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Advances in GPS Technology for Measuring Travel

By

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ABSTRACT: Since the late 1990s, GPS has begun to be used as a method for measuring personal travel. Early devices were for in-vehicle use only and derived their power from the accessory socket of the car. In the early 2000s, the first wearable devices appeared, using battery power from rechargeable batteries. The early wearable devices were heavy and ungainly, and success in having people use the devices was limited. In 2005, ITLS and NeveITS pioneered the use of a much smaller device with its own internal battery, similar in weight and dimensions to a mobile telephone. Subsequent to the initial deployment of this device, there have been further advances in the sensitivity of the antenna/receiver and we have developed with NeveITS a number of improvements to software. This paper describes some of the tests conducted on these GPS devices and demonstrates the capability of these devices to provide detailed and accurate data on travel movements. The latest technologies for GPS devices indicate its potential to replace many conventional methods of data collection that are flawed because of known errors and inaccuracies.

KEY WORDS: ***GPS Devices, Testing, Wearable GPS, Travel Data, Accurac, Signal Acquisition, Urban Canyon, Development***

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1. Background

Transport research often requires data on the geographic and temporal aspects of travel and the performance of the transport system. However, in interview surveys, most people can provide only rather inaccurate data about where they go, and often do not provide accurate information about when they travel or how long their travel takes (Stopher, 2004). In addition, the transport analyst has need of accurate information about travel speeds at different times of the day in various locations and also may desire precise information about routes travelled through the networks. Before GPS devices became available to use for this, obtaining such data was extremely difficult, if not impossible. GPS offers the capability to obtain very precise information about where a person, vehicle, or consignment is at a given time, what route is being travelled, how fast the object of concern is travelling, where the object started out on the travel, and where it goes. This information is provided at a level of accuracy of plus or minus a few metres for location, and to the nearest second or less for temporal data.

In the mid-1990s, the US Federal Highway Administration (FHWA) undertook a proof of concept test of the use of a GPS device to measure travel behaviour (Wagner, 1997). Since then, the use of GPS to measure travel has escalated rapidly. Initially, GPS devices were restricted to use in a car, because they had no integral power supply and needed to be powered from the car itself. The earliest devices comprised a GPS antenna/receiver that was connected to a Personal Data Assistant (PDA), and required the respondent to enter data as his or her travel proceeded, also called "Active GPS". Following the successful proof-of-concept test, a number of independent studies used either the same GPS/PDA devices developed for FHWA, or other off-the-shelf devices. However, these proved to be somewhat unsatisfactory. At the same time, the Dutch also developed a GPS device, with its own battery power. This was designed to be able to be taken on a bicycle (Draijer, Kalfs, and Perdok, 2000) and represented the first "wearable" device. However, this device weighed 2 kilograms, making it rather heavy to carry on a bicycle or walking.

In the next few years, work in the US began on developing passive GPS devices (Stopher, 2001; Stopher and Bullock, 2001; Stopher, Bullock and Horst, 2002). These are devices that require no input by the survey respondent during use. The devices were designed to be on while the car's accessory socket was live, and to be off when power was no longer provided (Wolf, Guensler, and Bachman, 2001; Wolf et al., 2003). Such devices still, however, remained in-vehicle devices, because they did not have any power supply of their own. In procedures pioneered by the Institute of Transport and Logistics Studies (ITLS), the additional information that was previously captured on the PDA was collected in a prompted-recall survey (Stopher, Greaves and FitzGerald, 2005). In subsequent work at ITLS, the prompted recall survey was also developed into an internet survey, with animation of each trip, to allow respondents to indicate if there had been an intermediate stop that was not detected by the researchers, or to indicate that what was presented as two trips was really one (Stopher and Collins, 2005). A wearable version of the GPS device was subsequently developed from the in-vehicle device. This device consisted of the same recording box used in the in-vehicle device, which was carried in a small bag, together with a battery pack, and an antenna/receiver about the size of a standard computer mouse, which was mounted on the bag strap, so that it would sit on the shoulder of the wearer. The device weighed close to 300 grams, thus representing a significant improvement over the Dutch wearable device, but still representing a significant device weight.

This device was used in two research projects in Australia. In the first one, respondents to the Sydney Household Travel Survey were asked to take GPS devices for several days, with the purpose of checking the validity of the home interview survey results, as is reported elsewhere (Stopher, Xu, and FitzGerald, 2005). In this case, only those households that indicated that at least one person in the household was a regular public transport user were asked to take a wearable device, and one was then provided for each such regular public transport user. Out of some 72 households that received devices and provided data, only 20 were given wearable devices, with a total of 21 persons providing data from wearable devices. We obtained 56 days of data from these 21 persons, for an average of just under three days per person. It should be kept in mind that households were recruited for the GPS in this survey if the interviewer arrived at the house at least three days before the day for which the household would be asked to complete a travel diary, so that the GPS device could be used for 1 to 4 days in total. Two problems with the device were its weight and its appearance. A number of people raised objections to wearing the device, which is shown in **Figure 1.**

The second use of this device was in an evaluation of a pilot Travel Behaviour Change program in the Canberra area, aimed at households that had just moved. As with the Sydney project, the idea was again to give wearable devices only to individuals who indicated that they regularly used public transport. All other individuals received in-vehicle devices. In this case, respondents were asked to use the device for a week. There was both a before and an after survey, and 17 persons took the wearable devices in the before survey, and 28 in the after survey. From this total of 45 wearable devices accepted for use, we obtained a total of 245 days of data, 103 from the before survey and 142 for the after survey. Thus, in the before survey, each person accepting a wearable device provided an average of just over 6 days of data, while we received just over 5 days per person of data in the after survey. Given that some people will not leave home on some days of the week, these represent a high level of conformance to the requested task. One of the anecdotal objections that was made more than once in this case was to the effect that wearing such a device to work at a new job was simply not acceptable.

