High-Level Energy Saving Strategies for Mobile Location-Based Services on Android Devices

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***Abstract*— The use of mobile location-based services (LBS) on modern smartphones, especially continuous utilization of GPS, significantly reduces the operating times of batteries. Considering the fact that the exhausting exploitation of power for determining the current location is unnecessary for various situations (e.g., when the device is not being moved), several high-level energy saving strategies can be developed in order to extend the batteries' operating times. This paper sketches the architecture for high-level energy saving strategies for LBS on Android devices encapsulated in a social-web application ("Spotnick") and illustrates their positive results.**

Keywords - Energy Saving Strategies; Location-Based Services; Android; Spotnick.

I. INTRODUCTION

A manifold of location-based services (LBS) utilizing GPS, cellular network triangulation, or WLAN SSID mapping have evolved as more or less beneficial apps available for modern smartphones. Built-in positioning technology for location determination in the mobile devices is considered state-of-the-art and supports its consumers to find a path from A to B, recognize things around one's own position, record your training routes, or exchange current whereabouts with your friends. LBS are therefore considered an indispensable paradigm in mobile computing environments.

Nevertheless, continuous use of LBS still faces a considerable drawback in terms of batteries' operating times, which are likely to be reduced to less than 10% compared to the operating times in standby mode or to a maximum of 12 hours depending on the type of device (please, refer to the exact measurements in the following sections). In addition, the devices generate substantial heat, which is not always perceived as pleasing. In most cases, the exhausting use of GPS is the main reason for draining the battery. There is evidence on this statement due to several experiments, which we have conducted in order to figure out the energy guzzlers in LBS (see Section V). Naturally, the transmission of packets via the cellular network or WLAN also impacts operating times. The reduction of data transmission is not subject of this survey, though.

So, our main research issue for mobile LBS was to find a way to extend the batteries' operating times of smartphones for continuous active operation (i.e., in foreground and in background mode). Of course, there cannot be a general answer or method to this issue because LBS strongly differ in terms of required accuracy and/or latency of reaction times. If a service e.g., claims permanent use of GPS due to exact location-based examinations, there is hardly any chance to develop a strategy for energy saving. Thus, we define a family of LBS applications with constraints to be fulfilled in order to be suitable to apply the energy saving strategies, which we propose in this paper. The constraints are defined as follows:

(i) The service is continuously operational, i.e., the position of the device must be determined both in foreground and in background mode. (ii) When in foreground mode, the best possible position of one's own device is required. (iii) The service dynamically offers location-based points of interest (POIs), which have to be triggered, i.e., their content displayed, an alarm set off, an external service initiated, etc., when the device reaches spatial proximity to them. (iv) An observation mechanism is included within a network of participating clients, i.e., the service shows the current whereabouts of other floating devices. (v) When in observation mode (presuming that there is no permanent monitoring station), the best possible positions of the monitored devices are required.

This means, that within a distributed LBS environment an exact position is only needed when the application is in foreground, observed by another client or close to POIs. For the remaining time (which represents the major part during operation in many cases, e.g., when the device is in background mode, not moving, not observed, or generally in a static position in the office or at night times, etc.), less energy consuming positioning methods (e.g., cellular network triangulation) could be used in order to extend the batteries' operating times. Hence, we propose to avoid utilization of GPS as often as possible and therefore present strategies for Android devices for implementing this paradigm (with the drawback of less accurate position determination in background mode and latency for the reactivation of GPS when required). The strategies are encapsulated in a social-web app named "Spotnick", which is available on Google Play and on the App Store, and provides the measuring results included in this paper.

The paper is structured as follows: Section 2 deals with selected points of state-of-the-art methods and technology. Section 3 gives an insight into the proposed energy saving

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strategies. Section 4 sketches the test scenarios and measuring metrics. Section 5 provides figures and measured results and finally, Section 6 concludes the paper and prospects future work.

