An Assisted-GNSS Solution for Demanding Road Applications using the EGNOS Data Access System (EDAS)

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BIOGRAPHY

Kevin Sheridan is Technical Manager at NSL where he is currently working on the development of robust GNSS positioning solutions for urban applications. He has been involved in the design and development of Galileo for the last ten years, as well as working on GPS and EGNOS applications across various modes of transport. He completed his PhD at University College London in 2000.

Don Wells is a Senior Software Engineer at NSL where he is implementing and testing positioning algorithms for an experimental onboard unit (OBU) for road-user-charging (RUC).

Cyril Botteron is leading, managing, and coaching the research and project activities of the GNSS and UWB research subgroups at EPFL, the Ecole Polytechnique Fédérale of Lausanne in Switzerland. He received the Ph.D. degree from the University of Calgary in Canada in 2003 and has authored or co-authored over 40 international papers and 3 patents in the field of positioning systems, ultra low power RF communications, RF integrated circuits design, and baseband signal processing.

Jérôme Leclère is a PhD student at EPFL, the Ecole Polytechnique Fédérale of Lausanne in Switzerland, since February 2009. His current research focus is on acquisition and high sensitivity GNSS receivers

Fabrizio Dominici is the head of the technologies for Galileo/EGNOS applications and embedded systems at ISMB. He received the Master Degree in Communications Engineering from Politecnico di Torino in July 2005. He is the project manager for the ISMB navigation lab of many R&D programs funded at national and international level. His main research activities are focused on the PVT algorithms, embedded NAV/COM platforms, GNSS/INS integration and augmentation systems such as: EGNOS, LADGPS/RTK and A-GPS.

Antonio Defina received the Master Degree in Communications Engineering from Politecnico di Torino in July 2005. Since 2005 he has been working as researcher in NavSAS Group at ISMB. His research interests cover the field of localization, navigation and communication addressed to GNSS technologies for applications, focused in particular to the implementation of Local Element systems prototypes relying on EGNOS features and on different communication channels.

1. INTRODUCTION

Roads right across Europe are becoming more congested and governments and regional authorities are looking for ways to better manage the existing road network. One tool that is being increasingly promoted to tackle the congestion challenge is Road User Charging (RUC).

Recording journey information using a GNSS receiver embedded in an OBU is a convenient and flexible solution to support the automated fee collection process. If GNSS positioning is to be used as the basis for billing drivers though it must meet stringent reliability and availability requirements, and at the same time, be based on low-cost equipment.

This paper describes a prototype solution which has been developed to provide both the positioning availability and integrity required for this application. The SIGNATURE (**SI**mple **GN**SS **A**ssisted & **T**r**U**sted **RE**ceiver) solution includes an assistance service which provides ephemeris data and corrections from the EGNOS Data Access Service (EDAS), optimized for the user location. Assistance messages are sent to OBUs which can either host an experimental receiver or a Commercial-Off-The-Shelf (COTS) receiver. Measurement data from the receiver is then processed with application-specific navigation algorithms on the OBU which aim to improve the integrity of the position solution relative to standard solutions.

The paper describes the SIGNATURE solution and how it is being tested in the course of the project. It then presents initial results from field trials which are assessing its performance in a range of representative conditions. The tests assess the contribution that assistance can make to positioning performance, and illustrate options for enhancing standard assistance solutions. Enhancements to assistance encompass modifications to the message content and alternative means of communications, showing the benefits and feasibility of a broadcast service. The impact of including EGNOS corrections through a broadcast assistance service in urban areas is also under investigation.

2. GNSS ROAD USER CHARGING

The use of RUC has the potential to reduce congestion, lower vehicle emissions and generate revenue streams for infrastructure improvement. It can ensure that revenues are based on actual road usage creating a financial incentive for changing driving behaviour. This might include using private cars less overall and, in particular, reducing peak-times levels of travel in urban areas by effectively spreading out the morning and evening ‘rush hour’. RUC can also encourage commuters to use alternative forms of public transport.

To automate the process of collecting charges, Electronic Fee Collection (EFC) systems have been developed over the last two decades based largely on Dedicated Short Range Communications (DSRC). In a DSRC solution a simple tag on the vehicle receives a signal when it passes a roadside beacon and a charge is computed accordingly. Cameras with Automatic Number Plate Recognition (ANPR) technology are also widely used, mainly as an enforcement tool. Both these technologies rely on fixed roadside infrastructure. As charging schemes to date have focused on specific areas (e.g. individual Cities) or road infrastructure (e.g. major motorways, tunnels and bridges) this type of technology provides an adequate solution. To meet future policy goals however, this technology is not feasible. For more extensive charging schemes that will need to cover far greater areas, more road types, more classes of vehicle and which will vary charges depending on location and time of day, a far more flexible solution is required. Flexible schemes require the positioning element to be onboard the vehicle and GNSS-based devices, possibly augmented with other sensors, have been identified as the best option to achieve this.

