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Sazid Zaman Khan
Thilek Silvadorai
Tan Chen-Wei
Sureswaran Ramadass
Toni Anwar

CONTEXT AWARE HANDOVER ALGORITHMS FOR MOBILE POSITIONING SYSTEMS

Abstract

This work proposes context aware handover algorithms for mobile positioning systems. The algorithms perform handover among positioning systems based on important contextual factors related to position determination with efficient use of battery. The proposed solution is implemented in the form of an Android application named Locate@nav6. The performance of the proposed solution was tested in selected experimental areas. The handover performance was compared with other existing location applications. The proposed solution performed correct handover among positioning systems in 95 percent of cases studied while two other applications performed correct handover in only 50 percent of cases studied.

Battery usage of the proposed solution is less than one third of the battery usage of two other applications. The analysis of the positioning error of the applications demonstrated that, the proposed solution is able to reduce positioning error indirectly by handing over the task of positioning to an appropriate positioning system. This kept the average error of positioning below 42.1 meters for Locate@nav6 while the average error for two other applications namely Google Latitude and Malaysia maps was between 92.7 and 171.13 meters.

Keywords handover among mobile positioning systems, power efficient mobile positioning, switching between indoor and outdoor positioning systems

1. Introduction

As people cross familiar geographic boundaries and explore new places, receiving location related information becomes an essential part of a travelers experience. With the unparalleled increase in smartphone usage, receiving location related information from internet has become a common trend. The variations in the type of location bring up the issue of variations in positioning techniques. The reason is that, one single positioning technique is not adequate to provide positioning in both indoor and outdoor spaces [22]. For example, GPS can provide position in line of sight scenario only; it is not available in indoor spaces. On the other hand, outdoor spaces often lack sufficient WLAN infrastructure required for WLAN positioning. Therefore, handover mechanisms among outdoor positioning systems such as GPS and indoor positioning systems are required to ensure continuous and ubiquitous positioning for the user in indoor and outdoor spaces. Context aware handover among these positioning systems can guarantee such type of positioning. This is the main issue which has been addressed in this work.

A good ubiquitous positioning solution with context aware handover among positioning systems should also have a decent battery usage to make it worthwhile. Thus, controlling battery drainage associated with positioning has also been addressed. In this paper, the performance of the implemented solution named Locate@nav6 is compared with two Location dependent applications named Google Latitude and Malaysia maps. Rest of the paper has the following sequence: Section 2 describes the related literature. In this section, integrated positioning solutions which combine different types of positioning techniques are reviewed. As integrated positioning solutions require handover among different positioning technologies, an analysis of the major factors related to handover among positioning systems is presented in Section 3. Based on this analysis, the system design and the associated algorithms are presented in Section 4. Section 5, 6–9 and 10 present the implementation, results and conclusion respectively.

2. Literature review

A number of positioning technologies are available for localizing mobile devices or assets. In [16], the authors carried out a broad survey of these positioning technologies. In this paper, the authors explained different positioning algorithms and principles such as Time of Arrival, Time difference of Arrival, Location Fingerprinting, etc. In addition, different positioning systems and solutions based on GPS, RFID, WLAN, Bluetooth, etc were discussed. In the present work integrated positioning technologies related to Location based Services will be emphasized. As mentioned before, this work will emphasize on handover techniques for positioning systems and integration of different positioning systems.

2.1. Combination of WLAN, GPS, Cellular and Bluetooth positioning

This type of integrated positioning seems to be the most common trend. StreamSpin [8] addressed the issue of handover among indoor and outdoor positioning technologies in detail. In this work, four mechanisms for handover between WLAN and GPS are provided. These are called: 1. Always Prefer GPS, 2. Always Prefer Wi-Fi, 3. Prefer GPS Until Lost Signal, 4. Prefer GPS Upon Continuous Readings. The performances of these solutions are studied too. StreamSpin uses a combination of WLAN and GPS to determine the position. Another system that makes use of both GPS and WLAN for tracking indoor and outdoor position of individuals working in a construction site is described by Behzadan et al. [2]. The distinctive feature of this system is that it aims to enhance the positioning of an individual by providing data about his present head orientation. This information is helpful in understanding the context of the user. The system uses augmented reality to give the emergency responders information about the responder's position and their places of interest. Assisted GPS (AGPS), which is a hybrid type of Global Positioning System, is commonly used to reduce the time required for a GPS based position. Weyn et al. [24], based on AGPS model, suggested the use of an assistance server that employs WLAN location fingerprinting to calculate the approximate position of a mobile station. Location fingerprinting is a technique of recording the signal strengths received at a particular place from multiple cell towers or WLAN access points in a database. The signal strengths for a location can be used as a unique identifier for the location. The identifier is called the fingerprint. Therefore a fingerprint database contains vectors of signal strengths from access points or cell towers against each unique location. Later on, when a mobile user requests his location, his received signal strength vector is compared with the signal strength vectors of each location stored in the database. The location, for which the signal strength vector has least dissimilarity with the received signal strength vector, is considered as the location of the user. According to [24], the assistance server uses the approximate location to send Ephemeris data to the mobile station. The mobile station is expected to receive the Ephemeris data quicker from the server compared to the case when it receives the same data from satellite. Consequently, the time required for a position fix is reduced. Zhou et al. [27] explained a mathematical framework that uses Euclidean and Mahalanobis distance together with likelihood functions to estimate the position.

A concept named 'Always Best Located' was discussed by Reyero et al. In this work, the authors compared the performances and coverage of several positioning systems. The authors concluded that a combination of GPS and WLAN would ensure the best positioning. Pei, et al. [17] implemented a combination of several positioning techniques on a Nokia N95 which works on Symbian S60 platform. Three main types of positioning techniques were applied: multi-sensor based technique, satellite (GPS and Assisted GPS) based technique and terrestrial based positioning technique. The multi sensor based positioning techniques made use of accelerometers, inclinometers and digital compasses of the mobile device. For terrestrial positioning in cellular networks, cell identification (cell-id), advanced forward link trilateration, time difference of arrival methods were employed. WLAN fingerprinting was suggested for WLAN positioning. Layered software architecture was used for implementation of the combined positioning solution. Klepal et al. [12] also presented a similar system named Opportunistic Localization System (OLS). OLS uses GPS, Cellular network, WLAN, Accelerometers and Bluetooth for adaptive positioning in indoor or outdoor spaces.

