1. Introduction

You reach the top of a hill and find a brass plaque pointing out the features of interest on the skyline. You are following a trail, one of many in a forest, and at every junction find a post displaying the path to take for each route. You are in an unfamiliar building, using signposts on the walls to guide you to your destination. What do all these scenarios, and many others, have in common? They all rely on signposts to indicate features of interest. In some cases only a bearing is indicated, as in a corridor signpost. In other situations, for example the panorama plaque, the sign might associate an arc and distance with each feature.

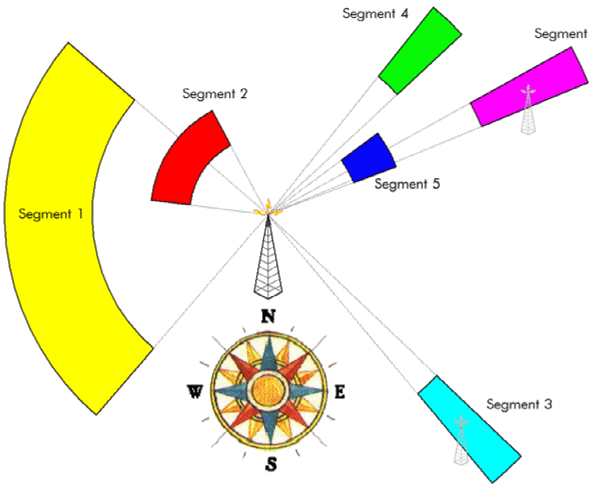
Signposts have been used for centuries, and provide a cost-effective solution for navigating around our environment. With the advent of affordable GPS devices, in conjunction with portable chart plotters, it is natural to ask whether physical signposts will become redundant. The advantage of a GPS-based approach is that it is relatively self-contained, not relying on any fixed infrastructure other than the satellites themselves. But the approach also has its fair share of disadvantages as well. In addition to the need for accurate electronic charts, the coverage is also a problem. It doesn't work indoors, and even when outside the reception can be adversely affected by tree cover, for example. The maps themselves, whilst providing a lot more information than a simple signpost, can often provide too much detail, making them hard to interpret. The cost of such a solution is also still prohibitive to a large sector of the population. For these reasons it seems clear that signposts, in one form or another, still have some advantages in many areas of navigation.

In this note we describe a different approach to providing low cost electronic navigational hints. Instead of putting all the intelligence, and cost, in the user device, we explore whether we can deploy electronic signposts to assist in this task. There are a variety of devices that could be constructed to act as signposts, differing in their level of sophistication, and wireless technology. At one extreme, the signpost could simply broadcast its location using a low-power radio link such as Bluetooth or 802.11. When multiple transmitters are within range, we can use triangulation techniques based on angle of arrival, or signal strength, to allow us to determine our position. This is the area being targeted by Bluetooth's local positioning profile, for example. The market for location-based services is forecast to be huge. However, it is important to note that merely knowing your position does not tell you how to navigate to a desired destination. Such approaches therefore still rely on the user device having access to mapping information, at least when used as part of a navigation solution.

At the other extreme, the signposts themselves could store the maps of their surroundings, allowing user devices to query the signpost for directions. Whilst attractive in principle, we would like to keep the signposts very simple. To a crude approximation, adding more intelligence to a device increases its cost, a serious issue if we wish to deploy millions of devices. Equally seriously, it often takes more power. We would like to deploy signposts in areas where there is either no existing power supply, or where accessing it would greatly increase the installation cost. Ideally, if a signpost was solar powered, and hence self-contained, it could be deployed much more flexibly. Simple signposts might require only a small amount of power, or none at all in the case of RF tags, but place too many demands and cost on the user devices. Making the signpost smart simplifies the user appliance, but is likely to yield a device that is too expensive and power hungry. In this note we describe a point between these two extremes, balancing the need for low-cost signposts with our requirement for affordable receivers.

2. Bluetooth Signposts

A signpost typically displays the direction to one or more features of interest. In some cases the distance, absolute or relative, is also provided. Most signposts associate a single bearing with each feature. In this document we generalize our notion of signpost to also include arcs. The following picture illustrates a signpost's view of the world.