II. RELATED WORK

Investigations concerning energy consumption for location-based services on mobile devices have been the focal point of research in various scientific and industry labs [2][3][8][12]. Bareth and Kupper [5] e.g., have confirmed our experiments and derived findings about energy consumption of the different positioning technologies available on smartphones (see Table I), where they have measured the energy consumption for GPS, WiFi-, and cell-based positioning techniques.

TABLE I. PROPERTIES OF POSITIONING TECHNIQUES [5]

Technology	Accuracy	Precision	Energy
A-GPS	10m	95%	6.616Ws
WiFi	50m	90%	2.852Ws
Cell-Id	5km	65%	1.013Ws

Generally, there are three ways to face the draining problems: (1) directly on a hardware-related level, where ameliorations are achieved e.g., by considering Kalman filters [4], (2) by several software-based and application-related high-level strategies utilizing available SDK functions, software-architectures and framework [1][6][7][9] and (3) with hybrid approaches using additional (less energy consuming) sensor technology (e.g., accelerometers) and context-based movement detection algorithms as a substitute or an extension of functionality [11][13].

As the strategy described in this paper can be classified to approach (2), let us find out how similar methodologies work: Kjaergaard et al. [10] e.g., have developed a context-based model which tries to estimate and predict system conditions and movements in order to calculate a schedule for utilization of GPS. In a way, our approach can be compared to that, trying to schedule different positioning techniques due to system states (e.g., device is not moving). Although, the authors have succeeded in significantly saving energy using their high-level strategies using a Nokia N95, we try to give a more up-to-date approach using a less complex algorithm and utilizing enhanced positioning techniques on an Android device.

III. ENERGY SAVING STRATEGIES

The energy saving strategies for our approach are settled on a high application-oriented level, cleverly using, not using and switching between system functions and operations provided by standard SDKs. They are not based on hardware-related optimization attempts.

In principle, the strategy aims at avoiding usage of GPS whenever applicable. Instead, it uses cellular- or WiFi-based positioning or region monitoring (a technique which utilizes the WLAN and Cell-Id handover functions of the phone in order to detect a potential movement) and continuously tries to switch between those operation modes according to particular events. Thus, the architecture results in a Finite State Machine (FSM) and has to take decisions for state conversions between those states built upon the following properties and its values:

1. Application mode: the app is either in *foreground mode (f)* (the user looks at it) or in *background mode (b)* (the app is idle).
2. Movement: the user/device is either *moving (m)* or *stationary (s)* (not moving).
3. Observation mode: the device is either *observed (o)* or *unobserved (u)*.
4. POIs nearby: points of interest for a device/user are either *near (n)* (i.e., within a distinct radius) or *distant (d)*.

Thus, there are four properties having two values each, which makes 16 different states, strictly speaking (see Table II). Most of them can be combined, though, because it is irrelevant for the strategy if the device is moving, observed or POIs are near or not when the app is in foreground mode (i.e., states 1 to 8 can be combined to one). In this state, the most accurate position is required. Also states 9 to 11 can be combined to one state, in which GPS is likely to be turned on, because the device is either being observed while in background mode (states 9 and 10) or a POI is near, the approach to it must be exactly determined (state 11). From a technical point of view, those two combinations of states 1 to 8 and 9 to 11 can be merged, once more, for they require the best possible position as a common characteristic. State 12 is unique: the app is in background mode, the device is moving, but not observed or any POIs near. This means that nobody takes notice of the app at that moment. Positioning must continue, though (by an inaccurate technique), in order to reactivate GPS at spatial proximity to a POI (which exactly requires to be triggered, transferred, etc.; for a deeper insight into location-triggered processes see [14]) within the inaccuracy range of the used positioning method. Finally, states 13 to 16 can again be combined to one state where region monitoring is used in order to recover from an idle mode where the app is in the background and not moving (observation and POIs are irrelevant at that state).