These experiences led us to consider the specifications of a more desirable wearable device. The desired specifications and reasons for them are described in Stopher, Greaves, and FitzGerald (2005). In the next section, we describe briefly the resulting devices.

2. Actual Specifications of the New Wearable Device

The actual specifications that could be achieved were not always the same as those we had specified for the ideal case. In terms of the form factor, we succeeded in having a device developed that is about the size of a mobile telephone, as shown in **Figure 2**, which also weighs about the same at 103 grams. The device, also known as the *NEVE StepLogger*, uses a uBlox antenna/receiver and custom circuitry for processing and storing data. Comparing Figures 1 and 2, it can be seen that this new device is very much smaller than the first generation of wearable device. The device shown in Figure 2 includes the battery, the antenna/receiver, and the logger.

In addition, the device comes with a case that has a clear front and a belt clip on the back. The loop for the key ring was added as a method to make it more likely that the device would be carried. It is suggested that respondents attach their existing key ring to this ring, so that the device is always with their keys. This also means that the device will normally hang in an almost vertical position when attached to the key ring on which there is an ignition key, thereby providing an optimal orientation when in the car.

The battery life of the initial design of this device was significantly less than had been desired, but is the maximum that is currently available at this size. The battery runs for about 18-20 hours if the device is unused. If recording position for a normal period of an hour or so per day, then the battery will last between 12 and 16 hours. Normally, this was sufficient, provided that respondents remembered to recharge the device overnight. The battery recharged fully in about 2 hours and cannot be overcharged. Therefore, leaving the device plugged in overnight does not result in any harm to the device. We return to the issue of battery life later in this paper.

When we were testing the device, we found that it was very easy to turn off the device unintentionally when it was dropped into a pocket or a bag. The red and white button on the front of the device was originally the on-off switch. Because of the unintended turning off, the switch was redesigned to turn the device on only, but not off. This is now the function of the switch. It is an on-switch and the device cannot be turned off by the user.

Time required to acquire position has been found to be highly variable. If the device remains static, position acquisition appears to take from as little as 15 seconds to as much as 120 seconds. If the device is put in motion immediately that it is taken out of a building, then acquisition of position may take as long as 15 minutes or more, depending both on speed and the presence or absence of tall buildings, dense tree canopies, etc., although it may still gain position as quickly as in 15 seconds or less. This appears, as best we have been able to determine, to be about the norm for current GPS devices. Indeed, the earlier versions of a wearable device have a similar position acquisition time, and newer GPS receivers do not seem to have made much difference in this. For the StepLogger (the device shown in Figure 2), the manufacturer experimented with improving the shielding of the antenna/receiver, and provided some gains in this area from the original design. However, the device was still slower than desired in acquiring position.

So far as memory is concerned, we found ourselves at the mercy of the chip manufacturers. At the time that the specifications were developed, we had every expectation of being able to obtain 16 Mb of memory for the device. However, when it came time to order this component, it was found that the manufacture of 16 Mb chips had been discontinued. The choice was then to go with a 32 Mb chip, which would have encountered a delay of several months to acquire the needed number of chips, or to go with a smaller 8 Mb chip that was readily available. Because of the need to begin testing and deployment of the devices in the early part of 2005, the decision was to go with the 8 Mb chip. In addition, the device comes with a slot that can accept a standard memory card. At present, this capability is not utilised, partly because we have not resolved the issue of security of the memory card. In the current design, the memory card could be removed by a respondent and used in some other device that accepts the same type of memory card.

There are a number of functions of the final device that are also able to be changed by the researcher, through the software dialogue box (**Figure 3**). One of these is the frequency of position recording. Currently, we are recording position every second, which we have found to be ideal for walking and public transport trips. Longer periods can be set through the software interface, with logging intervals being able to be set to any interval required. Another feature that is programmable is whether or not the device logs all data points or whether it attempts to detect when it is stationary and does not record those points. Currently, we set the devices not to record data when the device appears to be stationary (i.e., when the velocity is zero). In using the first version of these devices, we set them to "sleep" after 180 seconds if there are not the required number of satellites in view. The device sleeps for 90 seconds at which time it "wakes up" for another 180 seconds to again search for satellites. Once the required number of satellites have come into view and position has been acquired, the device continues to record data until no GPS signal is being received such as when the device is inside a building or a tunnel. This saves both on storage requirements of the logging data and on power consumption. If battery life allowed, it would be more desirable to have the device on "continuous tracking" in which case the device never sleeps, but is constantly looking for satellites and when GPS signal is received it is constantly recording data.

Four lights on the front of the device assist in determining how the device is functioning. On the extreme left (in Figure 2) is a status light. This light flashes once every 5 seconds when the device is on. When the device is turned off, or the battery has been exhausted, this light is off. Next is the battery status light, which flashes when the device is running low on power. This occurs for about the last half hour before the battery is drained. When the device is charging, the battery light is on and steady. Once the device is fully charged, the battery light turns off. The third light from the left is the GPS indicator, which is on and steady when the device is receiving GPS data and recording position. In normal operation, the leftmost light would be flashing and the third light from the left would be steady, meaning that the device is successfully recording position. The rightmost light is the memory light and comes on as a steady light when the memory is full, indicating that no further data are being stored. When the device is turned on, all four lights will flash together five times at one second intervals.

On the bottom of the device, there are three sockets. One of these is for the power input to recharge the battery. It is a simple circular socket that accepts a standard one-pin plug. The charger is capable of receiving 90 to 264 volts AC, with a cycle rate from 47 to 63 Hz, therefore being suitable to just about any domestic electrical system in the world. Output is 6 volts DC and 2.5 amps, which, as noted earlier, will recharge the battery in about 2 hours. The other two sockets are for data transfer, although only one of these is currently used.

