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How effective can GSM signals, using DCM, be as an aid to coastal navigation?

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Abstract

The growth of the Global System for Mobile communications (GSM) network has been considerable in recent years, and coverage can be expected in the majority of larger ports around the world. Additionally, the positioning of base stations means that coverage often extends some distance out to sea. Previous research has established that by using GSM signals a relatively accurate position can be determined when using the Database Correlation Method (DCM) in built-up urban areas (Ahonen and Eskelinen, 2003).

Conducted in the Plymouth Sound area using commercially available software, this project examines the effectiveness of GSM signal positioning using DCM in coastal areas, specifically examining the possibility of using this technology to position vessels.

The results from this research show a clear trend of decreasing accuracy with increasing distance from shore, making vessel positioning impractical beyond 500m of the shore datum. However, the results do show that effective positioning can regularly be achieved to within approximately 200m once on the shore, with errors as low as 25m at times.

Further analysis breaks down these errors, establishing that approximately 13% of the recorded error is likely to be due to fixed errors, most likely caused at the time of database establishment. A major part of this is GPS error at this time, accounting for 10% of the fixed error.

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"Bessie" in Plymouth Sound

Photo Courtesy of A. Eccleston

Introduction

The principal aim of this project was to conduct a study into the feasibility of using GSM signals as a positioning aid when navigating in coastal areas. Specifically examining the question: “How effective can GSM signals, using DCM, be as an aid to coastal navigation?”. This may be for small pleasure craft as well as large commercial vessels.

GSM carrier signals are those used by the majority of the mobile phone networks around the world (with a few notable exceptions). If they could, therefore, be utilised for other means there is a very large potential market. There are several methods available when calculating position from received signals; however, the method most commonly used in previous studies is that of using signal strength from individually identifiable base stations (mobile phone masts), (Mexens Technology, Inc., 2007).

The last decade has seen a leap in the number of base stations in rural areas, so that companies can now boast 99% UK coverage (Orange, 2008). In coastal areas base stations tend to be placed right on the coast, and where possible, headlands in order to maximize coverage. The author’s own experience has shown that in the Channel, mobile phones will often work up to 12 nautical miles from land, and close-in on a clear day two or three base stations can often be spotted from any one position. These observations are backed-up by phone network coverage maps published by mobile phone operators such as Orange UK (Orange, 2008). Therefore, it was considered probable that moderately accurate positioning in coastal areas using GSM signals can be a reality.

This project’s study has been limited to coastal areas, specifically considering pilotage and when close-in to land. The project examines the level of accuracy achievable using software commercially available, and how it may be used in this marine environment.

The choice to narrow the research to that using the DCM is due to previous research that has been carried out. This consistently showed that, regardless of the initial position-determining method used, when data are compared to that in a pre-existing database, the interpolated position is more accurate. The GSM network naturally lends itself to this method as while signals are being measured for strength, access can be gained to the Internet via the same signal, and a central database accessed remotely.

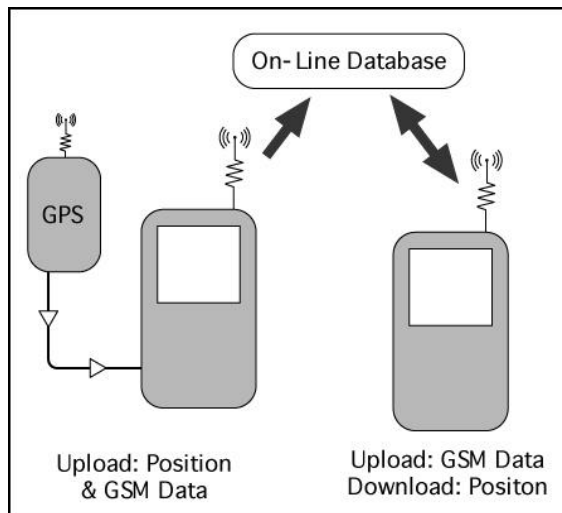


Figure 1: DCM Schematic

Fig.1 illustrates how DCM works in this application. GPS position and GSM signal strength data is uploaded to a central database. This information can then be interrogated at a later date by a phone without GPS data so that position may be interpolated.

This project report follows the chronological order of the project. Firstly the research undertaken is explained, providing the background to this project. The methodology used for data collection techniques are covered in detail, followed by the results from the data collection, and any problems encountered. The results are discussed, and further examination of the results made as a result. Finally, the conclusion examines what has been learned from this project and suggests further research that could be made into this subject area.

Work Plan

The Gantt chart at Appendix A sets out the timescale for this project. This has generally been adhered to quite closely. Overall the time allowed was more than adequate to complete this project. Much of the research was completed before the summer of 2008, therefore allowing for data collection to be completed in the relatively fine summer months.

The original intention had been to complete some data collection aboard commercial ships in foreign ports during summer sea-time. Due to circumstances beyond anyone's control this was not possible. Whilst this is unfortunate, it does not detract from the original project aims.

Research

The fundamental technology used when positioning radio signals, GSM or otherwise, falls under the heading Electronic Distance Measurement (EDM). Rüeger (1996) and Burnside (1991) provide considerable background information on the subject, of which the latter describes Scale and Zero (Index) error in considerable detail. Whilst the Database Correlation Method (DCM) used in this project varies somewhat from previously used radio positioning aids, although there are a number of principles that remain constant. The

methods described by Rüeger (pages 119 - 120) form the basis for some of the data collection methods used in this project and, in particular, the quantifying of possible errors.

One of the premises of this project is that in coastal areas there will be less obstructions to affect the propagation of the GSM signal. Both Mouly and Pautet (1992) and Lee (1995) examine the effects of physical obstructions on propagation path. The latter describes the results of propagation over water (p. 123), notably stating showing that the free space path loss for land-to-mobile over water is 20dB/dec as opposed 40dB/dec for land-to-mobile over land. This helps to back-up the evidence witnessed by the author at sea, where SMS messages have been received up to 12 nm from the shore.

The effect of weather on propagation was an initial concern, as this will alter with time. Hence, DCM cannot take account of its effects. Janes (1986) carried out considerable research into tropospheric effects on radio positioning. Despite its age, this research is particularly relevant as the Ultra High Frequency (UHF) frequency ranges researched are comparable to that of GSM. The research states that in a worst-case scenario (with unstable air masses), the atmospheric and tropospheric influences would appear to limit the accuracy of trans-horizon UHF ranging to 100-500 ppm. In the context of positioning a vessel during coastal navigation, or even pilotage, this value becomes relatively insignificant. This inaccuracy can be considered to be reduced further as ranges required for the purpose of this project are limited by the power of GSM transmissions: no more than 12 nautical miles based on the evidence above. To quantify this further, if a vessel was 5km from a base station the error would, at worst, be 2.5m based on the outcome of this research.

'Database correlation method for GSM location' (Laitinen, Lahteenmaki, et al., 2001), appears to be the first research of note on the subject of GSM (DCM) location, and has been subsequently referenced by nearly all papers examining the subject. The paper looks at the concept of using DCM with GSM and other phone signals and describes practical research carried out by the authors examining the accuracy of the technology. The research focused mainly on urban and suburban areas, which at the time would have provided the necessary base-station density for research. The testing was carried out using a vehicle travelling at 45 km/h, which whilst fine for the purposes of the research, may result in a decrease in accuracy. Data from a static or relatively stable slow moving receiver (for example a large ship at manoeuvring speed) could benefit from the ability to average results. Advances in technology since the writing of this paper resolved many of the issues raised by its authors; for example, the establishment of a central database.

