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Location-Based Services: Navigation for the Masses, At Last!

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This paper covers the current status of wireless network location capabilities, including a view of each method describing the strengths and weaknesses of the various approaches. The paper will describe developments in network-assisted GPS to reveal the capabilities of the so-called high sensitivity receivers. The question of what has to be done to get GPS to work indoors will be answered, together with the impact of this capability on the positioning of mobile telephones fitted with GPS capability. The paper discusses the concepts of integrating terrestrial network-derived location with GPS/GNSS and very short range location systems such as Bluetooth. It will explain how Location-Based Services are operated, when they will become widely available, some of the key applications and the impact of this technology on some of the traditional sciences, in particular mapping. This area of navigation is developing extremely rapidly, with potentially a huge market for navigation on land.

KEY WORDS

1. Location-Based Services. 2. GPS. 3. Human Navigation.

1. INTRODUCTION. How many times have you arrived in a strange place and found yourself in need of a hotel, a restaurant, toilet or the nearest car park? For some among us, this is a frequent occurrence – especially those who earn their living moving all over the country, often into unfamiliar territory. For these people in particular, and a huge part of the population in general, the advent of the mobile telephone has been a godsend. It enables people to communicate in a way hitherto impossible. It makes it easy to call somebody to ask for directions to wherever or whatever it is that he or she wishes to visit. Communications have burst upon the population of the developed world and have been almost universally embraced.

2. BACKGROUND. Those of us working in the field of navigation have witnessed the development of methods of location using radio signals. This work has been going on since the 1940s but, until the late 1980s, was largely confined to the navigation of vessels and aircraft. The development of hand-held Global Positioning System (GPS) sets (Figure 1) by such companies as Magellan and Garmin heralded a breakthrough in personal navigation. Portable equipment became available that would allow a person to determine his or her location anywhere on the surface of the Earth to within a few tens of metres. On these early sets, the location information was

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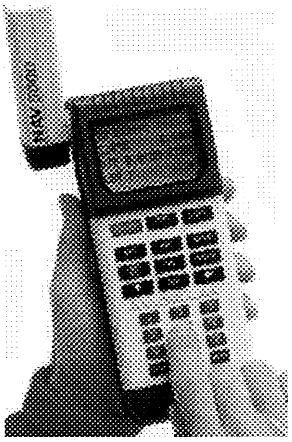


Figure 1. A typical hand-held GPS receiver.

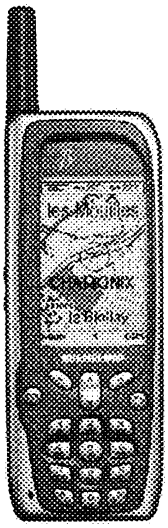


Figure 2. Benefon NAV 5000.

only presented in latitude and longitude or in X and Y Grid coordinates. In more recent times, the purely numeric presentation of location has given way to the use of maps with various levels of detail.

3. TODAY'S SITUATION. We now have a situation where, with a GPS receiver in one hand and a mobile telephone in the other, a user can communicate his location to somebody else. If that 'somebody else' is equipped with a way of plotting the roving caller's location, instructions can then be given to 'navigate' the rover to wherever it is that they wish to get. This is the basic principle behind Location-Based Services (LBS). The 'gadgety' people among us have used this technique under experimental conditions for personal navigation, but the clutter of equipment makes it a non-starter for the vast majority of potential users.

The integration of communications and location into one user-friendly device is the

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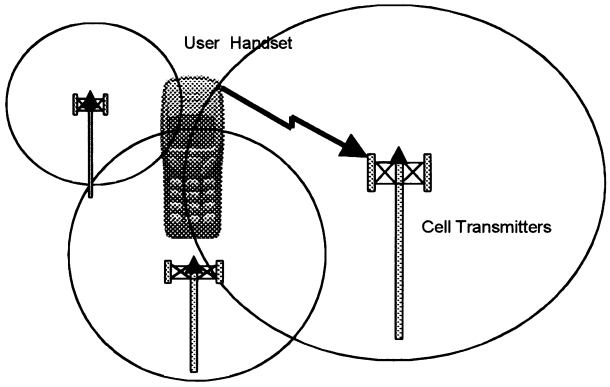


Figure 3. With the Cell-ID method, location may not be to the closest cell.