Using GNSS, the OBU tracks the location of the vehicle and this is matched against the road network to calculate a charge. A GNSS solution can support many different charging strategies including time distance and place (TDP) based charging for road sections, geographic areas and cordon schemes. While GNSS offers great potential there are a number of operational and performance limitations which have prevented more widespread adoption to date. Operationally, OBUs are relatively expensive, fraud prevention is potentially complex and charging schemes must also be able to accommodate infrequent users. GNSS performance is limited in terms of the ability to provide sufficiently accurate positions with high availability and integrity in all operating conditions.

To be fully flexible and to target congested areas, OBUs must work in all environments including urban areas. The problems of the so-called “Urban Canyon” are well documented, with satellite signals being blocked and reflected. In some cases, not enough signals are available to determine a position and when there are enough satellites the ranges will be prone to errors and the geometry is likely to be poor. Signals are more likely to be available in the longitudinal direction of the street, but with few or no satellites on either side of the vehicle. Signal blockage is a particular problem when the GNSS receiver is started-up and it attempts to decode ephemeris data from the satellites. This requires around 30 seconds of uninterrupted tracking with a relatively strong signal for each satellite, and in an obstructed urban environment it may take many minutes to determine the first receiver position (an issue referred to as Time-To-First-Fix or TTFF). Charging schemes typically aim to charge for at least 99% of road usage. If a typical journey length is 30 minutes this means that only 18 seconds with no usable position solution can be tolerated and hence TTFF must be below 18 seconds, and ideally much lower. When positions can be determined they must be sufficiently accurate to be able to identify the correct road segment that the vehicle was on and they must be reliable. Reliability, or integrity, becomes critical if road users are to be charged on the basis of GNSS-derived positions. Users must have confidence that they are being charged correctly for schemes to be effective and to gain public acceptance.

Whilst GNSS-based solutions are entering the market, for example in Germany and Slovakia for Heavy Goods Vehicles, there are still barriers to wider adoption. Many countries are considering the use of GNSS based road pricing and they all face similar challenges in ensuring the accuracy, integrity and availability of a GNSS based solution for nationwide deployment.

3. SIGNATURE SOLUTION

The principal objective of the SIGNATURE project is to prototype a GNSS-based solution for flexible road user charging that can provide the required high integrity and high availability in a cost-effective and scalable manner.

This robust, high-availability, high-integrity solution is delivered firstly through providing reliable assistance (A-GNSS) data from the EGNOS Data Access System (EDAS) to optimise the receiver acquisition and tracking capabilities and reduce Time To First Fix(TTFF), and secondly through the implementation of embedded GNSS reliability algorithms into an Onboard Terminal, providing assurance of positioning information (Figure 1).

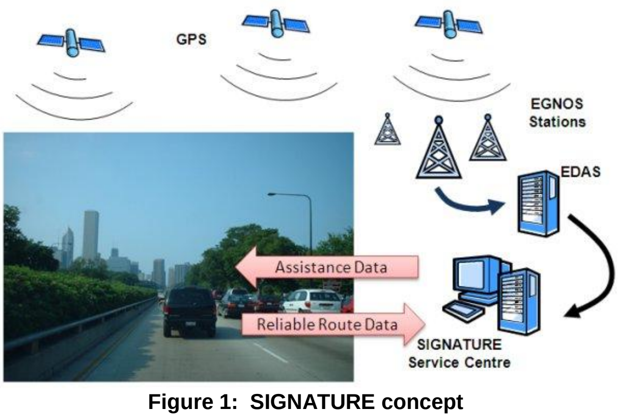

Figure 1: SIGNATURE concept

These features are intended to make a positive contribution in terms of the key performance criteria of RUC, as defined by the GNSS Metering Association for Road User Charging, GMAR [1]:

- Charging Accuracy (right cost per trip)
- Charging Integrity (probability and amount of overcharging)
- Charging Availability (amount of charged usage)

The main elements of the SIGNATURE solution are described in sections 3.1 to 3.3.

3.1Assistance Server

An assistance service, supplying suitably equipped OBUs is one means to maintain rapid TTFF and meet the requirement for high positioning availability. The most significant contribution assistance can make to TTFF is to provide the ephemeris data which takes 30s to download from a satellite signal. Assistance data can also reduce the frequency search space when a receiver is acquiring signals as the expected Doppler frequency can be computed from the approximate receiver and satellite positions. Typically, an assisted receiver will have a TTFF of 3 to 4 seconds.