Software now available, including that proposed for use with this project, has capitalised on the rapidly developing mobile communication and mapping technology, overcoming the greatest perceived problem in this earlier research.

'Mobile terminal location for UMTS', Ahonen and Eskelinen (2003), developed on the above research by using Universal Mobile Telecommunications System (UMTS) networks, and again research focused on the urban environment. (UMTS is the next evolution of GSM, often referred to as 3G and 2G respectively.) Crucially this research differed from the earlier work by using a software model to predict accuracy making it difficult to assess how it may differ from 'genuine' data. Of particular note, however, is the fact that an accuracy of 25m for a 67 percentile was achieved in this study. Accuracy of this magnitude would almost certainly have a practical use in the the real world, an especially in the marine environment.

Ahonen and Laitinen developed this research, specifically looking at DCM (Ahonen and Laitinen, 2003). Not surprisingly, the paper quotes much of the same research and results, although geared to looking at it from a DCM perspective. The simulation results presented give an accuracy of 50m for 84% of the time and 100m for 92% (p. 2669). However, this paper also notes that the "hearability" of base stations could become a hindrance on UTMS networks. There is a conflict between those wishing to monitor multiple base stations, and the operating companies, who are trying to limit unnecessary bandwidth usage. For this reason the operators have a tendency to minimise the "hearability" of some base stations, thereby avoiding mobile receivers switching back and forth between stations.

'Cellular Based Location Technologies for UMTS' (Ludden and Lopes, 2000), examines the use of Observed Time Difference Of Arrival (OTDOA) location method using the UMTS network, rather than GSM. The simulations produce promising results with only 13m (67 percentile) error in rural areas for non-time-aligned measurement, but would be subject to the limitations described above.

'Database correlation for positioning of mobile terminals in cellular networks using wave propagation models' (Zimmermann, Baumann, et al., 2004), primarily examines the use of models to establish a database. The positional accuracy of the results obtained are not overly significant given the use of a calculated database, however, the research does present some points that are especially relevant to the proposed project. The manor in-which the data was collected and its subsequent presentation gives clear indications as to how best collect and process the data for the proposed project. Of course, there would be crucial differences between the research in this project and the proposed. This paper is the only one found on the subject that explores map matching; a software algorithm than 'snaps' a position back to a know path, normally a road. This highlights one of the key difficulties when positioning on water. There is no fixed road to navigate along.

The automotive sector has established itself as a major consumer market for navigation devices. Sage (2001) explored what might form the technology base for this market in 'Future Positioning Technologies and their Application to the Automotive Sector'. In the years since this paper was published this sector has rapidly developed, however, Sage's explanation of the (then) future technologies is of particular relevance to this project. The Time of Arrival (TOA) method of positioning, whilst not the method to be used by this project, is rapidly developing as a realistic option and has been explored in other papers including those described below. With the latest generation of mobile phones

integrating GPS receivers, one of the primary obstacles in rolling out TOA positioning method has been removed: measuring the time of arrival by using the GPS time code.

Part of the original concept for this project was the premise that this technology may have possible applications and assist with safety at sea. Wilde, G. (2002) highlights that Location Based Services (LBS) have considerable revenue potential, notably in the Assisted GPS (A-GPS) market.

'Integration of a GSM Receiver with GPS for Integrated Navigation or for Quick Satellite Signal Acquisition', Favey, Megnet, et al. (2005), emphasises the fact that GPS is far from infallible. It may give inaccurate positions for a variety of reasons, or be unable to receive satellite signals at all. Therefore, non-GPS based electronic positioning aids can have a number of possible uses. The most obvious is as a back-up to GPS, or acting as a autonomous double check from a totally independent source. The study has shown that GSM signals can also be used to improve weak or poor GPS results if integrated in a hybrid system. (Although not referred to by name in the paper, this is a derivation of A-GPS). In fact, this paper went one step further and illustrated the potential for a weak GPS signal to increase the accuracy of GSM, by utilising the highly accurate satellite time code. This may have great potential given the introduction (in 2007) of the very latest generation of mobile phones, which now integrate GPS receivers into the handset (Apple, 2008 and Nokia, 2008).

The Volpe Report (2001) into the vulnerability of transportation infrastructure which relies on the GPS system is regarded as the seminal work exploring GPS weaknesses. In particular it states that there should be "an effort to... encourage the development of affordable vehicle-based backups" (Volpe, 2001). Whilst the system proposed for this research relies upon GPS for the establishment of the on-line database, any system, provided it was accurate enough, could be used to establish the database.

As its title suggests (despite its early publication date), '*GPS and Cellular Radio Measurement Integration*', Kitching (2000), is of relevance. Paragraph 3.4 describes the Circular Method of measuring position using the TOA. Although the TOA is not the method used by the software in this project, Figure 5. could equally apply to the Received Power Level method of distance measurement. The Cell Identity Method described in paragraph 3.2, is utilised by the Navizon software when initially determining a position, (Mexens Technology, Inc., 2007).

'*Database Correlation Method for Multi-System Positioning*' (Kemppi and Nousiainen, 2006), has developed the findings of several of the works reviewed here, primarily that by the VTT research centre, proposing an algorithm to exploit multiple network inputs. Although no new data relating to GSM (DCM) positioning is presented, the paper explains the Kalman filtering techniques used. The paper is tended towards urban navigation, utilising wireless networks (WiFi) and map-matching, however, much of the information presented is applicable to navigation in the marine environment.

Although not directly associated with this project, the Emergency Call (eCall) European Community requirements (encompassing the E-112 and E-911 requirements), described in the eSafety Support website (2007), remind us that

the ever-more accurate positioning of phones is becoming a legal requirement. Whilst GPS may provide the needed accuracy for such a system, GPS's vulnerability to interference, deliberate or not (as highlighted by Volpe, 2001), could render this system ineffective.

Methodology

Equipment Used, Location, and Common Method

Data collection was carried out on foot and from a yacht in the Plymouth Sound area of Devon as indicated in Figure 2. Plymouth Sound forms part of HMNB Devonport, however, access is rarely restricted for non-government vessels and the general public.

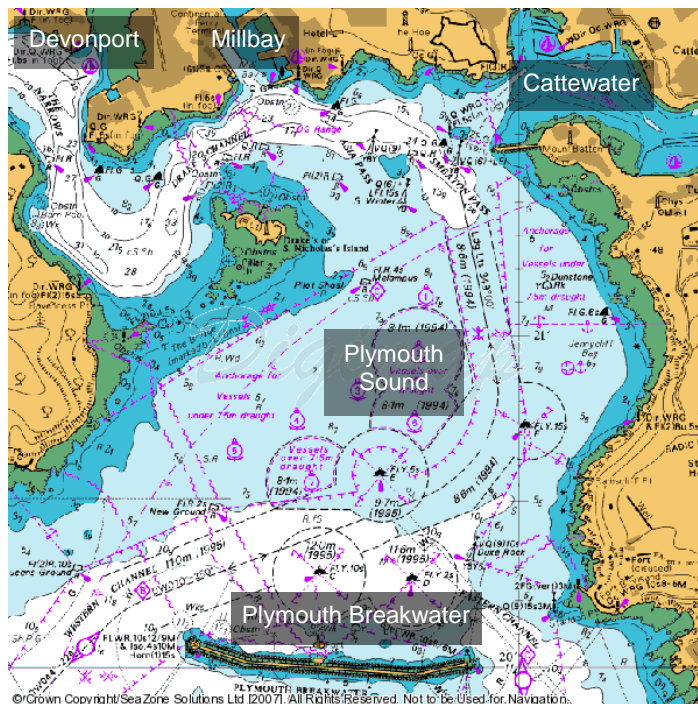


Figure 2: The Plymouth Sound Area

Chart: © Crown Copyright/SeaZone Solutions Ltd. [2007]. All Rights Reserved. Not to be used for Navigation.