TABLE II. DIFFERENT STATES OF THE FSM

No.	App. mode	Movement	Obs. mode	POIs near	No.	App. mode	Movement	Obs. mode	POIs near
1.	*f*	*m*	*o*	*n*	9.	*b*	*m*	*o*	*n*
2.	*f*	*m*	*o*	*d*	10.	*b*	*m*	*o*	*d*
3.	*f*	*m*	*u*	*n*	11.	*b*	*m*	*u*	*n*
4.	*f*	*m*	*u*	*d*	12.	*b*	*m*	*u*	*d*
5.	*f*	*s*	*o*	*n*	13.	*b*	*s*	*o*	*n*
6.	*f*	*s*	*o*	*d*	14.	*b*	*s*	*o*	*d*
7.	*f*	*s*	*u*	*n*	15.	*b*	*s*	*u*	*n*
8.	*f*	*s*	*u*	*d*	16.	*b*	*s*	*u*	*d*

The consolidation of states reduces the complexity of the FSM to three states. Its state transitions are extractable from Table II, which is a simplified depiction of the concept, though; the actual implementation considers several details, which cannot be discussed here due to space limitations except the following (see Figure 1):

When transiting to a state requiring high accuracy, we do not immediately turn on the GPS provider of the Android platform. We first check the accuracy value of the network provider (which both combines Cell- and WiFi-based positioning on Android systems). If this value is good (i.e., just a few meters inaccuracy, which refers to a WiFi-based determination), then there is no need to activate GPS, e.g., when residing within a building where GPS is unavailable, anyway. Only a high inaccuracy value triggers the GPS provider (see Figure 1).

To turn GPS off again (and switch back to network positioning) several requirements have to comply: While moving, no other client must be observing and no POI must be near (i.e., within the inaccuracy radius of the network provider position). However, deactivation of GPS can also lead to a passive state where region monitoring is enabled (i.e., the app is completely idle until a system signal wakes it up again due to a network handover event among WLAN access points or cellular antennas). In order to detect a non-moving device, we have defined a distance threshold ε, which may not be crossed, and a time interval t, which must be exceeded until we assume a stationary state where the device is not moving (see Figure 1).

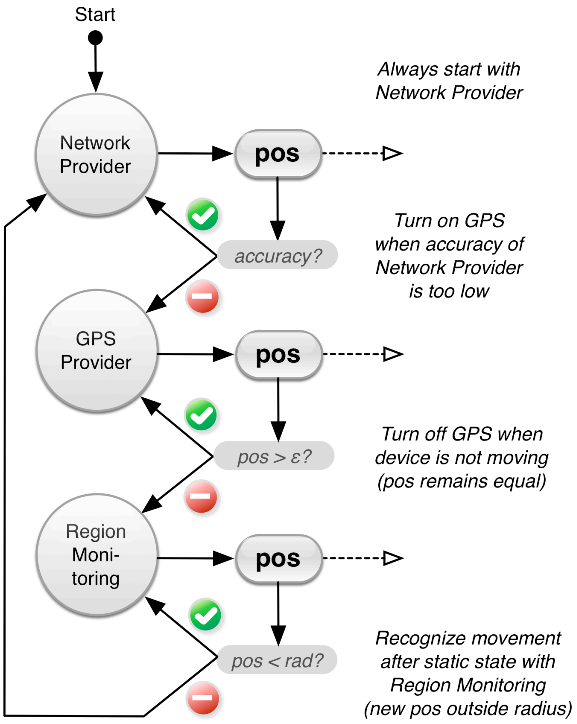

Figure 1. Flow Chart of Energy Saving Strategy (Simplified Excerpt)

The FSM as described above including several technical and strategic tricks as indicated briefly but omitted in detail have been implemented as an *intent service* in the core of a social-web application named Spotnick. Spotnick comprises a friend finder component for a user's Facebook friends with the opportunity of mutually perceiving their current whereabouts with just a few seconds delay. When looking at the app, users are able to view their own position and those of their observed friends with maximum accuracy (depending on the devices' positioning capabilities). In addition, a user can trigger so called *spots*, i.e., self-set POIs that actively announce the arrival of a user on his Facebook wall when he reaches spatial proximity to it. Thus, Spotnick requires best possible accuracy when the app is in foreground mode, when observing friends or at regional closeness to spots. For the remaining time of usage (which we presume represents the major part of a day for a human being, e.g., when he/she is in his/her office or at night times), less accurate positioning methods comply in order to keep the app functional but not wasting energy.