The assistance Server developed in the SIGNATURE project is based on EDAS (EGNOS Data Access Service) which is currently available as a beta version. EDAS allows a user to plug into EGNOS to receive the data collected by all the current EGNOS RIMS (Ranging and Integrity Monitoring Stations). This makes it possible to access EGNOS data when there is no clear sight to the EGNOS Geostationary satellites, which can often be the case in urban areas, particularly at higher latitudes. As well as supplying EGNOS messages, EDAS also provides GPS observation and navigation (broadcast ephemeris) data, which is the key component as far as an assistance service is concerned. By recording the ephemeris data being received at the extremities of the monitoring network it is possible to ensure that the current ephemeris for any GPS satellite in-view to users over Europe is available and can be supplied in an assistance message. The other data streams provided by EDAS can also be used to enhance the assistance solution.

The main enhancement being tested in the SIGNATURE project is the use of EGNOS corrections within the assistance message. EGNOS today consists of a Space Segment of three Geostationary Satellites, broadcasting correction and integrity information in the L1 band. Three sets of corrections are broadcast to users:

- Fast corrections – used to compensate short-term disturbances in GPS signals, generally attributable to satellite clocks
- Long-term corrections - used to compensate for the longer-term drift in satellite clocks and the errors in the broadcast satellite orbits
- Ionospheric corrections – broadcast as a grid of vertical delays (GIVD) from which a user receiver can determine a slant correction to be applied on each range measurement to compensate for the delay experienced by the signal as it passes through the ionosphere.

Fast and long-term corrections are added to the ephemeris data in the assistance message. Rather than relaying the GIVD data to the OBU and letting the receiver reconstruct the ionospheric grid and calculate slant corrections, this is done within the assistance server. A slant correction is provided for each satellite which will be in view at the user location. This approach is valid provided the OBU updates the corrections regularly enough to take account of the changing satellite elevations and ionospheric conditions. It provides a significant saving in terms of processing and memory consumption at the OBU, while still delivering the accuracy benefit of the EGNOS ionospheric data. To correct for the tropospheric delay a zenith value (ZTD) determined from the RTCA model is also included in the assistance message. Mapping this zenith value to a slant correction to be applied to satellite ranges is a straightforward process and is easily accommodated on the OBU.

Figure 2 is a schematic showing how data from EGNOS RIMS is collected at the assistance server at NSL in Nottingham, UK, and then used to generate messages. In this case the assistance data was provided for trials being conducted in Brussels. The figures at the bottom of the plot are the EGNOS correction values being provided for all 10 of the GPS satellite being used in the positioning solution.

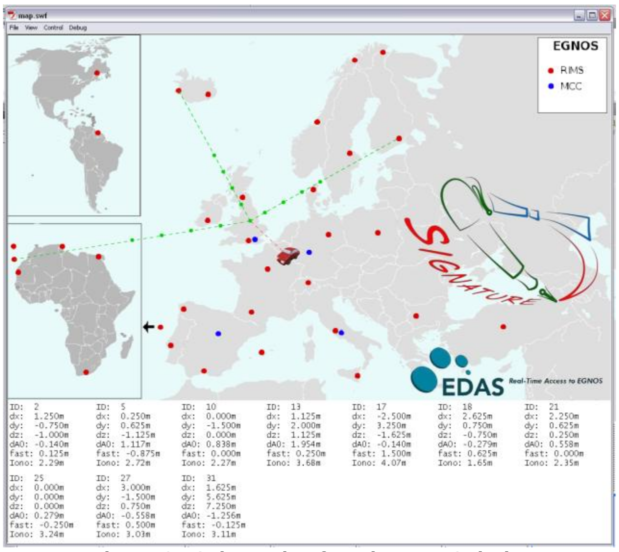

Figure 2: Schematic of Assistance Solution

Further enhancements are also possible using the GPS observation data provided through EDAS. Firstly, for areas close to RIMS a local differential solution can be applied using standard DGPS techniques to provide pseudorange corrections rather than wide-area EGNOS corrections. This has the potential to give greater accuracy for certain areas and is an option which is being investigated further. By combining EDAS data sources a GNSS performance monitoring and prediction service has also been created (Figure 3). This provides an assessment of GPS and GPS+EGNOS positioning performance (accuracy, availability of corrections, integrity) at known reference stations as well as monitoring the availability of EDAS data from its central server. Monitoring of this kind can be used as a further tool to identify system-level problems which would significantly degrade user positioning solution, perhaps to a level at which charges could not confidently be applied. It can also aid the enforcement process where it helps as a diagnostic tool to identify if missing or misleading data from an OBU could be due to a system-wide fault or is due to a more localised source.