The data are downloadable using the WinStep® software provided by the manufacturers (**Figure 4**). While download times are clearly dependent on the amount of data recorded, we have figured on roughly 30 - 45 seconds/day of data, which is clearly an acceptably short period of time. The resulting data file is in *.dat format, which can easily be converted to *.csv or other formats as required.

2.1 Subsequent Developments

Since the initial devices were manufactured, several improvements have been made. The most notable was the acquisition of a new antenna/receiver with much higher sensitivity. The new antenna was found to be able to obtain position inside a brick and concrete building, so long as it was on the upper one or two floors. Lower down the building, no position was able to be obtained. The downside of this more sensitive antenna has been that the device is now recording valid position information for more time, which reduced the battery life to about 8 to 10 hours. This has proved to be a problem, because for most respondents travelling to and from work, the elapsed time that they are out of the home is usually more than the battery life.

Various improvements have been made in the power management for the device in an attempt to overcome some of this problem. The latest development is the acquisition of a new battery with about one-third longer life than the initial battery. Unfortunately, this battery is slightly larger than the existing one and requires some re-engineering of the device casing to fit it in. We have not tested any of these improvements in power management and battery life, however.

3. Testing the Devices

Over the past year or so, we have undertaken a number of tests of these devices to determine what they are capable of doing. In the remainder of this paper, we document some of the tests that we have performed and indicate the results that have been achieved. These tests were primarily undertaken by staff at the ITLS, with known travel patterns, so that the tests would allow us to ascertain what errors occurred in the data acquisition. The devices have also subsequently been deployed in a full-scale survey in South Australia, as documented in Stopher et al.(2005) and Stopher, FitzGerald, and Biddle (2006).

3.1 Signal Acquisition

One of the issues with GPS devices is that they are not necessarily quick at gaining their position. For example, a person may carry a GPS device out of a building and immediately start travelling. The device must now first locate at least four satellites in the sky and then compute position from them. If it has been less than an hour since the GPS was last in use with satellites in view, then the last position is considered to be the most likely starting point, and acquisition of a new position usually takes place in a matter of less than a minute. However, if it has been longer than an hour, the device starts over as though there is no memory of last position. This can take up to two minutes for position acquisition when the device is stationary, and up to 15 minutes if the device is in motion, especially at a relatively high speed. **Figure 5** shows a car trip with the device with the initial antenna, and shows the poor initial pick up of position at the bottom left of the picture, where the device did not obtain position for a time after departure. This was actually a relatively rapid position acquisition for this antenna. In contrast, **Figure 6**, which includes three trip ends – one on the lower right of the map at Newport, and two at the upper right – shows that the new antenna has had no problem in picking up position, whilst the old antenna has missed huge amounts of the travel.

3.2 Urban Canyons

A common problem with GPS devices is what happens when the device is taken into an area where there are tall buildings on both sides of the device. In this case, the view of the sky is restricted, and there is signal bounce off the buildings, which can result in spurious position information. The old antenna version of the new StepLogger suffered from this problem. However, on a drive through the CBD of Sydney, the new antenna registered no problems, and accurately recorded the path of the vehicle, as shown in **Figure 7**. We have done repeated tests of this type and found that the new antenna consistently tracks the correct path through an urban canyon, whilst older versions of antennas and devices could not do so. Indeed, in our previous software development for the interpretation of the GPS records, we had a routine that permitted interpolation via a minimum path algorithm for the lost data points through an urban canyon. As can be seen, the new antenna does not require such data repair to be undertaken.

3.3 Device Location

We also found, through a variety of experiments, that the position in which the devices with the original antennas was carried made a significant difference to the record of position, whereas the new antenna seemed to be much less sensitive to this. The devices were variously carried in a pocket, in a bag, and with the bag located in various places, including on the back seat of a car, on the floor of the car, and on the front passenger seat of the car. In the case of the old antenna, a typical result is shown in **Figure 8**, where no data were collected throughout the trip. In the case of the new antenna, there was no difference in acquisition by having the device in a bag, located anywhere in the car. In all cases, a complete record of the trip was obtained. When carried in a pocket, both for walking and in a car, the result is shown in **Figure 9**. Here, again, the new antenna is capable of providing a complete record of the trip, both in the car and walking, while being in the respondent's pocket, whilst the old antenna is unable to provide such data.

3.4 In Other Vehicles

One of the problems we found with the earlier version of the StepLogger was recording in the bus, train or ferry. **Figure 10** shows an example of the old antenna used for bus and walk. While the walk is quite well tracked, the bus is very spotty. In contrast, **Figure 11** shows the result from using the new antenna on train, ferry, and walk. In this case, the trip is complete except for the section of train that is in tunnel, where no signal would be expected under any circumstances. However, the route is not in question, in this case, because the alternatives are limited. **Figure 12** shows another example of the new antenna providing excellent tracking in a trip that involved walk, car, walk, and bus. The entire trip is recorded, even through the Sydney CBD.

4. Summary

In the vast majority of the tests that we show here, the new antenna far outperformed the older version of the StepLogger and also provided results that were far superior to any results we have found with previous portable or wearable GPS devices. Indeed, we find that the completeness of tracking with the new devices is extremely impressive, with the major problems occurring only when in certain vehicles, where the interference with the signal is so substantial as to result in no signal reception. Also, although the new device is much improved, it can still suffer from significant position acquisition delays, resulting in loss of the initial part of a trip. However, we have also found that this device is capable of recording indoors in many structures, so that the position acquisition problem disappears if the device has been able to maintain position whilst remaining stationary in a building.