See Appendix B for larger chart.

To the North East of the Sound lies the mouth of the River Plym, and within this the Cattewater, a commercial harbour area, where wood, oil, other petrochemicals and many other commodities are loaded and discharged daily. To the North West lies HMNB Devonport, home to Royal Naval Submarines, Frigates, Amphibious Assault Ships, and HMS Ocean, the largest vessel in the Royal Navy. To the North, Millbay docks, receiving cross channel ferries daily. In addition, thousands of pleasure craft are moored around the sound and its tributaries. South of Plymouth Breakwater is The English Channel.



Figure 3: GPS Receiver and Mobile Phone Used

The GPS data was collected using a GlobalSat bluetooth GPS receiver, either paired with a laptop (for collection of GPS data), or paired with a phone when uploading combined GSM and GPS data to the DCM database (Fig 3.). The phone used was a HTC 710 running Microsoft Windows Mobile 6. This allowed for a GSM data to be output to a serial port and logged as if GPS data in a NMEA format file. Prior to data collection the laptop clock was synchronised with the GPS time using the inbuilt software utilities, and the phone then automatically synchronised with the laptop, thus ensure all time recording was in sync. The software to be used in this project, called Navizon, is currently the only commercially available software using GSM signals and DCM, and although only recently developed has grown a large customer base. This software uses data recorded by customers using GPS receivers connected to their mobile phones, which is then uploaded to the Internet. As new data is uploaded this is added to the global database, which can then be accessed by anyone using a GSM phone or similar device.

On land, data was collected on foot, as all equipment could be easily carried. At sea data was collected onboard the yacht Bessie. For the majority the data collection the yacht was used as a power-driven vessel. She is equipped with state of the art electronic charting equipment with autopilot (Fig. 4)



Figure 4: The navigation equipment used during data collection
Photo courtesy of A. Eccleston.

enabling simple navigation, ensuring the vessel could follow the charted navigation channels. Additionally, this gave a level of redundancy, as passage data could be easily saved and utilised for the project if necessary. The GPS and GSM receivers were secured on the main upper deck forward for the cockpit; here they were protected from rain and spray by the canvas and plastic screen. The laptop could be secured safely in the main cabin with a power supply, if needed, utilising the GPS's wireless Bluetooth link.

Prior to undertaking any data collection it was necessary to ensure adequate satellite visibility, as GPS will be required to compare GSM derived positions against. This was done using Trimble Navigation Ltd. software, and results can be found at Appendix C.

As the project makes use of commercially available software (Navizon), the database from which position will be calculated is already established. However, the software website provides live information on data collected, and it was clear that current recorded data for the Plymouth Sound area was scanty at best. To ensure this is up to date, an initial run around the study area was made to build and update the database where necessary.

The datum used throughout this project is WGS84 unless otherwise stated.

Static Trial (Onshore)

An initial static trial was carried out on the shoreline using an Ordnance Survey (OS) Trig Point. After ensuring the database for the area was up to date, the GSM receiver was placed on the trig point and left to record for one hour. The trig point (Fisher's Nose) having a known position of 50°21.79263402'N, 004°08.07155903'W provided the ideal location for data recording (Ordnance Survey, 2008). The position was synchronised with the online database at 20 second intervals. The results from this trial are shown in the 'Results' section.

Establishing GPS Receiver Accuracy (Onshore)

The GPS receiver was placed on an OS trig point on the waterfront for one hour, similar to the static trial, above, and the position recorded every second. The results are shown in Figure 9, in the 'Results' section.

Moving (Afloat)

GSM derived position data was recorded over the duration of the trip around Plymouth Sound. Simultaneously and independently, GPS position was logged for later comparison. The precise speed of the passage is not important, as it is envisaged that speeds of greater than 6 kts are unlikely given physical and local restrictions.

Static Control Range (Onshore)

In a separate experiment a baseline was established along Plymouth Sound water-front to establish the constant errors within the GSM positioning equipment. Acting as a control range, this baseline consisted of static positions recorded on prominent piers, jetties, and trig points. This is shown in Fig. 5, below. The GSM derived position of each of the four positions was recorded, the results from which are shown in Figure 12, within the 'Results' section. Each of the positions was recorded in turn, walking from one to the next. Before recording the Latitude and Longitude, the receiver was left on the position for 2 minutes to ensure the position had settled and had synchronised with the online database.

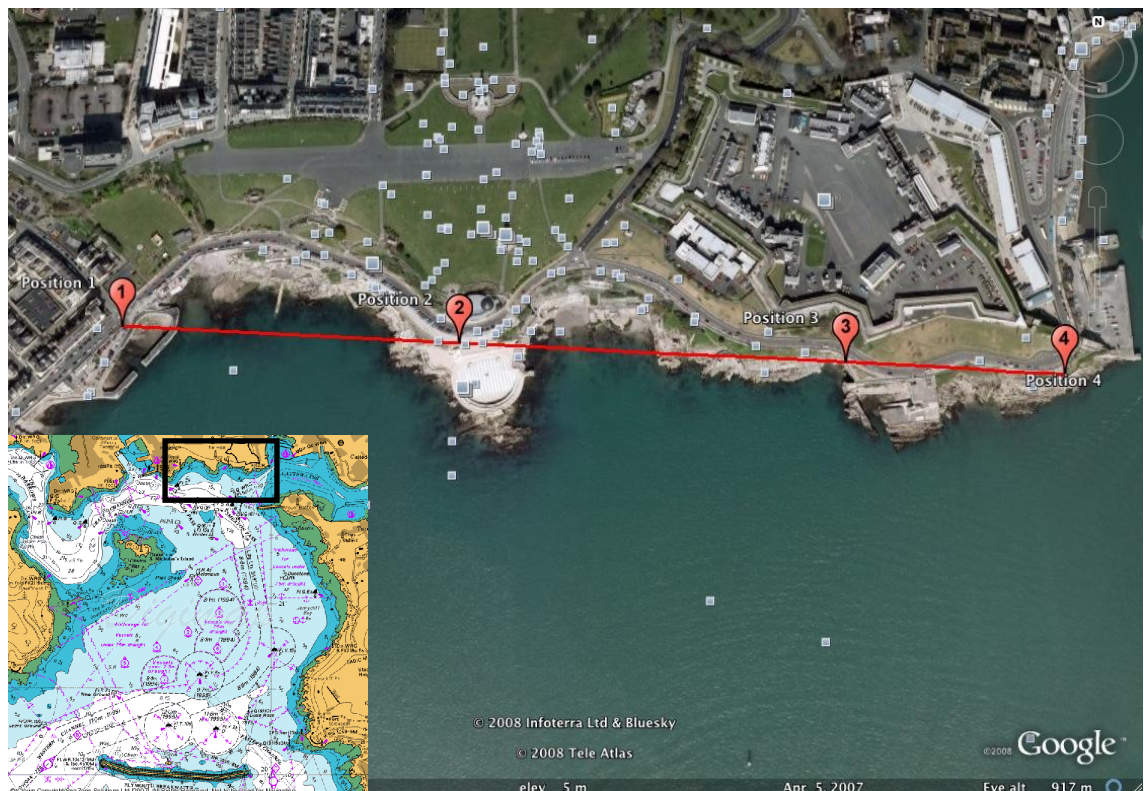


Figure 5: Collection Area for Baseline Data

Aerial Photo: ©2008 Google, ©2008 Tele Atlas, ©2008 Infoterra Ltd. and Bluesky.