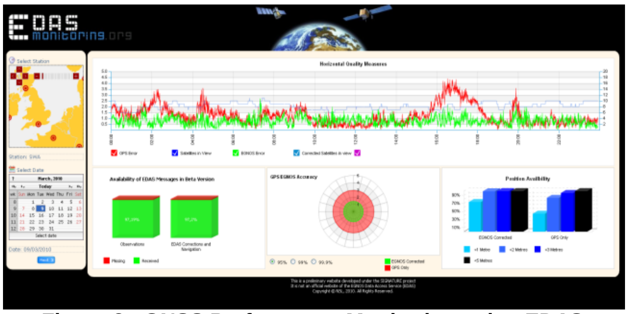

Figure 3: GNSS Performance Monitoring using EDAS

The approach described above relies on the approximate user position being known at the assistance server. To maintain the validity of the corrections it would also require a receiver to update its assistance data at a much high rate than would usually be the case. For a large scale operation this would be unfeasibly expensive using cellular communications (GSM/GPRS) however it would be possible using a *broadcast* assistance approach. Using a Radio Data Service (RDS) broadcast for example, ephemeris data and EGNOS corrections could be provided on a continuous basis. RDS is an auxiliary signal to the FM radio broadcast system and is used routinely for supplying travel information to in-car navigation systems. As data is broadcast from known locations and over a definable coverage area, messages can be generated which are applicable for all users receiving data from a given transmitter. A drawback of RDS is that it has a relatively low bandwidth and it takes approximately 2 seconds to broadcast an ephemeris message for a single satellite. A further argument against RDS as a long-term solution is that analogue radio signals are progressively being phased out in favour of digital alternatives. With the far greater bandwidth of Digital Audio Broadcasting (DAB), ephemeris data for 12 satellites could be broadcast in less than 1 second.

Within the SIGNATURE project, alternative message content and transmission options are being evaluated to determine if real benefits can be gained by providing additional content, other than the ephemerides, in the assistance message. A test solution which can transfer assistance data to the OBU over an RDS channel has already been established. If a low bandwidth solution of this kind is employed, any additional content in the message will increase the time taken to transfer the most important data (ephemeris) to the user which would increase TTFF and therefore be counter-productive. These trade-offs will be taken into account in this assessment.

3.2 Onboard Unit

The SIGNATURE prototype OBU (Figure 4) has been developed by ISMB and is based on a single board computer (SBC) offering a high degree of flexibility. It can host alternative receivers and positioning algorithms and manipulate different assistance data with a high degree of configurability. It is a powerful platform for developing and assessing OBU devices and their component parts. The prototype is based on a Mirach SBC that delivers the benefits of Intel® architecture with a small form factor, thermally constrained and fanless embedded applications. It is implemented in 45nm technology, this power-optimized processor provides robust performances per-watt in an ultra-small 13x14 mm package. The key features are:

- Intel® Atom™ Processor family up to 1GB DDR2 RAM
- Intel® Graphics Media Accelerator 500: 2D, 3D and advanced 3D graphics support
- Dual Head Video (LVDS up to 1280x1024 and SDVO up to 1080i)
- H264 hardware codec up to 1080i@30fps,
- High Profile, L4.1 (MPEG2-4,VC1, and WMV9 supported)
- HDA Audio up to 4 audio streams (up to 16 channels each), 32-bit sample depth, and sample rates to 192 KHz
- 8 USB 2.0 Host (1 client configurable)
- Interfaces: LPC, IDE, PCI-Ex 1x, GPIO, UART, IRDA
- Operating temperature: 0º...+60ºC; -40º...+85ºC

The OBU hosts a bespoke receiver which exploits the continuous availability of assistance data available through a HSDPA connection and does not attempt to decode navigation data directly from satellite signals. This allows its design to focus on rapid signal acquisition with high sensitivity and to achieve a rapid time to first fix (TTFF) even in areas where conventional receivers struggle. The SIGNATURE prototype has been designed using the well known SAT-SURF & SAT-SURFER platform [4].

Figure 4: SIGNATURE Prototype Onboard Unit (OBU)

The bespoke receiver has been developed by the EPFL. It is based on the Terasic Altera DE3 System which contains a high density Stratix III FPGA (EP3S260), and on the Rakon GRM8652 high performance front end. As high sensitivity is required, the receiver implements massive parallelization by making use of the FFT, leading to a processing power equivalent to approximately 650,000 equivalent correlators. The minimum sensitivity in acquisition is –145 dBm, obtained using coherent and non-coherent integrations. Thanks to the massive parallelization and the assistance, the TTFF at -145dBm is still below 3 seconds.