5. Conclusions

We believe that wearable GPS devices have a significant future in transport planning applications. The substantial miniaturisation that we have been able to achieve with the newest device makes it much more likely that people will use the device. So far, while a 26 percent recruitment rate is lower than one would ideally like, there is the potential that this rate may yet rise. We are subsequently experimenting with alternative methods of recruitment, from which it may be possible that higher response rates can be achieved. Preliminary evidence shows that, at least in South Australia, a small monetary incentive is of little value in improving response, and may even have acted as a deterrent. It will be important to determine whether there are any apparent biases in the recruited respondents, compared to the full population.

We also believe that there are potentials to make the GPS devices more useful. There is already the possibility to make them into functioning mobile telephones, although we decided that this was not as useful as it first seemed. The manufacturer also tells us that it would be easy to add the capabilities of an MP3 player. Other possibilities may also be considered. To the extent that functionality can be added that does not increase the risks of people not returning the devices, this may also help to make the devices more acceptable for use. However, we are very much mindful of the fact that making the devices too useful to users may result in a problem about getting the devices returned at the end of the study.

A third direction of potential development is the addition of a second positioning capability, so that when GPS signals are lost, some other positioning process, less accurate than GPS, may be able to take over. One possibility here is the use of triangulation to mobile phone antennae. Other possibilities are also being explored. The devices described herein also have a capability for GPRS communication, although we did not choose to activate this. With this activated, data on position can be collected in real time. Another possibility would be to add a button to the device that a person would press each time a new trip is started and each time a trip is ended. This information could be sent by GPRS, while position information is still stored on the device, or could be stored on the device with the GPS data.

We have also recently learned of some new developments for the technology that is described here. We have determined that there is a capability to record the time when movement begins and when movement ceases, even if position is not acquired at the time the trip begins or ends. This will provide much better information for use in the software for inferring missed travel and stops. There is also supposed to be a new battery with about 30 percent longer life than the present one we are using, but of similar weight and dimensions.

With the many potential future directions for development, we believe this technology represents a major future means of tracking person travel. It is simply a matter of determining in which directions to move with it, and to develop the new capabilities.