The 3G iPhone uses a hybrid method for estimating the position of the user, namely: AGPS, WLAN and Cellular positioning [26]. For outdoor environment AGPS positioning is used while WLAN and Cellular positioning are preferred in the absence of reliable AGPS position fix. The authors compared the accuracy of the integrated AGPS receiver of the iPhone with that of the Garmin GPS. The results showed that, the horizontal and vertical position error of 3G iPhone was significantly higher than those of Garmin GPS receiver. A similar approach to combine GPS, WLAN and Cellular positioning for Android phones was implemented by Pereira et al. [18]. Lin et al. [15] on the other hand investigated ways of reducing power consumption associated with positioning. In some cases, Cellular network based positioning can provide sufficient levels of accuracy. GPS is more power hungry though more accurate. Therefore, activating GPS in such cases may not be necessary. In this work, a mechanism able to use GPS, Cell-ID, Bluetooth or WLAN positioning based on accuracy requirement was implemented. Energy efficient positioning for smartphones is also described in [28] and [7] by using complementary positioning techniques and by ensuring selective use of GPS. The architectural aspect of an indoor-outdoor location sensing technology has been discussed by Flora et al. [5].

2.2. Combination of GPS, RFID, UWB positioning

Seamless GPS and RFID positioning for logistics management is described by Chi-Yi et al. [14]. Jiang et al. [10] described a system for indoor and outdoor positioning which uses GPS for outdoor and Ultra Wide Band (UWB) for indoor positioning. It switches automatically between GPS and UWB positioning in indoor and outdoor spaces. The use of UWB provided centimeter range accuracy. Integrating GPS and UWB positioning was also discussed in [6]. This system consists of a number of Pseudolites capable of transmitting UWB signals. The position of a mobile terminal which has the capability of receiving the UWB signal could be deduced by using the same techniques used for GPS positioning. A simulated model depicting positions of fixed UWB transceivers in a shopping mall has been provided. The authors discussed issues related to interference faced and caused by the UWB transceivers, too. It was shown by Chiu et al. [3] that, the lack of indoor positioning support of GPS can be overcome by augmenting UWB with GPS. The experimental results confirmed the robustness of UWB to multipath signals. However, it required the mounting of UWB device on top of the GPS receiver.

A low cost hybrid positioning system is described in [19]. The components of the system are: Stationary Infrared Beacons which transmit location information, mobile Infrared (IR) receiver, Radio Frequency (RF) badges and smart Internet Protocol

(IP) bridges which are used to store location information or forward the information to a location server on the IP based Intranet. Retscher et al. [20] used RFID (Radio Frequency Identification) based positioning in which RFID tags are attached on the device that needs to be positioned. RFID transceivers placed at known location or road segments communicate with the RFID tags and deduce a position. To estimate the position, the signal strength is converted into a distance measurement based on the Okumura- Hata model [9]. In addition, techniques for integration of RFID based positioning technique with GPS based positioning systems are explained. In a later research, Retscher et al. [21] tried to combine RFID with an Inertial Navigation System in order to provide improved positioning accuracy. The system uses an array of RFID tags and a reader to estimate the position of a travelling user who carries a RFID reader. Depending on the accuracy needs, RFID Trilateration, RFID fingerprinting or RFID Cell of Origin may be used.

3. System analysis: major factors related to handover among positioning systems

There are a number of contextual factors which influence the handover and selection for positioning systems. Some of these factors are related to the positioning system itself while others stem from user preferences. The importance of these factors differs considerably. A mathematical system which takes into account these factors and accommodates the varying influence of the factors is necessary. These factors are briefly described below:

- Time to First Fix (TTFF): It is the time required for a GPS receiver to start up, acquire satellite signals, to get position related data and to calculate its current position [13]. A low TTFF value is essential for most applications which make use of position of the user.
- Accuracy: Different positioning systems have varying accuracy. The accuracy of a positioning system may change with time and space. Thiagarajan et al. [23] showed that, smartphones GPS receivers may have positioning errors between 6.6 to 70 meters in different environments. On the other hand, WLAN (Wireless Local Area Network) positioning system may have errors as low as 1.2 meters [1]. It should also be noted that, the accuracy requirement is not constant all the time. In one situation, the mobile user may require high accuracy, in other situations a modest accuracy serves the purpose.
- Coverage: The coverage of positioning systems may vary significantly. For example, cellular networks have relatively wide coverage. One base station may cover one square kilometer or more. On the contrary, WLAN access points can merely cover a few hundred meters. This limitation poses problems for a highly mobile user even if he is travelling at walking speed. GPS satellites usually require clear sky view which is rare in dense urban environments and inside buildings. It has been found during the experimental phase of this work that, even densely grown vegetation may block the signals from GPS satellites.

- Battery Power Consumption: Positioning systems often discharge the battery of the mobile device rapidly. This is due to the fact that, mobile devices need to activate specific interfaces such as GPS receiver and WLAN interface for positioning. Sometimes, mobile devices need to perform computational tasks as part of positioning process. These activities drain the battery considerably. However, the rate of battery power consumption also depends on the type of positioning system. It has been shown by Constandache et al. [4]that, in general, GPS positioning drains the battery of the mobile more rapidly compared to GSM or WLAN positioning.

4. System design: strategies to conserve battery power and to perform handover based on contextual factors

The proposed design aims to minimize the battery power consumption associated with positioning. To achieve this, first the system tries to identify places without GPS connectivity. If such a place is identified, GPS positioning is avoided in the place to save the battery power drain associated with failed attempts to get GPS position fix. The details of the algorithm to achieve this are described in Subsection 4.1. The design also makes sure that no positioning system is allowed to operate for an indefinite period of time without getting a position fix. If a positioning system is unable to find a position within a pre-defined threshold time, a handover to another positioning system is performed. To perform handover based on contextual factors, a weighted sum method is used which is described in Subsection 4.2. In this work, we build on and greatly improve our previous work [11] and present extensive experimental results.