3.3 Positioning Algorithms

The OBU hosts positioning algorithms which have been designed by NSL to provide high accuracy, availability and integrity through exclusion of outlying measurements and provision of quality metrics (Horizontal Protection Levels). Numerous positioning algorithms and outlier detection strategies are being investigated. These include *consistency checks* applied to raw measurements and computed positions and RAIM (Receiver Autonomous Integrity Monitoring). EGNOS corrections are applied to improve accuracy and integrity indicators (User Differential Range Error Indices) are used as coarse fault detection barrier. Consistency checks on measurements include differencing pseudoranges between epochs and checking that this rate is below a defined threshold. A RAIM (Receiver Autonomous Integrity Monitoring) algorithm is then applied to detect and exclude outliers before measurements enter the main navigation filter. Positions and velocities determined by the filter are then checked again as a further fault barrier. Checks at this stage identify if speeds are within expected ranges for the application and whether height changes are reasonable for example.

The RAIM algorithm is based on the Maximum Normed Residual Method. For the detection procedure the test statistic is calculated based on weighted sum of the squares of the residuals. This test statistic undergoes a Globaltest (Chi-Square distribution), and is tested against thresholds which are computed based on the probability of false alarm (Pfa) and degrees of freedom (number of measurements minus number of unknowns). The exclusion procedure is based on an outlier detection technique developed by Baarda [2], also known as data-snooping which is based on normed residuals and applied within the range domain. This technique uses measures of internal and external reliability, where the internal reliability gives estimates of how reliable the outlier detection procedure is, while the external reliability gives estimations of the *influence* of an outlier.

In the final step of the exclusion procedure the *maximum normed residual* is tested against a *critical value* based on the *Normal inverse cumulative distribution*, which in turn depends on the Pfa, and a decision is made on whether or not to exclude measurements. Having performed fault detection and fault exclusion until no further outliers are found, a Horizontal Protection Level (HPL) is calculated. This HPL is the maximum horizontal position error which is guaranteed by the algorithm not to be exceeded, in accordance with the required probabilities of missed alarm and false alarm. HPL is a function of visible satellites, expected error characteristics and user geometry. Measurements which have been "screened" using the RAIM Fault Detection and Exclusion are then processed in a Kalman Filter.

Within the project, many alternative algorithms and configurations are being tested. As well as using RAIM in a snapshot mode to screen measurements entering the Kalman filter, fault detection can also take place within the innovation sequence of the filter itself. Weighting strategies which consider signal to noise ratios (SNR) as well as satellite elevations are also being used. This combined weighting is useful in reducing the impact of measurements affected by multipath in urban areas where simple elevation dependent models are often not applicable. The ultimate aim is to produce a robust GNSS positioning solution optimized for RUC in urban areas which balances the requirements of providing high availability with high integrity.

4. TEST METHODOLOGY

The SIGNATURE end-to-end solution will be tested in a series of field trials taking place in the UK and Italy from April to June 2010. Trials will take place in range of operating conditions from rural areas with open skies to dense urban environments. In all trials, assistance data is provided from the service centre in Nottingham, with messages tailored for the designated test area. The OBU records real-time position solutions as well as logging all raw measurements. Journey records can be sent back to the service centre over a GPRS connection or can be downloaded back at the office. This allows alternative solutions to be applied to the original datasets in post processing.

The position solutions will be assessed through comparisons with high-accuracy GNSS reference solutions provided by additional onboard equipment and through processing with a map matcher (NSL's Matchbox). Each journey record from a trial will be compared against the known reference journey record to determine charging availability, accuracy, and integrity.

Figure 5 for example shows how positions determined during tests in Brussels have been matched against road segments. By assigning a charge to each road segment a total bill per journey can then be calculated. For each road segment identified a confidence measure is determined based on factors including the number of data points (OBU positions) matched to that segment, the distance between data points and the segments to which they are matched, and the integrity indicators associated with the OBU data points.