Inset Chart: © Crown Copyright/SeaZone Solutions Ltd. [2007]. All Rights Reserved. Not to be used for Navigation.

These can be verified using Admiralty charts available for the sound, thereby removing any GPS induced error in comparison data. The positioning of these points has been chosen to allow zero (index) error to be calculated, based on the methodology described by Burnside (1991), pp. 119 - 120. It is important to note that the original object of this project is to study the practical application of GSM ship-positioning on water, survey-grade DGPS data for these static locations would be completely unnecessary in normal navigational situations.

Problems Encountered

As the software is commercially available, and therefore well tested, it was considered that the data collection should provide few problems. However, projects rarely go to plan, and this was no exception. These issues are discussed below:

Refresh Period

A short static feasibility study was conducted in the area of study, Plymouth Sound, to ensure the software worked in the region. These provided surprisingly accurate results, giving considerable confidence in the data collection method. (These are shown the 'Results' section, below.) However, subsequent results proved to have little accuracy with GSM signal strength not appearing to refresh, except at the initial switch-on. Communications with the software developers (Øveraas & Brewer, 2008) concluded that this was most likely due to attempting to communicate with the online database too frequently (every two seconds), therefore not allowing the software enough time to establish the signal power strength.

The interval was increased to 20 seconds (as in the static trial), and the collection exercise rerun. The 2 second and 20 second refresh results are shown in Figure 10. In the marine environment, fixing at this sort of interval is not only impractical, but unnecessary. Although a 20 second interval would not provide apparently seamless updating on an electronic chart, similar to GPS, it is not strictly necessary. Traditional fixing is only required at a 3 minute interval in pilotage situations (Bowditch, 1995).

Base Station Location

The Navizon software provides an online map of areas where the DCM database has been established, indicating the positions of base stations. Whilst not a problem for this project it was observed that over the test period, as the database was updated, base stations appeared and disappeared from the online map. The reason was not initially clear, however, when compared to the OFCOM online database (OFCOM, 2008) the base station positions do not correlate, as is illustrated in figures 6 and 7. It is perhaps worth noting that when looking at Fig. 7, several companies' antennas may be on a single mast. These would be represented as a tight cluster in Figure 6. Some are close to their actual position; however, there are many additional 'virtual' LBS locations. It is not clear if this is a source of error, or simply an error in the graphic representation. As it is possible that this could be a source of error, it is an issue that would need to be resolved prior to this method being employed in any practical application.

A limitation of DCM is that it is completely dependent on the accuracy of the original GPS data used when uploading GSM/GPS positional information to the database. In the case of this project, it was hoped that re-establishing the database for the study area, as described in the methodology, would help eliminate this additional source of error.

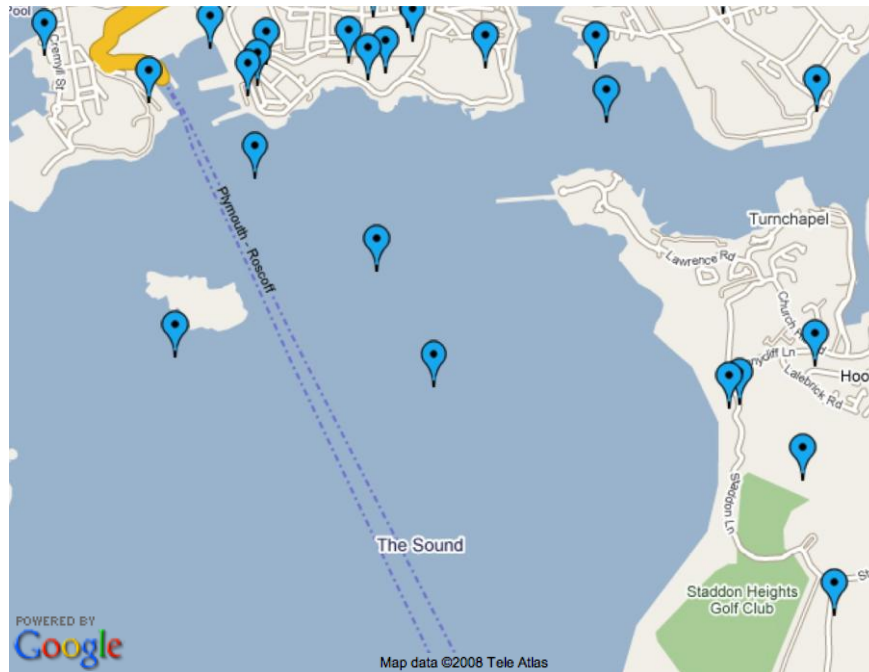


Figure 6: Navizon generated DCM Database LBS Location Map

Powered by Google - Map Data ©2008 Tele Atlas

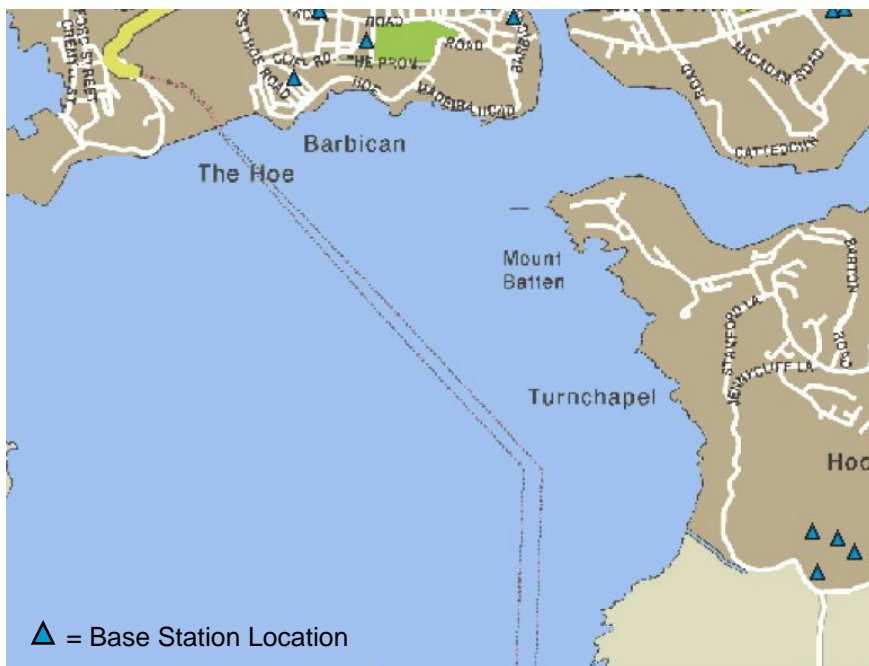


Figure 7: OFCOM (2008) Sitefinder Database LBS Location Map

Results

The results from the data collection are shown below. The initial overall impression is that the results have provided a useful data-set, however, there are several issues which are discussed in the analysis.

Static GSM Trial

Examination of the data in Fig. 8 shows that the error jumped from 218m error (A) down to 34m (B) just over two thirds of the way during the experiment. These positions have been plotted on a aerial photo shown in Fig. 9. No position could be estimated for 1% of the results.