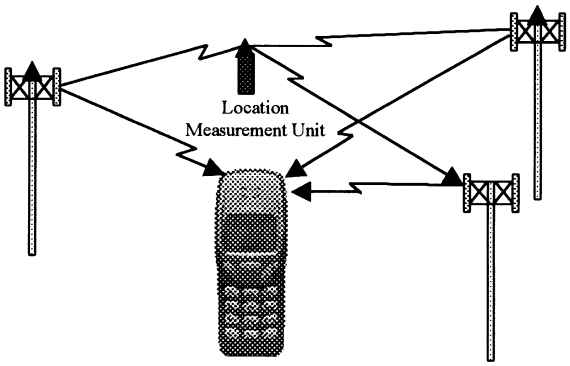


Figure 4. A Location Measurement Unit calibrates network timing.

next major step in this fascinating area. Already we have seen examples of GPS devices designed to combine the mobile phone battery and a GPS receiver as a clip-on accessory or enhancement to the phone. Devices like these are but a stop-gap before the fully integrated location-enabled mobile communicators become commonplace. Such devices have already been introduced this year (by Benefon in Finland, see Figure 2) but it will be the end of 2002 before we begin to see these devices available in large quantities.

4. EMERGENCY CALLS. One of the driving forces behind the development of the location-enabled cellular telephone has been the problem of emergency calls being made from mobile phones that are not automatically located. Where is the caller who may need urgent medical or similar attention? The current generation of mobile telephones can be located but only to within the cell area in which they are operating; this is known as the Cell-Identification (Cell-ID) method (Figure 3). Unfortunately, the cell area varies and may be as much as 300 square kilometres in rural areas or down to 30 in an urban area; a very large area in which to find the caller who may not be able or capable of giving a more exact location from visual clues. Because of signal propagation anomalies, a base station that is not the closest to the user may also be handling the call. This complicates the problem of locating the caller even more.

There are other techniques of locating telephones using the cellular network. These

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techniques involve trilaterating from at least two, and preferably three, base stations to get a fix on the user's phone. This is achieved by measuring the relative timing between each transmitter site and the mobile user. A Location Measurement Unit is used to calibrate the network timing (Figures 4). These methods of location are known as E-OTD (Enhanced Observed Time Delays) and OTDOA (Observed Time Difference of Arrival). They meet the E911 emergency location requirements in the right circumstances. However, current levels of accuracy inhibit some of the applications of Location-Based Services where sub-20 metre accuracy is desired.

5. THE ROLE OF GPS. Since the 2nd of May 2000, GPS has shown itself capable of some incredible levels of accuracy without any form of outside assistance or augmentation. Typically it can locate the user to better than ten metres and in most cases well below five metres. Now we have a positioning solution that can answer most, if not all, of the requirements for personal location.

When GPS first became available, it was hailed as the answer to a navigator's dream. It offered 30 metres accuracy to anybody using a suitable receiver on land, at sea and in the air. Then came the degradation of the service by Selective Availability, where civilian and the non-friendly military users were denied access to the real accuracy of the system as it was deemed too dangerous in the hands of people with 'evil intent'. It did not take long for wily civilian technologists to find ways of getting around the effects of this denial of accuracy. Eventually, ways were found to utilize the civilian GPS signals to get accuracies of better than five metres, then one metre and, currently, better than one centimetre.

The point of describing this accuracy issue is to say that history shows that if you give people an accuracy of 100 metres, they will want 10; give them 10 and they will want one metre and so on. I can foresee the time when mobile telephones will be able to give a location to one centimetre! Who needs it? you may well ask – somebody will, and suddenly another new application will open up. Most of today's location-based services will function adequately with sub-20 metre accuracy, but better than 10 metres would give more system credibility, allowing guidance to the correct door. This may be particularly important when the system is used by the visually impaired.

So now we are looking at a hand-held device in the form of today's typical mobile phone or in the form of a Personal Digital Assistant (PDA). In the former case, the limitation of the display size and resolution will limit the use of visual images, but instructions and information given by voice or other audio means can be extremely effective. An example of such a system is the turn-by-turn route guidance system for drivers and pedestrians developed by the Yeoman Group, which is about to go into volume production.

The larger area of screen, with high resolution, the greater computing power, the combination of GPS and a cellular telephone, into the PDA format, will make this device very attractive, especially to those who like their lives well organised! These devices will allow detailed information to be displayed including maps, pictures and diagrams of current locations and associated data such as train or bus schedules, cinema showing times and car park space availability.

Once the location element is added to the ability to communicate, a massive potential market begins to open up. There will doubtless be applications that look attractive initially but will fall by the wayside; in their place will come others as yet un-dreamt of and untested.

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6. IN-BUILDING OPERATION OF LOCATION SYSTEMS. One area of use of these systems, currently limited by standard GPS technology, is the operation of LBS inside buildings. Because of the very high frequency of GPS radio signals and the very low power levels transmitted by the satellites, receiving GPS inside buildings or even under trees has been a problem. In the past few years, techniques have been developed that begin to address these issues. It has been recognized that for LBS to become really useful, users need the ability to locate themselves when inside buildings or in tree-covered areas.