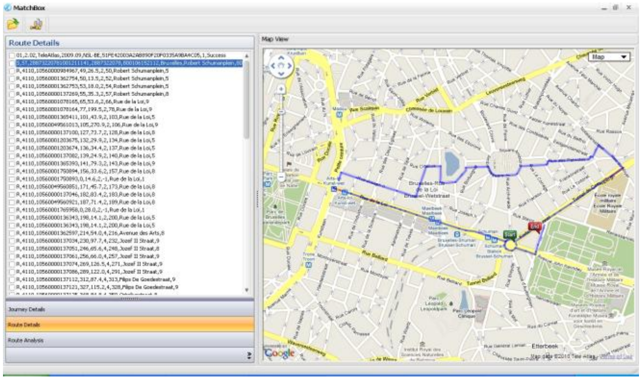

Figure 5: Journey Record View in Matchbox

Using this approach it is possible to assess whether improvements in the OBU position output are significant in terms of matching the vehicle location correctly to more road segments and with higher confidence. From direct comparisons between OBU positions and a high accuracy reference solution it is not possible to determine the significance of any changes in the OBU output in terms of final charging performance. Extensive trials of GNSS OBUs in London for example did not observe a relationship between location error (from OBUs) and performance at road segment level (map-matching) as map-matching can compensate for many errors [3]. A strong relationship was observed between data availability and performance though. Ultimately it is important to consider how successfully vehicle position can be related to charging objects, be they road segments, cordons or virtual toll-gates.

The objectives of the field test campaign are to:

- Demonstrate that all elements of the end-to-end solution work as expected
- Assess the impact of assistance on TTFF
- Evaluate benefits of EGNOS data
- Investigate alternative positioning algorithms to optimize availability and integrity
- Demonstrate the feasibility of broadcast assistance using RDS

5. PRELIMINARY RESULTS

The majority of field trials and subsequent analyses will take place in May and June 2010, after the submission of this paper, but preliminary results already obtained give some indication of the expected outcomes.

5.1 Demonstrate End-to-End Solution

Field trials took place around Nottingham (UK) and Torino (IT) in April 2010 to test all elements of the solution. These tests confirmed the successful generation, transmission and use of assistance data, including EGNOS corrections. Positions solutions determined onboard were transferred back to the service centre and processed with the map matcher. Figure 6 shows an example from a test in Nottingham city centre in which all the road segments travelled on have been correctly identified.

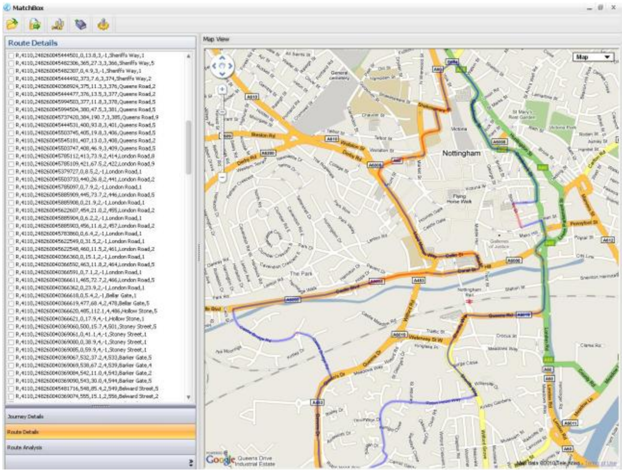

Figure 6: Journey Record View from Nottingham test

5.2 Assess Impact of Assistance on TTFF

As a starting point for examining the benefits of assistance, some initial trials were conducted by ISMB to determine the TTFF of consumer grade receivers typically used in road applications. They assessed TTFF in the following modes:

- *Hot Start*: receiver has up-to-date almanac and ephemeris information so only needs to obtain timing/ranging information from each satellite to return its position fix;
- *Warm Start*: receiver has the almanac information stored in its memory, but it does not have any ephemeris information. It has also an approximate time and position knowledge. It can use this information to search for satellite but will then need to demodulate the ephemeris data from acquired signals;
- *Cold Start*: receiver has no almanac, ephemeris or approximate position information to achieve a position fix.

Figure 7 shows the results from testing 3 different receivers over many repeated tests in urban areas. In these test conditions when no valid ephemeris (cold and warm cases) is available on a receiver at start-up it will take around a minute to determine the first position. When ephemeris information is already available on the receiver this reduces to around 10 seconds.

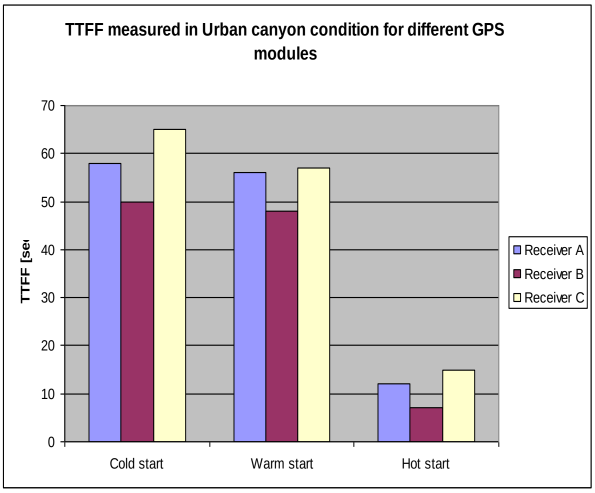

Figure 7: TTFF in Urban Areas

Further tests are now underway to determine TTFF performance for latest generation COTS receivers and the bespoke receiver developed for SIGNATURE. Initial tests in Nottingham indicate that with assistance, TTFF is typically around 3 to 5 seconds. Cold start tests in semi-urban conditions have found fix times ranging from 34 to 48 seconds. In worst cases with a vehicle starting from a car park in the City centre this can extend to around 2 minutes.