The segments in this picture might represent hills, paths, buildings, departments, or a variety of other features of interest to the user. Consider a simple Bluetooth device that has been programmed to broadcast a representation of such a diagram. Initially we assume the location of the device is fixed, and therefore the signpost information is also fixed. Suppose you wanted to deploy such devices pervasively, wherever physical signposts are currently used. This raises a large number of challenging questions. How cheaply could each device be made if mass-produced? A signpost costing $50 is unlikely to be deployed very pervasively, whereas one costing $5 becomes a disposable commodity, allowing them to be deployed almost everywhere. Without expert advice on the current state of the art in this area, it is not clear whether the technology has reached the stage where such devices could be produced cost-effectively. But there are other costs that are equally important. What would a consumer require to access the information provided by the signposts? And how could the signposts be initialized in a cost-effective fashion? After all, there is no point in producing a device costing $5 if it then takes another $10 of someone's time to initialize it, or a device costing hundreds of dollars to use it. The rest of this report explores some of these issues.

3. Receivers

Mobile phone manufacturers are starting to produce handsets that include electronic compasses. You might think that the primary driving force for such developments is the recreational market, with the phones being targeted at hikers. However, the real driving force for much of this development comes from a more unexpected source. Muslims have used a short messaging service for years as a digital muezzin, texting them to prayer five times a day from the cellular towers instead of minarets. Now, taking the concept further, some mobile phone companies are developing GPRS phones equipped with a compass, and programmed to indicate the direction to Mecca. Bluetooth support is also becoming widespread in mobile phones, to support wireless headsets for example. A mobile phone, complete with a display, built-in compass, and Bluetooth connectivity, could form an ideal platform for interrogating our electronic signposts. Could we deploy a Java application in such a phone to display this information? For example, you reach the hilltop, and then pan around, with your phone displaying the prominent features of the landscape. You reach an intersection in an unfamiliar building, with your phone showing you what departments can be reached along each of the corridors. There are other advantages to using phones as the user device. For example, you could configure the phone to record the signposts you pass on the way from the office entrance to your desk. You send the route to a colleague, using SMS, and they can then program their phone to guide them along this route at a later date.

A variety of other consumer devices could also exploit the information provided by Bluetooth signposts. For example, some binoculars already contain electronic compasses. The addition of a Bluetooth link, plus a small display, would allow you to annotate the view with additional information as you panned around. Similarly, incorporating such features in video cameras, in conjunction with a Bluetooth signpost in the centre of a piazza, might be used to annotate the view with the names of historically significant buildings.

There may be many features of interest along a particular bearing, raising the question of how to display all this information. In some cases it may be sufficient to display all the features, ordered by distance. In other cases we might use other hints to narrow the choice. For example, in the case of binoculars, or a video camera, the focusing mechanism could be used to provide the required distance hints. Some electronic compass modules can provide pitch information, and this could also be used to provide a natural form of scrolling. Angling the device closer to the ground would display features closer to the user, whilst objects further away could be displayed by angling the phone towards the horizon.

Even setting aside cost issues, there are clearly many aspects to the problem that would need to be explored in more detail before we could be confident that such a system could be built. For example, in a typical Bluetooth deployment there will be a maximum of seven active slaves and a single master in a piconet. In our scenario the communication for much of the time is of a very simple form, with the master broadcasting a message periodically to an unknown number of listeners. However, due to Bluetooth's use of Frequency Hop Spread Spectrum (FHSS), the signpost master, and the slave user devices, need to stay synchronized. Furthermore, in a crowded environment there may be more than seven user devices. We can overcome this limitation, and keep the user devices synchronized, by using Bluetooth's Park mode.

We also need to decide on whether the master or the slave should initiate the connection when they move within range of each other. If the signpost has to initiate the connection, it needs to constantly check which slaves are within range. Furthermore, this inquiry takes a minimum of 1.28 second, and as long as 10 seconds if you want to find all devices. Since it is impossible to communicate during an inquiry because the device has to be in hold-mode, if the signpost takes the initiative it cannot communicate with any of its other slaves during this period. However, if the user device does the inquiry, the signpost can continue to communicate with the other slaves. Of course if the slave initiates the connection, it becomes the master of this connection, requiring a role switch after the connection has been established.