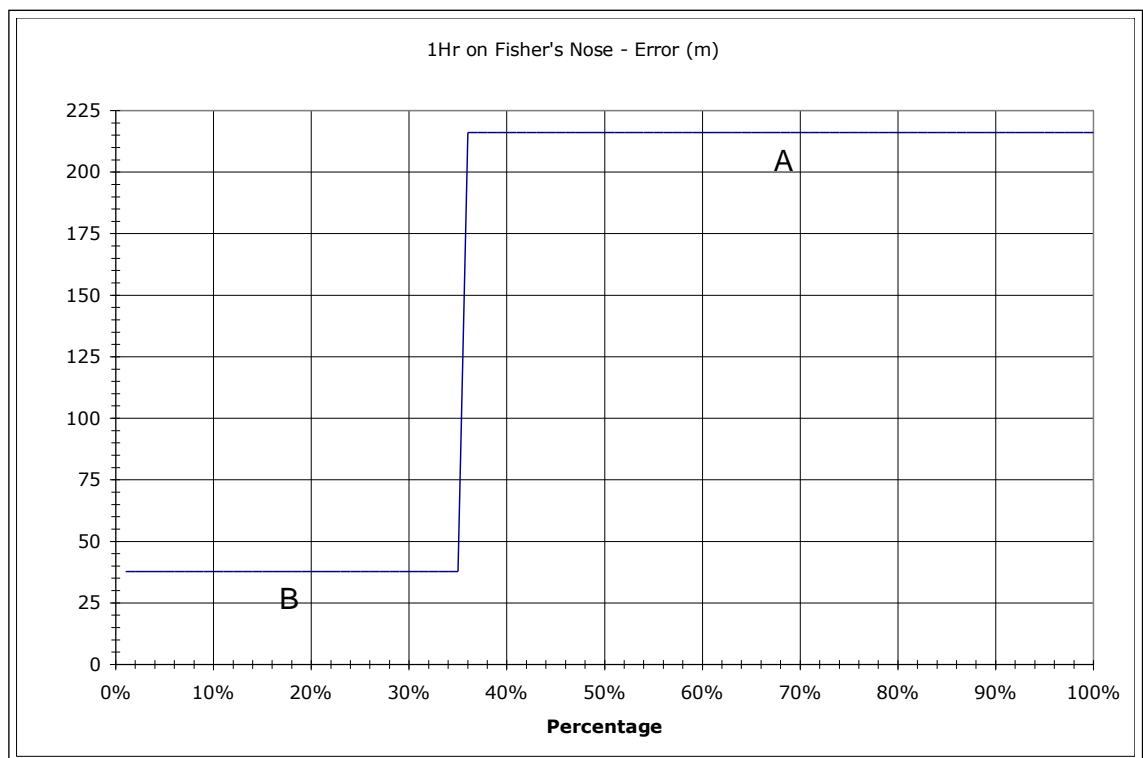


Figure 8: Static GSM Error

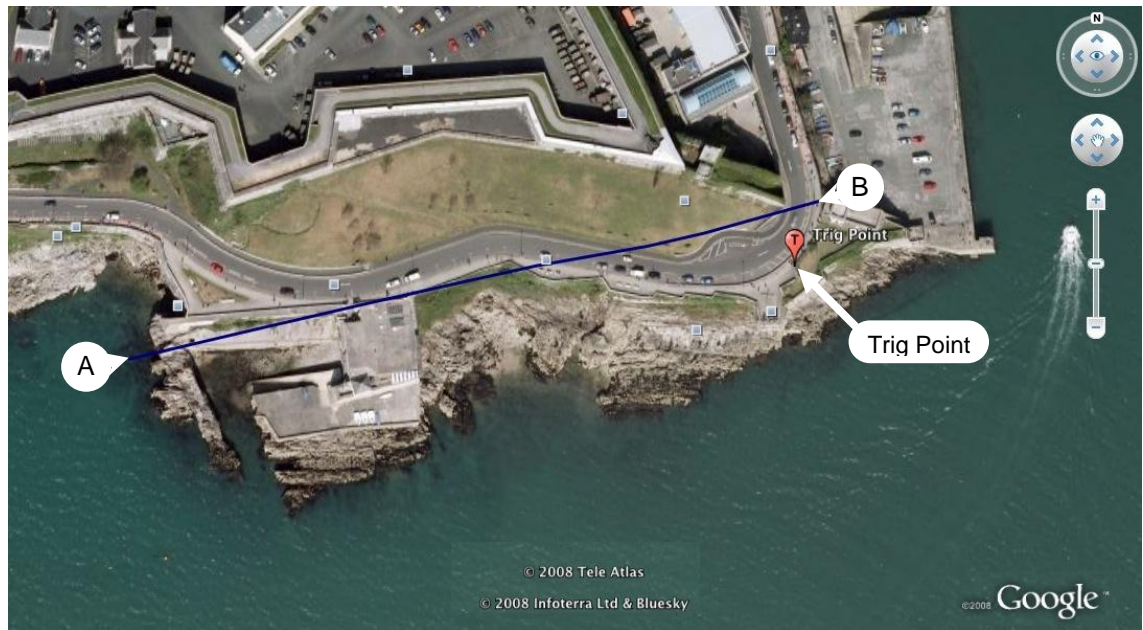


Figure 9: Static GSM recorded positions.

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Establishing GPS Receiver Accuracy

The plotted graph shows the error (in meters) as a percentage of the recording time. For example, the receiver recorded a location within 2.2m of the actual location for 80% of the time.

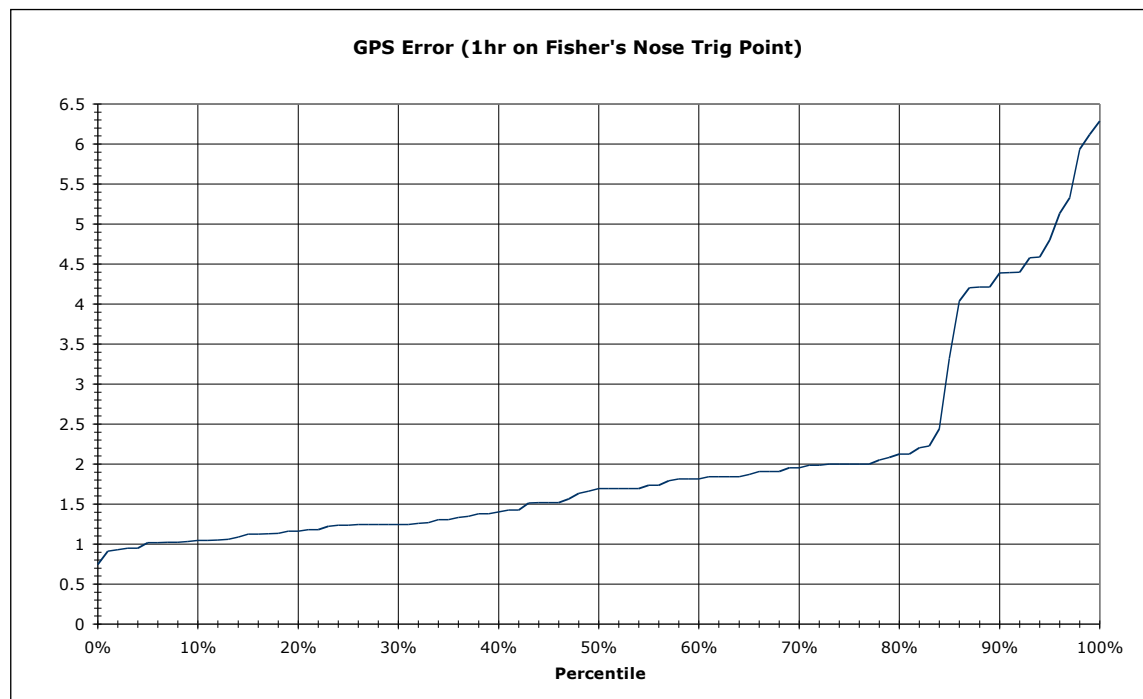


Figure 10: GPS Error

Moving GSM Trial

The purpose of collecting these results was to see how the results would vary if moving, as this would be more representative of actual navigation. Initial results whilst moving were not as good as hoped as described above under the heading 'Problems Encountered'. After consideration the source of the error was deemed to be refresh time. The results below show the initial 2 second refresh, and the subsequent 20 second refresh interval results.