Testing will also analyse the accuracy of initial positions. Position solutions determined based only on the first few available satellites can be inaccurate. Tests to date show multiple cases where positions determined for up to 10 to 15 seconds after the first fix are not good enough to identify the correct road segment in the map-matcher. The routing logic applied in the matcher can then exaggerate this effect if it attempts to bridge the gap between these data points and later, more accurate, fixes. At the completion of the trials more comprehensive results will be available, but initial indications are that assistance will be essential in meeting the availability requirements for RUC schemes. Solutions which rely on interpolating a vehicle route between the last GNSS position recorded on the previous journey and the first position determined on a new journey introduce significant ambiguity.

5.3 Evaluate Benefits of EGNOS Data

The SIGNATURE solution has the ability to provide EGNOS data to positioning algorithms on the OBU and to vary the rate at which this information is updated and used. Field tests will assess the potential benefits of this source of data in various environments, starting from the case in which EGNOS messages are continuously available for the positioning solution and then investigating how any beneficial effects lessen as the data is provided less frequently.

To judge the kind of accuracy improvements that might be expected a first comparison has been made by processing data from a static reference station (Figure 8). In this example data accessed through EDAS has been used to estimate positions every second on an epoch-by-epoch basis at a reference station over 24 hours. The left plot shows the scatter of position estimates when a standard GPS single frequency solution applying the Klobuchar model to estimate ionospheric delay is used, with the right showing the same dataset but with EGNOS corrections applied. Applying the EGNOS corrections significantly improves the precision of the solution. In this case the 95% horizontal accuracy improves from 2.6m (GPS only) to 1.3m with corrections applied. Clearly this test is not entirely representative of dynamic urban conditions where multipath is likely to be dominant error source and a filtered solution would be applied, but it provides some indication of the potential impact of EGNOS corrections.

Figure 8: Reference station position estimates using a standard GPS solution (left) and with EGNOS corrections applied (right)

Road tests have been carried out in which two COTS receivers were connected to a common antenna, with one receiver configured to use EGNOS and the other not. These two solutions were compared against a high accuracy carrier phase solution providing a reference solution with an accuracuy of a few centimetres (Figure 9). Data collected with the SIGNATURE OBU has also been processed in positioning solutions both with and without EGNOS corrections (Figure 10). To date, the application of corrections has had some impact on the accuracy of the final solution, but the changes have not been so great that they impact the map-matching results. Further testing will continue to see if there are situations in which these benefits are more significant and if there are possibilities to exploit EGNOS corrections and integrity data in some "non-standard" ways to obtain performance benefits.

Figure 9: GPS track (green), GPS+EGNOS track (magenta) and High Accuracy Reference (points)

Figure 10: GPS positions (red) vs GPS+EGNOS (yellow)

5.4 Investigate Positioning Algorithms

Figures 11 to 13 present some results which show the impact of applying the RAIM algorithm described in section 3.3. The red dots in figure 11 show OBU locations estimated with no RAIM applied and clearly show some etsimated positions which lie a long way from the true road locations. Applying RAIM has successfully identified the satellite measurements in these solutions which were most contaminated by multipath. By removing these meaurements and re-computing the OBU location, better position estimates are obtained.

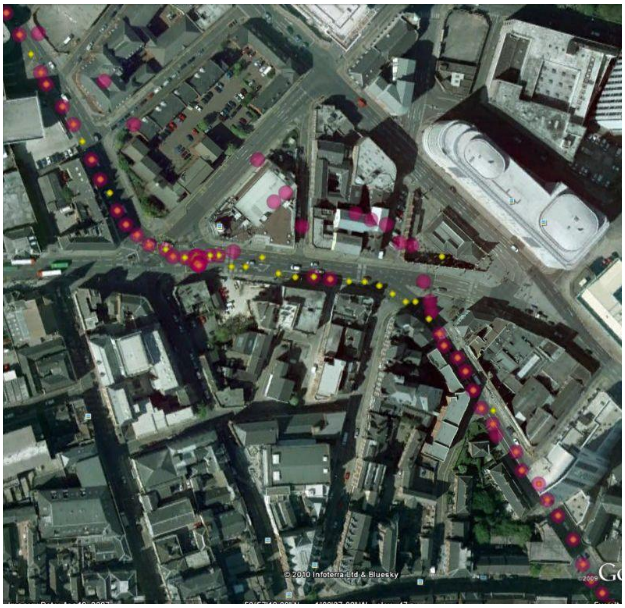

Figure 11: RAIM Impact (red = no RAIM, yellow = RAIM)