In the worst case the time to establish a connection is significant, particularly where signposts are used within a building. Can the connection mechanisms keep up with the speed of someone walking down a corridor? There has been some work on tweaking Bluetooth to improve connection times. Would such modifications be required in some signpost deployments? Can we use the Service Discovery Protocol to restrict our attention to just those user devices that represent signpost receivers? We will also require a mechanism for updating the information in a signpost. However, this requires the establishment of a traditional point-to-point link between the signpost and a (portable) management station. Furthermore, the connection times are less of an issue in this case.

Note that the signpost situation is almost the opposite of the Bluetooth roaming scenario. When roaming, we want to be able to see multiple Bluetooth units from the user device, to permit seamless handovers of a long-lived connection. In the signpost scenario we want to minimize, or indeed eliminate, this possibility, to avoid conflicting information. The use of SDP should allow us to distinguish between the different device types, allowing both kinds of usage within a site.

4. Deployment

Each signpost is different. In addition to a unique ID it must be configured with the data it should broadcast. At one level the specialization of the signpost is simple. We just need a mechanism for establishing a point-to-point connection to the signpost. This can then be used to upload the appropriate information for the location where the signpost will be deployed. The signpost stores this data and transmits it for ever, or at least until it is next updated by the management station. But where does this information come from? In some cases it may need to be constructed manually. For example, consider the situation where you are deploying a signpost at the junction of some forest trails. A mobile management station could be used to record the direction of each path. This information would be augmented with details of what routes were associated with each path, and then the information would be uploaded to the signpost, perhaps glued to the top of a physical signpost. In other cases we may already have detailed maps of the area where the signposts are to be deployed, for example office or street plans. In these cases it may be sufficient to indicate the location of the signpost on the plan, with software automatically calculating the information that needs to be uploaded to the device. One obvious type of feature is another signpost. We assume the radio links are only short-range, and therefore the signposts are not directly aware of each other. Nevertheless, a management station could easily configure each device with knowledge of other devices within the vicinity. Such information could be valuable when following a route and missing a turn. Clearly there are a whole range of applications, and supporting hardware, that could be developed to assist in the deployment of signposts in a variety of different environments.

Many Bluetooth devices already have mechanisms to adjust their power output to avoid overloading the receivers of nearby devices. However, we may also need to alter, or constrain, the transmit power to suit the deployment position. For example, the bearings are given relative to the signpost itself. Where the features themselves are close by, you may need to ensure the user stands near to the signpost to prevent ambiguity. Reducing the range of the signpost can ensure this. Similarly you may need to reduce power to stop signals from an adjacent signpost, perhaps across a partition or wall, confusing the user. In contrast, where the features are far away then the difference in bearing to each feature from the user and the signpost may be negligible, even if many meters separate them.

5. Security

In some cases it may be sufficient to initialize a signpost just once. But in many scenarios we need a mechanism for updating the signpost information after the initial deployment. Departments move, buildings are renamed, and so on. There are obvious security implications here, in that we don't want to permit unauthorized people making such changes. Standard password-based authentication techniques may be sufficient to ensure the required degree of protection. But there is a more subtle security problem associated with our Bluetooth signposts. If they can be made very cheaply, and deployed widely, then we must assume they will also be available to malicious users. What happens if additional devices are deployed around a site, broadcasting misleading information? Public-key authentication can help here. For example, on entering an Agilent site a Bluetooth station at the Security desk could broadcast the public key for Agilent. The user's mobile phone could then be instructed to store this key and only listen to signposts that can be authenticated with this key whilst in the building. When following forest trails you might use the public key of the Department of Agriculture Forest Service, and so on.