4.1. Wireless Access Point based Place Identification (WAPPI) algorithm (algorithm-1)

This algorithm (Fig. 1) uses a group of WLAN access points as an identifier of areas without GPS connectivity. To put this algorithm into practice a training phase is carried out in the experimental area. During this phase, WLAN access points with signal levels consistently above -80 dBm in indoor and GPS signal-less places are identified. The Media Access Control (MAC) addresses of these access points are put in a database which is called the WAPPI database (WAPPIdb). This database only stores information about places without GPS signal. Therefore each GPS-signal-less area is identified by a corresponding group of WLAN access points and this information is stored in the WAPPI database. During the positioning phase if the user happens to be in one of such areas, the WLAN interface of the mobile device will detect a group of access points. Matching this detected group of access points with the information stored in the WAPPI database will most likely identify that the user is in one of the GPS signal-less areas. Therefore, GPS positioning will not be attempted in that place resulting in conservation of battery power and reduction in delay of positioning. Occasionally, the number of access points in a detected group during positioning phase may not be exactly same as the groups stored in the database. To counter this, a threshold number is used. For example, let us consider a GPS signal-less area A1. During the rigorous training phase, five access points named AP1, AP2,AP5 are found to have high (above the -80 dBm for this work) signal levels consistently in area A1. During the positioning phase, however, only four access points AP1, AP2, AP3 and AP4 are detected.

```
START
Scan WLAN access points
Store detected access point data in Measurements
K=Length (Measurements)
For i = 1 to K
 {For j = 1 to W
   If (Measurements.get(i).accesspointmac
   Equals WAPPIdb.get(j).accesspointmac)
      {
        Add MAC address of Access Point to Matchedmaclist
        Add corresponding area to Matchedmacarealist
        }
   }
Matchedmac = Length (Matchedmaclist)
L = Length (Matchedmacarealist)
If (Matchedmac>=Matchedmac_th)
 {
   For m = 1 to L-1
   {
    If (!(Matchedmacarealist.get (m)
    Equals Matchedmacarealist.get (m+1)))
      {
        Start WS Algorithm
        }
     }
    Start WLAN Positioning
   }
END
```

Figure 1. WAPPI algorithm.

To decide whether the user is in area A1, one can determine a threshold number (Matchedmacth) of matched WLAN access points. For example, if the threshold number is equal to or above 4, detection of 4 access points namely AP1 to AP4 during positioning phase indicates that the user is in GPS signal-less area A1. This threshold number can be adjusted to suit the nature of the WLAN environment. Finally, the algorithm makes sure that, the detected and matched WLAN access points are from the same GPS signal-less area and not from different GPS signal-less areas. The last part of the algorithm includes this mechanism. Based on this logic, if the algorithm finds enough matched WLAN access points from a single area, it assumes that the user carrying the mobile device is in a GPS signal-less area. Therefore, it directly goes to WLAN positioning saving the power and time associated with a potentially failed GPS fix. Otherwise, handover between positioning systems is decided by the

WS algorithm which is described in Subsection 4.3. WAPPI algorithm (algorithm-1) is implemented as an Android Service in the Android application. The application (discussed later) actually starts with this algorithm.

4.2. Timeout based Handover (TH) condition

The unavailability of a positioning system can also be predicted by observing the time required to get a position fix from a particular positioning system. For example, if the GPS positioning module is activated and it exceeded a timeout value, a handover to WLAN positioning system would be triggered. The time spent t_{P1} to search for a position fix with a particular positioning system is compared with the amount t_{FP1} which is the amount of time the user is willing to wait to get a position fix with that positioning system. The user can set this time from the application. This is checked and if time spent t_{P1} exceeds t_{FP1}, a handover to another positioning system is triggered.

4.3. Weighted Sum (WS) algorithm (algorithm-2)

A number of contextual factors influence the handover and selection of the appropriate positioning system as discussed in Section 3. A technique is required to measure the influence of these factors. This technique should take inputs which are dependent on the context of the user. This technique will process the inputs. By doing so, it will produce an output which is actually the decision on handover and selection of positioning system. A Weighted Sum algorithm (Fig. 2) is proposed to achieve this.

```
START
  For i  =  1 to J
   {
     Pt_pi = 0
     For k = 1 to n
      {
        Pt_pi  =   W_k × f_pik  +  Pt_pi
      }
     Score[i] =  Pt_pi
   }
Pt_max = Score [1]
  For y = 2 to J
   If (Score[y] > Pt_max)
    {
     Pt_max = Score[y]
    }
  Handover to the positioning system pi with Pt_max
END
```

Figure 2. WS algorithm.

Different positioning systems have their own strengths and weaknesses. For example, GPS positioning is consistently accurate. However, TTFF value is high for GPS. On the other hand, WLAN positioning systems are sometimes inconsistent in terms of accuracy but TTFF value for WLAN positioning can be very low. The wide coverage of cellular network based positioning makes it a suitable choice in many situations but often accuracy of these positioning techniques can be quite low. These varying characteristics of positioning systems justify the use of a Weighted Sum method. To explain the Weighted Sum approach, consider three positioning systems P1, P2 and P3. Each of these systems receives weighted points based on the context of the user. There are three contextual factors (TTFF, Accuracy and Coverage) on which weighted points are assigned to the positioning system. The weights are used to accommodate the changing effects of different factors. If TTFF is the primary concern, GPS would get a lower weighted point than WLAN fingerprint based positioning, as GPS positioning has relatively high TTFF value. If accuracy is the main concern, GPS gets higher weighted point than WLAN fingerprint based positioning, because GPS is comparatively more accurate. If coverage is the primary concern, Network Provider based positioning receives higher weighted points than both GPS and WLAN fingerprinting. This is because Network Provider based positioning has coverage in both indoor and outdoor spaces. Once weighted points are defined, all the points received for each of the factors are summed up to get the total score of the positioning systems. Therefore, the following equation gives the total score of a positioning system.

$$Pt_{pi} = \sum W_k \times f_{pik} \tag{1}$$

In equation (1), Pt is the total score of positioning system pi, W_k is the weight of the factor (TTFF, Accuracy, Coverage) k, f_{pik} is the point received by positioning system pi for factor k. Now if there are n contextual factors which are influential in selecting the positioning system, $k = 1$ to n. Therefore, from (1)

$$Pt_{pi} = W_1 \times f_{pi1} + W_2 \times f_{pi2} + \ldots + W_n \times f_{pin} \tag{2}$$

Thus, the score of each positioning system pi is calculated using (2) and handover is performed to the positioning system with the highest score.

4.4. State diagram of the proposed design

The two context aware algorithms (WAPPI and WS) cooperate with each other to perform context aware handover among positioning systems and thus the algorithms ensure uninterrupted power efficient positioning for the mobile user. Figure 3 shows the state diagram of the proposed design for context aware handover for positioning systems.

The directional arrows show how the system moves from one state to another. The transitions from one state to another state are influenced by events. The states are shown by circular shapes and the events are shown beside the arrows. The ‘Start state goes to 'WAPPI algorithm because of the event 'Request Position. From this algorithm, two states can be reached depending on the events 'Not enough matched MACs from same area and 'Enough matched MACs from same area respectively. From 'WS, three states can be reached depending on the scores of the positioning systems. 'TH condition performs handover when positioning systems exceed the handover timeout value without getting the position fix. Finally, to provide continuous positioning update, the positioning systems trigger 'WAPPI algorithm after the user specified location update interval t_u. This ensures regular and continuous location update for the mobile user.