Figures and photographs

Figure 1: Early Wearable GPS Device Shown by a Mobile Telephone

Figure 2: New GPS Device Compared to Mobile Telephone

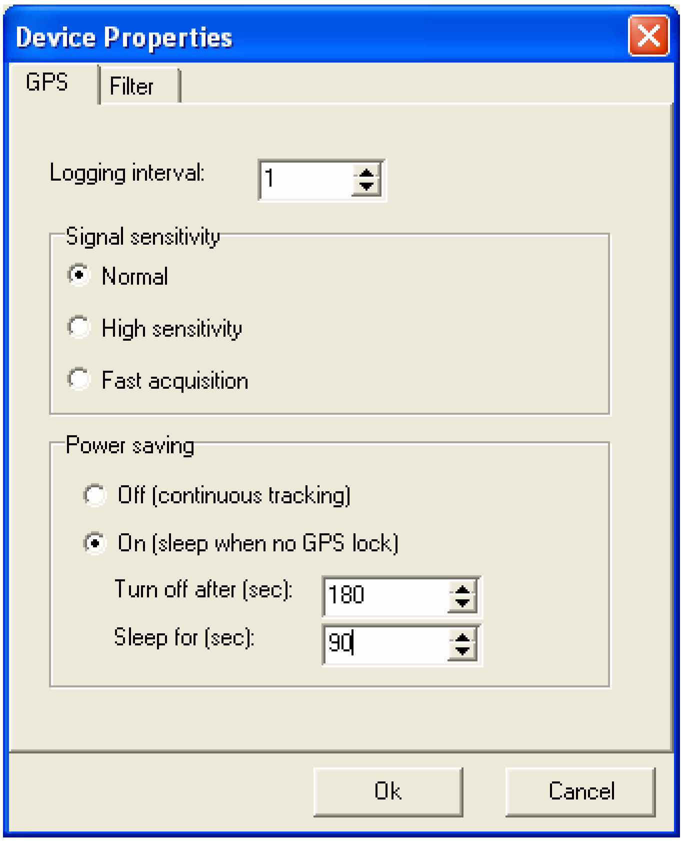

Figure 3: Dialogue Box for the StepLogger

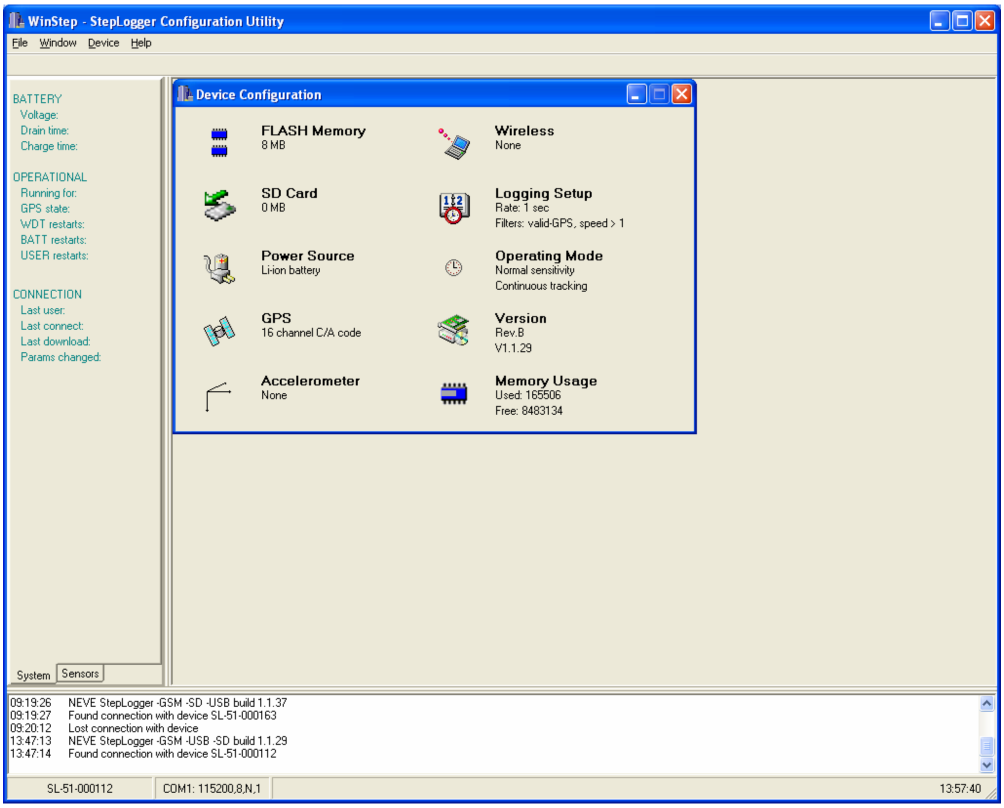

