Homework 3 (Due: before class in week 8)

Part A. Mobile Location Tracking
Two important respects in which mobile devices differ from traditional desktop computers is that they are equipped with sensors that enable rich interactions, and they have scarce energy resources because they are powered by a battery. Applications are now emerging in which mobile sensors are kept on for long periods of time to monitor user behavior to, for example, help people exercise or live a greener life. This stresses battery lifetime. In this homework you will explore this tension by developing an always-on location tracking service that conserves energy yet still tracks your location accurately.

You are encouraged to work with a partner (teams of two only) for this part of the homework, and to help each other with Android questions (but not actual homework solutions) on the discussion board.

Experimental Setup
You will use your Nexus One mobile for this experiment. Android provides a Location API that allows you to use the GPS, 3G and WiFi as sensors to estimate location. GPS determines the location from the known positions of satellites. 3G and WiFi use geolocation techniques to estimate the location from the known positions of nearby basestations and APs. The different methods have different accuracies (GPS is usually more accurate), and estimates of location accuracy are returned along with a location. The different methods also have different energy costs (GPS consumes more energy). In this assignment you will use only the GPS and WiFi sensors as location providers since we have not provided you with access to 3G networks.

Applications use the Location API to subscribe to location updates from providers, e.g., WIFI or GPS. These subscriptions indicate the maximum update rate and the minimum change in location that should trigger an update. Based on these parameters, the OS periodically triggers a callback in the application and passes a Location parameter indicating the latitude, longitude and measurement accuracy. (Look here for more details.) This model allows the OS to optimize location sensing, for example by combining the requests of multiple applications, letting applications sleep until a location update is ready, and deciding when to turn the GPS, WiFi, and 3G sensors on and off. However, in this homework we want you to manage when to turn the sensors on/off – we want you to act like part of the OS so that you can more directly experiment with the tradeoffs. To do this, your application will determine what sensor to use, when to turn them on, and how long to wait for an accurate measurement.

The location tracking service you will build, starting with a baseline application we give you, simply keeps track of where the mobile is at all times, writing the information to a log. A good service will keep an accurate track of the mobile location and use little energy. We will say more about how to gauge accuracy and energy usage later. The point for now is that these two goals are in conflict since always powering sensors such as GPS may give an accurate location track but will take much energy, and turning off sensors most of the time will save energy but give a poor location track. Proceed through the three questions below to progressively build and evaluate your service.
**LocationTracker Application**

We provide you with the LocationTracker application as a starting point for this project. The application was developed against the Android 2.3.6. Please update your phone to this Android version before installing the application. Also, when building the application be sure to target API version 10.

The baseline application turns on GPS and WiFi every minute and subscribes to location updates from both providers. The subscriptions indicate a 0 for update rate (update as often as possible) and a minimum change in location of 0 (update even if there is no movement). **For this assignment, you must keep these parameters set to 0.** When a location update is received, the location is logged and both sensors are turned off for one minute. A timer wakes them up, and the application again subscribes for updates.

For this homework, you will need to modify this application. We provide function calls to turn on/off both WiFi and GPS, and also a function call for logging the location information to the log file. **You must use these functions to turn on/off the sensors and to log the location.** This is because we have integrated the energy and accuracy measurements into these function calls.

When running the LocationTracker application, be sure that no other location aware applications are running (e.g., Google Maps) as they may interfere with the application. We suggest powering the phone off and then back on before any experiments, not using your own SIM in the phone, and not syncing with your Google accounts (to reduce background WiFi traffic). Also, using WiFi to determine location requires that you have network access to communicate with the location server. Hence, you must have WiFi access through an AP if you want to use WIFI to determine location.

**Question 1. Sensor Energy and Accuracy**

Let us begin by gathering some data on energy consumption. Since your location service will use GPS and WiFi as sensors, we want to know how much power it takes to keep each of these sensors on. To learn this you will use a research tool called PowerTutor. First, install the PowerTutor application from the MarketPlace or developer website (http://ziyang.eecs.umich.edu/projects/powertutor/) and have a quick look at its documentation. PowerTutor uses a model of the phone hardware to infer energy consumption for different phone components and apps from measurable data, such as the number of packets that are sent. We will read the accompanying paper as a weekly reading.

a) The LocationTracker application is initially configured to have the GPS and WiFi on at all times and to sample them continuously. Run this program for a period of time, and use PowerTutor to estimate the power draw of the GPS and WiFi sensors. Turn in both power estimates. Also, in the LocationTracker application, change the WIFI_POWER and GPS_POWER variables to reflect these measured values. They will be used by the application to estimate energy usage.

Now let us look at the accuracy of both sensors. Note that the accuracy (and possibly the energy) of a sensor will depend on the location and movement pattern; we encourage you to experiment in different places and while moving and stationary.

b) The LocationTracker application has a flag to turn off the GPS sensor (USE_GPS). In a location where WiFi works, take 20 location measurements using just WiFi and plot the accuracy of the measurements vs time.
c) Now, reverse the flags so only GPS is used. Find a location where GPS works and repeat the above experiment. Turn in a plot of the accuracy of the 20 measurements vs time.