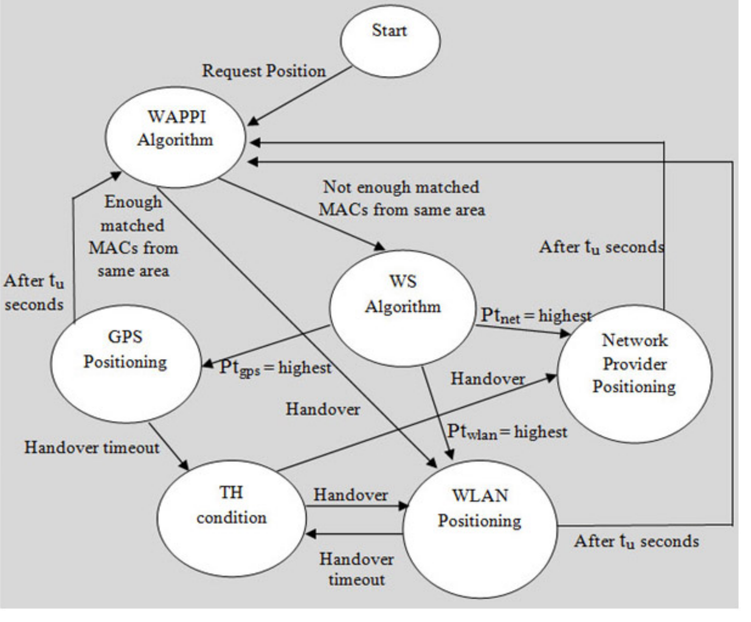

Figure 3. State diagram of proposed design.

The algorithms may be applied for any positioning systems and the state diagram will work in the same manner as Figure 3.

5. Implementation

An application named Locate@nav6 (Fig. 4) was developed which implemented the proposed algorithms and techniques.To implement the proposed algorithms, Android was chosen as the development platform. Java programming language was used for development along with Android software development kit.

Android was chosen because of its open source environment, its increasing popularity and flexibility. An internet map platform named OpenStreetMap was chosen to show the mobile users position on the map. The high computational power of mobile

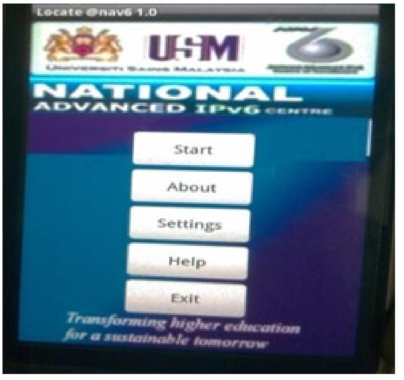

Figure 4. Screenshot of Locate@nav6.

devices allows use of wide variety of programming languages [25] for mobile application development. This application is expected to demonstrate the efficiency of the proposed context aware handover algorithms. The results obtained after rigorous experiments with the Locate@nav6 application are discussed in Section 6.Locate@nav6 was run and tested on two smartphones named HTC Desire A8181 and HTC Wildfire A3333.

6. Experimental results and discussion

After the implementation of the proposed system design was done, measuring the performance of the implemented system was utterly important. Testing the performance of the implemented solution may include a wide variety of data. The systems behavior has to be validated to make sure that it works in accordance with the system design and complies with the design goals. It has to be checked whether the implementation follows the rules specified in the system design. Finally, it should be checked whether the implementations unique way of tackling the research problems is viable and whether the implementation is able to use the devices resources in an efficient way. Keeping all these matters into consideration, the experimental procedures and the associated data are described in the following subsections.

6.1. Use of WAPPI and WS algorithms

Figure 5 shows the result of the experiment for HTC Desire and HTC wildfire in both indoor and outdoor spaces.The WAPPI and WS algorithms described in Subsection 4.1 and 4.3 perform handover by considering important contextual factors namely: time to first fix, accuracy, coverage requirements and battery power consumption. WAPPI algorithm is designed to identify the places which do not have GPS connectivity.

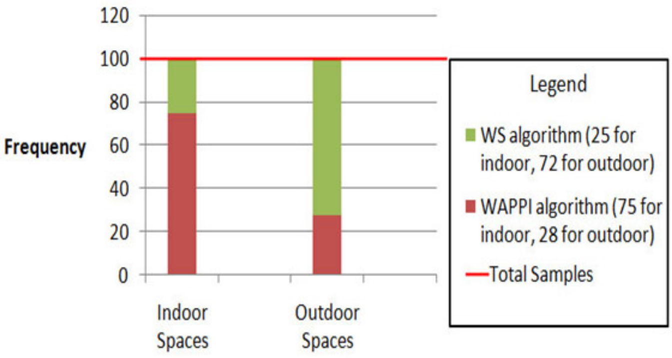

Figure 5. Use of WS and WAPPI algorithm in indoor and outdoor spaces on HTC Desire and HTC Wildfire.

This technique is used to save the battery power drain and time consumption related with unsuccessful GPS position fix. On the other hand, WS algorithm performs handover based on the scores obtained by positioning systems from the contextual factors. This section will present a comparison between cases in which the WAPPI method is used for handover among positioning systems and the cases in which WS method is used for handover among positioning systems. The experiment was carried out by running Locate@nav6 on HTC Desire and HTC wildfire as a user carrying these smartphones traversed the experimental area.Experimental Samples were taken at different points in both indoor (within the building) and outdoor spaces. Total samples for both indoor and outdoor spaces were 100. The result shows that, the system had used WAPPI algorithm for handover among positioning systems for most cases (75 times out of 100) in indoor spaces. The WS algorithm was used for most cases (72 times out of 100) in outdoor spaces. In indoor spaces, there are more WLAN access points compared to outdoor spaces. Therefore, in indoor spaces, more MAC addresses of detected WLAN access points match with the WAPPI database compared to outdoor spaces. This in turn triggers the WAPPI algorithm more frequently for handover among positioning systems in indoor spaces. However, in outdoor spaces few access points are detected and matched with the MAC addresses stored in the database. This incident triggers the WS algorithm more often in outdoor spaces. The results are the same for HTC Wildfire. As the user of Locate@nav6 moves further into outdoor space, the WS algorithm is used more frequently to select the positioning system. Figure 6 proves this statement. As the distance between the indoor space and the user operating Locate@nav6 increases, percentage of WS algorithms usage increases and that of WAPPI algorithm decreases. This experiment also gave quite similar results for both smartphones. These results prove the effectiveness of Locate@nav6 in distinguishing indoor and outdoor spaces.