Figure 4: WinStep Data Downloading Software Screenshot

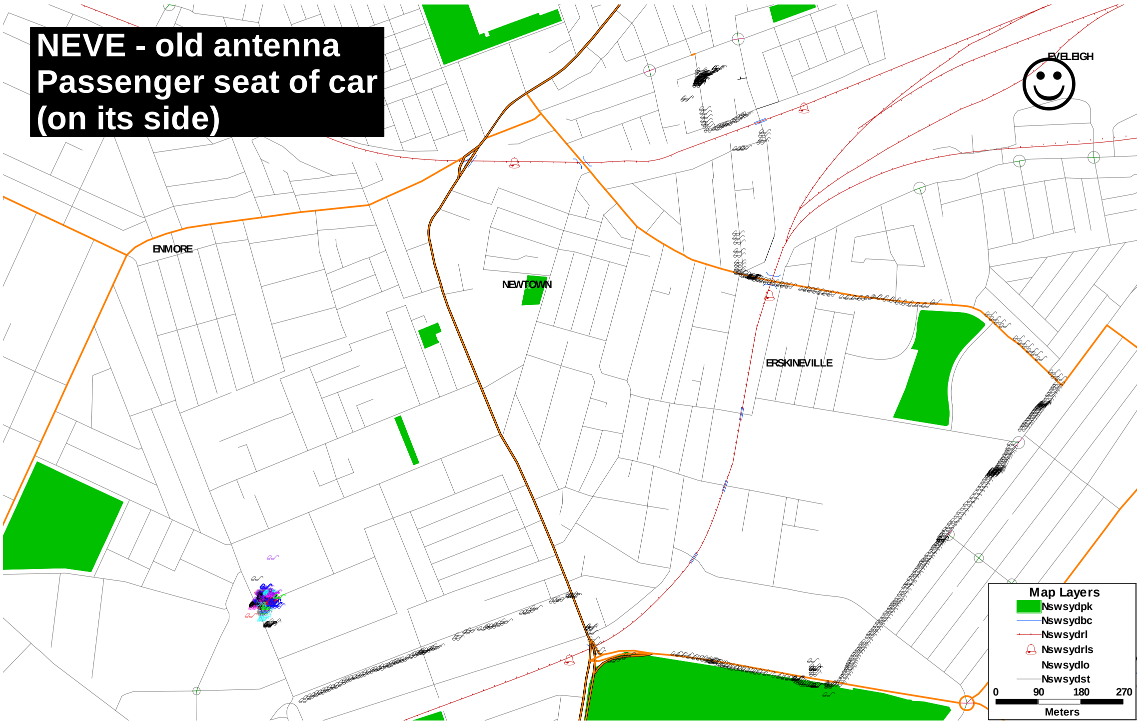

Figure 5: Old Antenna in Car

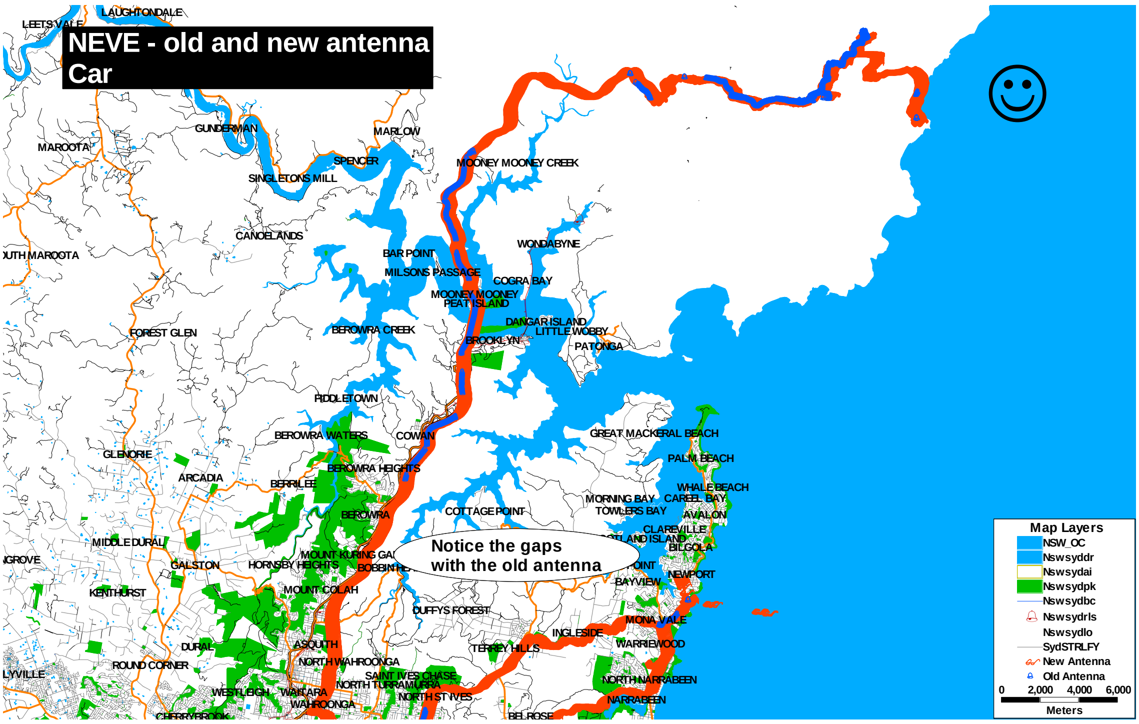

Figure 6: Old versus New Antenna in Car

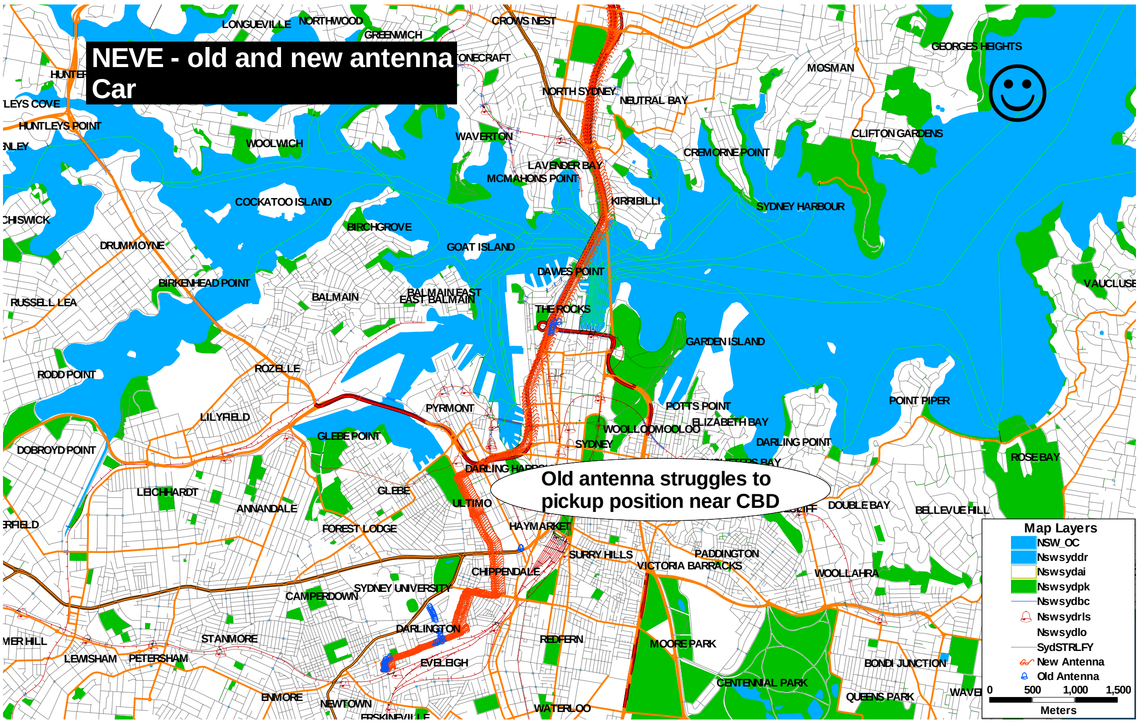