6. Mobile Signposts

In our discussions so far we have assumed the signposts are stationary. Now consider the situation where both the signpost and user are mobile, for example collocated on a boat or in a car. This environment allows us to alter some of the tradeoffs we have made. For example, in this setting we can push more intelligence into the signpost because it can be easily powered from batteries, and it doesn't need to be as cheap. In this section we consider the scenario where we also have access to a GPS feed and electronic charts. These features allow us to construct a Bluetooth signpost that can dynamically compute the information to be broadcast. Note that the Bluetooth profile used to convey this information, and the receivers themselves, do not have to change in this setting. Of course there are also many additional challenges that arise in such an environment. Charts contain a great deal of detail, and so we may require heuristics to determine what features should be identified along each bearing. In the marine environment large ships broadcast their position, heading and other details using a system called AIS. Such information could also provide an additional source of features to the mobile Bluetooth signposts, allowing ships to be identified as the user pans around.

Although we could still use a mobile phone as our display in this scenario, digital binoculars with an accurate compass and a Bluetooth link and display may form a more appropriate user device. When identifying features we need to take this variety of consumer devices into account. For example, a signpost may broadcast a detailed set of features, where many of these can only be distinguished using a high-end device. Simpler user appliances, such as the mobile phones, would then use knowledge of their own capabilities, for example the accuracy of their compass, to filter out some of these features.

7. Uses

We have already discussed many of the obvious uses of Bluetooth-based signposts. It seems likely there will be equally many initially less obvious ones. For example, if deployed pervasively in a building, the signposts could be used to ensure the night watchman followed the required route at the appropriate times. A simple application in the phone would record the signposts that were passed, and the time. This information could then be uploaded to a management station at the end of the shift. An orienteering application is another example. Instead of using punches to provide the evidence a competitor has passed a particular spot, Bluetooth signposts at these spots could provide electronic proof. Electronic yellow pages in tourist offices could send routes as SMS or Bluetooth messages to your phone. These could then be followed, using signposts, to reach the destination, whether it is a hotel, tourist site or chemist. Where the signposts are used to tag roads we may need to group them into sets. For example, depending on which side of the road you are walking on you may pass by a different set of signposts, but logically the route will be the same. By grouping all the signposts at a road junction into the same set, and using the set identities to construct our routes, we can avoid some of these problems.

When visiting a new site the receptionist could give you a smart visitors pass that directed you to your destination using signposts, with a simple red/green LED display showing you the way. Bluetooth signposts could also warn of dangerous routes. For example, they could be deployed near a cliff so a walker taking the wrong route off a hill would cause the phone to sound an alarm. Corridors leading to areas requiring special protective clothing could also trigger an alarm. At this stage the range of potential applications seems inexhaustible. Of course the problem is making the signposts, and deploying them, cheaply enough in the first place.

8. Conclusions

Developing a low-cost navigation solution is a challenging problem, requiring a careful balance between the sophistication and cost of any infrastructure, and the user appliances that support the navigation applications. We have argued that a system built around Bluetooth signposts, and mobile phones with built-in compasses, might be able to achieve such a balance. Our discussions have focused on what a signpost would need to broadcast in order to support a navigation application. Of course the same devices could also support various other Bluetooth profiles, such as the Local Positioning profile, as long as these didn't have a significant impact on cost or power consumption. The "signpost profile", for want of a better term, is not intended as a replacement for other location-based services, but rather to complement them.

The signpost concept has been presented in the context of Bluetooth networks, but the idea is not inherently dependent on this technology. Other competing standards, such as Zigbee, are on the horizon, and the signpost idea would be equally applicable to these cases. Indeed certain aspects of the Zigbee design may make it an even better platform for the signpost concept. However, a crucial part of the argument underpinning signposts is the ability to piggyback on existing user devices, namely Bluetooth-enabled mobile phones equipped with compasses. It remains to be seen to what extent other technologies, such as Zigbee, will become commonplace in the mobile market.

At first glance it looks like the market for Bluetooth-based signposts could be huge. There would also be a smaller, but significant, market for devices and software systems to configure these devices. Whilst the intention would be to use existing mobile phones as clients, there would also be a niche market for specialized clients, for example in the mobile signpost setting. Of course the million-dollar question is whether a solar-powered, weatherproofed, Bluetooth-based signpost could be manufactured cheaply enough to support such a market?

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