It was clear throughout the first run that positional data was not updating regularly, and the most accurate result recorded being some 500m from the vessels actual position, and 67% of results being 2134m from their true position.

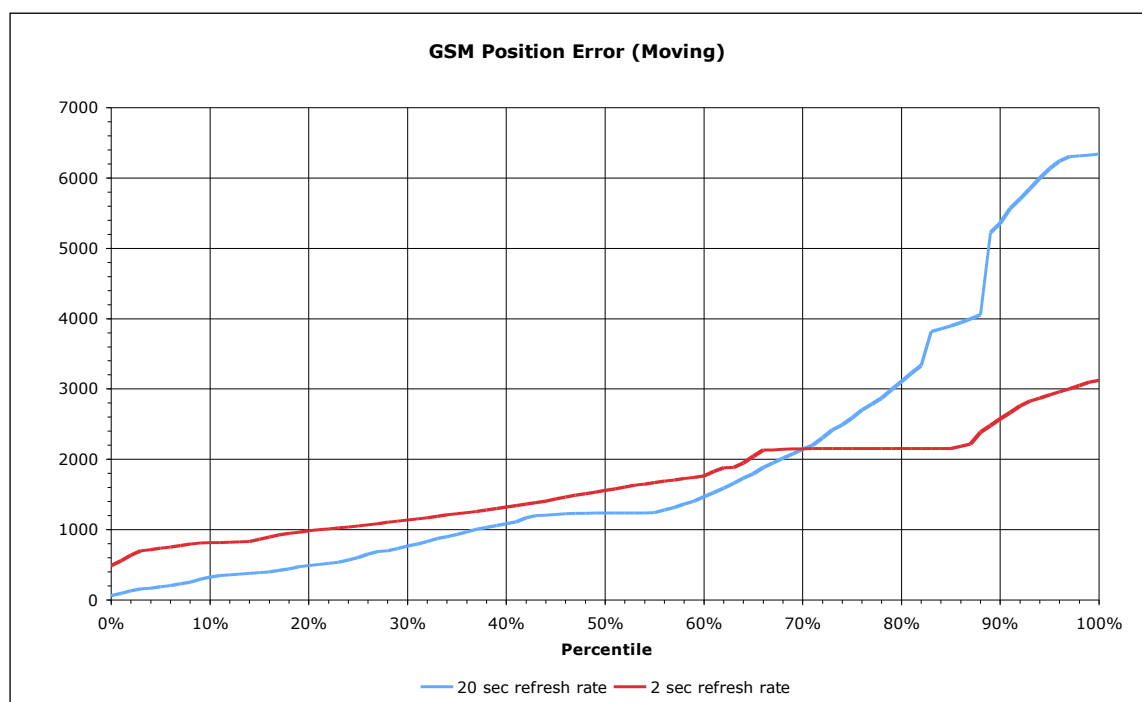


Figure 11: Moving GSM Accuracy

At first glance the second set of results appear to be less accurate; however, up to 67% of these are consistently 200 to 500m more accurate. The accuracy for 67th and 90th percentile of the results from the above trials are shown in Table 1:

	67%	90%
Static	218m	218m
Moving (2 sec refresh)	2134m	2574m
Moving (20 sec refresh)	1951m	5358m

Table 1: GSM Accuracies Recorded

The difference between the static and moving results is considerable, and somewhat higher than expected at the outset of this project. Neither set of results take into account GPS error during the establishment of the database.

Static Control Range

Figure 12 shows both the measured results from this experiment, and the original positions for comparison.

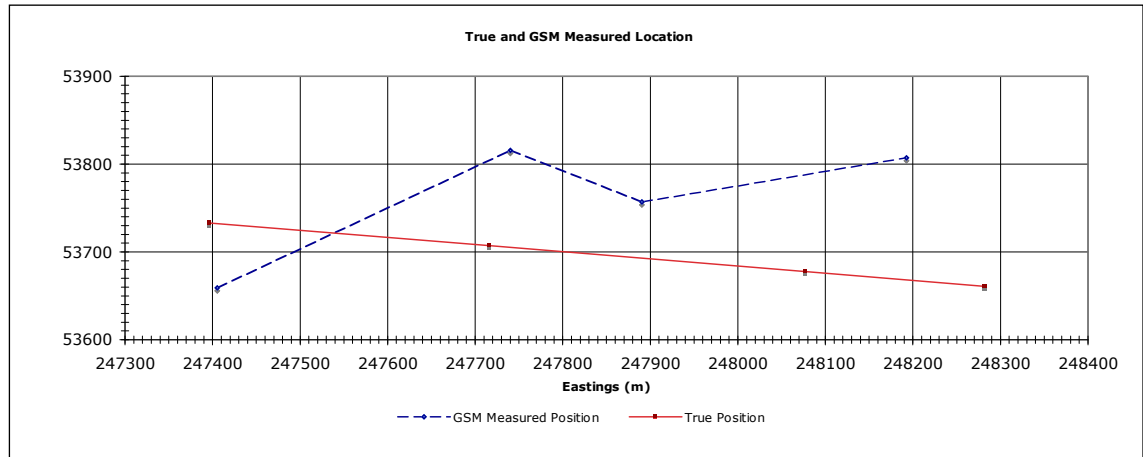
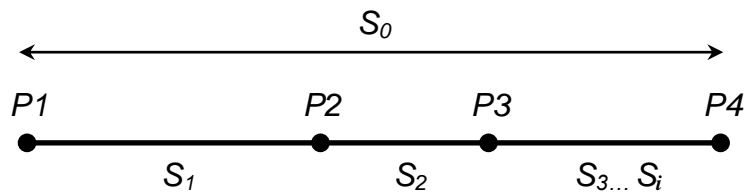


Figure 12: True and Measured GSM Baseline Positions

The Zero (Index) Error can be calculated from these results using the following equation (Burnside, 1991):

Where:



C = Zero Error

i = number of parts (3 in this instance)

S = True Distance between P1 and P4

Assuming: $S = S_0 + C$

and: $S = (\sum S_i) + iC$

$$C = \frac{S_0 - (S_1 + S_2 + S_3)}{i - 1}$$

The results of the calculations are shown in Table 2.

Distance	Relative Distances (m)		Zero (Index) Error Calculation (C)
	GSM Measured	Actual	C = -18.159 m
S ₁	369.57	320.79	
S ₂	161.31	362.38	
S ₃	306.49	205.82	
S ₀	801.06	888.98	

Table 2: Zero (Index) Error Calculation Results

To allow comparison with the previous static data Table 3 shows the four positions recorded.

Position	Error (m)
1	74.6
2	111.2
3	202.6
4	171.6
Mean Error	140.0

Table 3: Baseline GSM Position Errors

These values compare well with a mean error of 156m recorded during the initial static GSM trial (at Fig. 8).

Discussion

Static GSM Trial Results

The graph in Figure 8 shows that the power level monitoring resolution is probably somewhat lower than that anticipated, only altering the receivers measured position once during the one hour trial. This jump in measured position appears to be quite considerable (218m to 34m). However, the second position, settled on after 40 minutes, is somewhat closer than was expected when compared with previous tests reviewed whilst researching this project.

There could be several explanations for this, however, it might easily be something as simple a lorry parked near the transmitter or receiver that moved on, increasing base station visibility.