As long as the phone can communicate, the Cell-Identification (Cell-ID) method still works, and certain of the cellular network solutions such as E-OTD and OTDOA also offer some ability to locate users in buildings, but these rely on being able to see at least two base stations with good geometry (angle of cut). This may be the case in dense urban areas but may not prevail in sub-urban areas. They all suffer from noisy measurement data due to signal reflections in and around the building.

In the quest to try to squeeze the utmost out of the GPS signals, use can be made of the ability to communicate vital information to the GPS receiver via the cellular network. When GPS is operated inside a building, some of the energy from the satellites permeates the building and can be picked up by the GPS receiver. However, this signal is likely to be too weak for the receiver to be able to decipher the message that each satellite broadcasts giving its position in space. Without this information, although the user's equipment can determine the presence of a satellite, it cannot complete a fix calculation. The analogy is very similar to tuning a broadcast radio or TV into a very distant radio station. You can see or hear that something is there, and can probably determine where its centre frequency is located, but you cannot determine what the picture of sound is telling you.

With the combination of the cellular telephone and GPS, we can use the network to relay the missing satellite orbital data from a well-sited GPS reference station to the mobile user equipment. One reference station can provide this ephemeris data for the whole of the UK, for example. The data would be stored and updated on a network location server to be provided to any user when a GPS location fix is required. The provision of this data via the network also allows the mobile GPS receiver to lock onto the very weak signals extremely rapidly; this technique has become known as Assisted-GPS (see Figure 5). It is possible to lock on and get a fix in less than 5 seconds. This then means that the load on the handset battery can be greatly reduced as the GPS receiver can be shut down as various components complete their task. In hand-held applications, battery life considerations are of paramount importance – especially as the handset designs are driven to smaller and lighter formats, colour screens and ever-increasing processing power requirements. Full video streaming is expected to be offered within the next few months.

The performance of GPS receivers designed to operate inside buildings is very much dependent on the type of building structure, the material from which it is fabricated, its size and its location. There is little likelihood of a GPS receiver being able to operate in a lift in the centre core of a large multi-story building, for instance. Even if it were possible to track enough satellites, the resultant fix would be badly contaminated by multipath effects. Multipath is, in effect, reflections of the satellite signals off smooth conductive surfaces causing an apparent lengthening of the path between the satellite and the GPS receiver's antenna. Where multiple reflections are present, the receiver can find it extremely difficult to determine which is the straight-

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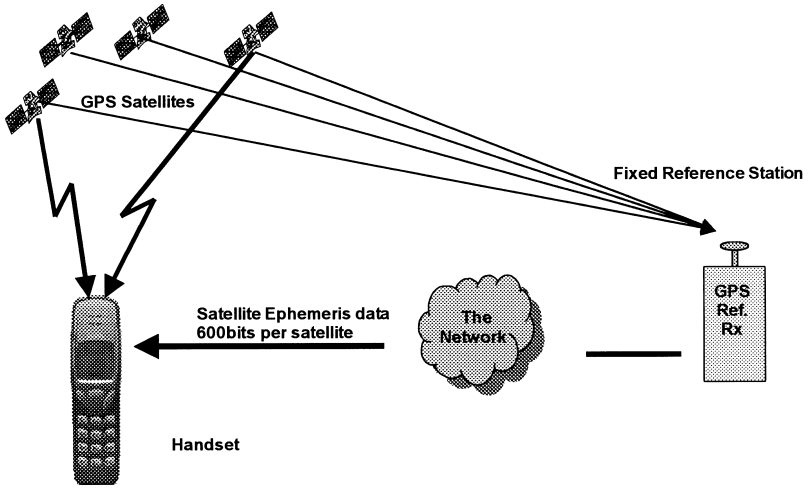


Figure 5. The principle of Assisted-GPS.

line signal as it is mixed up in a lot of radio noise. Some of the GPS receivers use very sophisticated signal processing techniques to mitigate against the effects of multipath, but if the only signals that are available are reflected off something, the resultant fix will have an error. The levels of errors can be from just a few metres to tens of metres.

For many LBS applications just knowing that somebody is within 30 metres of a building would be good enough. Ultimately, we need to find a technology that will allow reliable and accurate positioning of people inside buildings. This may utilize the Bluetooth technology, very short-range radio tags or some other ranging techniques. Once this comes about, it will be possible to direct a person to a particular shelf in a supermarket for goods that they require. This may not be in the shop owner's best interests for he wants us to 'shop around'. But, for those of us who are not 'shoppers', those who know what they want and need to get to it quickly, such shop navigation will be a great time saver. It does of course, depend on the shop telling the shopper where certain items are located.