Figure 7: Old versus New Antenna in Car – CBD Problems

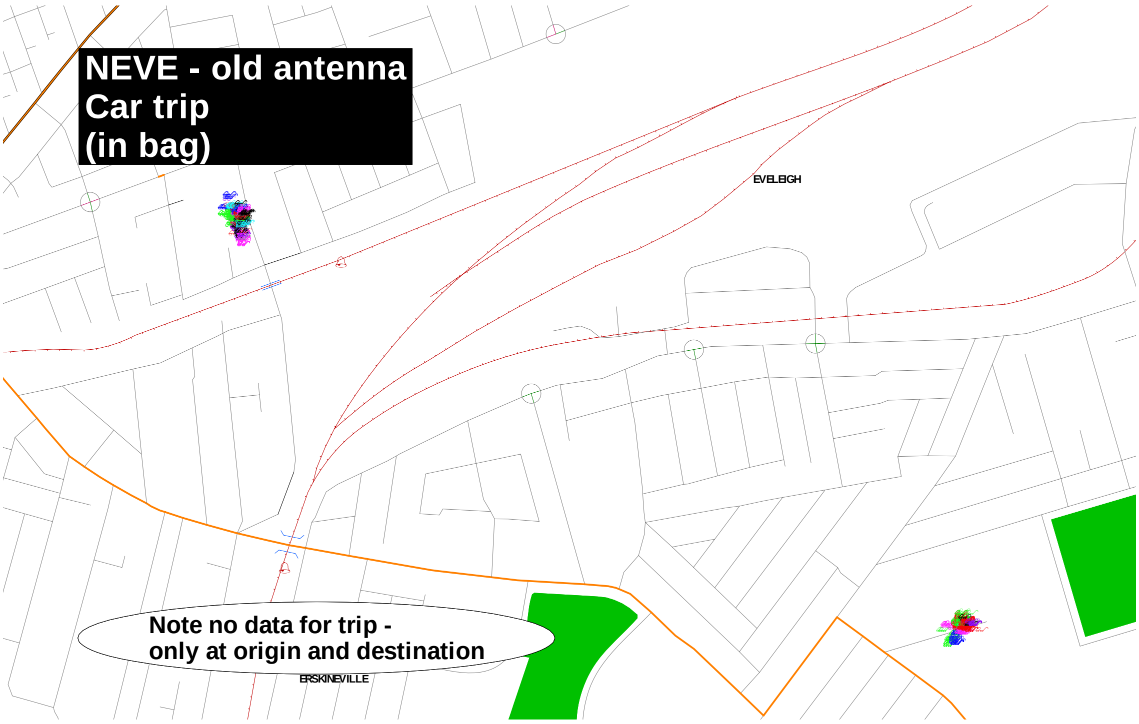

Figure 8: Old Antenna in Bag in Car

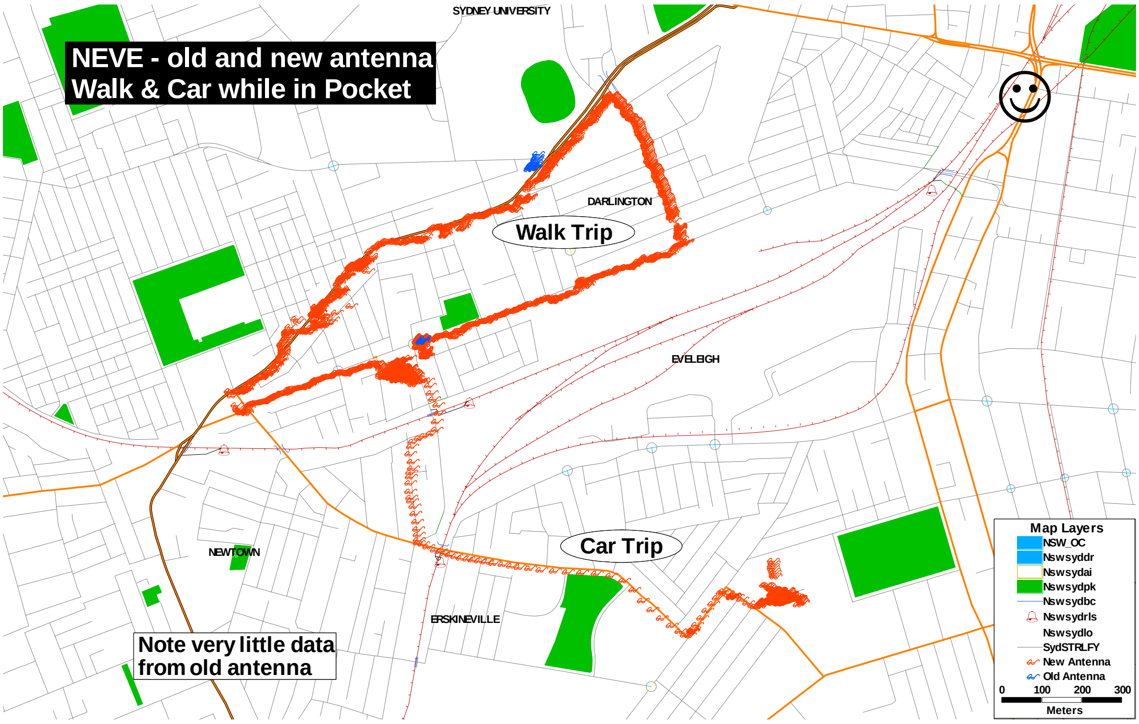

Figure 9: New versus Old Antenna in Pocket for Walk and Car

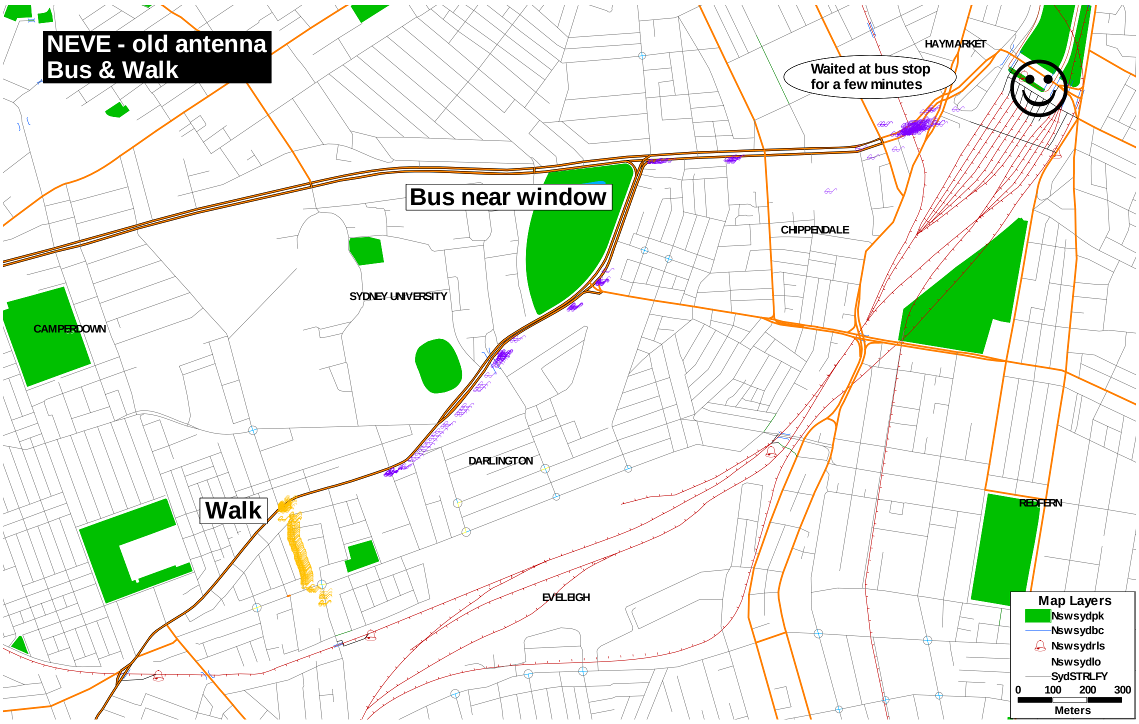