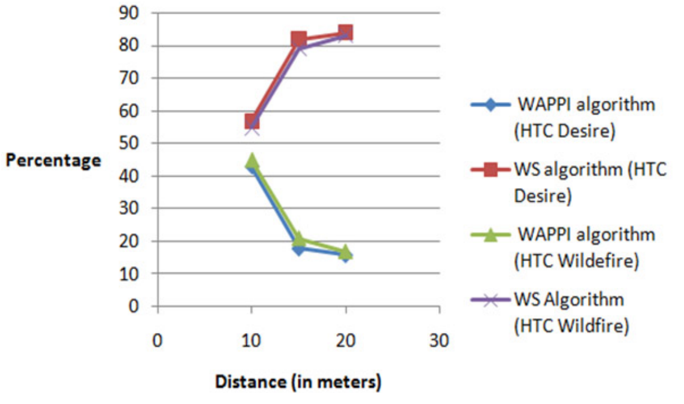

Figure 6. Distance versus percentage of usage of WAPPI and WS algorithm.

6.2. Comparison of handover performance

Google Latitude 6.10.0 is a location application from Google. It allows one to see his position on Google Map. The user can view the location of others if they allow revealing their location. In addition, the user can search for places of interests and can get directions with the application. Malaysia maps 2.0 is another location aware application designed specifically for Malaysia. In addition to providing the location of the user, it allows searching for nearest places of interest, traffic conditions and so on.In this experiment, Locate@nav6, Google Latitude and Malaysia maps are run for a certain period each as the user moved between indoor and outdoor spaces following a particular path (Fig. 7 and Fig. 8).

The experimental area spread From 5.35297 to 5.35492 Latitudes and 100.30075 to 100.30353 Longitudes. The transitions between indoor and outdoor spaces are recorded and the number of correct handovers among positioning systems is noted down for all the applications. Figure 7 shows the handovers performed by Google Latitude on HTC Desire for an experiment. The blue line in the figure shows the path followed by the user during experiment. In the figure, Start (S) and End (E) are denoted by Yellow and Black dots. Six transitions (T1 to T6) between indoor and outdoor spaces are shown by Red dots. The correct handovers between indoor and outdoor spaces are shown by Green stars. The Handover symbols (H1, H3 and H5) are numbered by following the convention used in the experiments with Locate@nav6, as shown in Figure 8.

Handovers to GPS in outdoor space and WLAN Positioning in indoor space are considered correct handovers. In Figure 7, it was observed that, Google Latitude only performed handover to GPS in outdoor spaces (denoted by H1, H3 and H5). Accuracy provided by Google Latitude in indoor space changed regularly but it cannot be considered handover. Therefore, it failed to perform handover in indoor space to WLAN positioning and unnecessarily kept looking for GPS based position.

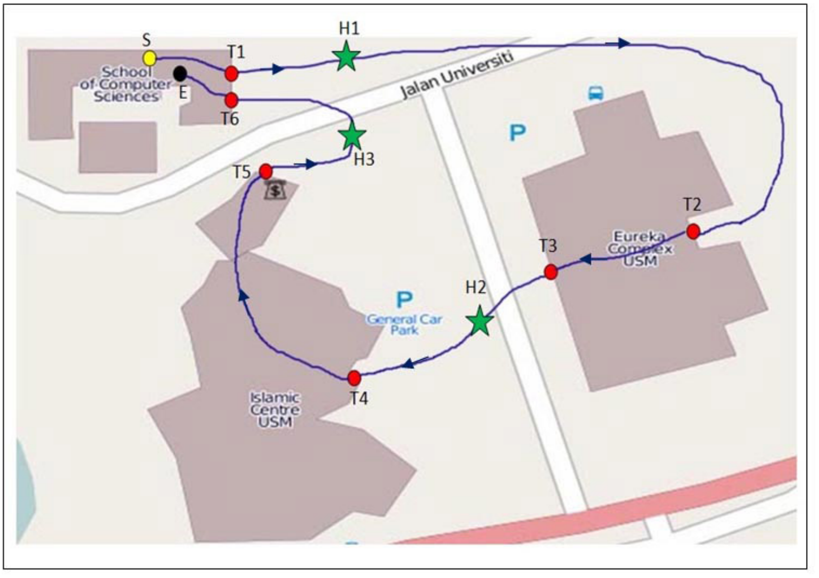

Figure 7. Handovers performed by Google Latitude on HTC Desire during experiment.

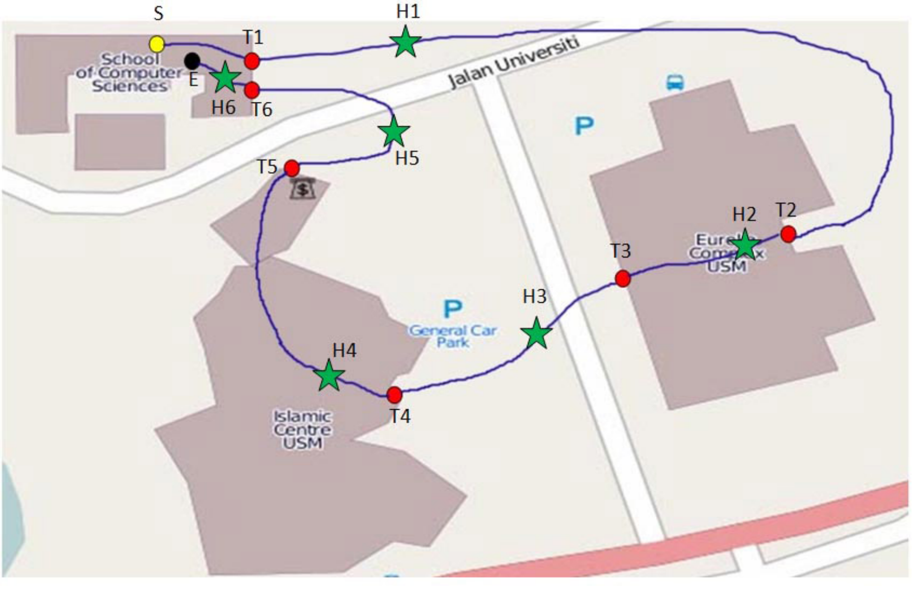

Figure 8. Handovers performed by Locate@nav6 on HTC Desire during experiment.