**Question 2. Benchmarking the LocationTracker Applications**

We have provided you with our location tracking service, which you will use as a baseline on which to improve. Before improving it, however, let us go over it and benchmark its performance.

To benchmark this program we would like to estimate its location tracking accuracy and energy consumption. Both present difficult issues! We will go over each in turn.

For estimating overall location tracking accuracy, all we need is to compare our location values with the ground truth of where the mobile actually was. We don’t have that data (or we wouldn’t need a location service)! What can we do instead? The accuracy estimates for each location sample help, but they don’t tell the full story since they do not account for movement of the mobile between successive location samples. To account for movement, we will use the idea that the distance between successive locations stands for one form of location inaccuracy. If the program is gathering locations rapidly, then the distance between successive estimates will be small even if the mobile is moving, and the location uncertainty is then also small. Conversely, infrequent location estimates may lead to large distances between successive estimates and large location uncertainty. We will add both factors as follows.

Given one location estimate L1 at position P1 with accuracy A1 and the next location estimate T seconds later L2 at position P2 with accuracy A2, define the accuracy to be:

\[
\text{Accuracy} = \frac{\text{distance}(P1 \text{ to } P2) \times T + (A1 + A2)/2 \times T}{T} \quad \text{or} \quad \frac{\text{distance}(P1 \text{ to } P2) + (A1 + A2)/2}{T}
\]

The accuracy of a trace of many location samples is simply the average of each accuracy sample weighted by its time period. We refer to this as the *track accuracy*, in contrast to the accuracy of any single GPS or WIFI measurement.

For estimating overall energy efficiency, all we need is hardware support that accounts for how the energy on the mobile is used. We don’t have this support at the level of granularity that we want it either! For example, PowerTutor estimates the energy cost of WIFI per application from the amount of data the application sends, as it is otherwise unclear how to apportion the cost across applications. It does not help us. Instead, we will consider the energy cost to come only from the GPS and WiFi sensors, with a little computation (and other sensors like the accelerometer) coming for free. The energy consumption of a location tracking service is then simply the amount of time that the WiFi and GPS sensors were on multiplied by their power consumptions. The first factor can be determined from the log. The second factor you measured in Question 1. The power needed to run the location-tracking service is then the energy consumed divided by the time period. The LocationTracker application logs the measurement accuracy, the track accuracy and the power consumption for each location written to the log.

a) For prior experiments, we wanted LocationTracker to keep the sensors on at all times. To conserve power, we now want the application for sleep for one minute between measurements. To do this, set the SAMPLE_CONTINUOUSLY flag to false. Then experiment with three variations of the LocationTracker application (using WIFI only, GPS only, and both GPS and WiFi) to gather some log data and plot several graphs. Run the experiments for the three variations in the same
scenario, for example during your commute. First, plot the location traces as a scatterplot of the latitude (y-axis) / longitude (x-axis) location samples in your log. Second, plot the average power for each location measurement (in mW) versus time. Third, plot the track accuracy (in meters) versus time. You will want to try several runs over reasonably large periods of time that include some motion; do not do this experiment while sitting at your desk. Note that the accuracy, and perhaps energy cost, will depend on the location and movement pattern, so there is no single correct answer here.

b) Turn in a representative set of three graphs for each of the three application configurations.

c) What seems to account for the most wasted energy?

d) What introduces the most inaccuracy?

Question 3. A Better Location Tracking Service!

Now you have a baseline on which to improve. Your goal is to obtain accuracy close to the best accuracy from the WIFI + GPS configuration above while consuming as little energy as possible. This is a deliberately open-ended question. Start by using your insights from the experiments above to try different strategies! Then look at the log data to see what happened and how you might improve. There are many different strategies you might try:

• Switch between using GPS and using WiFi as appropriate
• Take multiple location samples to get a more accurate estimate of the current location
• Adapt the frequency with which you check the location
• Adapt the way you check the location depending on motion
• Your idea here.

Use the accuracy and power metrics defined above that can be produced from logs to evaluate your design. As you develop your design you must respect some “rules of engagement”:

• It is possible to be adversarial to game the metrics, e.g. take a location sample only at 2am when you are home so there is no apparent motion in the log and hence no accuracy penalty. This is not in the spirit of the game.
• Use the Location API only as we allow so that you are solving the problem. Specifically, the requestLocationUpdates function call can only specify minTime and minDistance parameters as 0. Your application must manage turn on/off sensors and deciding what measurements to log.
• You do not have to log all location measurements, but you may not log a location sample more than once. That is, if you move from location X to location Y, then you may write X, Y to the log, but not X, X, Y. The latter might make it look like there was a quick movement from location X to Y that would lower the accuracy penalty.
a) Turn in a brief description of your design, concentrating on the key improvements you have made. (Half a page only.)

b) Turn in a set of three graphs of the form in Question 2b) for the same kind of representative location pattern as before to show how your design behaves.

c) Turn in the overall track accuracy and power consumption for the above run and tell us the percentage of the time that GPS was on and WiFi was on.

Part B. Textbook.

5.5, 5.6, 5.10, 5.27, 5.28, 5.33