IV. METRICS AND TEST SCENARIOS

In order to benchmark the energy saving qualities of our proposed methods using our app Spotnick, we have repetitively conducted a series of tests, which were organized as follows: All tests have been carried out sequentially on the same device, an HTC Desire HD with Android 2.3.5 as the operating system. All tests have used the same mini-app, which has recorded time stamps, WGS84 coordinates (if available) and the battery status via the Android SDK in regular time intervals.

Although, we have not been able to provide exact equal test conditions for the particular tests due to cellular network fluctuations, arbitrary WLAN availability, or the speed or duration of our trips while moving through the city traffic, we have at least tried to provide similar test conditions: Naturally, we have always used the same phone settings (i.e., WLAN on, Bluetooth off, UMTS preferred but EDGE allowed, no phone calls, no messages, no Internet surfing, no other apps running, etc.) and have performed daily recurring procedures, i.e., driven the same route from home to the office, which is about 20km distance or approximately half an hour of driving time (depending on the traffic situation) twice a day (bidirectional). At home and in the office, the app has been used in foreground for a minute to see where the other clients are residing. While driving, our device has been observed by another app for a minute and also been used in foreground for a minute. Thus, every possible status permutation has been created at least once (app in foreground, in background, device moving, not moving, observed, not observed, while driving, when stationary, etc.).

With these prerequisites, four test series have been conducted (using the mini-app for data recording):

1. *Standby Mode Test*: This test should examine the practical operating time when no app is running. It serves as a reference.
2. *Full GPS Test*: This test should examine the practical operating time when GPS is operational all the time.
3. *Full GPS and Data Transmission Test*: Same as test number 2, including the transmission of a simple HTTP data package every minute (simulating the transmission of position data for monitoring mode).
4. *Spotnick Test*: This test executed the app Spotnick, which contained the energy saving strategies described in the previous section.

V. RESULTS

According to the four test scenarios the measured results are as follows: Table III lists the parameters and typical results for one of the conducted *Standby Mode Tests*. The test was started on Jan. 31, 2013 and lasted for nearly 4 days until the battery was drained. All location services were turned off (i.e., no GPS and no cellular or WLAN-based positioning, however WLAN was turned on) and there was no data transmission during the test phase. We measured an average decline of 1,1% battery power per hour and took these values as a reference for the subsequent tests (i.e., the operating times are referred to as 100%).

TABLE III. MEASUREMENT RESULTS STANDBY MODE

HTC Desire HD, Android 2.3.5			
Start Date	Jan 31, 2013	*Duration*	3d 21h 36min
Location Services	off	*Avg. Decline*	1,1 % p.h.
Data Transmission	none, WLAN on	*Rel. Duration*	100,0 %

Figure 2 additionally illustrates the decline during the test phase. Please note, that the tests were not started at midnight – it is just the scale that starts at 0:00 for an easier comparison to the remaining tests. We do not recognize a clear linear decline of battery power, which we guess is due to varying environmental conditions, e.g., (wasted) attempts of the smartphone to connect to WLAN. However, we have not investigated these divergences in detail.