In outdoor spaces, only the GPS positioning was active but in indoor spaces both GPS and Network Provider based Positioning were kept active resulting in significant battery drain which will be shown in a later Subsection. This experiment was performed ten times for Google latitude on HTC Desire and HTC Wildfire. Similarly, Malaysia maps was run ten times on HTC Desire and ten times on HTC Wildfire as the user followed the path depicted in Figure 7 and 8. The results were similar to the experiments with Google Latitude. Therefore the experiments can be represented by the path shown in Figure 7 and 8 with Google Latitude and Malaysia maps on HTC Desire and HTC Wildfire. On the other hand, Locate@nav6 with its context aware algorithms is much more successful compared to Google Latitude and Malaysia maps in handling the transitions between indoor and outdoor spaces. Locate@nav6 is run ten times on HTC Desire and ten times on HTC Wildfire as the user followed the path depicted in Figure 7. It is notable that, each experiment has six transitions between indoor and outdoor spaces. Ten experiments results in sixty transitions between indoor and outdoor spaces. Among these 60 transitions, 59 transitions were handled rightly by Locate@nav6 on HTC Desire and 58 transitions were handled rightly by HTC Wildfire.It means that in 59 and 58 cases for HTC Desire and HTC Wildfire respectively, Locate@nav6 performed the right handover. The percentages of correct handover for the three applications are shown in Figure 9. Figure 9 proves that, Locate@nav6 performs handover to the appropriate positioning systems with a high percentage (over 95 percent) compared to low percentages (50 percent) of handover with two other applications.The figures also prove that, the handover performance offered by Locate@nav6 is valid and significant. Such accurate handover to proper positioning systems not only ensure uninterrupted positioning but also improve the accuracy indirectly which will be demonstrated in the next Subsection.

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6.3. Comparison of accuracy

During the course of the handover it is observed that, the context aware handover to WLAN positioning system improves the accuracy of indoor positioning. Therefore, even though Locate@nav6 does not specifically aim to improve the accuracy of positioning, context aware handover to the right positioning system indirectly improves the accuracy compared to Google Latitude and Malaysia maps. It should also be mentioned that, in outdoor spaces, the accuracy of Locate@nav6, Google Latitude and Malaysia maps are the same because all these applications use Android Location Managers GPS positioning in outdoor spaces. Thirty samples are taken for each of the smartphones. Figure 10 and Figure 11 show comparison between samples demonstrating the error of Google Latitude, Malaysia maps and Locate@nav6 on HTC Desire in indoor spaces during handover experiment. Figure 12 and Figure 13 compare the same on HTC Wildfire in indoor spaces. In the figures Red dot shows the actual position.

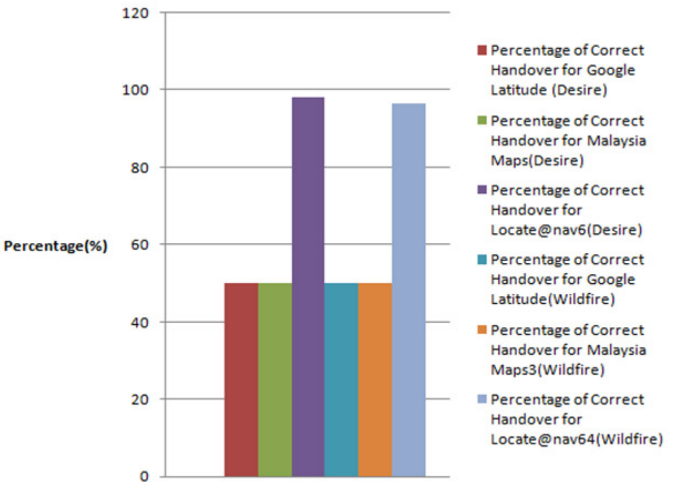

Figure 9. Percentage of correct handover for different applications on HTC Desire and HTC Wildfire.

The Blue arrowhead, Yellow human sign and Blue dot show the estimated positions of Google Latitude, Locate@nav6 and Malaysia maps respectively. The radius of the circle shows estimated errors.

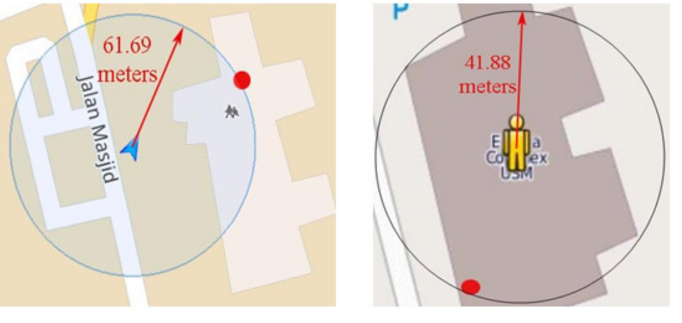

Figure 10. Samples showing actual and estimated position of Google Latitude (left) and Locate@nav6 (right) during handover on HTC Desire.

The user was actually inside the Eureka complex building when shown samples were taken. However, Google Latitude and Malaysia maps did not perform handover to indoor positioning systems. Therefore, the best estimated position (shown by arrowhead) of Google Latitude had an error of approximately 62 meters and the worst estimate (shown by the far left edge of the circle) had an error of approximately 124.75 meters.

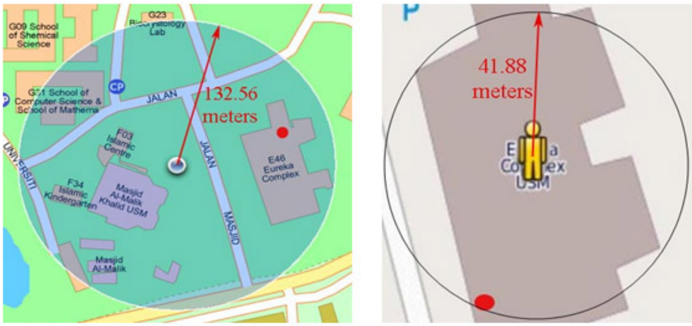

Figure 11. Samples showing actual and estimated position of Malaysia maps (left) and Locate@nav6 (right) during handover on HTC Desire.

On the other hand the best estimated position (shown by dot) of Malaysia maps had an error of approximately 96.47 meters and the worst estimate had an error of approximately 219.25 meters. However due to the handover to the right positioning system, Locate@nav6s RMSE (Root Mean Squared Error) was less than 42.1 meters.

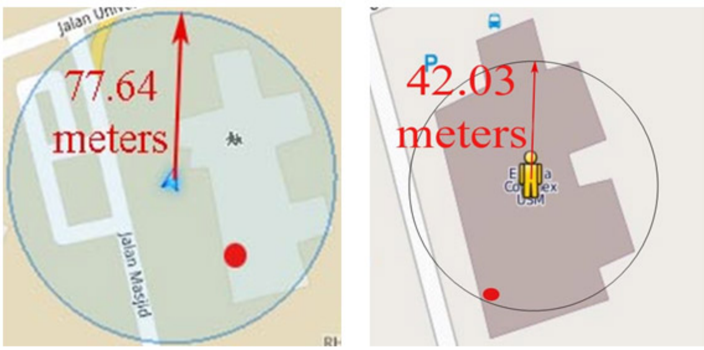

Figure 12. Samples showing actual and estimated position of Google Latitude (left) and Locate@nav6 (right) during handover on HTC Wildfire.

Figure 14 shows the bar graphs illustrating the RMSE of positioning for the three applications.

