2	X3
X2	0,659		
X3	0,582	0,753	
X4	0,717	0,890	0,918

Table 5: Correlation coefficient computed between the y-components, dataset 1 to 4.

	Y1	Y2	Y3
y2	0,768		
Y3	0,436	0,166	
Y4	0,511	0,802	0,342

To check for significant differences between x- and y-components of the different dataset 1-4, a zero hypothesis based on paired T-tests have been performed. Rejecting the zero hypothesis: H_0: $\mu_d = \mu_0$, when the expectation value of paired differences are different from zero. The test did not show a significant difference between the measurements in dataset 1 to 4. Based on high standard deviation of the measured coordinates this was no surprise.

As the results in Table 3 shows, the differences between the WiFi measurements and the true values are between 1.5 and 49.6 feet (0.5 and 15 meters). Some of the WiFi measured coordinates seem to have a tendency to get differences in the same magnitude, independent of new or old coordinates with and without fingerprinting. For example the x-coordinate of P-13 have low difference for all the measurement methods. This also shows very low variance for the measurement.

As stated earlier, positioning is a secondary task for the WiFi system, and when moving around inside a building the geometry of the involved access points and the mobile platform will be varying. Likewise will there be a variation in the distance to the closest access point and the number and thickness of walls a signal has to pass. Figure 4 shows the measured points during the campaign together with relevant access points. P-13 is the measured control point with the shortest distance to an access point where there are no walls or windows in between.

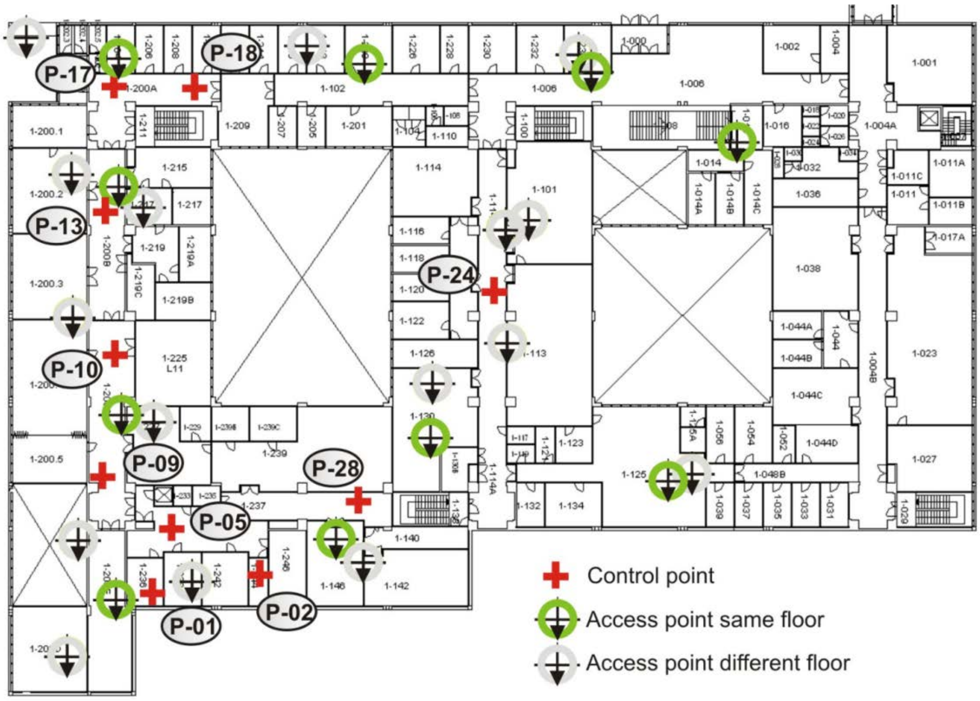

Figure 4: Measured points together with relevant access points.

Conclusion

When it comes to the questions: ”Will new and better coordinates for the access points improve the WiFi positioning” the short answer is; No. Our results indicate no significant improvement in the measured coordinates when new coordinates for the access points where introduced. We suspect that the variation of the location of the mobile platform and the geometry between this and the access points are the dominating obstacle for better precision and accuracy in the measurements.

In this study we did not store information about access points used in each measurement. To get a better insight into how geometry and obstacles influence on each measurement this would be interesting to look into in a further study.

The Cisco Mobility Services Engine provides improvement of the measured coordinates by using fingerprinting (FP). Even though we have some indications that FP gives lower variance between the measurements, no significant improvement in the difference between the WiFi measured positions and their true values are evident in our results.

Even though the results from this project has revealed levels of accuracy, precision and update frequency well below what is the industry standard of outdoor GPS positioning, the results have also shown that a commercial off-the-shelf indoor positioning system is capable of providing positions which can be used for many cartographic tasks. The requirements of high accuracy, precision and update frequency depends greatly on the task at hand. The explosion of GPS enabled handheld devices have contributed to a parallel explosion in the development of systems taking advantage of outdoor positioning. However, we argue that the high precision and high accuracy, possible with modern GPS devices, is not always required, or necessary for the majority of location based applications. Similarly, we argue that this is true for indoor location based applications. The need for high accuracy and precision becomes, however, prominent for some application groups, primarily turn-by-turn navigation. Turn-by-turn navigation requires very high accuracy, precision and not least, a reliable update frequency. The results found in this experiment do not support the ability for this kind of application with the positioning system in question. On the other hand, one can easily imagine several applications that do not set forward requirements for high precision and accuracy such as asset tracking and social applications. Asset tracking can be highly useful in larger buildings such as hospitals, large stores and malls. When dealing with problems of finding assets, the precision and accuracy does not need to be as high as for turn-by-turn navigation. Finding, for instance a patient, a wheel chair (Nordan 2011) or an ultrasound machine can be greatly helped by accuracies within 15 meters, and would be of even more help with better accuracy combined with correct vertical location.

Social applications, where the task is to get an overview of other peoples location, can also function equally well without an accurate and precise position. Providing users with systems that can filter out the friends within approximately 50 meters can be just as useful as systems that know which friend is close to you right now. Museum, library and shopping applications can similarly benefit from the accuracy found in the reported experiment. Museum applications can indicate approximately which objects are close to the user while shopping applications can give the consumer location sensitive coupons, both without accurately knowing the location of the user, but with an approximate location.

GPS positioning, navigation and location based systems have enabled users to “look into the future” by informing which turn is the next, if a gas station is within 50 miles and if there will be a congestion on the highway. Accuracy, precision and update frequency requirements for these applications are well below the full potential of GPS positioning. Designing systems able to take advantage of coarse indoor positions should be well within reach by clever system design and visualization. Are commercial off-the-shelf indoor positioning systems mature for cartographic tasks? With support from the results and experience during this project, we argue that they are for many cartographic tasks if the design is adapted to the limitations of the current positioning systems.

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