Figure 10: Old Antenna on Bus and Walk

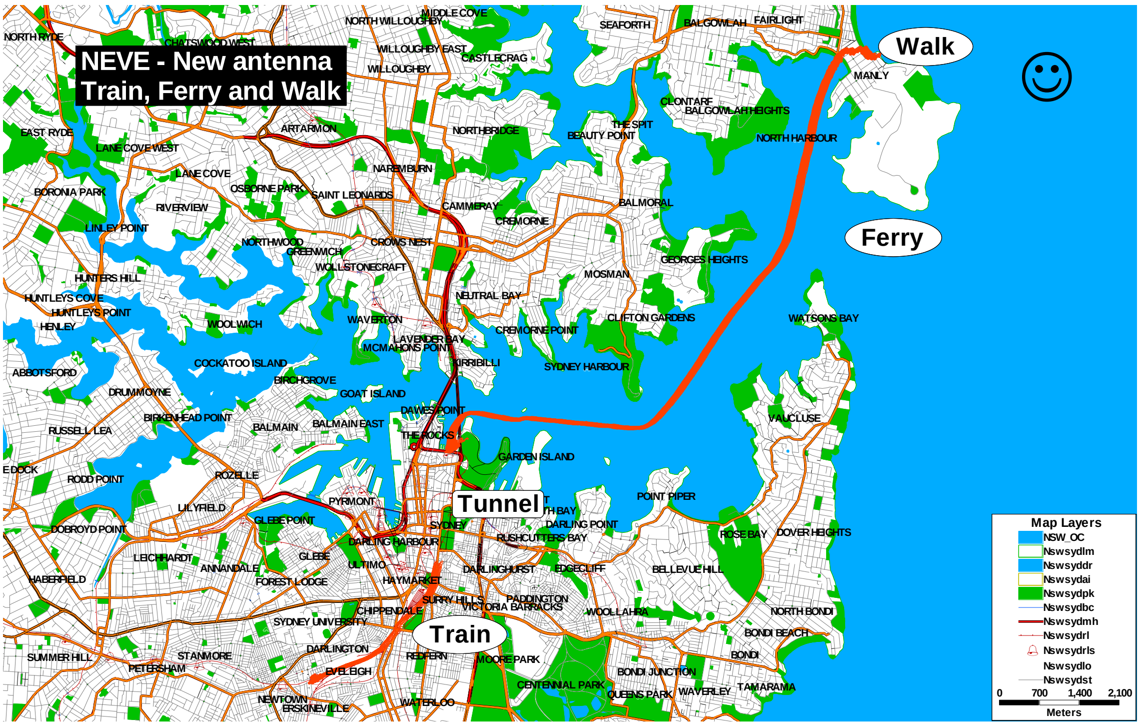

Figure 11: New Antenna on Train, Ferry, and Walk

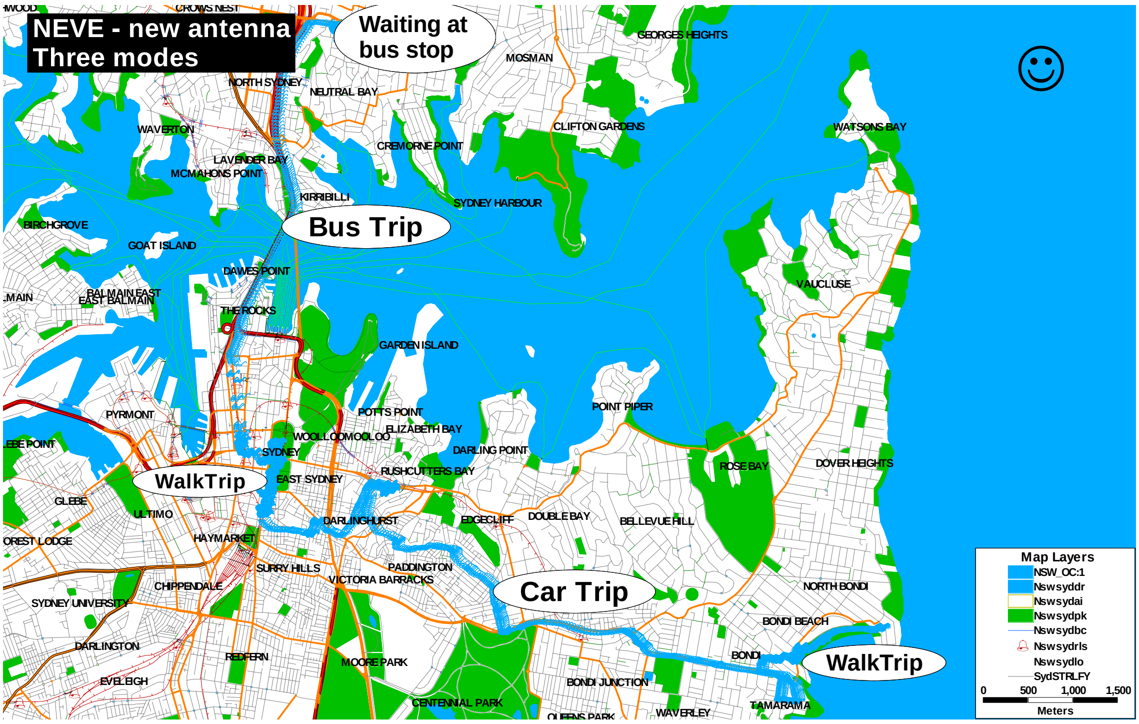

Figure 12: New Antenna for Car, Walk and Bus

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