There was the initial thought that a datum spheroid other than WGS84 might have been used for the Ordnance Survey trig point position (which would

impose a 100m of error). However, any concern regarding this was removed by placing the GPS receiver on the trig point in the test below.

Establishing GPS Receiver Accuracy

Based on experience, the errors recorded in Fig. 10 were in the region of that expected. For the purpose of this project errors of a few meters are of little concern when positioning vessels. However, the error must be taken into account in any final calculations. At no time was the error greater than 6.3m and the 67th percentile was within 1.9m of the actual location.

Moving GSM Trial Results

The reason for the sudden divergence of the results between 70% and 100% in Fig. 11 would appear to be caused by a totally independent factor. As the second data set was collected over a larger area there was the thought that this could be due to proximity from the shore. Initial examination of the raw data suggests this would be plausible.

As a follow-up a chart was plotted to show the accuracy of the GSM derived position against distance from shore. These results are plotted in Fig. 13, below.

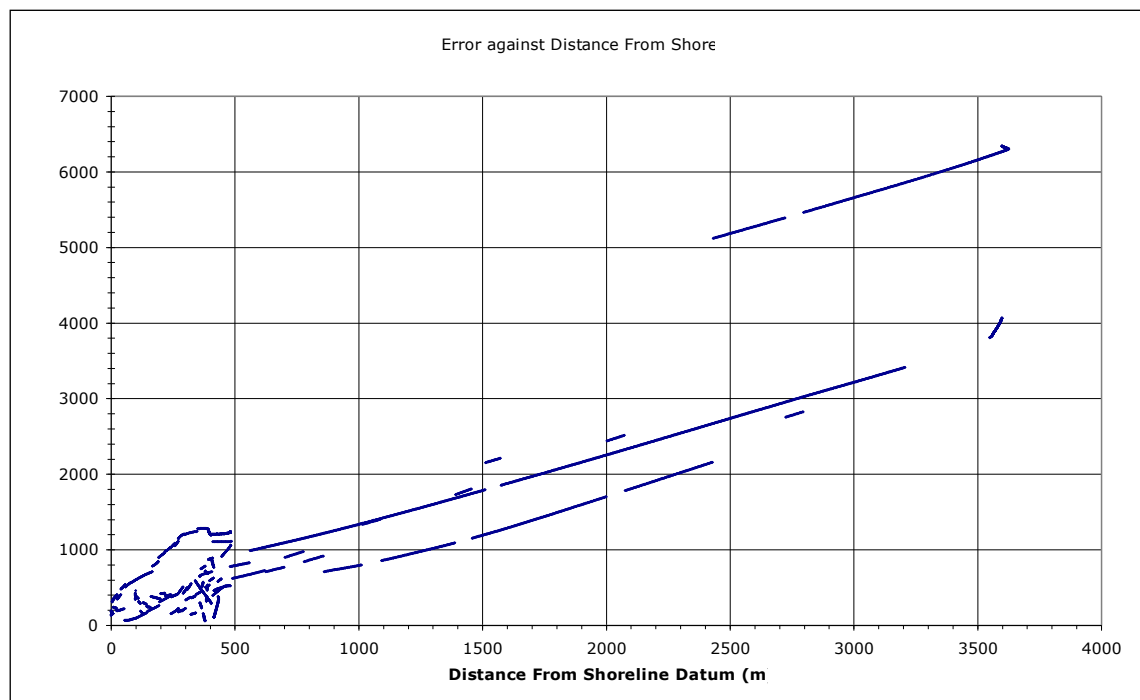


Figure 13: Error Plotted Against Distance From Shore

Above about 500m there is an almost exponential decrease in the fixing rate, indicated by the breaks in the lines. Correlating to this, the results show a clear trend of decreasing accuracy with distance from shore. This is discussed further in "Conclusion and Discussion" heading, below. The gradient of these lines can also present us with further information. A gradient of 1, seen for much for the graph indicates that the GSM receiver had positioned us on a line

perpendicular to the shore datum. Essentially it has placed us correctly along the shoreline, but has incorrectly calculated the distance from the shore. A vertical line would indicate the receiver being placed the correct distance from the datum, but unable to position it along the datum line. This is expanded upon and the reasons are discussed further in the "General Analysis" section, below.

Static Control Range

The Zero (index) Error is a constant error that arises from many sources. It is likely that a great deal of these errors have originated from within the GSM receiver equipment, in its measurement of the signal power strength. As the true positions were determined independently from GPS, this error also includes any GPS error recorded during establishment of the online database. Once in the database this error will become a constant applied to every reading. As indicated in Figure 10, the error can be over 6m, and an error greater than 1m should be expected for nearly all of the time. However, this GPS error could easily be worse, especially if taken at a time of poor satellite visibility or at a time with high dilution of precision (DOP). Unfortunately, as the GPS/GSM data can be uploaded by anyone at anytime, the quality of this data cannot be assessed.

Composition of Zero (Static) Error

If the 67th percentile values are used as a guide, approximately 10% (1.85m) of the zero error is likely to be down to GPS inaccuracies. A percentage of the index error is also likely to be caused by the distance between the GPS receiver and the GSM receiver at the time of database establishment. As this cannot be measured due the database already being established by unknown third parties an estimation must be made for this value. If this is assumed to be 0.5m, this accounts of a further 3% of the error. In all, this would put approximately 87% of the zero error down to a combination of constant errors in the power measurement of the receiving equipment and algorithms errors within the database.

Overall, the zero error accounts for approximately 13% of the total error experienced. The cause of the remaining error is explored below.

General Analysis

The research at the outset of this project showed that the original concept and question posed is sound. There were some areas that were a cause for concern; however, initial testing went some way to negating these issues.

The difference between the static results and those taken onboard a vessel cannot be overlooked. It would be wrong to presume that these differences are solely down to one set being static, and the other not. The static results are of similar magnitude to those recorded in previous studies such as Kemppe and Nousiainen (2006), where accuracy for the 67th percentile was 280m in the urban and suburban environment (compared with 218m in this study). Kemppe and Nousiainen also note that topography is likely to be the biggest cause for

disparity between results in their study of urban and suburban areas. It is highly probable that this is the reason for the disparities in this project also.

One of the initial premises for this project was that the coastal environment would provide an excellent topography from which to obtain a position from GSM signals, however, it would appear that this technology is heavily dependant on the position of base stations to provide an optimum fix. The original intended purpose of the mobile phone network requires a phone to lock onto a single base station. As highlighted by Ahonen and Laitinen (2003), it is not in the network operators' interest for a base station beyond that being locked on to be visible to a handset. This wastes power and bandwidth. Figs. 14 and 15 show how this can become an issue.

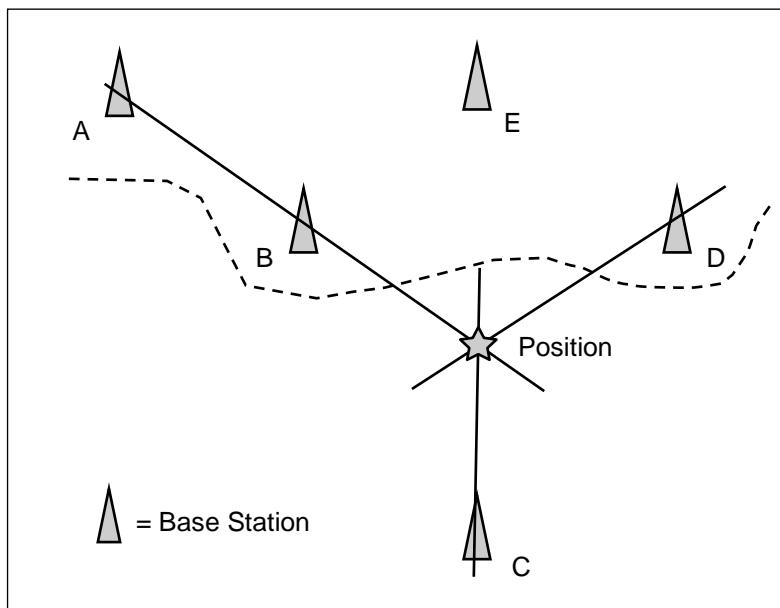


Figure 14: Example of optimum and poor position fixing situation.