Figures 12 shows the results from the map-matcher when the OBU locations with no RAIM applied are used as an input. Although the matcher is still able to identify the correct road segments and reconstruct the journey the confidence with which it has matched certain road segments is low due to the presence of the outlying OBU positions. This is indicated through the use of purple and pink colours which correspond to the lowest possible confidence levels as shown in the key at the bottom left. When the OBU locations determined with RAIM applied are used as an input, a more consistent set of data is available to the matcher and as a result it can match segments with a greater confidence. The final impact of these results depends on the use which is made of the confidence indicators in a billing calculation, but greater confidence should lead to higher charging integrity, accuracy and availability.

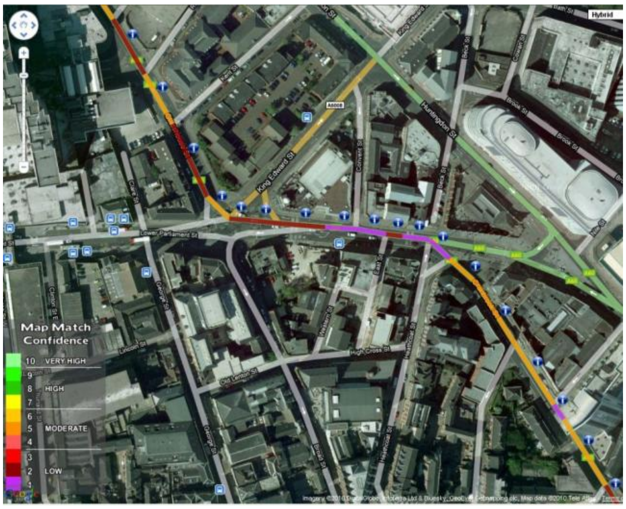

Figure 12: Map-matching without RAIM

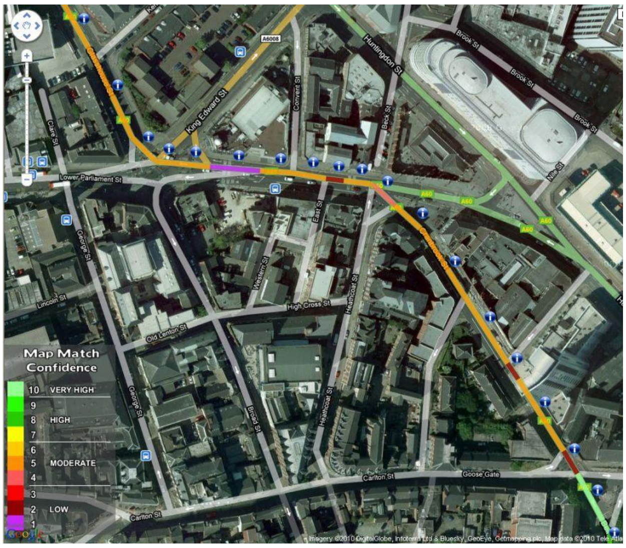

Figure 13: Map-matching with RAIM

6. CONCLUSIONS

This paper has presented a prototype solution which has been developed to provide a high availability and high integrity GNSS solution to support Road User Charging applications. It includes an assistance server using data from the EGNOS Data Access Service (EDAS) and a flexible onboard unit which hosts an experimental receiver and bespoke positioning algorithms. Field trials are now underway to rigorously assess this solution.

Using an assistance service it is possible to achieve a Time To First Fix of a few seconds which supports the high availability requirements of RUC. Field trials will determine if providing EGNOS information over the assistance data link has a significant performance benefit, and will examine the feasibility of using a broadcast solution.

Robust positioning solutions have been developed which improve the position estimates determined by an onboard unit and a test methodology has been put in place to assess the impact on charging availability, accuracy and integrity. All results to date indicate that GNSS based road charging offers the performance and flexibility to meet current and future requirements provided availability and integrity issues are properly taken into account.

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Full details of the project can be found at www.gnsssignature.org. Any views expressed here are entirely those of the authors and do not necessarily represent the EC.

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