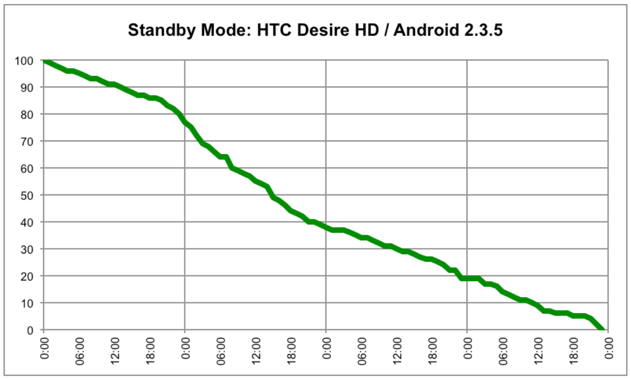

Figure 2. Battery Consumption in Standby Mode

Test number 2 was the *Full GPS Test*. Table IV lists the parameters and results for a typical test run carried out on Feb. 4, 2013. Continuous use of GPS and network-based location determination (i.e., cellular triangulation and WLAN mappings) reduce the operating time down to approx. 9 hours (which is only 9,7% of the *Standby Mode Test*) with an average decline of 11% battery power per hour.

TABLE IV. MEASUREMENT RESULTS CONTINUOUS GPS

HTC Desire HD, Android 2.3.5			
Start Date	Feb 4, 2013	*Duration*	9h 07min
Location Services	GPS+Network	*Avg. Decline*	11,0 % p.h.
Data Transmission	none, WLAN on	*Rel. Duration*	9,7 %

Figure 3 illustrates this drastic decline of battery operating times. For a better impression of the difference the original scale in this graph is the same as in Figure 2.

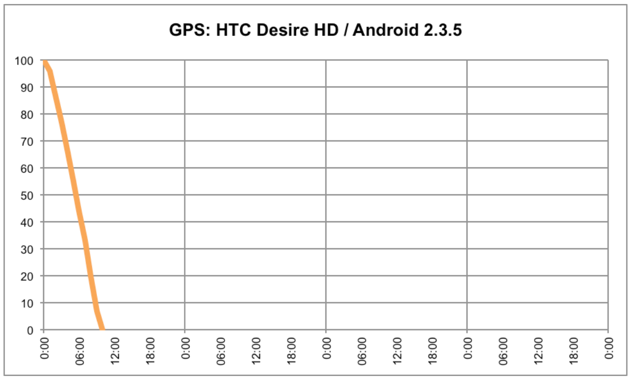

Figure 3. Battery Consumption with continuous GPS

However, it still goes worse. If we additionally transmit small HTTP packets in regular time intervals (i.e., every minute in this example) containing a timestamp, the current position and accuracy of the device's positioning technique such that other observing clients may perceive the current whereabouts of this device (*Full GPS and Data Transmission Test,* see Table V and Figure 4) then we measure an operating time of only 7 hours or 7,5% compared to the *Standby Mode Test*. The battery loses power by 14,3% per hour!

TABLE V. MEASUREMENT RESULTS GPS+HTTP REQUESTS

HTC Desire HD, Android 2.3.5			
Start Date	Feb 6, 2013	*Duration*	7h 00min
Location Services	GPS+Network	*Avg. Decline*	14,3 % p.h.
Data Transmission	Every Minute	*Rel. Duration*	7,5 %

The measured results of tests 2 and 3 tell their own tale. It is obvious that continuous utilization of GPS (and beyond that coupled with regular data transmission) decisively decrease batteries' operating times and therefore the attractiveness of location-based services for mobile devices continuously using GPS.

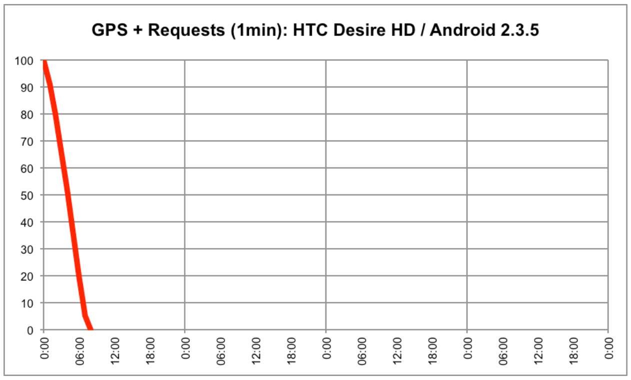

Figure 4. Battery Consumption for continuous GPS usage and HTTP Requests every Minute

Hence, the results for our proposed high-level energy saving strategies presented in section III are vital (regarding the *Spotnick Test*). They are consolidated in Table VI. The test lasted 2 ½ days, which is 65,5% compared to the *Standby Mode Test* with an average decline of 1,6% of battery power per hour.