Figure 14 demonstrates that, while Google Latitude and Malaysia maps suffer from significant errors in indoor spaces due to the lack of handover to the appropriate positioning system, Locate@nav6 indirectly improves the accuracy of positioning by handing over to the appropriate positioning system. It is also noted that, accuracy of Google Latitude and Malaysia maps vary considerably on two smartphones.

Figure 13. Samples showing actual and estimated position of Malaysia maps (left) and Locate@nav6 (right) during handover on HTC Wildfire.

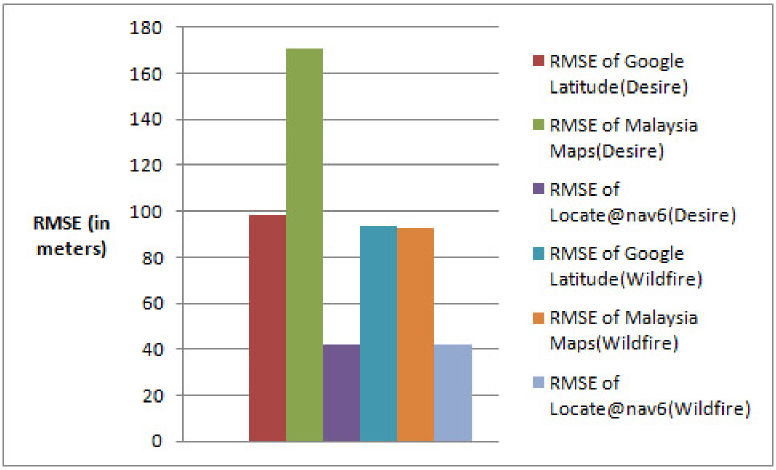

Figure 14. RMSE of positioning for the applications on HTC Desire and HTC Wildfire.

However, the performance of Locate@nav6 with an RMSE between 41.88 meters for HTC Desire and 42.03 meters for HTC Wildfire is relatively consistent for two different smartphones.

6.4. Comparison of CPU usage

In this and the later subsections, the CPU, Memory and Battery consumption of Locate@nav6 will be compared with Google Latitude and Malaysia maps. To do this, the applications were operated on both smartphones. As the applications were run, the user moved between indoor and outdoor spaces in the experimental area of Universiti Sains Malaysia campus. As the user moved, performance measures such as CPU usage, memory usage and battery drainage data were recorded in the background. Ten samples were taken for each of the applications on each of the smartphones. The data were taken using an application named System Monitor Lite 4 Android. Figure 15 compares the percentages of average CPU usage of Locate@nav6, Google Latitude and Malaysia maps on HTC Desire. Some experimental data samples of CPU usage which show screenshots of the experiments are provided in Section-7.

Figure 15 shows that average CPU usage during Locate@nav6s runtime at 16.8 percent is less than that of Google Latitude which is 26 percent. Average CPU usage during Locate@nav6's runtime is slightly less than that of Malaysia maps which stands at 17.4 percent. It also shows the percentages of average CPU usage on HTC Wildfire.

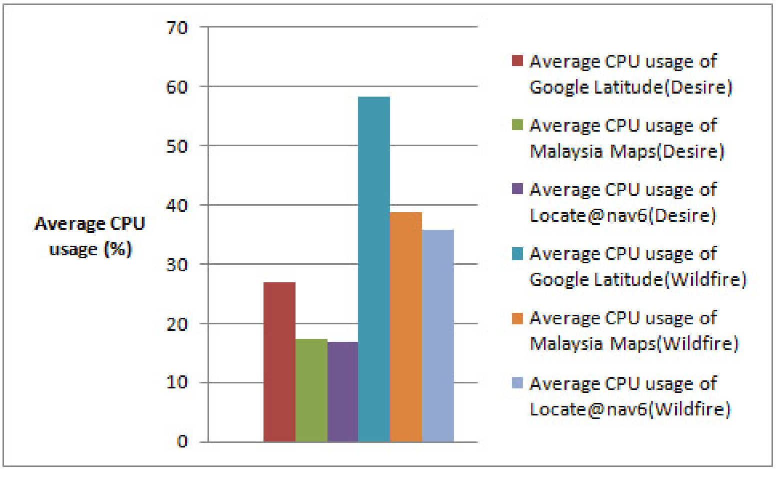

Figure 15. Percentage of average CPU usage on HTC Desire and HTC Wildfire.

It is notable that on HTC wildfire, percentages of average CPU usage of all applications are higher than the percentages with HTC Desire. However, performance of Locate@nav6 with 35.7 percent average CPU usage is significantly better than Google latitude (58.4 percent) and slightly better than Malaysia maps (35.7 percent). Locate@nav6 has relatively lower CPU usage because unlike the other two applications, Locate@nav6 does not look for position at every moment. Rather it looks for position at user specified intervals.

6.5. Comparison of memory usage

Figure 16 shows the percentages of memory usage during runtime of Google Latitude, Malaysia maps and Locate@nav6 on HTC Desire and HTC Wildfire.

It is observed that, average memory usage of Locate@nav6 is better than Google Latitude and Malaysia maps by only a small margin (less than 3 percent). Some samples of memory usage data are given in Section-8.

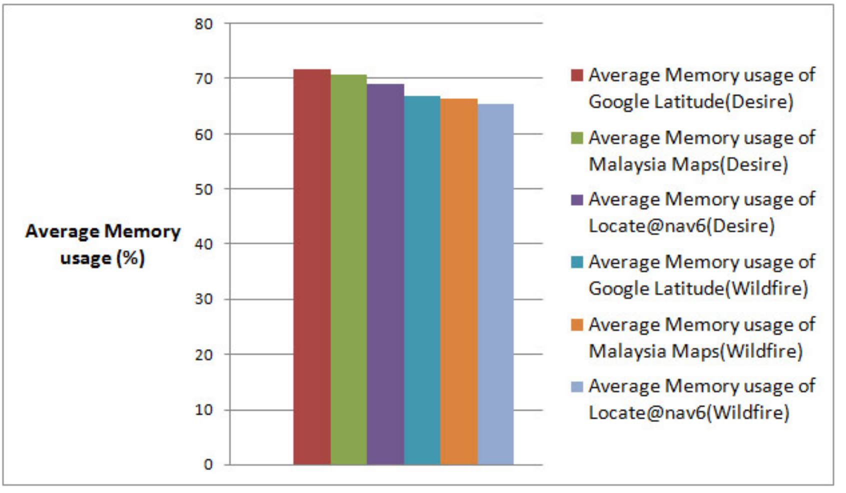

Figure 16. Percentage of average Memory usage on HTC Desire and HTC Wildfire.