7. THE DIRECTION AND HEIGHT PROBLEM. One weakness of current location techniques is that they do not give direction unless the receiver unit is moving. If a user is standing on a street corner wondering which way to go, the location system will tell him which corner he or she is standing on but will not be able to say 'turn right' or 'turn left'. To this end, some manufacturers are looking at adding a magnetic compass module to their handset device. Under most conditions this will be sufficiently accurate to give an approximate direction. Other ways of overcoming this limitation are for the location server, when it gives route guidance instructions, to say, 'proceed with number 126 on your right hand side'.

Although GPS is a three-dimensional system, its ability to provide accurate height measurement is severely hampered in areas of bad signal blocking. The terrestrially-based systems, EOTD, OTDOA and Cell-ID can only really give two-dimensional position fixes. In certain applications it is very useful to know whether a user is on the ground floor or thirty stories up in a building – especially if they are making an emergency call. In such cases, it is feasible to use an aneroid capsule to measure

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differential height change. By intelligent use of the map database, it is possible to determine from a latitude and longitude, what height the user is at as they enter a building. This height is used to set the aneroid so that, as their height within the building rises, the aneroid capsule can report the changes. These units are capable of detecting height change of half a metre or better.

With the advent of very low cost inertial sensors, it is even possible to produce a product that will give full attitude stability to a handset. In this case, potential applications become very exciting. Imagine that when the handset is held parallel with the ground, it shows a map or two-dimensional diagram of where the user is located. If the unit is now raised to the vertical, the display changes from a flat map to a picture showing the facades of buildings or the view in front of the user. In this way, it would be possible to show the actual buildings with an indication of the names, addresses, and even the occupiers. Such a system could be used even when driving down a road to indicate the appearance of a building that the driver wishes to visit.

Making such detail available to a hand-held device will become commonplace in the next two to three years. If we can stream video to handsets to allow people to watch their favourite goal being scored or horse race finish, then we are close to being able to offer pictorial presentation of geographic features. Such technology will require a much more detailed collection of geographic information both from the air and from the street. Digital photogrammetry together with image processing will make such systems as commonplace as today's paper maps. The keys to this advance are broadband wireless communications and highly detailed server-based geographic databases. Considerably improved display technology on the handsets will be needed to bring these services 'alive'.

In the rush for better and more interesting information for pedestrians, we must not lose sight of the problems of visual displays to certain classes of user. Vehicle drivers will, almost certainly, find that there will be legislation banning the use of many types of visual displays while the vehicle is moving. In this case, it is necessary to develop means of communicating to the driver, clear and unambiguous directions and information. This needs to be in a format that can be assimilated even when the driver is under pressure due to external traffic conditions. There is also the possibility that even talking to a driver may be deemed to be dangerous and distracting.

8. THE PRIVACY ISSUE. Privacy will be a major issue when these enhanced LBS are introduced; however, you hear very little complaint today that the mobile telephone operators using current technology know reasonably accurately where each and every phone user is when he or she makes a call. If the location technology is in the phone itself, then the user can have the right to make their location available to the network or to deny it. In some of the network-centric location systems, the network operator 'owns' the user's location and can do what they like with it within the law as it currently stands. The idea of walking down a high street and having your mobile phone call you up to tell you that you are just about to pass a pharmacy where there is a major promotion on health products, is enough to make even the hardiest advertising junkie wince. But it could happen and can be done.

9. CONCLUSIONS. Cellular communications and location are coming together in a format that will be available to anybody who might buy a mobile phone today. In little over a year, starting with the South East of the UK, location-enabled

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telephones will become commonplace. When that happens, the Location-Based Services revolution will begin. It will be every bit as popular as messaging has become today. Many users will at first be completely amazed that their 'phone knows where they are'. They will then migrate to wanting to find out where their friends are, who have similar capabilities in their phones. 'Find-a-friend' will become the new game with no more missed rendezvous. No more excuses of being outside the wrong Red Lion pub. Location-based dating will take off too! Such systems will also allow the tracking of handicapped and elderly people with memory problems.

Children can be given a geo-fenced area out of which they are not supposed to travel; if they do, the system can call their guardian and warn them of the transgression. Even a dog can be fitted with a tracking device capable of calling the owner if it strays outside given limits. Giving blind people the ability to become much more adventurous in their travels is also a potential bonus for the system. Here we will see new methods of communicating 'steering' information through the use of miniature vibration-motors placed at sensitive points on the chest and back. In this way, people who are both deaf and visually impaired can still be given guidance in unfamiliar environments.

Location and navigation, the arts of knowing where you are and getting from there to where you want to go, are about to become available as an automatic service to anybody who can use a telephone. Now we will be able to get very precisely lost but still find our way home!

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