TABLE VI. MEASUREMENT RESULTS SPOTNICK

HTC Desire HD, Android 2.3.5			
Start Date	Feb 17, 2013	*Duration*	2d 13h 16min
Location Services	Spotnick Strategy	*Avg. Decline*	1,6 % p.h.
Data Transmission	On Pos. Update	*Rel. Duration*	65,5 %

Figure 5 shows the corresponding graph. Considering the descent of the curve it is not clearly recognizable when the device was moving, stationary or observed, which applies to the fact that GPS was only used on demand (i.e., when the application was in foreground mode or the device had been observed – both situations occurred seldom during the tests and are therefore not evident in the graph).

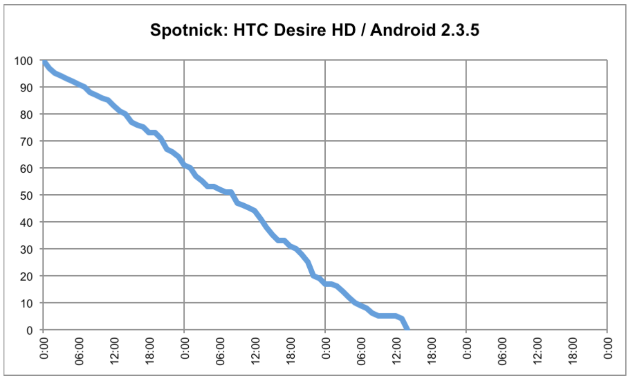

Figure 5. Battery Consumption using Spotnick

Considering the accuracy of the calculated positions, we refer to the successive two maps in Figures 6 and 7. Figure 6 Figure 6. shows a clipping of the daily way from our office at the University of Linz (starting in the top right corner of the map) to a home location (beyond the left edge). The red line marks the detailed path measured by GPS (recorded at test number 2). It represents the most accurate path we can get from the used mobile device (HTC Desire HD). The blue line marks the path from the Spotnick app including all energy saving mechanisms presented in section III. In the urban areas (in the right half of the map) the recorded positions are clearly distinguishable from the GPS points, however, for this use-case still accurate enough to recognize an unambiguous movement along a particular city district. In the rural areas (in the left half of the map) the recorded positions were less in amount (because farther apart) and less accurate (because of rural cellular positioning which is imprecise due to distant antennas). Nevertheless, also here an unambiguous movement is recognizable for possible observers for the short period of time until the moving device is informed about being monitored and therefore turns on GPS with a slight latency.

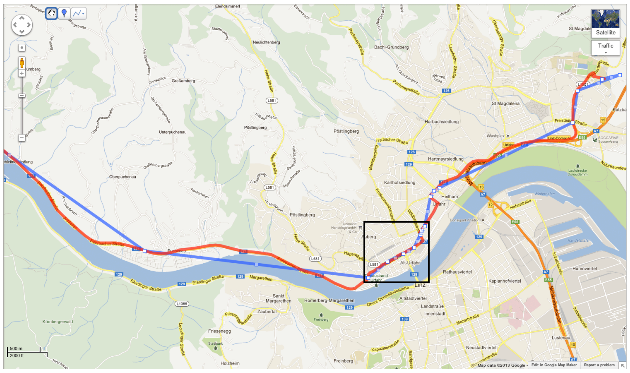

Figure 6. Accuracy Comparison GPS (red) vs. Spotnick (blue)

Figure 7 shows the switching on of GPS for a short period of time when a device is being monitored (see the blue line, clipped part out of Figure 6). Coming from the top right corner in this map, GPS has been turned on after the junction where the blue line diagonally crosses a block of buildings.