6.6. Comparison of battery usage

Battery consumption data are shown in Figure 17. One of the main objectives of the system design of Locate@nav6 is to reduce the battery power drain associated with positioning.

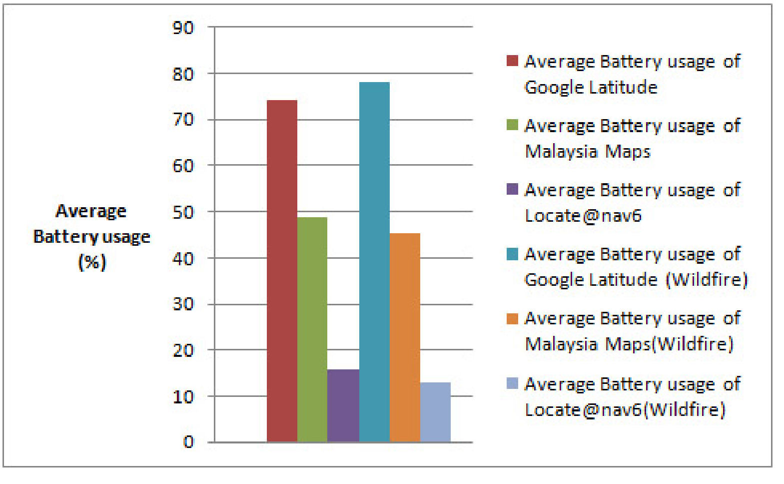

Figure 17. Application-wise average battery usage of the applications on HTC Desire and HTC Wildfire.

This is achieved through careful use of GPS positioning and by making sure that no positioning system is allowed to run indefinitely without getting a position fix. A very good indicator of an applications battery power consumption is Androids default application which provides battery consumption statistics of individual applications as a percentage. Analysis of this figure shows that, the battery usage of Locate@nav6 is less than one third of the battery usage of Google Latitude and Malaysia maps for both smartphones. For all experimental samples, battery usage performance of Locate@nav6 is extremely promising compared to Google Latitude and Malaysia maps. These results indeed show the effectiveness of the battery saving mechanisms of Locate@nav6 which are part of WAPPI algorithm (algorithm-1) and TH condition described in subsection 4.1 and 4.2 respectively. Some samples of battery usage data are provided in Section-9.

7. Samples of CPU usage data

Figures 18–20 show some samples of CPU usage data.

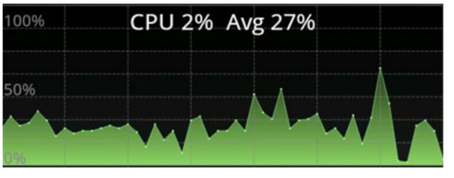

Figure 18. Runtime CPU usage for Google Latitude on HTC Desire.

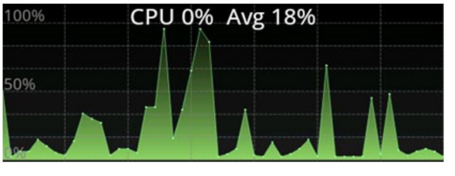

Figure 19. Runtime CPU usage for Malaysia maps on HTC Desire.

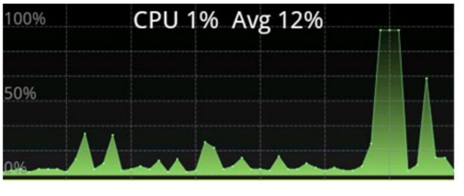

Figure 20. Runtime CPU usage for Locate@nav6 on HTC Desire.

8. Samples of memory usage data

Figures 21–23 show some samples of memory usage data.

Figure 21. Runtime memory usage for Google Latitude on HTC Wildfire.

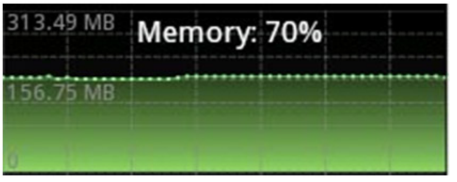

Figure 22. Runtime memory usage for Malaysia maps on HTC Wildfire.

Figure 23. Runtime memory usage for Locate@nav6 on HTC Wildfire.

9. Samples of battery usage data

Figures 24–26 show some samples of Battery usage data.

Figure 24. Application-wise battery usage during runtime of Google Latitude on HTC Desire.

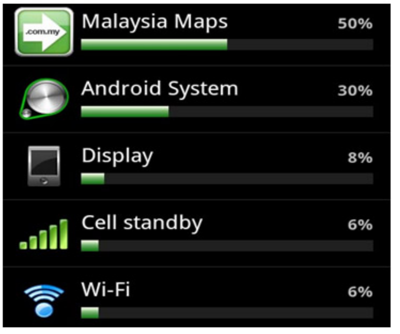

Figure 25. Application-wise battery usage during runtime of Malaysia maps on HTC Desire.

Figure 26. Application-wise battery usage during runtime of Locate@nav6 on HTC Desire.

10. Conclusion

In this work the features of two context aware handover algorithms for positioning systems are described in detail. The algorithms are primarily designed to ensure context aware handover among positioning systems and to reduce the power drain associated with mobile positioning. The proposed solution was implemented on Android platform and was named Locate@nav6. It was tested on HTC Desire and HTC Wildfire smartphones. Subsection 6.1 and 6.2 proved that, context aware handover among positioning systems in indoor and outdoor spaces was achieved providing better handover performance compared to Google Latitude and Malaysia maps. Subsection 6.3 demonstrated that, such handovers improve the accuracy of positioning of Locate@nav6 significantly compared to Google Latitude and Malaysia maps. Subsection 6.4 showed that, average CPU usage of Locate@nav6 is slightly better compared to the other mentioned applications. Finally, Subsection 6.6 proved that the battery saving mechanism of the proposed algorithm is extremely promising compared to Google Latitude and Malaysia maps. In fact, the average application-wisebattery consumption was less than one third of the application-wise battery usage of other applications.

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Affiliations

Sazid Zaman Khan
National advanced IPv6 centre, Universiti Sains Malaysia, 11800 USM Pulau Pinang Malaysia, szkhanctg@yahoo.com

Thilek Silvadorai
Heidelberg Mobil International, 69190 Walldorf, Germany, thilek.silvadorai@rwth-aachen.de

Tan Chen-Wei
National advanced IPv6 centre, Universiti Sains Malaysia, 11800 USM Pulau Pinang Malaysia, tanchenwei@gmail.com

Sureswaran Ramadass
National advanced IPv6 centre, Universiti Sains Malaysia, 11800 USM Pulau Pinang Malaysia, sures@nav6.usm.my

Toni Anwar
Faculty of Computing, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia, tonianwar@utm.my

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