Base stations B, C, and D together make the optimum position for obtaining a fix. Because of the nature of the GSM network it is likely that A will not be visible to the receiver. Similarly, it is unlikely that E would be visible as both B and D, with probably closer, stronger, and uninterrupted signals would shield it. Should C be unavailable the position must be obtained from B and D.

This is almost the exact situation once a vessel leaves the shore. If locations A, B, and D are on land, C is unlikely to exist as it is over water.

Fig. 15 illustrates how this might affect the accuracy of a fix. In this scenario a long narrow cocked-hat is formed. Notably, this indicates good positional accuracy along the coastline, but poor accuracy at determining distance from the coastline. This is very similar to the actual data collected and plotted in Fig. 13, and provides a plausible explanation for the inaccuracies seen.

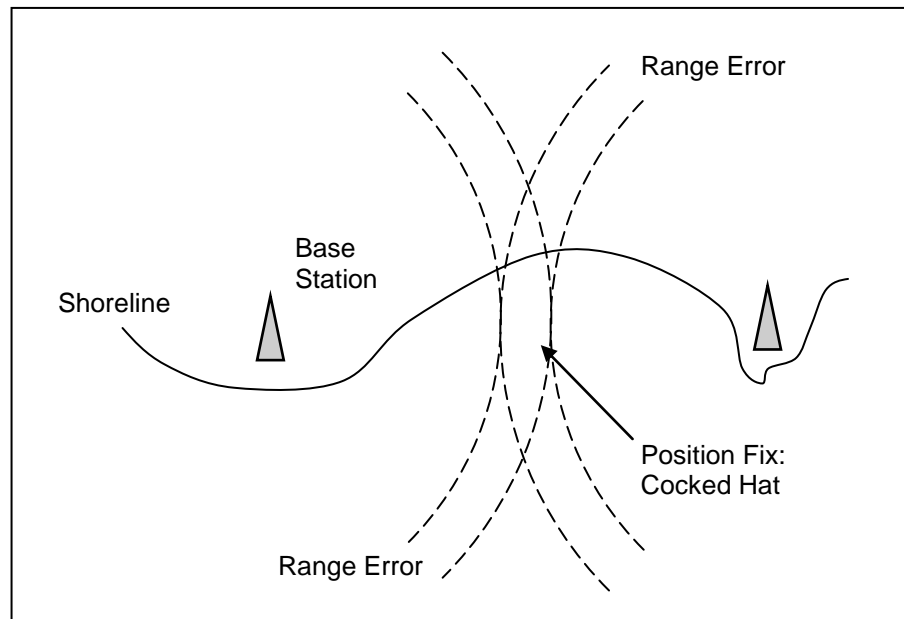


Figure 15: Example of a cocked hat resulting from a poor position fix.

The sensitivity of the receiving equipment will also play a significant factor. The mobile phone used is a standard commercially available model. It may be possible that more accurate equipment, with more sensitive hardware and software would be capable of more regular updates. Given the increase in accuracy closer to shore seen in Figure 13, these factors provides the most likely explanation for the large discrepancy between the static and moving results.

Repeatability of Results

In any experiment such as this with reasonably limited data collection there is the concern that the results are repeatable. The results from the two independent data collection exercises shown in Fig. 11 go some way to overcoming this concern, with the results up to 70% being consistent with each other. In addition the data collected on shore in the baseline test and during initial trials give results comparable with previous studies undertaken. The average errors between tests in this project produced similar values (140 m and 156m), and the 67th percentile error for the static data compared well with accuracies Kemppe and Nousiainen (2006) achieved, as discussed above.

Conclusion

Previous research by Favey, Megnet, et al. (2005) has shown that this method of positioning has more applications than simply giving an estimated position. Its strengths appear to lie in the relative ease with which it can be combined with GPS, where both systems may complement one another. The idea of radio positioning is not new, having existed for sometime. An interesting aspect of the data analysis will be to see how GSM (DCM) positioning compares to older radio positioning systems.

Burnside (1991) states that there are three fundamental questions that must be asked when undertaking the measurement of distances with positioning aids. These are:

1. "What quantity (or effect) is actually being measured?"
2. "How accurately is this being done?"
3. "What is the relationship between what is being measured and the quantity actually required?"

Although not its specific aim, this project has addressed these three questions. As the latest mobile phones continue to incorporate more technology, such as GPS, it is likely that this technology may be quickly superseded for the casual user. However, in coastal navigation where life, vast assets, and the environment depend on the safe navigation of vessels, it is clear that emerging technologies such as this may be incorporated with existing systems, where it will compliment rather than replace them.

The results from this project, in particular those shown in Fig. 11, show that there is a large error associated with GSM (DCM) positioning in the coastal environment. Whilst an error of perhaps a few hundred metres might have provided a workable position, an error of thousands of metres is simply not acceptable, would not be able to provide anything like the information needed to position, regardless of size. Figure 13 confirms this and provides additional information. In particular, once more than 500m away from the shore datum, not only does the accuracy drop, but the frequency with which the equipment is able to update its position declines rapidly. In this particular case, at 1600m from the datum, the vessel travelled nearly a nautical mile before being able to update its position.

The system's ability to position itself with more accuracy closer to land may have potential if viewed from the perspective that accuracy increases with the risk of running aground on the shore. However, the risk of running aground may be equally large miles away from a shoreline. Therefore, as a standalone system, it must be concluded that GSM positioning using DCM, is not a feasible option for coastal navigation at present.

Where this system may prove to be useful is in search and rescue (SAR) applications. As the European Communities eCall Driving Group has confirmed, there can be no doubt that being able to position a mobile phone to within a couple of hundred meters is important (eSafety Support, 2007). In particular, where someone might have fallen from cliffs, or got into trouble on a remote coastal path or beach, there are significant benefits. Unlike a vessel at sea, this is the sort of environment where people would be less likely to have a GPS receiver to hand. Whilst this falls outside the scope of this project, the results in Fig. 13 clearly show that there is significant potential for GSM (DCM) positioning to be used on the shore-line, or very close-in to shore. This would require further study to establish if it could be used over larger areas of the coastline.

The research undertaken by Favey, Megnat et al (2005), showed that there is potential for integration of GSM and GPS positioning to reduce satellite acquisition time in AGPS. The latest generation of mobile phones are now making use of this technology. This includes the first to utilise AGPS, which was released during the research and writing-up of this project (Apple, 2008 and Nokia, 2008). In a safety-critical application, such as the marine environment, the integration of DCM could reduce acquisition time further due to the increased accuracy (as shown by Laitinen, Lähteenmäki, et al.) associated with this technology. With ever-increasing bandwidth available over the mobile network many of the obstacles previously associated with DCM technology are gone.

Whilst this project has proven that GSM positioning using DCM may not be a viable stand-alone solution for coastal navigation, it is clear that the improved accuracy associated with it, when compared with other systems has significant potential in the marine environment.

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Appendices

The appendices to this report can be viewed in the folder 'Supplementary Files' located in the Reading Tools menu list.