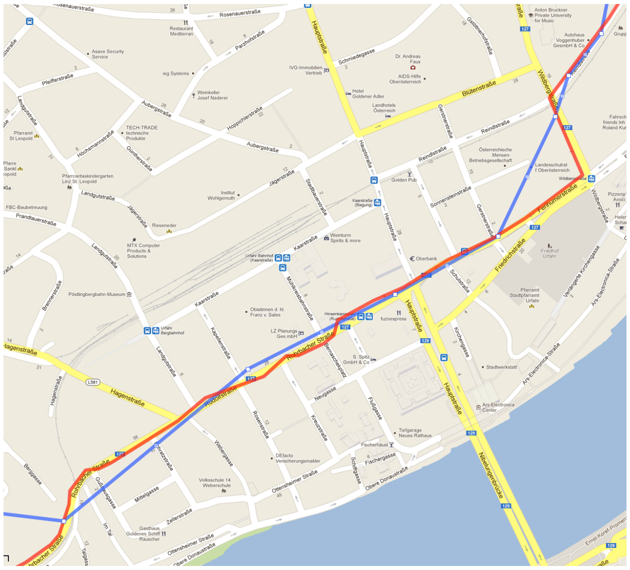

Figure 7. Detailed Accuracy Comparison GPS (red) vs. Spotnick (blue)

Please note, that the blue line (even when GPS is on) is built upon just a few measured points, which is due to a minimum distance to be covered and a minimum period of time to be elapsed for a position to be recorded and transferred. At the very left edge of Figure 7 the observation phase has ended and GPS turned off again, which immediately results in a clear deviation in the successive points.

VI. SUMMARY, CONCLUSION AND FUTURE WORK

Continuous utilization of GPS in LBS for modern smartphones expedites the process of draining batteries. In order to extend operating times we have developed high-level strategies for saving energy. In particular, we avoid usage of GPS whenever possible and use region monitoring and network-based positioning when a device is not moved, e.g., at night times or while residing in the office. As a consequence, accuracy is diminished in certain situations (e.g., while moving with the app in background) and we have to accept latency for the reactivation of GPS whenever needed (e.g., when being monitored by other devices). Nevertheless, we succeeded in saving energy while guaranteeing a full functional service regarding location-based operations. Figure 8 summarizes the results of our conducted tests with a theoretical optimum when the device is in standby mode (green line) and a worst result with GPS engaged and regular data transmission (red line). In between is our energy saving strategy with Spotnick (blue line), which indicates a clear improvement compared to the exhaustive utilization of GPS.

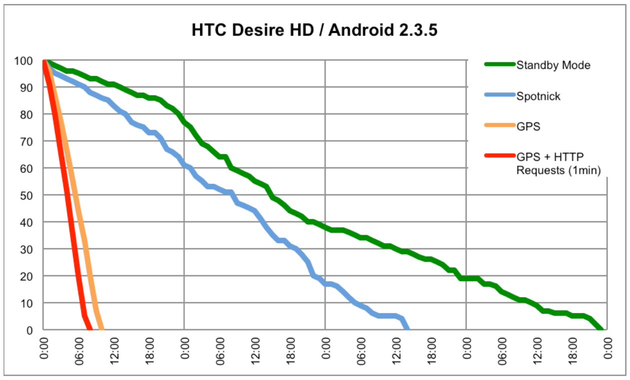

Figure 8. Battery Consumption HTC Desire HD with Android 2.3.5

In principle, these strategies also apply to further devices and operating systems. We have implemented them for iOS devices, as well. The technical details are different, because Apple restricts access to hardware-related functions and to system-related operations like process execution in background mode. However, the basic concept is similar, and also the results seem promising. Although, investigations on energy saving strategies for iOS devices are still underway, the first version of Spotnick including these strategies is available for iPhones in the App Store. Presuming comparable success for iOS, our proposed high-level energy saving strategies could be regarded as code of practice for mobile LBS, in general.

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